CUET

Common University Entrance Test

DU | BHU | JNU | JMI | AMU

|| Biology ||

THE LIVING WORLD

Life is a unique, complex organization of molecules, expressing through chemical reactions which lead to growth, development, responsiveness, adaptation & reproduction.

A **living organism** is self-replicating, evolving and self-regulating interactive system capable of responding to external stimuli.

PROPERTIES OF LIVING ORGANISMS

1. Growth

- It is the increase in number & mass of cells by cell division.
- In plants, growth continues throughout their lifespan.
- In animals, growth is only up to a certain age. However, cell division occurs to replace lost cells.
- Basically, growth is the increase in mass & size. Thus non-living objects also grow (surface accumulation of material). So growth is not a defining property of living organisms.
- In living organisms, growth is from inside.

2. Reproduction

- It is the production of progeny having features similar to those of parents.
- Organisms reproduce asexually and sexually.
- In unicellular organisms, growth & reproduction are same because they reproduce by cell division.
- Many organisms do not reproduce (e.g. mules, worker bees, infertile human couples, etc). Hence, reproduction is not a perfect defining property of living organisms.

3. Metabolism

- It is the sum total of all biochemical reactions taking place inside a living system.
- It is the defining feature of living organisms.
- Metabolic reactions can be demonstrated outside the body in cell-free systems. Isolated metabolic reactions *in vitro* are not living things but are living reactions.

4. Cellular organization

- Organisms are made up of one or more cells.
- It is the defining feature of living organisms.

5. Consciousness

- It is the ability of organisms to sense their environment and respond to environmental stimuli (like light, water, temperature, other organisms, chemicals, pollutants, etc).
- All organisms are 'aware' of their surroundings. So, it is the defining property of living organisms.
- Human is the only organism having **self-consciousness.**

DIVERSITY IN THE LIVING WORLD

- The number and types of organisms present on earth refer to **biodiversity**.
- Number of species described is **1.7-1.8 million.**
- **Taxonomy** is the study of **identification, classification** & **nomenclature** of organisms.
  Systematics (Latin '*systema'* = systematic arrangement) deals with evolutionary relationships among organisms.
- ***Systema Naturae*** is the book written by **Linnaeus.**

Basic processes of taxonomy

- **Characterization:** It is the understanding of characters of organisms such as external and internal structure, structure of cell, development process, ecological information etc.
- **Identification:** It is the correct description of the organism so that the naming is possible.
- **Classification:** It is the grouping of organisms into convenient categories (**taxa)** based on characters.
- **Nomenclature** (**naming):** It is the standardization of names of the organisms such that an organism is known by the same name all over the world.

  The system of naming with two components is called **Binomial nomenclature.** It is proposed by **Linnaeus.**
  Botanical names are based on the rules in **International Code for Botanical Nomenclature (ICBN).**
  Zoological names are based on **International Code for Zoological Nomenclature (ICZN).**

Universal rules of Binomial nomenclature

- Scientific names are in ***Latin*** or Latinised and written in ***italics.*** When handwritten, they are underlined separately.
- The first word is genus name (**Generic name)** and second word is the species name **(specific epithet).**
  E.g. ***Homo sapiens***- *Homo* represents the genus name and *sapiens* represents the species name.
- The Genus name starts with capital letter and the species name starts with small letter.
- Name of the author (in abbreviated form) appears at the end of the biological name.
  E.g., *Mangifera indica* Linn. It indicates that this species was first described by Linnaeus.

TAXONOMIC CATEGORIES

- Classification involves hierarchy of steps in which each step represents a **taxonomic category (rank).**
- All categories together constitute a **taxonomic hierarchy**.
- A group of organisms occupying a particular category is called a **taxon (pl. taxa).** E.g. Class Mammalia.
- Each **category** or **taxon** represents a unit of classification.

Taxonomic hierarchy in ascending order

Category	Taxon
Kingdom	Animalia
↑	↑
Phylum/Division	Chordata
↑	↑
Class	Mammalia
↑	↑
Order	Primata
↑	↑
Family	Hominidae
↑	↑
Genus	Homo
↑	↑
Species	Sapiens

Species: It is a group of closely related organisms capable of interbreeding to produce fertile offspring.
It is the lowest category. E.g.

Common name	Generic name	Specific epithet
Mango	*Mangifera*	*indica*
Potato	*Solanum*	*tuberosum*
Nightshade	*Solanum*	*nigrum*
Tomato	*Solanum*	*lycopersicum*
Brinjal	*Solanum*	*melongena*
Lion	*Panthera*	*leo*
Tiger	*Panthera*	*tigris*
Leopard	*Panthera*	*pardus*
Modern man	*Homo*	*sapiens*

Genus: It is the aggregates of closely related species.
E.g. Potato, tomato & brinjal are species of genus *Solanum.* Lion, leopard & tiger are species of genus *Panthera*. This genus differs from genus *Felis* (genus of cats).

Family: It is a group of closely related genera. E.g.
Family Solanaceae includes Genus *Solanum*, Genus *Petunia* and Genus *Datura.*
Family Felidae includes Genus *Panthera* and Genus *Felis.*

Order: It is the assemblage of related families. E.g.
Order *Polymoniales* includes Family *Convolvulaceae* and Family *Solanaceae.*
Order *Carnivora* includes Family *Felidae* & Family *Canidae.*

Class: It is the assemblage of related orders. E.g.
Order *Primata, Carnivora* etc. is placed in class *Mammalia.*

Phylum (Division in case of plants**):** It is the assemblage of related classes.
E.g. Classes *Amphibia, Reptilia, Aves, Mammalia* etc. come under phylum Chordata.

Kingdom: The assemblage of related phyla. It is the highest category. E.g. Kingdom Plantae, Kingdom Animalia etc.

Organisms with their taxonomic categories

Common name	Man	Housefly	Mango	Wheat
Biological name	*Homo sapiens*	*Musca domestica*	*Mangifera indica*	*Triticum aestivum*
Species	*sapiens*	*domestica*	*indica*	*aestivum*
Genus	Homo	Musca	Mangifera	Triticum
Family	Hominidae	Muscidae	Anacardiaceae	Poaceae
Order	Primata	Diptera	Sapindales	Poales
Class	Mammalia	Insecta	Dicotyledonae	Monocotyledonae
Phylum/Division	Chordata	Arthropoda	Angiospermae	Angiospermae
Kingdom	Animalia	Animalia	Plantae	Plantae

TAXONOMICAL AIDS

a. Herbarium

- It is a store house (repository) of plant specimens that are dried, pressed and preserved on sheets and are arranged according to universally accepted classification.
- Herbarium sheets are labelled with information about date and place of collection, English, local and botanical names, family, collector's name etc.

b. Botanical gardens

- These are specialized gardens having collections of living plants for reference and identification.
- Each plant is labelled with its botanical name and family.
- **Famous botanical gardens:**
  - Royal Botanical Garden at Kew (England).
  - Indian Botanical Garden, Howrah (India).
  - At National Botanical Research Institute, Lucknow (India).

c. Biological Museum

- It is a collection of ***preserved plants and animals*** for study and reference.
- A museum contains
  - Specimens preserved in preservative solutions in containers or jars.
  - Preserved dry specimens of plants and animals.
  - Insects preserved in insect boxes after collecting, killing and pinning.
  - Stuffed larger animals like birds and mammals.
  - Collections of animal skeletons.

d. Zoological Parks (Zoos)

- These are the places where ***live wild animals*** are kept in protected environments under human care.
- It helps to learn about their food habits and behaviour.

e. Key

- It is an analytical method of identification of organisms based on similarities and dissimilarities.
- It is based on the contrasting characters generally in a pair called **couplet.**
- Each couplet has two opposite options. Of these, only relevant option is accepted and other is rejected.
- Each statement in the key is called a **lead.**

Flora, manuals, monographs & catalogues

- **Flora:** Actual account of habitat and distribution of plant species of a given area.
- **Manuals:** The record that contains information for identification of names of species found in an area.
- **Monographs:** The records that contain information on any one taxon.
- **Catalogue:** Alphabetical list of species.

BIOLOGICAL CLASSIFICATION

Aristotle's classification

- Aristotle was the earliest to attempt a more scientific basis for classification of organisms.
- He classified plants to **trees, shrubs & herbs** and animals into 2 groups- those **with red blood** &**without red blood.**

Linnaeus's Two-kingdom classification

- **Linnaeus** (1758) classified organisms into **Two Kingdoms**- Kingdom **Plantae** & Kingdom **Animalia.**

Drawbacks of 2-kingdom classification:

- **Prokaryotes** (Bacteria, cyanobacteria) and **eukaryotes** (fungi, mosses, ferns, gymnosperms & angiosperms) were included under 'Plants' based on the presence of cell wall. But they are widely differed in other characteristics.
- It included the unicellular and the multicellular organisms in same group. E.g. *Chlamydomonas* and *Spirogyra* were placed under algae.
- It did not differentiate between the heterotrophic fungi and the autotrophic green plants. Fungi have chitinous cell wall while the green plants have cellulosic cell wall.

Five Kingdom Classification

- It is proposed by **R.H. Whittaker (1969).**
- It includes Monera, Protista, Fungi, Plantae & Animalia.
- This is based on cell structure, thallus organization, mode of nutrition, reproduction and phylogenetic relationships.

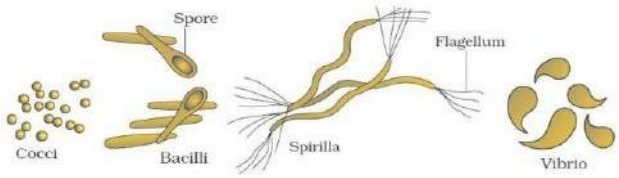
Three-domain system: It divides Kingdom Monera into two domains. Eukaryotic kingdoms are included in third domain. Thus it is **six-kingdom classification.**

Characteristics of the five kingdoms

Characters	Monera	Protista	Fungi	Plantae	Animalia
Cell type	Prokaryotic	Eukaryotic	Eukaryotic	Eukaryotic	Eukaryotic
Cell wall	Non-cellulosic (poly-saccharide + amino acid)	Present in some	Present (Chitin & polysaccharides)	Present (Cellulose)	Absent
Nuclear membrane	Absent	Present	Present	Present	Present
Body organisation	Cellular	Cellular	Multicellular, loose tissue	Tissue/organ	Tissue/organ/ organ system
Mode of nutrition	Autotrophic (photosynthetic & chemosynthetic) and heterotrophic (saprophyte/parasite)	Autotrophic (photosynthetic) and heterotrophic	Heterotrophic (saprophytic or parasitic)	Autotrophic (photosynthetic)	Heterotrophic (holozoic, saprophytic etc.)

1. KINGDOM MONERA (BACTERIA)

- Bacteria are the most abundant microorganisms.
- Hundreds of bacteria are present in a handful of soil.
- They also live in extreme habitats such as hot springs, deserts, snow & deep oceans. Many are parasites.
- Based on shape, bacteria are 4 types: **Coccus** (Spherical), **Bacillus** (Rod-shaped), **Vibrium** (Comma-shaped) & **Spirillum** (Spiral).



- Some bacteria are **autotrophic** (synthesize food from inorganic substrates). Majority are **heterotrophs** (they do not synthesize food but depend on other organisms or on dead organic matter for food).

I. Archaebacteria

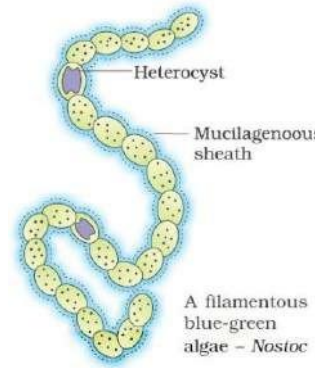
- They live in harshest habitats such as extreme salty areas **(halophiles)**, hot springs **(thermoacidophiles)** and marshy areas **(methanogens).**
- Archaebacteria have a different cell wall structure for their survival in extreme conditions.
- **Methanogens** are present in the guts of ruminant animals (cows, buffaloes etc). They produce **methane (biogas)** from the dung of these animals.

II. Eubacteria ('true bacteria')

- They have a **rigid cell wall** and **a flagellum** (if motile).
- They include **Autotrophs (photosynthetic** and **chemosynthetic)** and **Heterotrophs.**

a. Photosynthetic autotrophs (E.g. Cyanobacteria):

- They have **chlorophyll *a*** similar to green plants.
- Cyanobacteria (blue-green algae) are unicellular, colonial or filamentous, marine or terrestrial algae.
- The colonies are generally surrounded by **gelatinous sheath.**
- They often form blooms in polluted water bodies.
- Some of them fix atmospheric nitrogen in specialized cells **(heterocysts).** E.g., *Nostoc* & *Anabaena.*



b. Chemosynthetic autotrophs:

- They oxidize inorganic substances such as nitrates, nitrites & ammonia and use the released energy for ATP production.
- They help in recycling nutrients like nitrogen, phosphorous, iron and sulphur.

c. Heterotrophic bacteria:

- They are the **most abundant** in nature.

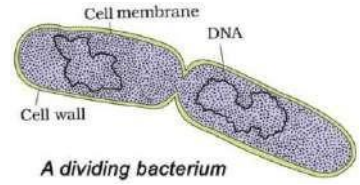
- The majority are important **decomposers.**

Impacts of Heterotrophic bacteria on human affairs:

- They are used to make curd from milk.
- Production of antibiotics.
- Fixing nitrogen in legume roots etc.
- Some are pathogens causing diseases. E.g. Cholera, typhoid, tetanus and citrus canker.

Reproduction in Bacteria:

- Bacteria reproduce mainly by **fission.**
- Under unfavourable conditions, they produce **spores.**
- They also reproduce by a sort of sexual reproduction (DNA transfer from one bacterium to other).



A dividing bacterium

Mycoplasmas are organisms without a cell wall. They are the **smallest living cells.** They can survive without oxygen. Many are pathogenic in animals and plants.

2. KINGDOM PROTISTA

- It includes **single-celled eukaryotes.**
- The cell contains a well-defined nucleus and other membrane-bound organelles. Some have flagella or cilia.
- Protists are primarily aquatic.
- It is a link with plants, animals and fungi.
- They reproduce asexually and sexually (cell fusion and zygote formation).
- Protista includes **Chrysophytes, Dianoflagellates, Euglenoids, Slime moulds** and **Protozoans.**

I. Chrysophytes

- Found in fresh water and marine environments.
- Microscopic and float passively in water currents (plankton).
- Most of them are photosynthetic.
- It includes **diatoms & golden algae (desmids).**
- **Diatoms:** They have siliceous cell walls forming two thin overlapping shells, which fit together as in a soap box. The cell wall deposit of diatoms over billions of years in their habitat is known as **'diatomaceous earth'.** This is used in polishing, filtration of oils and syrups.
- Diatoms are the chief 'producers' in the oceans.

II. Dinoflagellates

- Mostly marine and photosynthetic.
- They appear yellow, green, brown, blue or red based on the main pigments present in their cells.
- The cell wall has stiff cellulose plates on the outer surface.
- Most of them have **2 flagella;** one lies longitudinally and the other transversely in a furrow between the wall plates.
- **Red dinoflagellates** (E.g. *Gonyaulax)* undergo rapid multiplication so that the sea appears red **(red tides).** They release toxins that kill marine animals like fishes.

III. Euglenoids

- Mainly fresh water organisms found in stagnant water.
- Instead of a cell wall, they have a protein rich layer called **pellicle.** It makes their body flexible.
- They have **two flagella,** a short and a long one.
- They are **photosynthetic** in the presence of sunlight. In the absence of sunlight, they behave like **heterotrophs** by predating on smaller organisms.
- The pigments are identical to those in higher plants.
- E.g. *Euglena.*

IV. Slime Moulds

- They are saprophytic protists.
- The body moves along decaying twigs and leaves engulfing organic material.
- Under suitable conditions, they form an aggregation called **plasmodium.** It may spread over several feet.
- Under unfavourable conditions, plasmodium differentiates and forms fruiting bodies bearing **spores** at their tips. Spores have true walls. They are highly resistant and survive for many years. Spores are dispersed by air.

V. Protozoans

They are heterotrophs (predators or parasites).
They are the primitive relatives of animals.

There are 4 major groups of protozoans:

- **Amoeboid protozoans:** They live in fresh water, sea water or moist soil. They move and capture prey by putting out **pseudopodia** (false feet). E.g. *Amoeba.* Marine forms have silica shells on their surface. Some of them are parasites. E.g. *Entamoeba.*
- **Flagellated protozoans:** They are free-living or parasitic. They have **flagella.** The parasitic forms cause diseases like **sleeping sickness.** E.g. *Trypanosoma.*
- **Ciliated protozoans:** They are aquatic, actively moving organisms using thousands of **cilia.** They have a cavity **(gullet)** that opens to outside. By the movement of cilia, the water with food enters gullet. E.g. *Paramoecium.*
- **Sporozoans:** They have an infectious spore-like stage in their life cycle. E.g. *Plasmodium* (malarial parasite).

3. KINGDOM FUNGI

- It is a unique kingdom of heterotrophic organisms.
- Fungi are cosmopolitan.
- They grow in warm and humid places.
- E.g. mould on bread & rotten fruits, mushroom, toadstools.
- White spots on mustard leaves are due to a parasitic fungus.
- Some fungi are the source of antibiotics, e.g., *Penicillium.*
- Some unicellular fungi (e.g. yeast) are used to make bread and beer.
- Other fungi cause diseases in plants and animals. E.g. wheat rust-causing *Puccinia.*
- Except yeasts, fungi are filamentous. Their bodies consist of thread-like structures called **hyphae.**

- The network of hyphae is known as **mycelium.**
- Hyphae are 2 types:
  - **Coenocytic hyphae:** They are continuous tubes filled with multinucleated cytoplasm.
  - **Septate hyphae:** They have septae or cross walls.
- Fungal cell wall is made of **chitin & polysaccharides.**
- Most fungi are **saprophytes** (absorb soluble organic matter from dead substrates). Some are **parasites.**
- Some live as **symbionts.** E.g. **Lichens** (fungi+ algae), **mycorrhiza** (fungi + roots of higher plants).

Reproduction:

- **Vegetative propagation:** By fragmentation, fission & budding.
- **Asexual reproduction:** By spores such as **conidia, sporangiospores** and **zoospores**.
- **Sexual reproduction:** By **oospores, ascospores** and **basidiospores.** They are produced in distinct structures called **fruiting bodies.**

- The sexual cycle involves 3 steps:
  a. **Plasmogamy:** Fusion of protoplasm between two motile or non-motile gametes.
  b. **Karyogamy:** Fusion of two nuclei.
  c. **Meiosis** in zygote to give haploid spores.
- When a fungus reproduces sexually, **two haploid hyphae** of compatible mating types come together and fuse.
- In some fungi, the fusion of two haploid cells immediately results in **diploid cells (2n).**
- In ascomycetes and basidiomycetes, a **dikaryotic stage** or **dikaryophase** (n + n i.e. two nuclei per cell) occurs. Such a condition is called a **dikaryon.** Later, parental nuclei fuse and the cells become diploid.
- The fungi form fruiting bodies in which reduction division occurs, leading to formation of haploid spores.

Based on morphology of mycelium, mode of spore formation & fruiting bodies, Fungi are classified into different classes:

1. Phycomycetes **2. Ascomycetes**
3. Basidiomycetes **4. Deuteromycetes**

I. Phycomycetes (Lower Fungi)

- They occur in aquatic habitats and on decaying wood in moist and damp places or as obligate parasites on plants.
- The mycelium is **aseptate** and **coenocytic.**
- **Asexual reproduction:** By motile **zoospores** or by non-motile **aplanospores.** These are produced in sporangium.
- **Sexual reproduction: Zygospores** are formed by fusion of two gametes. These gametes are **isogamous** (similar in morphology) or **anisogamous or oogamous** (dissimilar).
- E.g. *Mucor, Rhizopus* (bread mould) and *Albugo* (parasitic fungi on mustard).

II. Ascomycetes (sac-fungi)

- They are unicellular (e.g., yeast, *Sacharomyces*) or multicellular (e.g., *Penicillium*).
- Mycelium is branched and septate.
- They are saprophytic, decomposers, parasitic or coprophilous (growing on dung).
- **Asexual reproduction:** By **conidia** produced exogenously on the special mycelium called **conidiophores.** Conidia germinate to produce mycelium.
- **Sexual reproduction:** By **ascospores** produced endogenously in sac like asci (sing. ascus). The asci are arranged to form fruiting bodies called **ascocarps.**
- E.g. *Aspergillus, Claviceps* and *Neurospora.*
- *Neurospora* is used in biochemical and genetic work.
- Morels & truffles are edible.

III. Basidiomycetes

- Includes **mushrooms, bracket fungi or puffballs.**
- They grow in soil, on logs and tree stumps and in living plant bodies as parasites (e.g. rusts and smuts).
- The mycelium is branched and septate.
- The asexual spores are generally not found, but **vegetative reproduction** by fragmentation is common.
- The sex organs are absent, but **plasmogamy** occurs by fusion of two vegetative or somatic cells of different strains or genotypes. The resultant structure is dikaryotic which gives rise to **basidium**. Karyogamy and meiosis take place in basidium producing four **basidiospores** exogenously. Basidia are arranged in fruiting bodies **(basidiocarps).**
- E.g. *Agaricus* (mushroom), *Ustilago* (smut) and *Puccinia* (rust fungus).

IV. Deuteromycetes

- Commonly known as **imperfect fungi** because only their asexual or vegetative phases are known.
- When perfect (sexual) stages were discovered, they were often moved to ascomycetes or basidiomycetes.
- It is also possible that **asexual and vegetative stage** have been given one name placing under **deuteromycetes** and the **sexual stage** another name placing under **another class.** When the linkages were established, the fungi were correctly identified and moved out of deuteromycetes.
- They reproduce only by asexual spores **(conidia).**
- The mycelium is septate and branched.
- Some are saprophytes or parasites. Majority are decomposers of litter and help in mineral cycling.
- E.g. *Alternaria, Colletotrichum* and *Trichoderma*.

4. KINGDOM PLANTAE (PLANT KINGDOM)

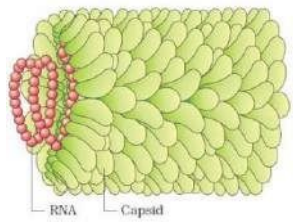
- Plants are **eukaryotic chlorophyll**-containing organisms with **cellulosic cell wall.**
- Some are partial heterotrophs (e.g. insectivorous plants like bladderwort & Venus flytrap) or parasites (e.g. *Cuscuta*).
- Plantae includes **algae, bryophytes, pteridophytes, gymnosperms** and **angiosperms.**
- Life cycle of plants has 2 phases: **Diploid sporophytic** & **haploid gametophytic.** These phases alternate with each other. This is called **alternation of generation.**
- Among different plant groups, length of the haploid & diploid phases is varied. Also, these phases are free living or dependent on others.

5. KINGDOM ANIMALIA (ANIMAL KINGDOM)

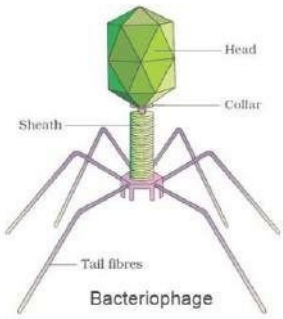
- Animals are **multicellular, heterotrophic, eukaryotic** organisms **without cell wall.**
- They directly or indirectly depend on plants for food.
- They digest their food in an internal cavity and store food reserves as glycogen or fat. Their mode of nutrition is **holozoic** (by ingestion of food).
- They have a definite growth pattern and grow into adults that have a definite shape and size.
- Higher forms show sensory and neuromotor mechanism.
- Most of them are capable of locomotion.
- The sexual reproduction is by copulation of male and female followed by embryological development.

VIRUSES, VIROIDS, PRIONS AND LICHENS

- In the five-kingdom classification, acellular organisms (viruses, viroids & prions) and lichens are not mentioned.
- Viruses are non-cellular and not truly 'living'. So they are not included in five-kingdom classification.
- Viruses have an inert crystalline structure outside the living cell.
- Viruses are **obligate parasites.**
- When they infect a cell, they take over the machinery of the host cell to replicate themselves, killing the host.
- **Louis Pasteur** gave the name **virus** (means venom or poisonous fluid).
- **D.J. Ivanowsky (1892)** discovered virus. He recognized certain microbes that cause mosaic disease of tobacco. They were smaller than bacteria because they passed through bacteria-proof filters.
- **M.W. Beijerinek (1898)** demonstrated that the extract of the infected tobacco plants cause infection in healthy plants and called the fluid as *Contagium vivum fluidum* (infectious living fluid).
- **W.M. Stanley (1935)** showed that viruses could be crystallized and crystals consist largely of proteins.
- A virus is a **nucleoprotein**, i.e., it has a **protein coat (capsid)** & **genetic material (RNA or DNA).**
- The genetic material is infectious.
- No virus contains both RNA & DNA.
- Generally, plant viruses have single stranded RNA. Animal viruses have either single or double stranded RNA or double stranded DNA. **Bacteriophages** (viruses that infect bacteria) usually have double stranded DNA.
- The **capsid** made of small subunits **(capsomeres)** protects nucleic acid. Capsomeres are arranged in **helical or polyhedral geometric** forms.



Tobacco Mosaic Virus (TMV)



Bacteriophage

- Viruses cause diseases like **mumps, small pox, herpes, influenza & AIDS.** In plants, the symptoms can be mosaic formation, leaf rolling and curling, yellowing and vein clearing, dwarfing and stunted growth.
- **Viroid:** It is an infectious agent with a free low molecular weight RNA and no protein coat. These are smaller than viruses. It is discovered by **T.O. Diener** (1971). He found that it caused **potato spindle tuber disease.**
- **Prions:** These are **abnormally folded protein** that cause some infectious neurological diseases. These are similar in size to viruses. They cause **bovine spongiform encephalopathy (BSE) or mad cow disease** in cattle and its analogous variant **Cr-Jacob disease (CJD)** in humans.

LICHENS

- Lichens are symbiotic associations (mutually useful associations) between **algae & fungi.**
- The algal component is called **phycobiont** (autotrophic) and fungal component is **mycobiont** (heterotrophic).
- Algae prepare food for fungi and fungi provide shelter and absorb mineral nutrients and water for its partner.
- Lichens are very good **pollution indicators.** They do not grow in polluted areas.

PLANT KINGDOM

Systems of Biological classification

1. Artificial classification systems

- Earliest systems of classification.
- They were based on vegetative characters or superficial morphological characters such as habit, colour, number and shape of leaves, etc.
- **Linnaeus's artificial system** of classification was based on the androecium structure.

Drawbacks:

- They separated the closely related species since they were based on a few characteristics.
- Equal weightage to vegetative and sexual characteristics. This is not acceptable since the vegetative characters are more easily affected by environment.

2. Natural classification systems

- These are based on natural affinities among organisms.
- It considers external features and internal features (ultrastructure, anatomy, embryology & phytochemistry).
- E.g. Classification for flowering plants given by **George Bentham & Joseph Dalton Hooker.**

3. Phylogenetic classification systems

- It is based on evolutionary relationships among organisms.
- This assumes that organisms in the same taxa have a common ancestor.

Other sources to resolve the problems in classification:

- **Numerical Taxonomy:** It is based on all observable characteristics. It is easily carried out using computers. Number & codes are assigned to all the characters and the data are processed. Thus, hundreds of characters can be equally considered.
- **Cytotaxonomy:** It is based on cytological information like chromosome number, structure, behaviour etc.
- **Chemotaxonomy:** It uses chemical constituents of plants.

ALGAE

- Algae are simple, thalloid, autotrophic, chlorophyll-bearing and aquatic (fresh water & marine) organisms.
- They also occur in moist stones, soils and wood.
- Some occur in association with fungi (lichen) and animals (e.g., on sloth bear).
- The form and size of algae is highly variable.
  - Microscopic unicellular forms: E.g. *Chlamydomonas.*
  - Colonial forms: E.g. *Volvox.*
  - Filamentous forms: E.g. *Ulothrix* and *Spirogyra.*

Reproduction:

- **Vegetative reproduction:** By fragmentation. Each fragment develops into a thallus.
- **Asexual reproduction:** By the production of spores. E.g. **zoospores** (most common). They are flagellated (motile) and on germination gives rise to new plants.
- **Sexual reproduction:** Through fusion of two gametes. It is many types:
  - **Isogamous:** Fusion of gametes similar in size. They may be flagellated (e.g. *Ulothrix*) or non-flagellated (non-motile, e.g. *Spirogyra*).
  - **Anisogamous:** Fusion of two gametes dissimilar in size. E.g. Some species of *Eudorina*.
  - **Oogamous:** Fusion between one large, non-motile (static) female gamete and a smaller, motile male gamete. E.g. *Volvox, Fucus.*

Benefits of algae:

☺ Through photosynthesis, they fix half of the total CO_2 on earth and increase the level of dissolved oxygen.

☺ They are primary producers and the basis of the food cycles of all aquatic animals.

☺ Many marine algae (70 species) are used as food. E.g. *Porphyra, Laminaria* and *Sargassum.*

☺ **Agar** (from *Gelidium* & *Gracilaria*) is used to grow microbes and in ice-creams and jellies.

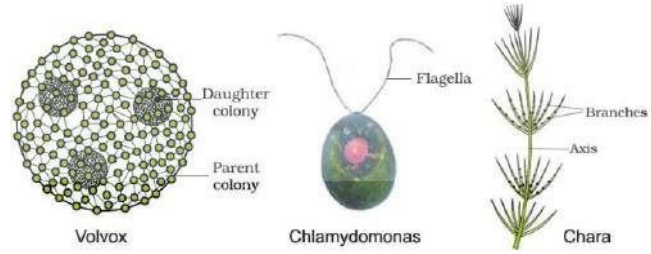
☺ Some marine brown & red algae produce **hydrocolloids** (water holding substances). E.g. **algin** (brown algae) and **carrageen** (red algae). These are used commercially.

☺ Protein-rich unicellular algae like *Chlorella* & *Spirullina* are used as food supplements by space travellers.

Algae include 3 classes: **Chlorophyceae, Phaeophyceae** and **Rhodophyceae**.

1. Chlorophyceae (green algae)

- Unicellular, colonial or filamentous.
- They are usually grass green due to the pigments **chlorophyll a** and **b** in chloroplasts.
- The chloroplasts may be discoid, plate-like, reticulate, cup-shaped, spiral or ribbon-shaped in different species.
- Most of them have one or more **pyrenoids** (storage bodies) located in the chloroplasts. Pyrenoids contain protein besides starch.
- Some algae store food as oil droplets.
- They have a rigid cell wall made of an inner layer of cellulose and an outer layer of pectose.
- E.g. *Chlamydomonas, Volvox, Ulothrix, Spirogyra* & *Chara.*

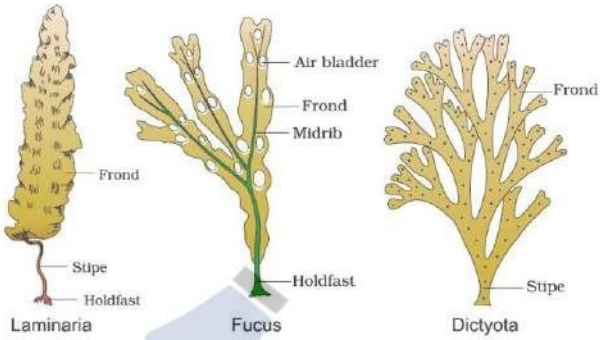


Reproduction:

- **Vegetative reproduction:** By fragmentation or by formation of different types of spores.
- **Asexual reproduction:** By flagellated zoospores produced in zoosporangia.
- **Sexual reproduction:** Isogamous, anisogamous or oogamous.

2. Phaeophyceae (brown algae)

- They are mostly marine forms.
- They show great variation in size & form. They range from simple branched, filamentous forms (E.g. *Ectocarpus*) to profusely branched forms (e.g. kelps- 100 m in height).
- They have chlorophyll *a*, *c*, carotenoids & xanthophylls.
- They vary in colour from olive green to brown depending upon the amount of a xanthophyll pigment, **fucoxanthin**.
- Food is stored as complex carbohydrates **(laminarin** or **mannitol).**
- The vegetative cells have a cellulosic wall covered by a gelatinous coating of **algin**.
- Protoplast contains plastids, central vacuole and nucleus.
- Plant body is attached to substratum by a **holdfast**, and has a stalk **(stipe)** and leaf like photosynthetic organ **(frond)**.
- E.g. *Ectocarpus, Dictyota, Laminaria, Sargassum* & *Fucus.*

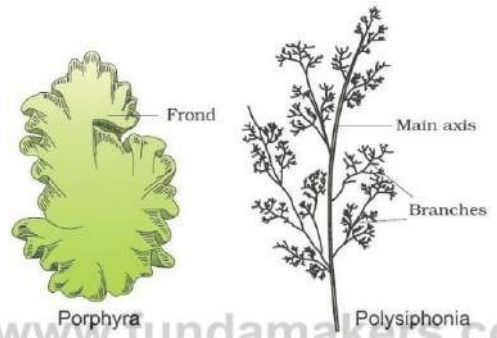


Reproduction:

- **Vegetative reproduction:** By **fragmentation.**
- **Asexual reproduction:** By pear-shaped **biflagellate zoospores** (have 2 unequal laterally attached flagella).
- **Sexual reproduction:** Isogamous, anisogamous or oogamous. Union of gametes occurs in water or withinthe oogonium (oogamous species). Gametes are pear-shaped (pyriform) bearing 2 laterally attached flagella.

3. Rhodophyceae (red algae)

- They have a red pigment, **r-phycoerythrin.**
- Majority are marine especially in the warmer areas.
- They occur in both well-lighted regions close to the surface of water and at great depths in oceans where relatively little light penetrates.
- The red thalli of most of the red algae are multicellular.
- Some of them have complex body organisation.
- The food is stored as **floridean starch** which is very similar to amylopectin and glycogen in structure.
- E.g. *Polysiphonia, Porphyra, Gracilaria* and *Gelidium.*



Reproduction:

- **Vegetative reproduction:** By **fragmentation.**
- **Asexual reproduction:** By non-motile spores.
- **Sexual reproduction:** Oogamous. By non-motile gametes. It has complex post fertilisation developments.

Classes	Chlorophyceae (Green algae)	Phaeophyceae (brown algae)	Rhodophyceae (Red algae)
Major pigments	Chlorophyll a, b	Chlorophyll a, c, Fucoxanthin	Chlorophyll a, d, Phycoerythrin
Stored food	Starch	Mannitol, laminarin	Floridean Starch
Cell wall	Cellulose	Cellulose and algin	Cellulose
Flagellar number & position of insertion	2-8, equal, apical	2, unequal, lateral	Absent
Habitat	Fresh water, salt water & brackish water	Fresh water (rare), salt water & brackish water	Fresh water (some), salt water (most) & brackish water

BRYOPHYTES

- They are called ***amphibians of the plant kingdom*** because they can live in soil but need water for sexual reproduction.
- They occur in damp, humid and shaded localities.
- Their body is more differentiated than that of algae. It is thallus-like and prostrate or erect, and attached to the substratum by unicellular or multicellular **rhizoids.**
- They lack true roots, stem or leaves. They may possess root-like, leaf-like or stem-like structures.
- The main plant body is haploid. It produces gametes, hence is called a **gametophyte**.
- The sex organs in bryophytes are multicellular.
- The male sex organ **(antheridium)** produces biflagellate **antherozoids**. The female sex organ **(archegonium)** is flask-shaped and produces a single **egg.**
- Antherozoids are released to water and meet archegonium. An antherozoid fuses with the egg to form **zygote.**
- Zygotes do not undergo meiosis immediately. They produce a multicellular body called a **sporophyte**.
- Sporophyte is not free-living but attached to the photosynthetic gametophyte and derives nourishment from it. Some cells of the sporophyte undergo meiosis to form haploid spores. They germinate to form gametophyte.

Importance of Bryophytes:

☺ Some mosses provide food for herbaceous mammals, birds and other animals.

☺ Species of *Sphagnum* (a moss) provide peat. It is used as fuel. It has water holding capacity so that used as packing material for trans-shipment of living material.

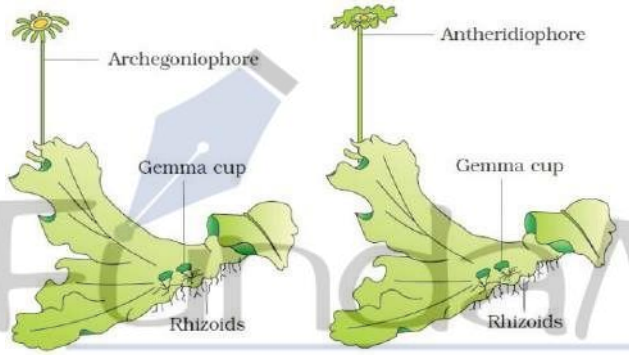
☺ They are ecologically important because of their role in **plant succession** on bare rocks/soil. Mosses along with lichens decompose rocks making the substrate suitable for the growth of higher plants.

☺ Since mosses form dense mats on the soil, they can prevent soil erosion.

The bryophytes are divided into **liverworts** and **mosses**.

Liverworts

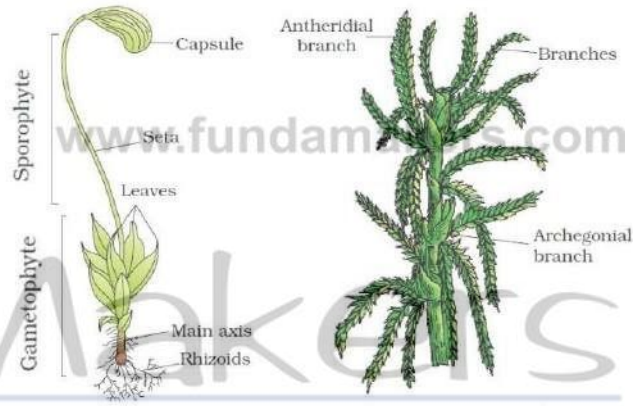
- They grow usually in moist, shady habitats such as banks of streams, marshy ground, damp soil, bark of trees and deep in the woods.
- Their plant body is thalloid. E.g. *Marchantia*. Thallus is dorsi-ventral and closely appressed to the substrate. The leafy members have tiny leaf-like appendages in two rows on the stem-like structures.
- **Asexual reproduction:** By **fragmentation** of thalli, or by the formation of **gemmae** (sing. gemma). Gemmae are green, multicellular, asexual buds that develop in small receptacles **(gemma cups)** on the thalli. Gemmae are detached from the parent body and germinate to form new individuals.
- **Sexual reproduction:** Male and female sex organs are produced on the same or different thalli. Sporophyte is differentiated into a **foot, seta** and **capsule.** After meiosis, spores are produced within the capsule. These spores germinate to form free-living gametophytes.



A liverwort – *Marchantia:* Female thallus & Male thallus

Mosses

- The predominant stage of the life cycle of a moss is the **gametophyte.** It consists of two stages.
  - **Protonema stage**: The first stage which develops directly from a spore. It is a creeping, green, branched and frequently filamentous stage.
  - **Leafy stage:** The second stage which develops from the secondary protonema as a lateral bud. They consist of upright, slender axes bearing spirally arranged leaves. They are attached to soil through multicellular and branched rhizoids. This stage bears the sex organs.
- **Vegetative reproduction:** By **fragmentation** and **budding** in the secondary protonema.
- **Sexual reproduction:** The **antheridia** & **archegonia** are produced at the apex of leafy shoots. After fertilisation, zygote develops into a sporophyte, consisting of a foot, seta and capsule. The sporophyte in mosses is more elaborate than that in liverworts. The capsule contains spores. Spores are formed after meiosis. Mosses have an elaborate mechanism of spore dispersal.
- E.g. *Funaria*, *Polytrichum* and *Sphagnum.*



Funaria, gametophyte & sporophyte — Sphagnum gametophyte

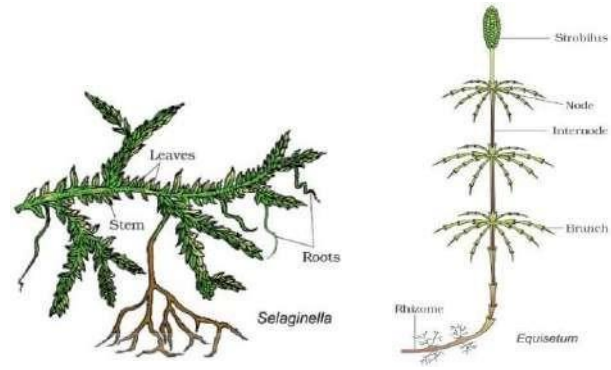
PTERIDOPHYTES

- They include **horsetails** and **ferns.**
- They are found in cool, damp, shady places. Some flourish well in sandy-soil conditions.
- Evolutionarily, they are the first terrestrial plants to possess vascular tissues (xylem & phloem).
- In bryophytes, the dominant phase in the life cycle is the gametophyte. In pteridophytes, the dominant phase (main plant body) is a **sporophyte.** It is differentiated to **true root, stem** & **leaves.** These organs have well-differentiated vascular tissues.
- The leaves in pteridophyta are small **(microphylls)** as in *Selaginella* or large **(macrophylls)** as in ferns.
- **Economic importance:** They are used for medicinal purposes and as soil-binders and ornamentals.

REPRODUCTION:

- The sporophytes bear **sporangia** that are subtended by leaf-like appendages called **sporophylls**. In some cases, sporophylls may form distinct compact structures called **strobili or cones** (E.g. *Selaginella, Equisetum*).
- Sporangia produce spores by meiosis in spore mother cells.
- The spores germinate to give inconspicuous, small, multicellular, free-living, mostly photosynthetic thalloid gametophytes called **prothallus**.
- Prothallus requires cool, damp, shady places to grow. Also, it needs water for fertilization. So, the spread of pteridophytes is limited and restricted to narrow geographical regions.
- The gametophytes (prothallus) bear male and female sex organs called **antheridia** and **archegonia,** respectively.
- Water is needed for transfer of **antherozoids** (male gametes from antheridia) to the mouth of archegonium.
- Antherozoid fuses with the egg in the archegonium to form zygote. Zygote develops to a multicellular well-differentiated **sporophyte.**
- Most of the pteridophytes produce similar kinds of spores **(homosporous plants).** Others produce two kinds of spores, **macro (mega)** & **micro spores.** They are **heterosporous**. E.g. *Selaginella* & *Salvinia.*
- The **megaspores** & **microspores** germinate and give rise to female and male gametophytes, respectively. The

female gametophytes are retained on the parent sporophytes for variable periods.
- Within female gametophytes, zygotes develop into young embryos. This event is a precursor to the **seed habit.** It is considered as an important step in evolution.
- The pteridophytes have 4 classes:
  1. **Psilopsida:** E.g. *Psilotum*
  2. **Lycopsida:** E.g. *Selaginella, Lycopodium*
  3. **Sphenopsida:** E.g. *Equisetum*
  4. **Pteropsida:** E.g. *Dryopteris, Pteris, Adiantum*



GYMNOSPERMS

- Gymnosperms (*gymnos:* naked, *sperma:* seeds) are plants in which the **ovules are not enclosed by ovary wall** and remain exposed before and after fertilization. **Seeds** that develop post-fertilization are **not covered (naked).**
- They include medium-sized trees or tall trees and shrubs. **Sequoia** (giant redwood) is the tallest tree species.
- The roots are generally **tap roots.**
- Roots in some genera have fungal association in the form of **mycorrhiza** *(E.g. Pinus).*
- In plants like *Cycas*, small specialized roots **(coralloid roots)** are associated with N_2- fixing cyanobacteria.
- Stems are unbranched (*Cycas*) or branched (*Pinus, Cedrus*).
- Leaves are simple or compound. They are well-adapted to withstand extreme temperature, humidity and wind.
- In *Cycas*, the pinnate leaves persist for a few years.
- In conifers (*Pinus, Cedrus* etc.), the needle-like leaves reduce the surface area. Their thick cuticle and sunken stomata also help to reduce water loss.

REPRODUCTION:

- Gymnosperms are **heterosporous.** They produce haploid **microspores** and **megaspores.**
- Some leaves are modified into **sporophylls.** They are compactly and spirally arranged along an axis to form **lax** or **strobili** or **cones**.
- Sporophylls bear **sporangia** in which spores are produced.
- Sporophylls are 2 types:
  - **Microsporophylls:** They are arranged to **male strobili (microsporangiate).** They bear **microsporangia.** The microspores develop into male gametophytes. It is highly reduced and confined to only a limited number of cells. This gametophyte is called a **pollen grain**. The pollen grains are developed within the microsporangia.
  - **Megasporophylls:** They are arranged to female strobili **(macrosporangiate).** They bear **megasporangia** (ovules). Megasporangium mainly consists of a body called **nucellus.** It is protected by envelopes. The megaspore mother cell is differentiated from a cell of the nucellus. Megaspore mother cell undergoes meiosis to form four megaspores. One of the megaspores enclosed within the **Megasporangium (nucellus)** develops into a multicellular female gametophyte that bears two or more **archegonia.** The multicellular female gametophyte is also retained within megasporangium.
- The male or female cones may be borne on the same tree (*Pinus*) or on different trees (*Cycas*).
- Unlike bryophytes and pteridophytes, in gymnosperms, the male and the female gametophytes do not have an independent free-living existence. They remain within the sporangia retained on the sporophytes.
- The pollen grain released from the microsporangium are carried in air currents and meet the opening of the ovules. The pollen tube carrying the male gametes grows towards archegonia in the ovules and discharges their contents near the mouth of the archegonia.
- After fertilization, zygote develops into an embryo and the ovules into seeds.

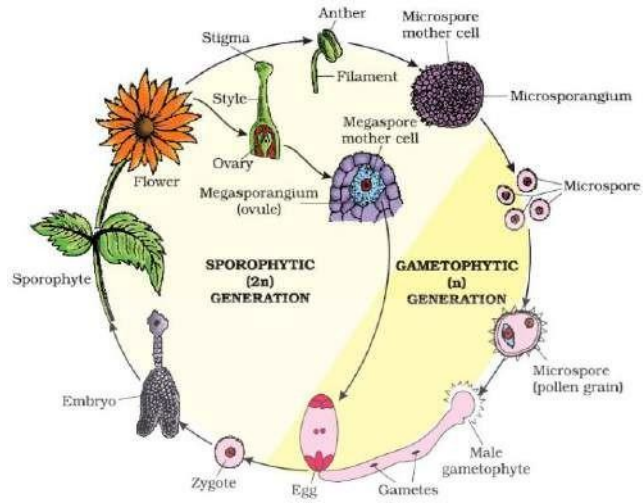
ANGIOSPERMS (FLOWERING PLANTS)

- They are an exceptionally large group of plants.
- They range in size from tiny, almost microscopic *Wolffia* to tall trees of *Eucalyptus* (over 100 metres).
- They include 2 classes: Dicotyledons & Monocotyledons.
  - **Dicotyledons:** Have 2 cotyledons in seeds, reticulate venations in leaves and tetramerous or pentamerous flowers (4 or 5 members in each floral whorl).
  - **Monocotyledons:** Have only one cotyledon, parallel venation in leaves and trimerous flowers (3 members in each floral whorl).

REPRODUCTION:

- **Flower** is the reproductive structure.
- Male sex organ in a flower is the **stamen.** Each stamen consists of a **filament** with an **anther** at the tip. Within the anthers, the **pollen mother cell** divides by meiosis to produce **microspores** which matures into **pollen grains.**
- Female sex organ in a flower is the **pistil.** It consists of a swollen **ovary** at its base, a long slender **style** & **stigma.** Ovary contains **ovules.** An ovule has a **megaspore mother cell** that undergoes meiosis to form 4 haploid **megaspores.** 3 of them degenerate and one divides to form **embryo sac.**
- Each embryo-sac has a 3-celled **egg apparatus** (one **egg cell** & two **synergids)**, 3 **antipodal** cells & 2 **polar nuclei**. The polar nuclei eventually fuse to produce a **diploid secondary nucleus.**

- Pollen grains dispersed from anthers are carried by wind or other agencies to the stigma of pistil. It is called **pollination.**
- Pollen grains germinate on the stigma and the resulting **pollen tubes** grow through the tissues of stigma and style and reach the ovule.
- Pollen tubes enter the embryo-sac where 2 male gametes are discharged. One male gamete fuses with egg cell to form **zygote (syngamy).** The other male gamete fuses with diploid secondary nucleus to produce triploid **primary endosperm nucleus (PEN).** Because of the involvement of two fusions, this event is called **double fertilisation.** It is an event unique to angiosperms.
- The zygote develops into an **embryo** (with one or two cotyledons). The PEN develops into **endosperm** which provides nourishment to the developing embryo.
- Synergids & antipodals degenerate after fertilization.
- During these events, the **ovules** develop into **seeds** andthe **ovaries** develop into **fruit.**
- The seeds are enclosed by fruits.

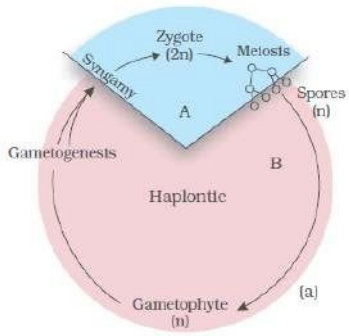


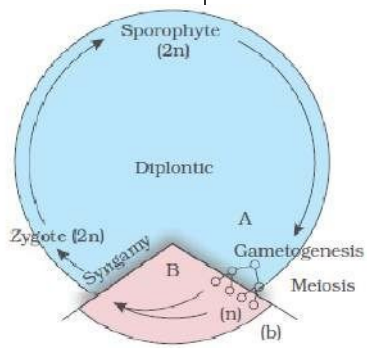
PLANT LIFE CYCLES AND ALTERNATION OF GENERATIONS

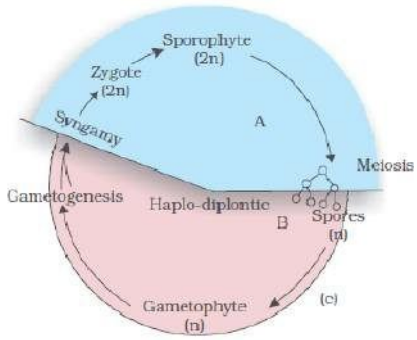
- In plants, both haploid and diploid cells can divide by mitosis. This forms haploid and diploid plant bodies.
- Haploid plant body **(gametophyte)** produces gametes by mitosis.
- After fertilization, the zygote also divides by mitosis to produce a diploid plant body **(sporophyte).** This produces haploid **spores** by meiosis.
- Spores divide by mitosis to form a haploid plant body.
- Thus, during the life cycle of any sexually reproducing plant, there is an alternation of generations between gametophyte (n) and sporophyte (2n).

Patterns of Plant life cycles

1. **Haplontic:** In this, sporophytic generation is represented only by the zygote. There are no free-living sporophytes. Zygote undergoes meiosis to form haploid spores. They divide mitotically to form gametophyte. The dominant, photosynthetic phase is the free-living gametophyte. E.g. Algae such as *Volvox*, *Spirogyra* and some species of *Chlamydomonas*.
2. **Diplontic:** In this, diploid sporophyte is the dominant, photosynthetic, independent phase. Gametophytic phase is represented by the single to few-celled haploid gametophyte. E.g. An alga, *Fucus* sp., all seed-bearing plants (gymnosperms & angiosperms - the gametophytic phase is few to multi-celled).
3. **Haplo-diplontic:** It is the intermediate condition between haplontic & diplontic. Both gametophyte & sporophyte are multicellular and often free-living. But they have different dominant phases. E.g. Bryophytes & Pteridophytes.







ANIMAL KINGDOM

Animals are **multicellular** and **heterotrophic** organisms **without cell wall** and **chlorophyll.**

Kingdom Animalia includes 11 major phyla:

1. Porifera
2. Cnidaria
3. Ctenophora
4. Platyhelminthes
5. Aschelminthes
6. Annelida
7. Arthropoda
8. Mollusca
9. Echinodermata
10. Hemichordata
11. Chordata

BASIS OF CLASSIFICATION

1. Levels of organization

Based on this, animals are grouped into four levels:

a. Cellular level of organization: Here, the cells are arranged as loose cell aggregates. E.g. Porifera.

b. Tissue level of organization: Here, the cells are arranged into **tissues.** E.g. Cnidarians and Ctenophores.

c. Organ level of organization: Here, tissues are arranged into **organs.** E.g. Higher animals (Platyhelminthes to chordates).

d. Organ system level of organization: Here, organs are associated to **organ system.** Each system performs a specific physiological function. E.g. Higher animals.

Organ systems of various animals show complexities. E.g.

Digestive system is 2 types:

- **Incomplete:** It has only a single opening that acts as mouth & anus. Seen in Cnidaria and Platyhelminthes.
- **Complete:** It has 2 openings (mouth & anus).

Circulatory system is 2 types: **open** & **closed.**

2. Body symmetry

It is the arrangement of similar bodyparts on 2 sides of main axis of the body. Based on symmetry, animals are 2 types: Asymmetrical and Symmetrical.

a. Asymmetrical: Here, body cannot be divided into 2 equal halves. E.g. Most Poriferans, Snails etc.

b. Symmetrical: Here, body can be divided into 2 equal halves. It is 2 types.

- **Radial symmetry:** Here, body can be divided into 2 equal halves in **any vertical plane** along **central axis** (oral-aboral axis) of the body. E.g. some Poriferans, Cnidarians, Ctenophores and Echinoderms (adult).
- **Bilateral symmetry:** Here, body can be divided into **right & left halves** in only **one plane.** E.g. Platyhelminthes to Chordata (except adult Echinodermata).

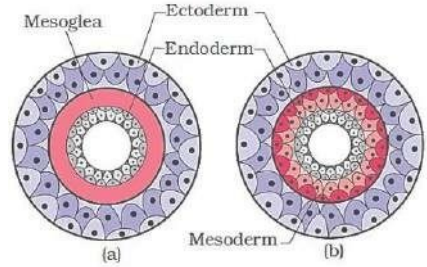
The body of bilaterally symmetrical animal has a **dorsal side** (upper), a **ventral side** (lower), left & right **lateral sides**, **anterior** (cephalic) side and **posterior** (anal or tail) side.

3. Germinal layers (Embryonic layers)

These are layers of embryo from which all the body organs are formed. Based on the number of germ layers, animals are 2 types- Diploblastic and Triploblastic.

a. Diploblastic animals: 2 germ layers- outer ectoderm and inner endoderm. In between these layers, an undifferentiated jelly-like layer called **mesoglea** is present. E.g. Cnidaria & Ctenophora.

b. Triploblastic animals: 3 germ layers- Outer ectoderm, middle mesoderm and inner endoderm. E.g. Platyhelminthes to Chordata.



(a) Diploblastic
(b) Triploblastic

4. Coelom (body cavity)

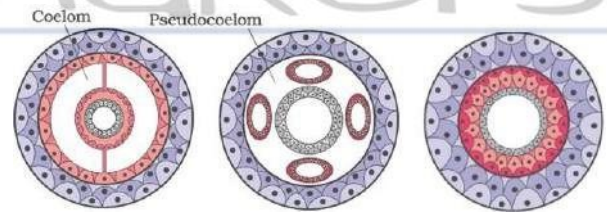
It is the cavity lined by mesoderm. It is seen between body wall and gut wall. Coelom separates the muscles of gut and body wall.

Based on the nature of coelom, animals are 3 types:

a. Acoelomate: No coelom. The space between body wall and digestive cavity is filled with matrix (parenchyma). E.g. Porifera to Platyhelminthes.

b. Pseudocoelomate: False coelom. Here, the body cavity is not lined by mesoderm. Mesoderm is scattered pouches. E.g. Aschelminthes.

c. Coelomate: True coelom. Here, the coelom arises from the mesoderm. Coelom is lined by peritoneal layer and filled with coelomic fluid. E.g. Annelida to Chordata.



Coelomate *Pseudocoelomate* *Acoelomate*

Functions of coelom:

- It accommodates visceral organs.
- Coelomic fluid reduces friction between visceral organs.
- It acts as shock absorber.

5. Metamerism (segmentation)

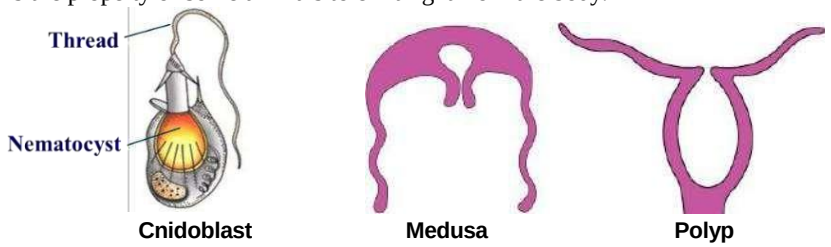
It is the phenomenon in which the body or organs is externally and internally divided into **repeated segments (metameres).** E.g. Annelids (earthworm etc.), Arthropods.

6. Notochord

It is a **mesodermally derived supporting rod** formed on the dorsal side during embryonic development in some animals. Animals with notochord are called **chordates** and those without notochord are called **non-chordates.**

Features	Porifera (Sponges)	Cnidaria (Coelenterata)	Ctenophora (Comb jellies or Sea walnuts)
Grades of organization	Cellular	Tissue	Tissue
Symmetry	Asymmetrical. Some are radial.	Radial	Radial
Germ layers	-	Diploblastic	Diploblastic
Coelom	Acoelomate	Acoelomate	Acoelomate
Habit and habitat	Aquatic (mostly marine). Sedentary. Solitary/colonial.	Aquatic (mostly marine). Sessile/free swimming. Solitary/colonial.	Exclusively marine. Solitary & pelagic
Digestive system	Absent. Intracellular digestion.	Incomplete. Intracellular & extracellular digestion.	Incomplete. Intracellular and extracellular digestion.
Respiratory system	Absent	Absent	Absent
Circulatory system	Absent	Absent	Absent
Reproduction	Asexual **(fragmentation)** & Sexual. Hermaphrodite. Internal fertilization. Development is indirect.	Polyp reproduces asexually (budding) and medusa sexually. Most are separate sexes. External fertilization. Development is indirect.	Only Sexual. Hermaphrodite. External fertilization. Development is indirect.
Unique features	**Water canal (water transport) system.** Millions of **ostia (pores).** **Spongocoel** & canals are lined with **choanocytes** (collar cells). Body is supported by **spicules** and **spongin** fibres.	**Tentacles** with **cnidoblasts.** **Gastro-vascular cavity (coelenteron)** with an opening (mouth) on **hypostome.** **Polyp** & **Medusa** forms are seen. Some shows **alternation of generation.** **Corals** have skeleton ($CaCO_3$).	Locomotion is by **8** vertical external rows of ciliated **comb plates**. Tentacles present. Shows **Bioluminescence.**
Examples	*Sycon (Scypha),* *Spongilla* (fresh water sponge), *Euspongia* (Bath sponge)	*Hydra, Obelia, Aurelia, Physalia* (Portuguese man of war), *Adamsia* (Sea-anemone), *Pennatula* (Sea pen), *Gorgonia* (Sea fan), *Meandrina* (Brain coral)	*Ctenoplana,* *Pleurobrachia*

1. **Water canal system:** Here, water enters through minute pores **(ostia)** in the body wall into a central cavity **(spongocoel),** from where it goes out through **osculum.** Canal system is used for food gathering, gas exchange and removal of wastes.
2. **Hermaphrodite (Monoecious):** Male and female sex organs are seen in same individual.
3. **Tentacles:** Finger-like structures which surrounds the mouth of coelenterates. Used for food capture &defense.
4. **Cnidoblasts (Cnidocytes):** These are stinging cells (present on the tentacles and the body) with a poison-filled capsule called ***nematocyst***. Cnidoblast is used for **anchorage, defense** and to **capture prey.**
5. **Polyp & Medusa:** 2 types of body forms in cnidarians.
   Polyp is tubular attached asexual form, with upwardly directed mouth & tentacles. E.g. *Hydra, Adamsia.*
   Medusa is umbrella like, free-swimming sexual form, with downwardly directed mouth & tentacles. E.g. *Aurelia* (Jelly fish).
6. **Alternation of generation (Metagenesis):** The phenomenon in which polyps produce medusae asexually and medusae form the polyps sexually. E.g. *Obelia.*
7. **Bioluminescence:** It is the property of some animals to emit light from the body.



Features	Platyhelminthes (Flatworms)	Aschelminthes (Roundworms)	Annelida (Segmented or Ringed worms)	Arthropoda (Joint-legged animals)
Grades of organization	Organ & Organ system	Organ system	Organ system	Organ system
Symmetry	Bilateral	Bilateral	Bilateral	Bilateral
Germ layers	Triploblastic	Triploblastic	Triploblastic	Triploblastic
Coelom	Acoelomate	Pseudocoelomate	Coelomate	Coelomate
Habit and habitat	Mainly aquatic. Endoparasites. Some are free-living.	Aquatic and terrestrial. Free living or parasitic in plants & animals.	Terrestrial, fresh water or marine. Free living or parasitic.	Cosmopolitan
Digestive system	Incomplete	Complete. Tubular alimentary canal with well-developed muscular pharynx.	Complete	Complete
Respiratory system	Absent	Absent	**Cutaneous** respiration. Some have **branchial (gill)** respiration.	**Gills/ book gills/ trachea/book lungs**
Circulatory system	Absent	Absent	Closed type	Open type
Reproduction	Asexual (fragmentation) and Sexual. Hermaphrodite. Internal Fertilization. Development is indirect. Many larval stages.	Dioecious. Sexual reproduction. Internal fertilization. Development is direct or indirect.	Sexual. Earthworms & leeches are monoecious. *Neries* is dioecious. Development is direct or indirect.	Mostly dioecious. Usually internal fertilization. Mostly **oviparous.** Development is direct or indirect.
Unique features	**Unsegmented, dorso-ventrally flattened body** (except tape worms). Excretion and osmo-regulation by **Flame cells (protonephridia).** Parasites have **Hooks** & **suckers.** Some absorb nutrients from the host through their body surface.	Body is circular in cross section. **Syncytial** epidermis. Thick cuticle. An excretory tube to remove body waste through excretory pore. **Sexual dimorphism** (females are longer than males).	Segmentation like rings. **Longitudinal and circular muscles** help in locomotion. Locomotory organs are **setae** (in earthworm) or **parapodia** (in *Neries*). Excretion by **Nephridia.** Paired ganglia connected by lateral nerves to a double ventral nerve cord.	**Jointed appendages**. Body has 3 regions: **head, thorax** & **abdomen.** Body is covered by **chitinous cuticle (exoskeleton).** Excretion by **Malpighian tubules.** **Sensory organs** are **antennae, compound** & **simple eyes, statocysts (balance organs)**.
Examples	*Taenia solium* (Tape worm), *Fasciola* (Liver fluke), *Planaria* (shows high regeneration capacity).	*Ascaris* (Roundworm), *Ancylostoma* (Hookworm), *Wuchereria* (Filarial worm).	*Pheretima* (earthworm), *Hirudinaria* (blood sucking Leech), *Neries* (aquatic. Parapodia for swimming).	Spider, Scorpion, Crab, Prawn, Insects etc. **Economically important insects:** *Apis*, *Bombyx*, *Laccifer*. **Vectors:** Mosquitoes (*Anopheles*, *Culex* & *Aedes*), Housefly etc. **Gregarious pest**: *Locusta*. **Living fossil:** *Limulus* (King crab)

1. **Dioecious:** Sexes are separate.
2. **Sexual dimorphism:** Morphological differences between male and female.
3. Arthropoda is the largest phylum. Over two-thirds of all named species are arthropods.

GENERAL CHARACTERS OF DIFFERENT PHYLA (NON-CHORDATES)

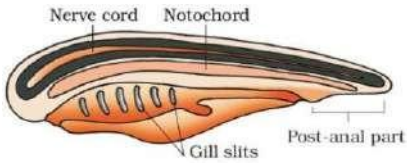
Features	Mollusca (Soft-bodied animals)	Echinodermata (Spiny-skinned animals)	Hemichordata
Grades of organization	Organ system	Organ system	Organ system
Symmetry	Bilateral	Adults radial. Larvae bilateral.	Bilateral
Germ layers	Triploblastic	Triploblastic	Triploblastic
Coelom	Coelomate	Coelomate	Coelomate
Habit and habitat	Aquatic. Few are terrestrial.	Exclusively marine.	Exclusively marine.
Digestive system	Complete	Complete. Ventral mouth and dorsal anus.	Complete
Respiratory system	**Gills** in aq. forms and **pulmonary sac** in terrestrial forms.	**Dermal branchiae (skin gills** or **papulae)** and **tube feet.**	**Gills**
Circulatory system	Open type	Open type	Open type
Reproduction	Dioecious. Oviparous. Development is direct or indirect.	Dioecious. External fertilization. Development is indirect. Ciliated free-swimming larva.	Dioecious. External fertilization. Development is indirect.
Unique features	Body has **head, visceral mass (visceral hump)** & muscular **foot.** Head has **sensory tentacles.** Calcareous shell. Feather-like gills for respiration & excretion. **Mantle** & **radula** are seen.	They have an endoskeleton of calcareous **ossicles** (Spiny bodied). Head absent. **Water vascular system** present. Excretory system absent. Shows **autotomy** & **regeneration.**	Worm-like cylindrical body formed of anterior **proboscis, a collar** and a long **trunk.** Collar bears **stomochord** (a rudimentary structure similar to notochord). Excretion by **Proboscis gland.**
Examples	*Pila* (Apple Snail), *Pinctada* (Pearl Oyster), *Sepia* (Cuttlefish), *Loligo* (Squid), *Octopus* (Devil fish), *Aplysia* (Sea Hare), *Dentalium* (Tusk shell), *Chaetopleura* (Chiton)	*Asterias* (Starfish), *Echinus* (Sea Urchin), *Echinocardium*, *Antedon* (Sea Lily), *Cucumaria* (Sea Cucumber), *Ophiura* (Brittle Star)	*Balanoglossus* (Tongue worm), *Saccoglossus*

1. **Mollusca** is the second largest phylum.
2. **Mantle (Pallium):** The membrane which covers visceral mass. Space between the hump and mantle is called ***mantle cavity.***
3. **Radula:** File-like rasping organ present in the mouth of molluscs. It is used for feeding.
4. **Water vascular (ambulacral) system:** In this system, sea water enters through a porous plate called ***madreporite*** and reaches the radiating canals and ***tube feet (podia).*** Its functions are locomotion, respiration, capture & transport of food and excretion.
5. Hemichordata was earlier considered as a sub-phylum of Chordata. Like chordates, it has pharyngeal gill slits.

PHYLUM CHORDATA

It includes animals with notochord, dorsal tubular nerve cord and pharyngeal gill slits.
Notochord is a flexible rod located in the mid dorsal line between the alimentary canal and the nerve cord in the embryo.

Differences between Chordata and Non-Chordata

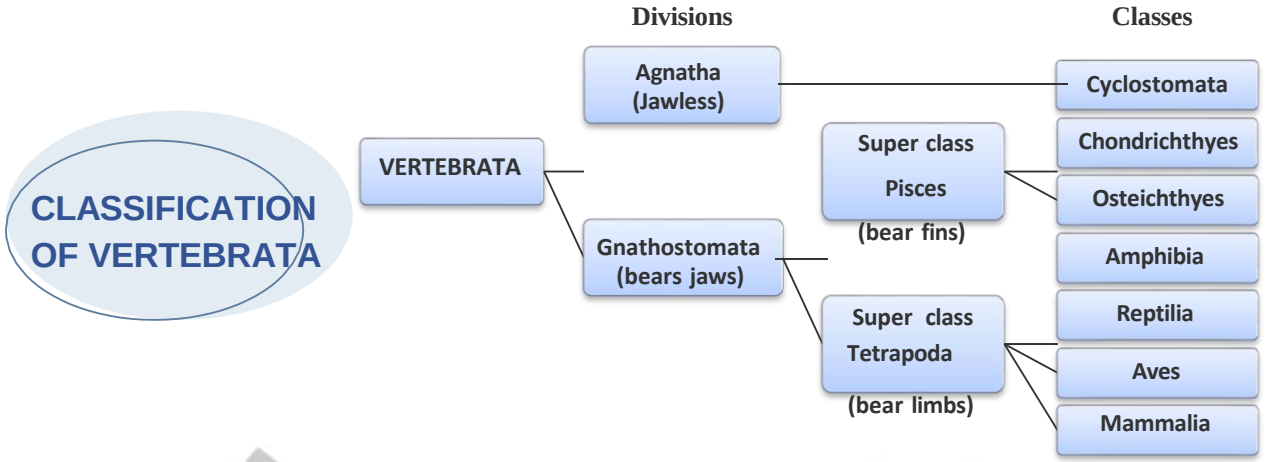


Chordata characteristics (Body plan)

Chordata	Non-Chordata
1. Notochord is found in the embryonic stage	Absent
2. Central nervous system is dorsal, hollow and single	Ventral, solid and double
3. Pharyngeal gill slits present	Absent
4. Ventral heart	Dorsal heart (if present)
5. A post-anal part (tail) is present	Absent

Phylum Chordata is classified into 3 subphyla: **Urochordata, Cephalochordata & Vertebrata.**

PROTOCHORDATA (ACRANIATA)		VERTEBRATA (CRANIATA)
Urochordata (Tunicata)	**Cephalochordata**	
• **Notochord** present only in larval tail. • Body is covered by **test** made up of **tunicin.** • Exclusively marine. • Hermaphrodite. • E.g. *Ascidia, Salpa, Doliolum.*	• Notochord from head to tail region and is persistent throughout the life. • Fish-like body. • Exclusively marine. • Sexes are separate. • E.g. *Branchiostoma* (Amphioxus or Lancelet).	• Possess notochord during the embryonic period. • Notochord is replaced by a cartilaginous or bony **vertebral column** in the adult. • **Ventral** muscular **heart.** • **Kidneys** for excretion & osmoregulation • **Paired appendages** (fins or limbs).



CLASS CYCLOSTOMATA

- All are ***ectoparasites*** on some fishes.
- Elongated body without scales and paired fins.
- 6-15 pairs of ***gill slits*** for respiration.
- Sucking and circular mouth ***without jaws.***
- ***Cartilaginous cranium*** and ***vertebral column.***
- Circulation is ***closed*** type.
- Marine, but migrate for ***spawning*** to fresh water. After spawning, they die. Their larvae, after metamorphosis, return to ocean.
- E.g. *Petromyzon* (Lamprey) and *Myxine* (Hagfish).

SUPERCLASS PISCES (FISHES)

Class Chondricthyes (Cartilaginous fishes)	Class Osteichthyes (Bony fishes)
Marine. Stream-lined body. Predaceous.	Marine & fresh water. Stream-lined body.
Cartilaginous endoskeleton. **Notochord** is **persistent** throughout life.	**Bony endoskeleton.**
Ventral mouth.	Terminal mouth.
Gill slits without operculum. Powerful jaws.	4 pairs of **gills** covered by **operculum** on each side.
Skin with **placoid scales.** Teeth are modified placoid scales which are backwardly directed.	Scales are **Cycloid, ctenoid** etc.
No air bladder. So, they have to swim constantly to avoid sinking.	**Air bladder** for buoyancy.
Poikilotherms (cold-blooded).	**Poikilotherms** (cold-blooded).
Two-chambered heart (one auricle and one ventricle).	**Two-chambered** heart (one auricle and one ventricle).
Sexes are separate. In males, pelvic fins bear **claspers.** Internal fertilization. Many of them **viviparous.**	Sexes are separate. External fertilisation. Mostly **oviparous.** Development is direct.

Examples	**Examples**
Scoliodon (Dogfish), *Pristis* (Saw fish), *Carcharodon* (Great white shark), *Trygon* (Sting ray- has poison sting), *Torpedo* (Electric ray- has ***electric organ).***	**Marine:** *Exocoetus* (flying fish), *Hippocampus* (seahorse) **Fresh water:** *Labeo* (Rohu), *Catla* (Katla), *Clarias* (Magur). **Aquarium:** *Betta* (Fighting fish), *Pterophyllum* (Angel fish).

SUPERCLASS TETRAPODA

Class Amphibia	Class Reptilia	Class Aves (Birds)	Class Mammalia
They live in aquatic & terrestrial habitats and need water for breeding.	Dry & cornified skin, epidermal ***scales*** or ***scutes***.	Presence of ***feathers*** and ***beak.*** Forelimbs are modified into ***wings.***	Presence of ***mammary glands*** (milk producing glands).
Body has head & trunk. Some have tail. ***Moist skin*** without scales. Most have 2 pairs of limbs.	Snakes and lizards shed their scales as ***skin cast.*** Limbs- 2 pairs (if present). Crawling mode of locomotion.	Dry skin without glands except the ***oil gland*** at the base of tail. Hind limbs have ***scales*** and are modified for walking, swimming or clasping tree branches. Hollow & pneumatic long bones.	Skin with ***hair.*** 2 pairs of limbs for walking, running, climbing, burrowing, swimming or flying.
Tympanum represents ear.	***Tympanum*** represents ear.	***Tympanum*** represents ear.	External ear ***(Pinnae).***
3-chambered heart (2 auricles + 1 ventricle).	***3-chambered*** heart (but a septum partially separates ventricle). Heart is ***4-chambered*** in **crocodiles.**	***4-chambered*** heart.	***4-chambered*** heart.
Poikilotherms	***Poikilotherms***	***Homoiotherms***	***Homoiotherms***
Alimentary canal, urinary & reproductive tracts open into a ***Cloaca*** which opens to exterior.	Well-developed alimentary canal.	Digestive tract has additional chambers, the ***crop*** & ***gizzard***.	Well-developed alimentary canal. Dentition is ***Heterodont, thecodont & diphyodont.***
Respiration is by ***gills*** (in larva), ***lungs*** & ***skin***	Respiration by ***lungs.***	Double respiration. ***Air sacs*** connected to lungs.	Respiration by ***lungs.***
Sexes are separate. External fertilisation. ***Oviparous***. Development is indirect.	Internal fertilisation. ***Oviparous.*** Development is direct.	Internal fertilisation. ***Oviparous.*** Development is direct.	Sexes are separate. Internal fertilisation. ***Viviparous*** (except *Echidna* and *Platypus*). Development is direct.
Examples *Bufo* (Toad), *Rana* (Frog), *Hyla* (Tree frog), *Salamandra* (Salamander), *Ichthyophis* (Limbless amphibia)	**Examples** *Chelone* (Turtle), *Testudo* (Tortoise), *Chameleon* (Tree lizard), *Calotes* (Garden lizard), *Crocodilus* (Crocodile), *Alligator*, *Hemidactylus* (Wall lizard). **Poisonous snakes**: *Naja* (Cobra), *Bangarus* (Krait), *Vipera* (Viper) etc. **Non-poisonous snakes:** *Python* etc.	**Examples** *Corvus* (Crow), *Columba* (Pigeon), *Psittacula* (Parrot), *Struthio* (Ostrich), *Pavo* (Peacock), *Aptenodytes* (Penguin), *Neophron* (Vulture) etc.	**Examples** *Ornithorhynchus* (Platypus), *Macropus* (Kangaroo), *Pteropus* (flying fox), *Camelus* (Camel), *Macaca* (Monkey), *Rattus* (Rat), *Canis* (dog), *Felis* (Cat), *Elephas* (Elephant), *Equus* (Horse), *Delphinus* (Commondolphin), *Balaenoptera* (blue whale), *Panthera tigris* (Tiger), *Panthera leo* (lion)

- **Poikilotherms (Cold-blooded animals):** Animals that lack the capacity to regulate their body temperature.
- **Homoiotherms (warm-blooded animals):** Animals having ability to maintain a constant body temperature.

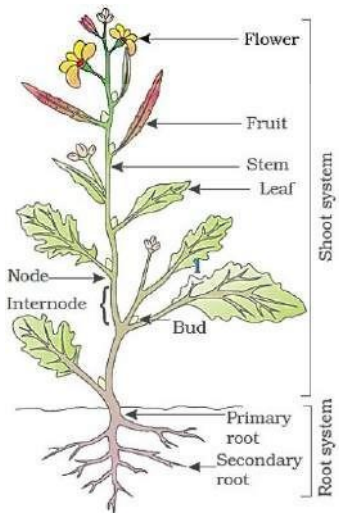
MORPHOLOGY OF FLOWERING PLANTS

- **Morphology** is the study of external forms of organisms.
- A flowering plant (Angiosperm) has 2 parts: **Root system** (underground part) & **Shoot system** (portion above the ground).

THE ROOT

It is the underground part formed from **radicle** of embryo.

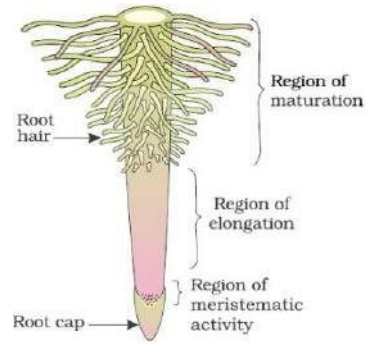
Root systems are 3 types:



- **Tap root system:** It consists of **primary roots (tap root)** and its branches (lateral roots such as **secondary roots, tertiary roots)**. Seen in dicots. Primary root is elongated from **radicle.** E.g. Mustard plant.
- **Fibrous root system:** In monocots, primary root is short lived and is replaced by many roots. They originate from the base of stem to form fibrous root system**.** E.g. Wheat.
- **Adventitious root system:** Roots that arise from parts other than radicle. E.g. Grass, *Monstera* and banyan tree.

Regions of the Root

- **Root cap:** It is the covering at the apex of root. It protects the tender apex of the root.
- **Region of meristematic activity:** Seen above the root cap. Here, the cells are very small, thin-walled and with dense protoplasm. They divide repeatedly.
- **Region of elongation:** Region just above the meristematic region. Here, cells undergo rapid elongation and enlargement. Helps in growth of the root in length.
- **Region of maturation:** It is proximal to elongation zone. Here, the cells differentiate and mature.



- **Root hairs:** Very fine, delicate, thread-like structures formed from epidermal cells in region behind region of elongation. They absorb water and minerals from the soil.

Modifications of Root

In some plants, roots are modified to perform functions other than absorption and conduction. E.g.

- **Swollen roots for food storage:** E.g. Tap roots of carrot, turnips and adventitious roots of sweet potato.
- **Prop roots**: Hanging structures that support banyan tree.
- **Stilt roots:** The supporting roots coming out of the lower nodes of the stem. E.g. maize & sugarcane.
- **Pneumatophores:** The roots that come out of the ground and grow vertically upwards to get oxygen for respiration. E.g. *Rhizophora* growing in swampy areas.

Functions of root

- ☺ Absorption of water and minerals from the soil.
- ☺ Provide a proper anchorage to the plant parts.
- ☺ Storage of reserve food material.
- ☺ Synthesis of plant growth regulators.

THE STEM

- It is the ascending part of the axis that develops from the **plumule** of the embryo of a germinating seed.
- It bears branches, leaves, flowers, fruits, buds (terminal or axillary), nodes and internodes.
- **Nodes** are the regions of the stem where leaves are born. **Internodes** are the portions between two nodes.
- Young stem is generally green and later often become woody and dark brown.

Functions of stem:

- ☺ Spreading out branches bearing leaves, flowers and fruits.
- ☺ It conducts water, minerals and photosynthates.
- ☺ Food storage, support, protection & vegetative propagation.

Modifications of Stem

- **For food storage:** E.g. underground stems of potato, ginger, turmeric, *zaminkand*, *Colocasia* etc. They also act as organs of perennation to tide over conditions unfavourable for growth.
- **Stem tendrils:** Slender and spirally coiled structures formed from axillary buds. They help plants to climb. E.g. Gourds (cucumber, pumpkins, watermelon) & grapevines.
- **Thorns:** Woody, straight and pointed structuresdeveloped from axillary buds. They protect plants from browsing animals. E.g. *Citrus*, *Bougainvillea*.
- **Phylloclade:** It is a green, flattened or fleshy cylindrical stem containing chlorophyll for photosynthesis. Found in some plants of arid regions. E.g. *Opuntia* (flattened stem), *Euphorbia* (cylindrical stem).
- **Stolon:** Slender lateral branch that arises from the base of the main axis and after growing aerially for some time arch downwards to touch the ground. E.g. mint & jasmine.
- **Offset:** It is a lateral branch with short internodes and each node bearing a rosette of leaves and a tuft of roots. E.g. aquatic plants like *Pistia* and *Eichhornia*.
- **Sucker:** The lateral branches that originate from the basal underground part of the main stem. It grows horizontally beneath the soil and come out obliquely upward giving rise to leafy shoots. E.g. Banana, Pineapple & *Chrysanthemum.*

Underground stems of grass, strawberry etc. spread to new niches. When older parts die, new plants are formed.

THE LEAF

- It is a lateral, flattened structure borne on the stem.
- It develops at the node and bears a bud in its axil.
- The **axillary bud** later develops into a branch.
- Leaves originate from shoot apical meristems and are arranged in an acropetal order.
- They are important vegetative organs for photosynthesis.

A typical leaf has 3 main parts:

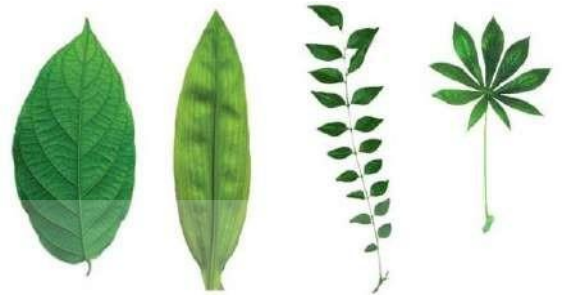
- **Leaf base:** With this, the leaf is attached to stem. It may bear two lateral small leaf-like structures called **stipules.** In monocots, the leaf base expands into a sheath covering the stem partially or wholly. In some leguminous plants, the leaf base may be swollen. It is called **pulvinus**.
- **Petiole:** It helps to hold the leaf blade to light. Long thin flexible petioles allow leaf blades to flutter in wind, thereby cooling leaf and bringing fresh air to leaf surface.
- **Lamina (leaf blade):** The green expanded part with veins & veinlets. The middle prominent vein is called **midrib.** Veins provide rigidity to lamina and act as channels of transport for water, minerals & food materials.

Venation

- It is the arrangement of veins and veinlets in leaf lamina.
- It is 2 types:
  - **Reticulate venation:** Here, the veinlets form a network. It is seen in dicotyledons.
  - **Parallel venation:** Here, the veins run parallel to each other within a lamina. It is seen in monocotyledons.

Types of Leaves

- **Simple leaf:** Here, leaf lamina is entire or when incised, the incisions do not touch the midrib.
- **Compound leaf:** Here, the incisions of the lamina reach up to the midrib breaking it into several leaflets.
  A bud is seen in the axil of petiole in simple & compound leaves, but not in the axil of leaflets of the compound leaf. The compound leaves are 2 types.
  - **Pinnately compound leaf:** In this, many leaflets are present on a common axis, the **rachis**, which represents the midrib of the leaf. E.g. neem.
  - **Palmately compound leaf:** In this, leaflets are attached at a common point (at the tip of petiole). E.g. silkcotton.



Phyllotaxy

It is the pattern of arrangement of leaves on the stem or branch. It is 3 types:

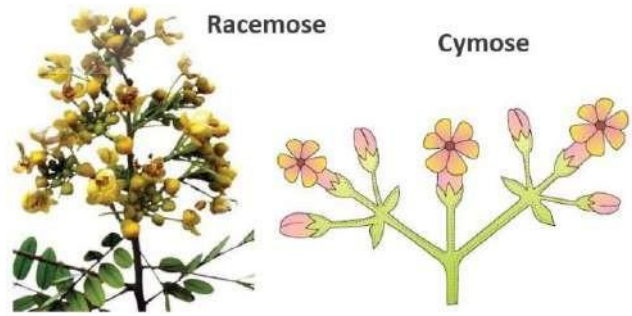
- **Alternate:** In this, a single leaf arises at each node in alternate manner. E.g. China rose, mustard & sun flower.
- **Opposite:** In this, a pair of leaves arise at each node and lie opposite to each other. E.g. *Calotropis* and guava.
- **Whorled:** In this, more than two leaves arise at a node and form a whorl. E.g. *Alstonia.*

Modifications of Leaves

- Leaves are modified to perform functions other than photosynthesis. E.g.
  - **Tendrils:** For climbing. E.g. peas.
  - **Spines:** For defense. E.g. cacti.
  - **Fleshy leaves:** To store food. E.g. onion and garlic.
- In plants such as Australian acacia, the leaves are small and short-lived. The petioles in these plants expand, become green and synthesise food.
- Leaves of some insectivorous plants (e.g. pitcher plant, Venus-fly trap) are also modified leaves.

THE FLOWER AND THE INFLORESCENCE

- A flower is a modified shoot wherein the shoot apical meristem changes to floral meristem.
- Internodes do not elongate and the axis gets condensed.
- The apex produces different kinds of floral appendages laterally at successive nodes instead of leaves.
- When a shoot tip transforms into a flower, it is solitary.
- The arrangement of cluster of flowers on the floral axis is called **inflorescence.**
- Based on whether the apex gets converted into a flower or continues to grow, inflorescences are 2 types: Racemose and Cymose.



- **Racemose:** In this, the main axis continues to grow. Flowers are borne laterally in an acropetal succession.

- **Cymose:** In this, main axis terminates in a flower, hence is limited in growth. Flowers are borne in a basipetal order.

THE FLOWER

- It is the **reproductive unit** in the angiosperms.
- It is meant for sexual reproduction.
- A flower has a **stalk (pedicel).** Its swollen end is called **thalamus (receptacle)**.
- Reduced leaf found at the base of the pedicel is called **bracts.** Flowers with bracts are called **bracteate** and those without bracts, **ebracteate**.
- A typical flower has 4 kinds of whorls arranged on thalamus- **calyx, corolla, androecium & gynoecium.**
- Calyx & corolla are accessory organs, while androecium and gynoecium are reproductive organs.
- In flowers like lily, the calyx and corolla are not distinct. It is termed as **perianth.**
- When a flower has both androecium and gynoecium, it is **bisexual**. A flower having either only androecium or only gynoecium is **unisexual.**

Based on symmetry, flowers are 3 types:

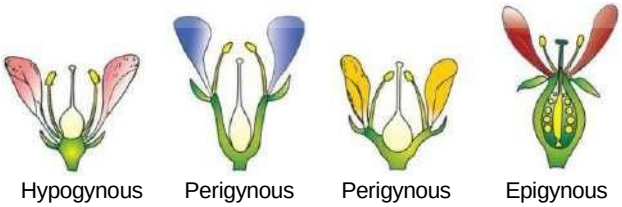
- **Actinomorphic** (radial symmetry): Here, a flower can be divided into 2 equal radial halves in any radial plane passing through the centre. E.g. mustard, *datura*, chilli.
- **Zygomorphic** (bilateral symmetry): Here, a flower can be divided into two similar halves only in a particular vertical plane. E.g. pea, gulmohur, bean, *Cassia*.
- **Asymmetric** (irregular): Here, a flower cannot be divided into two similar halves by any vertical plane passing through the centre. E.g. canna.

Based on number of floral appendages, flowers are classified as follows:

- **Trimerous:** Floral appendages are multiple of 3.
- **Tetramerous:** Floral appendages are multiple of 4.
- **Pentamerous:** Floral appendages are multiple of 5.

Based on the position of calyx, corolla and androecium in respect of the ovary on thalamus, the flowers are 3 types:

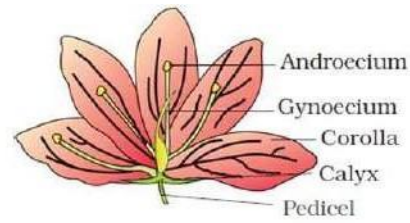
- **Hypogynous:** Here, gynoecium occupies the highest position while other parts are situated below it. The ovary is **superior.** E.g. mustard, China rose & brinjal.
- **Perigynous:** Here, gynoecium is situated in the centre and other parts are located on the rim of the thalamus at the same level. Ovary is **half inferior.** E.g. plum, rose, peach.
- **Epigynous:** Here, the margin of thalamus grows upward enclosing the ovary completely and getting fused with it. Other parts arise above the ovary. The ovary is **inferior.** E.g. Guava, cucumber, ray florets of sunflower.

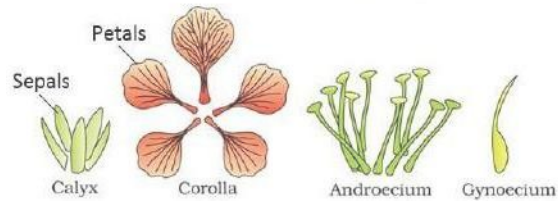


Parts of a Flower

a) Calyx

- It is the outermost whorl of flower. It is made of **sepals.**
- Generally, sepals are green, leaf like and protect the flower in the bud stage.
- The calyx may be **gamosepalous** (sepals united) or **polysepalous** (sepals free).



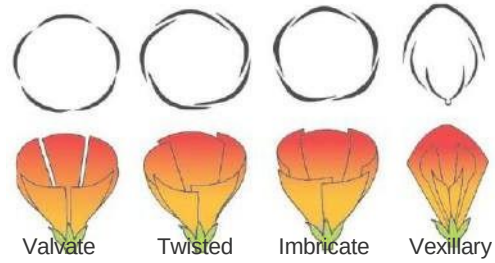


b) Corolla

- It is the whorl inner to calyx. It is composed of **petals.**
- Petals have bright colour to attract insects for pollination.
- Corolla may be **gamopetalous** (petals united) or **polypetalous** (petals free).
- Shape and colour of corolla vary in plants. Corolla may be tubular, bell-shaped, funnel-shaped or wheel-shaped.

Aestivation: It is the mode of arrangement of sepals and petals in floral bud. It is many types:

- **Valvate:** Sepals or petals in a whorl just touch one another at the margin, without overlapping. E.g. *Calotropis.*
- **Twisted:** One margin of the appendage overlaps that of the next one and so on. E.g. China rose, lady's finger & cotton.
- **Imbricate:** Margins of sepals or petals overlap one another but not in any particular direction. E.g. *Cassia* & gulmohur.
- **Vexillary (papilionaceous):** In this, there are five petals; the largest (standard) overlaps the two lateral petals (wings) which in turn overlap the two smallest anterior petals (keel). E.g. pea & bean.



c) Androecium

- The male reproductive part composed of **stamens.**
- Each stamen represents the male reproductive organ. It consists of a **stalk (filament)** and an **anther.**
- Each anther is usually **bilobed.**
- Each lobe has 2 chambers called **pollen-sacs.**
- In pollen-sacs, **pollen grains** are produced.
- A sterile stamen is called **staminode**.
- When stamens are attached to petals, they are **epipetalous.** E.g. brinjal. When stamens are attached to perianth they are **epiphyllous.** E.g. lily.
- If the stamens are free, it is called **polyandrous.**

- If they are united, it is called **synandrous.** It is many types:
  - **Monadelphous:** Stamens are united into one bunch or one bundle. E.g. China rose.
  - **Diadelphous:** Stamens are united into two bundles. E.g. pea.
  - **Polyadelphous:** Stamens are united into more than two bundles. E.g. citrus.
- There may be a variation in the length of filaments within a flower. E.g. *Salvia* and mustard.

d) Gynoecium (Pistil)

The female reproductive part made up of one or more **carpels.**

A carpel has 3 parts:

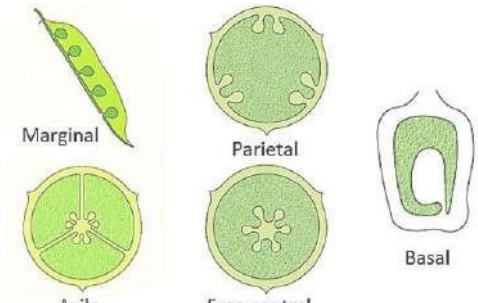
- **Stigma:** It is the receptive surface for pollen grains. It is usually at the tip of the **style.**
- **Style:** An elongated tube that connects ovary to stigma.
- **Ovary:** It is the enlarged basal part on which the style lies. Each ovary bears one or more **ovules** attached to a flattened, cushion-like **placenta**.

Polycarpellary pistils (pistil with many carpels) are 2 types:

- **Apocarpous:** Carpels are free. E.g. lotus and rose.
- **Syncarpous:** Carpels are fused. E.g. mustard and tomato.

Placentation: It is the arrangement of ovules on the placenta within the ovary. It is many types:

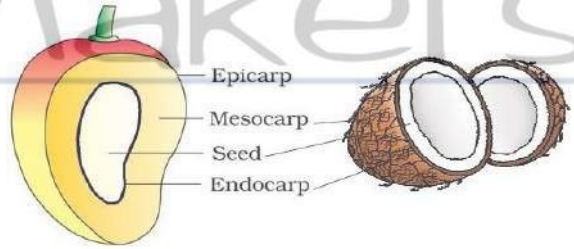
- **Marginal:** Here, the placenta forms a ridge along the ventral suture of the ovary and the ovules are borne on this ridge forming two rows. E.g. pea.
- **Axile:** Here, the placenta is axial and the ovules are attached to it in a multilocular ovary. E.g. China rose, tomato and lemon.
- **Parietal:** Here, the ovules develop on the inner wall of the ovary or on peripheral part. Ovary is one-chambered but it becomes two-chambered due to the formation of the false septum. E.g. mustard and *Argemone*.
- **Basal:** Here, placenta develops at the base of ovary and a single ovule is attached to it. E.g. sunflower, marigold.
- **Free central:** Here, ovules are borne on central axis and septa are absent. E.g. *Dianthus* and *Primrose.*



After fertilisation, the ovules develop into seeds and the ovary matures into a fruit.

THE FRUIT

- It is a **ripened ovary** developed after fertilisation.
- It is a characteristic feature of the flowering plants.
- A fruit formed without fertilisation of the ovary is called **parthenocarpic** fruit.
- In mango & coconut, fruit is called a **drupe.** They are one seeded and develop from monocarpellary superior ovaries.
- A fruit consists of
  - **Pericarp (fruit wall):** It may be dry or fleshy. Thick and fleshy pericarp is differentiated into outer **epicarp,** middle **mesocarp** and inner **endocarp**.
  - **Seeds**
- In mango, the pericarp is well differentiated into thin epicarp, fleshy edible mesocarp and stony hard endocarp.
- In coconut, the mesocarp is fibrous.

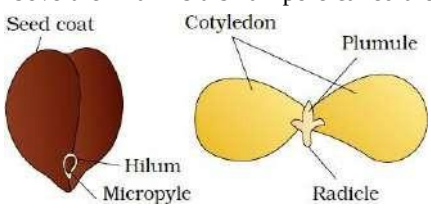


THE SEED

- It is the mature ovule developed after fertilisation.
- A seed is made up of a **seed coat** and an **embryo.**
- Embryo is made up of **a radicle, an embryonal axis** and **one** (e.g. wheat, maize) or **2 cotyledons** (e.g. gram & pea).

Structure of a Dicotyledonous Seed

- The outermost covering of a seed is the seed coat.
- Seed coat has 2 layers: outer **testa** and inner **tegmen**.
- On the seed coat, there is a scar called **hilum** through which the developing seeds are attached to the fruit.
- Above the hilum is a small pore called the **micropyle**.



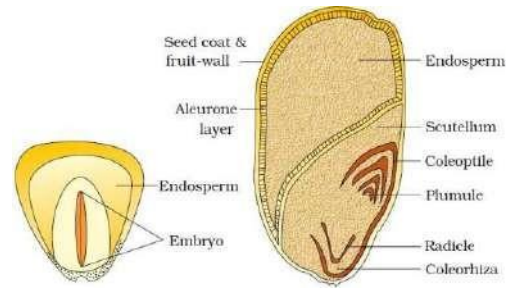
Structure of dicotyledonous seed

- Within the seed coat is the **embryo,** consisting of an **embryonal axis** and **two cotyledons.**
- The cotyledons are often fleshy and full of reserve food materials. At the two ends of the embryonal axis, the **radicle** and **plumule** are present.
- In some seeds such as castor, the **endosperm** is formed due to double fertilisation. It is a food storing tissue.
- In plants such as bean, gram and pea, the seeds are **non-endospermous** (endosperm is not seen in mature seeds).

Structure of Monocotyledonous Seed

- Generally, monocot seeds are **endospermic** but some are non-endospermic (e.g. orchids).
- In cereals such as maize, the seed coat is membranous and generally fused with the fruit wall.
- The endosperm is bulky and stores food.

- The outer covering of endosperm separates the embryo by a protein layer called **aleurone layer**.
- The embryo is small and situated in a groove at one end of the endosperm. It consists of one large and shield shaped cotyledon known as **scutellum** and a short axis with a **plumule** and a **radicle**.
- The plumule is protected in a sheath called **coleoptile** and radicle is protected in a sheath called **coleorhiza.**

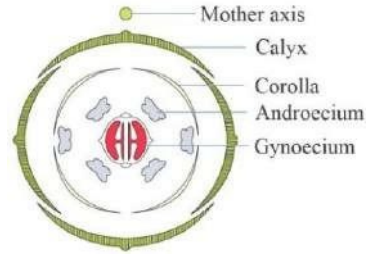


SEMI-TECHNICAL DESCRIPTION OF A TYPICAL FLOWERING PLANT

- The plant is described beginning with its habit, vegetative characters and then floral characters.
- Then a **floral diagram** and a **floral formula** are presented.
- Floral formula is represented by some symbols. They are

Br (bracteates)	**K** (calyx)	**C** (corolla)
P (perianth)	**A** (androecium)	**G** (Gynoecium)
$\underline{G}$ (superior ovary)	$\overline{G}$ (inferior ovary)	
♂ (male)	♀ (female)	⚥ (bisexual)
⊕ (actinomorphic)	% (zygomorphic)	

- Fusion is indicated by enclosing the figure within bracket and adhesion by a line drawn above the symbols of the floral parts.
- A floral diagram gives information about the number of parts of a flower, their arrangement and relation.



Floral formula

$\oplus ♂♀ K_{2+2}\, C_4\, A_{2+4}$

$\underline{G}_{(2)}$

Floral diagram of mustard plant (Family: *Brassicaceae*)

- Floral formula also shows cohesion and adhesion within parts of whorls and in between whorls.

SOME IMPORTANT FAMILIES

1. Fabaceae

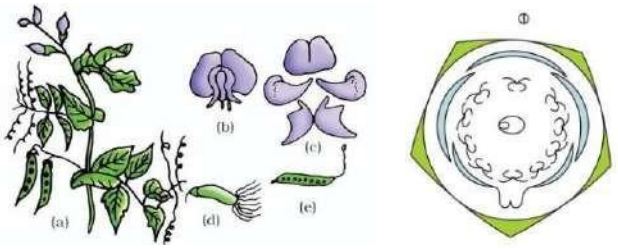
This family was earlier called **Papilonoideae,** a subfamily of family **Leguminosae.** It is distributed all over the world.

Vegetative Characters:

- Trees, shrubs, herbs; root with root nodules.
- **Stem:** erect or climber.
- **Leaves:** alternate, pinnately compound or simple; leaf base, pulvinate; stipulate; venation reticulate.

Floral characters:

- **Inflorescence:** racemose.
- **Flower:** bisexual, zygomorphic.
- **Calyx:** sepals five, gamosepalous; valvate/imbricate aestivation.
- **Corolla:** petals five, polypetalous, papilionaceous, consisting of a posterior standard, two lateral wings, two anterior ones forming a keel (enclosing stamens and pistil), vexillary aestivation.
- **Androecium:** ten, diadelphous, anther dithecous.
- **Gynoecium:** ovary superior, mono carpellary, unilocular with many ovules, style single.
- **Fruit:** legume; seed: one to many, non-endospermic.
- **Floral Formula:** $\%♂♀ K_{(5)}\, C_{1+2+(2)}\, A_{(9)+1}\, \underline{G}_1$



Pisum sativum (pea) plant: (a) Flowering twig (b) Flower (c) Petals (d) Reproductive parts (e) L.S.carpel (f) Floral diagram

Economic importance:

- Pulses: E.g. gram, *arhar*, *sem*, *moong*, soyabean.
- Edible oil: E.g. soyabean, groundnut.
- Dye: E.g. Indigofera.
- Fibres: E.g. sun hemp.
- Fodder: E.g. *Sesbania*, *Trifolium.*
- Ornamentals: E.g. lupin, sweet pea.
- Medicine: E.g. *muliathi.*

2. Solanaceae (Potato family)

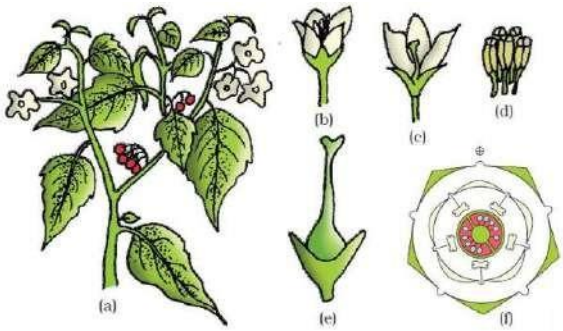
It is a large family. It is widely distributed in tropics, subtropics and even temperate zones.

Vegetative Characters:

- Plants mostly herbs, shrubs and small trees.
- **Stem:** herbaceous rarely woody, aerial; erect, cylindrical, branched, solid or hollow, hairy or glabrous, underground stem in potato (*Solanum tuberosum*).
- **Leaves:** alternate, simple, rarely pinnately compound, exstipulate; venation reticulate.

Floral Characters:

- **Inflorescence:** Solitary, axillary or cymose as in *Solanum.*
- **Flower**: bisexual, actinomorphic.
- **Calyx:** sepals five, united, persistent, valvate aestivation.
- **Corolla:** petals five, united; valvate aestivation.
- **Androecium:** stamens five, epipetalous.
- **Gynoecium:** bicarpellary obligately placed, syncarpous; ovary superior, bilocular, placenta swollen with many ovules, axile.
- **Fruits:** berry or capsule.
- **Seeds:** many, endospermous
- **Floral Formula:** $\oplus ♂♀ K_{(5)}\, C_{(5)} A_{(5)}\, \underline{G}_{(2)}$



Solanum nigrum (makoi) plant: (a) Flowering twig (b) Flower (c) L.S. of flower (d) Stamens (e) Carpel (f) Floral diagram

Economic Importance:

- Food: E.g. tomato, brinjal, potato
- Spice: E.g. chilli
- Medicine: E.g. belladonna, *ashwagandha*.
- Fumigatory: E.g. tobacco.
- Ornamentals: E.g. petunia.

3. Lilaceae (Lily family)

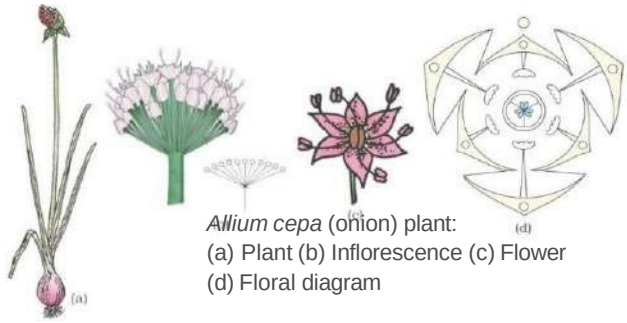
A characteristic representative of monocotyledonous plants. It is distributed worldwide.

Vegetative characters:

- Perennial herbs with underground bulbs/corms/ rhizomes.
- **Leaves** mostly basal, alternate, linear, exstipulate with parallel venation.

Floral characters:

- **Inflorescence:** solitary / cymose; often umbellate clusters.
- **Flower:** bisexual; actinomorphic.
- **Perianth** tepal six (3+3), often united into tube; valvate aestivation.
- **Androecium:** stamen six, (3+3).
- **Gynoecium**: tricarpellary, syncarpous, ovary superior, trilocular with many ovules; axile placentation.
- **Fruit:** capsule, rarely berry.
- **Seed**: endospermous
- **Floral Formula:** $\oplus \varnothing P_{(3+3)} A_{3+3} \underline{G}_{(3)}$



Allium cepa (onion) plant: (a) Plant (b) Inflorescence (c) Flower (d) Floral diagram

Economic Importance:

- Ornamentals: E.g. tulip, *Gloriosa*
- Medicine: E.g. *Aloe*
- Vegetables: E.g. *Asparagus*
- Colchicines: E.g. *Colchicum autumnale*

ANATOMY OF FLOWERING PLANTS

- Anatomy is the study of internal structure of plants and other organisms.

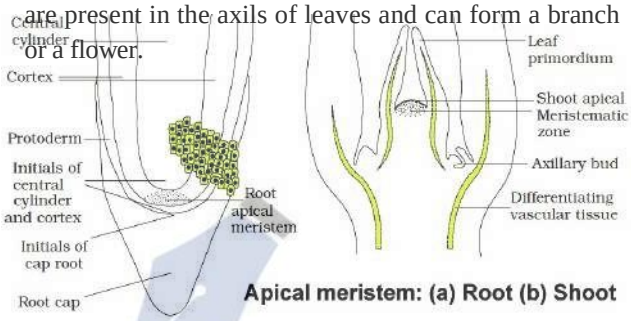
THE TISSUES

- A tissue is a group of cells having common origin and function.
- Based on the capability of cell division, plant tissues are 2 groups: **Meristematic** and **Permanent.**

MERISTEMATIC TISSUES (MERISTEMS)

These are the tissues where active cell division and growth occurs. Based on the position, meristems are 3 types:

- **Apical meristems:** They occur at the tips of roots and shoots and produce primary tissues. It is 2 types:
  - **Root apical meristem:** It occupies the tip of a root.
  - **Shoot apical meristem:** It occupies the distant most region of the stem axis. Some cells 'left behind' from shoot apical meristem, constitute the **axillary bud**. They are present in the axils of leaves and can form a branch or a flower.



Apical meristem: (a) Root (b) Shoot

- **Intercalary meristems:** They occur between mature tissues. They occur in grasses and regenerate parts removed by the grazing herbivores.

Apical and intercalary meristems are **primary meristems** because they appear early in a plant life and contribute to the formation of primary plant body. During that, specific regions of the apical meristem produce **dermal tissues, ground tissues** and **vascular tissues.**

- **Secondary (lateral) meristems:** The meristems that occur in mature regions of roots and shoots. They are cylindrical meristems. They are seen in gymnosperms and dicots.

E.g. **Fascicular vascular cambium, interfascicular cambium** & **cork cambium.** These are responsible for producing the secondary tissues.

PERMANENT (MATURE) TISSUES

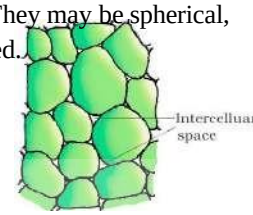
- The cells produced by primary and secondary meristems, become structurally and functionally specialized and lose the ability to divide. They are called **permanent (mature) cells** and constitute the **permanent tissues.**
- They are 2 types: Simple and Complex.

1. Simple Permanent Tissues

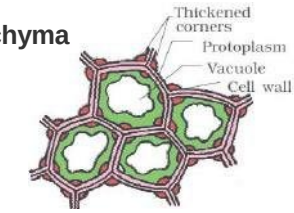
- The tissues having all cells similar in structure & function.
- 3 types: Parenchyma, Collenchyma and Sclerenchyma.

a. Parenchyma

- It forms the major component within organs.
- Cells are generally isodiametric. They may be spherical, oval, round, polygonal or elongated.
- Their walls are thin and made up of cellulose.
- Cells are closely packed or have small intercellular spaces.
- **Functions:** Photosynthesis, storage, secretion etc.

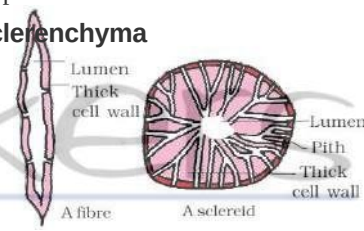


b. Collenchyma



- It occurs in layers below the epidermis in dicot plants.
- It is found as a homogeneous layer or in patches.
- It consists of cells with much thickened corners due to deposition of cellulose, hemicellulose and pectin.
- Intercellular spaces are absent.
- Cells are oval, spherical or polygonal and often contain chloroplasts.
- **Functions:** They provide mechanical support to the growing parts such as young stem and petiole of a leaf. The cells that contain chloroplasts assimilate food.

c. Sclerenchyma



- It consists of long, narrow cells with thick and lignified cell walls having a few or numerous pits.
- They are usually dead without protoplasts.
- Based on the form, structure, origin and development, sclerenchyma is 2 types: fibres & sclereids.
  - **Fibres:** These are thick-walled, elongated and pointed cells, generally occurring in groups.
  - **Sclereids:** These are spherical, oval or cylindrical, highly thickened dead cells with very narrow cavities (lumen). These are found in the fruit walls of nuts; pulp of fruits like guava, pear and sapota; seed coats of legumes and leaves of tea.
- **Function:** It provides mechanical support to organs.

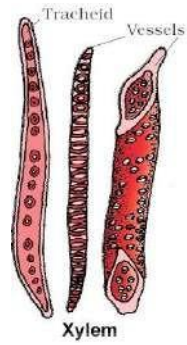
2. Complex Permanent Tissues

- These are made of more than one type of cells and they work together as a unit.
- 2 types: Xylem and Phloem.

a. Xylem

- It functions as a conducting tissue for water and minerals from roots to the stem and leaves.
- It also provides mechanical strength to the plant parts.
- It is composed of 4 kinds of elements: **tracheids, vessels, xylem fibres** and **xylem parenchyma.**

- **Tracheids:** These are elongated tube like dead cells with thick and lignified walls and tapering ends. Protoplasm absent. The inner layers of cell walls have thickenings which vary in form. In flowering plants, tracheids & vessels are the main water transporting elements.



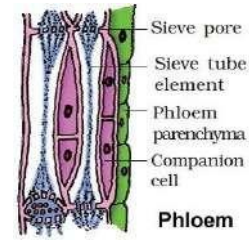
- **Vessel:** It is a long cylindrical tube-like structure made up of many cells **(vessel members),** each with lignified walls and a large central cavity. Protoplasm absent.
  Vessel members are interconnected through perforations in their common walls. The vessels are a characteristic feature of angiosperms. Gymnosperms lack vessels.
- **Xylem fibres:** They have highly thickened walls and obliterated central lumens. They are septate or aseptate.
- **Xylem parenchyma:** Living and thin-walled cells with cellulosic cell walls. They store food materials (starch or fat) and other substances like tannins. Radial conduction of water takes place by the ray parenchymatous cells.

- Primary xylem is 2 types:
  - **Protoxylem:** The first formed primary xylem.
  - **Metaxylem:** The later formed primary xylem.
- In stems, the protoxylem lies towards the centre (pith) and the metaxylem lies towards the periphery of the organ. This type of primary xylem is called **endarch**.
- In roots, the protoxylem lies towards periphery and metaxylem lies towards the centre. Such arrangement of primary xylem is called **exarch.**

b. Phloem (Bast)

It transports food materials from leaves to other parts.
In angiosperms, phloem is composed of **sieve tube elements, companion cells, phloem parenchyma** & **phloem fibres.** Gymnosperms have albuminous cells and sieve cells. They lack sieve tubes and companion cells.

- **Sieve tube elements:** These are long, tube-like structures, arranged longitudinally and are associated with companion cells. Their end walls are perforated to form the **sieve plates.** A mature sieve element has a peripheral cytoplasm and a large vacuole but lacks a nucleus. The functions of sieve tubes are controlled by the nucleus of companion cells.



  The first formed primary phloem **(protophloem)** consists of narrow sieve tubes. The later formed phloem **(metaphloem)** has bigger sieve tubes.
  Function: Conduction of food materials from leaves.
- **Companion cells:** Specialized parenchymatous cells closely associated with sieve tube elements. Sieve tube elements & companion cells are connected by pit fields present between their common longitudinal walls.
  Function: Maintain the pressure gradient in sieve tubes.
- **Phloem parenchyma:** It is made up of elongated, tapering cylindrical cells which have dense cytoplasm and nucleus. The cell wall is composed of cellulose and has pits through which plasmodesmatal connections exist between the cells. Phloem parenchyma is absent in most of the monocots.
  Function: It stores food material and other substances like resins, latex and mucilage.
- **Phloem fibres (bast fibres):** These are made up of sclerenchymatous cells. Generally absent in primary phloem but are found in the secondary phloem. These are much elongated, unbranched and have pointed, needle like apices. Cell wall is quite thick. At maturity, these fibres lose their protoplasm and become dead. Phloem fibres of jute, flax and hemp are used commercially.
  Function: Mechanical support & protection to soft tissues.

THE TISSUE SYSTEM

Based on structure and location, tissue systems are 3 types:

- **Epidermal tissue system**
- **Ground (fundamental) tissue system**
- **Vascular (conducting) tissue system**

1. Epidermal Tissue System

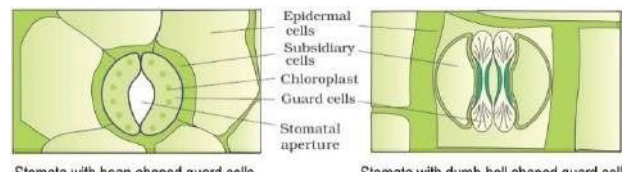
- It forms the outer-most covering of the whole plant body.
- It comprises **epidermal cells, stomata** and **epidermal appendages (trichomes & hairs).**

Epidermis

- It is the outermost layer of the primary plant body.
- Epidermis is usually single layered.
- It is made up of elongated, compactly arranged parenchymatous cells with a small amount of cytoplasm lining the cell wall and a large vacuole.
- The outside of the epidermis is often covered with a waxy thick layer **(cuticle).** It prevents the loss of water. Cuticle is absent in roots.

Stomata

- These are structures present in the epidermis of leaves.
- Stomata regulate the transpiration and gaseous exchange.
- A stoma is made of two bean-shaped cells **(guard cells).**
- In grasses, the guard cells are dumbbell shaped.



- The outer walls of guard cells (away from the stomatal pore) are thin and the inner walls (towards the stomatal pore) are highly thickened.
- The guard cells possess chloroplasts and regulate the opening and closing of stomata.
- Sometimes, a few epidermal cells near the guard cells become specialized in their shape and size. They are known as **subsidiary cells.**

- The stomatal aperture, guard cells and the surrounding subsidiary cells are together called **stomatal apparatus.**

Epidermal appendages

- The cells of epidermis bear many hairs.
- **Root hairs:** Unicellular elongations of the epidermal cells. They help to absorb water and minerals from the soil.
- **Trichomes:** They are the epidermal hairs on the stem. They are usually multicellular, branched or unbranched and soft or stiff. They may be secretory. Trichomes help to prevent water loss due to transpiration.

2. The Ground Tissue System

- All tissues except epidermis and vascular bundles constitute the **ground tissue.**
- It consists of **simple tissues** (parenchyma, collenchyma and sclerenchyma).
- Parenchymatous cells are present in cortex, pericycle, pith and medullary rays, in the primary stems and roots.
- In leaves, the ground tissue consists of thin-walled chloroplast containing cells and is called **mesophyll**.

3. The Vascular Tissue System

It consists of **complex tissues** (xylem and phloem).

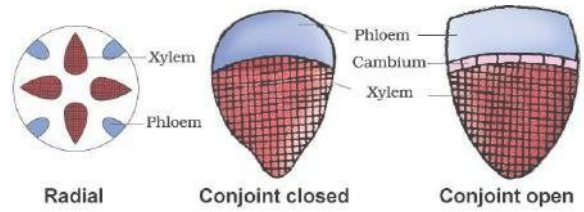
Xylem and Phloem together constitute **vascular bundles.**

Based on the presence or absence of **cambium,** vascular bundles are 2 types:

- **Open type:** In this, cambium is present between phloem and xylem. So vascular bundles can form secondary xylem and phloem tissues. E.g. **dicotyledonous** stems.
- **Closed type:** In this, cambium is absent. Hence, they do not form secondary tissues. E.g. **monocotyledons.**

Based on the arrangement of xylem and phloem, vascular bundles are 2 types:

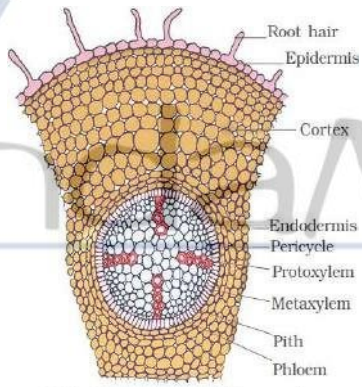
- **Radial type:** Xylem and phloem are arranged in an alternate manner on different radii. Seen in roots.
- **Conjoint type:** Xylem and phloem are jointly situated at the same radius of vascular bundles. Seen in stems and leaves. Conjoint vascular bundles usually have phloem located only on the outer side of xylem.



ANATOMY OF DICOTYLEDONOUS & MONOCOTYLEDONOUS PLANTS

Dicotyledonous (Dicot) Root

Transverse section of the sunflower root shows the following tissue organization:



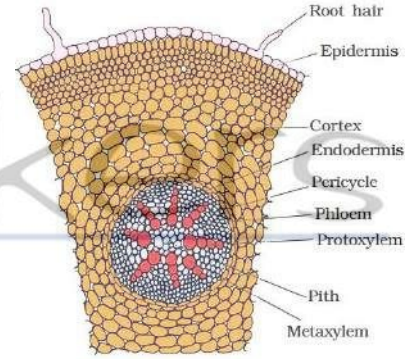
T.S of Dicot root (Primary)

- **Epidermis (epiblema):** The outermost layer. Many cells of epiblema protrude in the form of unicellular root hairs.
- **Cortex:** It consists of several layers of thin-walled parenchyma cells with intercellular spaces.
- **Endodermis:** Innermost layer of the cortex. It comprises a single layer of barrel-shaped cells without intercellular spaces.

  The tangential as well as radial walls of the endodermal cells have a deposition of water impermeable, waxy material-suberin-in the form of **casparian strips**.
- **Stele:** All tissues on the inner side of the endodermis together constitute stele. They include
  - **Pericycle:** A few layers of thick-walled parenchyomatous cells next to endodermis. Initiation of lateral roots and vascular cambium during the secondary growth takes place in these cells.
  - **Pith:** Innermost region of the stele. It is small or inconspicuous.
  - **Conjunctive tissue:** The parenchymatous cells which lie between the xylem and the phloem.
  - **Vascular bundles:** 2-4 xylem & phloem patches. Later, a cambium ring develops between the xylem & phloem.

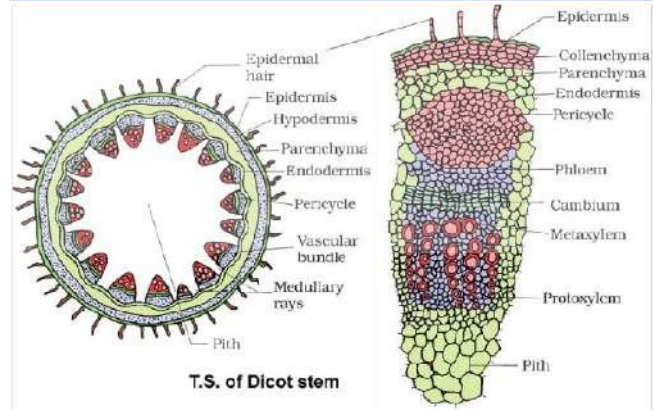
Monocotyledonous (Monocot) Root

- It has **epidermis, cortex, endodermis, pericycle, vascular bundles** and **pith.**
- There are usually more than six **(polyarch)** xylem bundles.
- Pith is large and well developed.
- Monocot roots do not undergo any secondary growth.



T.S of Monocot root

Dicotyledonous (Dicot) Stem



T.S. of Dicot stem

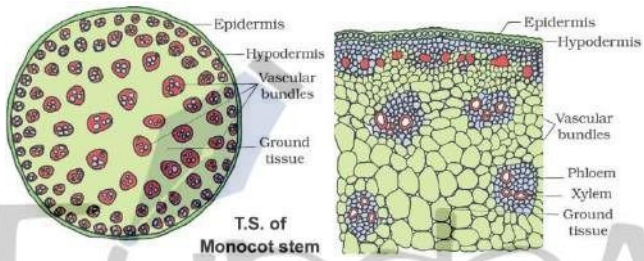
- **Epidermis:** Outermost protective layer. Covered with a thin layer of cuticle, it may bear trichomes & few stomata.
- **Cortex:** Multiple layers of the cells arranged in between epidermis and pericycle. It consists of 3 sub-zones:

- **Hypodermis:** Outer zone. It consists of a few layers of collenchymatous cells just below the epidermis. It provides mechanical strength to the young stem.
- **Cortical layers:** Below hypodermis. They consist of rounded thin walled parenchymatous cells with conspicuous intercellular spaces.
- **Endodermis:** Innermost layer. The cells are rich in starch grains. So the layer is also called as the **starch sheath. Pericycle** is present on the inner side of the endodermis and above the phloem in the form of semi-lunar patches of sclerenchyma.

○ **Stele:** Consists of **pericycle, vascular bundles, medullary rays & pith.**

- **Medullary rays:** These are few layers of radially placed parenchymatous cells in between vascular bundles.
- **Vascular bundles:** Large in number. They are arranged in a ring. Ring arrangement is a characteristic of dicot stem. Each vascular bundle is conjoint, open, and with endarch protoxylem.
- **Pith:** Central portion of the stem. It has many rounded, parenchymatous cells with large intercellular spaces.

Monocotyledonous (Monocot) Stem



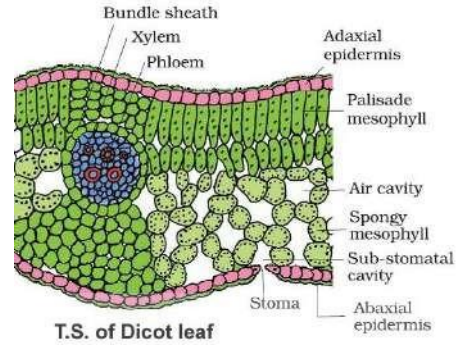
- It has a sclerenchymatous **hypodermis,** many scattered **vascular bundles,** each surrounded by a sclerenchymatous **bundle sheath,** and a large, conspicuous parenchymatous **ground tissue.**
- **Vascular bundles** are **conjoint** & **closed.** Peripheral vascular bundles are smaller than centrally located ones.
- The phloem parenchyma is absent, and water-containing cavities are present within the vascular bundles.

Dicotyledonous (Dorsiventral) Leaf

The vertical section of a dicot leaf through lamina shows 3 main parts: **Epidermis, mesophyll** & **vascular system.**

○ **Epidermis:** It covers both the upper surface **(adaxial epidermis)** and lower surface **(abaxial epidermis)** of the leaf. It has a conspicuous cuticle.
Abaxial epidermis generally bears more stomata than the adaxial epidermis. The latter may even lack stomata.

○ **Mesophyll:** The tissue between the upper and the lower epidermis. It is made up of parenchyma. They contain chloroplasts for photosynthesis. It has 2 types of cells:



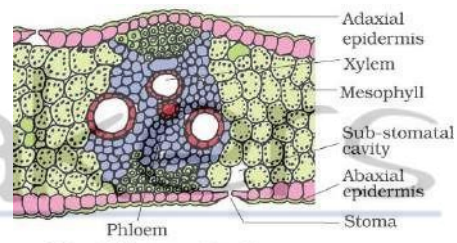
T.S. of Dicot leaf

- **Palisade parenchyma:** It is adaxially placed. Made up of elongated cells arranged vertically and parallel to each other.
- **Spongy parenchyma:** The oval or round and loosely arranged. It is situated below the palisade cells and extends to the lower epidermis. There are numerous large spaces and air cavities between these cells.

○ **Vascular system:** It includes vascular bundles. They can be seen in the veins and midrib.
Size of vascular bundles is dependent on the size of the veins. The veins vary in thickness in the reticulate venation of dicot leaves. Vascular bundles are surrounded by a layer of thick walled **bundle sheath cells**.

Monocotyledonous (Isobilateral) Leaf

The anatomy of monocot leaf is like that of the dicot leaf in many ways. It shows following differences:



T.S. of Monocot leaf

○ Stomata are present on both surfaces of the epidermis.

○ Mesophyll is not differentiated into palisade and spongy parenchyma.

○ In grasses, certain adaxial epidermal cells along the veins modify themselves into large, empty, colourless cells. These are called **bulliform cells.** When the bulliform cells have absorbed water and are turgid, the leaf surface is exposed. When they are flaccid due to water stress, they make the leaves curl inwards to minimise water loss.

○ Parallel venation is reflected in the near similar sizes of vascular bundles (except in main veins).

SECONDARY GROWTH

- The growth of the roots and stems in length with the help of apical meristem is called the **primary growth.**
- **Secondary growth** is the increase in girth of dicot plants.
- Tissues involved in secondary growth are the two **lateral meristems: Vascular cambium & cork cambium**.

Vascular Cambium

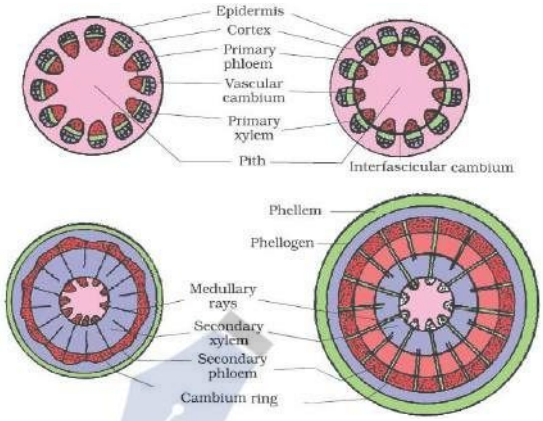
- It is the meristematic layer responsible for cutting off vascular tissues (xylem and phloem).
- In the young stem, it is present in patches as a single layer between xylem & phloem. Later it forms a complete ring.

Formation of cambial ring

- In dicot stems, cells of cambium present between primary xylem & primary phloem is **intrafascicular cambium**.
- Cells of medullary cells, adjoining this intrafascicular cambium become meristematic and form **interfascicular cambium**. Thus, a continuous ring of cambium is formed.

Activity of the cambial ring

- The cambial ring becomes active and cut off new cells, both towards the inner and outer sides. The cells cut off towards pith, mature into **secondary xylem.** The cells cut off towards periphery mature into **secondary phloem**.
- Cambium is more active on the inner side than on the outer. As a result, more secondary xylem is produced than secondary phloem and soon forms a compact mass.
- Primary and secondary phloems get gradually crushed due to the continued formation and accumulation of secondary xylem. However, primary xylem remains intact, in or around the centre. At some places, cambium forms a narrow band of parenchyma, which passes through the secondary xylem and the secondary phloem in the radial directions. These are the **secondary medullary rays.**



Secondary growth in a dicot stem – stages in transverse views

Spring wood and autumn wood

- Many physiological & environmental factors control the activity of cambium.
- In spring season, cambium is very active and produces many xylary elements having vessels with wider cavities. This wood is called **spring wood (early wood)**. It is lighter in colour and has a lower density.
- In winter, cambium is less active and forms fewer xylary elements having narrow vessels. This wood is called **autumn wood (late wood)**. It is darker and has higher density.
- These two kinds of woods that appear as alternate concentric rings constitute an **annual ring.** This is used to estimate the age of tree (Dendrochronology).

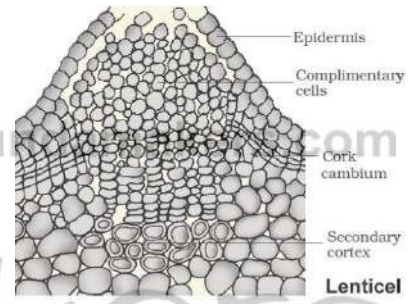
Heartwood and sapwood

- **Heartwood:** It is the hard, dead, dark brown-coloured, highly lignified and non-functional central part of the secondary xylem of old trees. The dark colour is due to deposition of organic compounds (tannins, resins, oils, gums, aromatic substances, essential oils etc). These substances make it hard, durable and resistant to the attacks of microorganisms and insects.

  Function: It gives mechanical support to stem.
- **Sapwood:** It is the peripheral region of secondary xylem. It is living and lighter in colour. It is involved in the conduction of water and minerals from root to leaf.

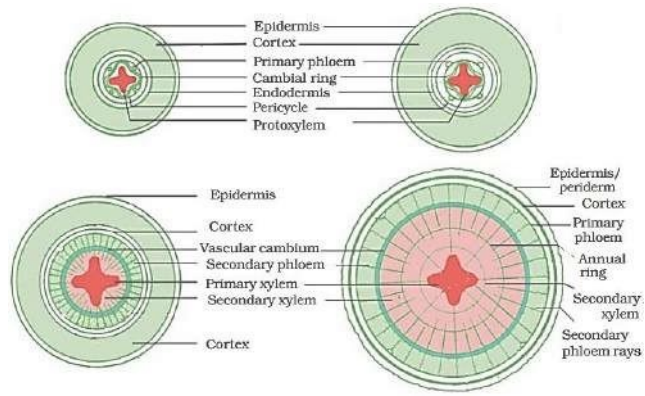
Cork Cambium

- As the stem continues to increase in girth due to the activity of vascular cambium, the outer cortical & epidermis layers get broken. It is to be replaced to provide new protective cell layers. Hence another meristematic tissue called **cork cambium (phellogen)** develops, usually in the cortex.
- Phellogen is a couple of layers thick. It is made of narrow, thin-walled and nearly rectangular cells.
- Phellogen cuts off cells on both sides. The outer cells differentiate into **cork (phellem)** while the inner cells differentiate into **secondary cortex (phelloderm).** Cells of secondary cortex are parenchymatous.
- The cork is impervious to water due to suberin deposition in the cell wall.
- Phellogen, phellem, and phelloderm are collectively known as **periderm**. Due to activity of cork cambium, pressure builds up on the remaining layers peripheral to phellogen and ultimately these layers die and slough off.
- **Bark** is a non-technical term that refers to all tissues (such as periderm & secondary phloem) exterior to the vascular cambium. It is 2 types:
  - **Early (soft) bark:** It is formed early in the season**.**
  - **Late (hard) bark:** It is formed towards end of season.
- **Lenticels:** At certain regions, phellogen cuts off closely arranged parenchymatous cells on outer side. These cells rupture epidermis, forming a lens shaped openings called **lenticels.** They occur in most woody trees.



Function: Lenticels permit gas exchange of between the outer atmosphere and the internal tissue of the stem.

Secondary Growth in Roots



Different stages of the secondary growth in a typical dicot root

- In dicot root, vascular cambium is completely secondary in origin. It originates from the tissue located just below the phloem bundles (a portion of pericycle) above the protoxylem forming a complete and continuous wavy ring. It later becomes circular. Further events are similar to those of a dicotyledon stem.
- Secondary growth also occurs in stems and roots of gymnosperms. However, secondary growth does not occur in monocotyledons.

STRUCTURAL ORGANISATION IN ANIMALS

ANIMAL TISSUES

A group of cells having ***same origin, structure and function*** are called the **tissues.** Animal tissues are 4 types:

(i) Epithelial (ii) Connective (iii) Muscular (iv) Neural

I. EPITHELIAL TISSUE (EPITHELIUM)

- It has a **free surface** that faces **body fluid** or **outside environment.**
- **Covers** or **lines** body or body parts.
- Compactly packed cells with **little intercellular matrix.**
- Epithelial tissues are 2 types: **Simple** and **Compound.**

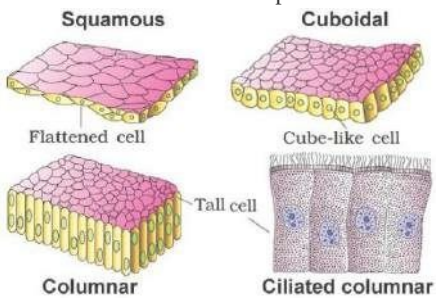
1. Simple epithelium

It is composed of a **single layer of cells.** It lines body cavities, ducts and tubes. Based on **structural modification of cells,** simple epithelium is 3 types:

o **Squamous epithelium:**
- Thin layer of flattened cells with irregular boundaries.
- Found in the walls of blood vessels and lung alveoli.
- **Functions:** Form a diffusion boundary.

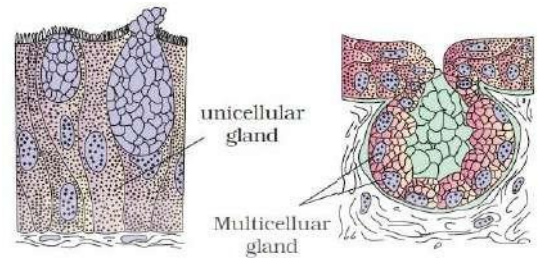
o **Cuboidal (cubical) epithelium:**
- Composed of cube-like cells.
- Found in ducts of glands and tubular parts of nephrons.
- **Functions:** Secretion and absorption.
- The epithelium of **proximal convoluted tubule (PCT)** of nephron in the kidney has **microvilli.**

o **Columnar epithelium:**
- Composed of tall and slender cells.
- Their nuclei are located at the base.
- Free surface may have microvilli.
- Found in the lining of stomach and intestine.
- **Functions:** Secretion and absorption.



Modification of columnar or cuboidal cells

- **Ciliated epithelium:**
  - Cells bearing **cilia** on their free surface.
  - Present in the inner surface of hollow organs like **bronchioles** and **fallopian tubes.**
  - **Functions:** To move particles or mucus in a specific direction over the epithelium.
- **Glandular epithelium**: For secretion. They are 2 types:
  - **Unicellular:** Consists of isolated glandular cells. E.g. Goblet cells of the alimentary canal.
  - **Multicellular:** Contains cluster of cells. E.g. salivary glands.

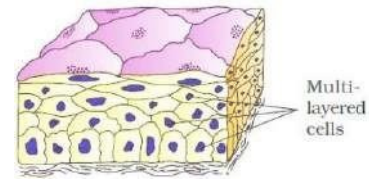


(a) Unicellular (b) Multicellular

Based on mode of pouring of secretions, glands are 2 types:

- **Exocrine glands:** Here, secretions are released through **ducts (tubes).** Exocrine glands secrete **mucus, saliva, earwax, oil, milk, digestive enzymes** etc.
- **Endocrine glands:** Ductless. They produce **hormones.**

2. Compound epithelium



- Made up of more than one layer **(multi-layered)** of cells.
- Limited role in secretion & absorption.
- They cover dry surface of **skin,** moist surface of **buccal cavity, pharynx, inner lining of ducts of salivary glands** and **pancreatic ducts.**
- **Function:** Protect against chemical & mechanical stresses.

Cell junctions: The junctions that provide structural and functional links between adjacent cells. They are found in epithelium and other tissues. They are 3 types:

i. **Tight junctions:** Help to stop substances from leaking across a tissue.
ii. **Adhering junctions:** Perform cementing to keep neighbouring cells together.
iii. **Gap junctions:** Facilitate communication b/w adjoining cells by connecting the cytoplasm for rapid transfer of ions, small molecules and sometimes big molecules.

II. CONNECTIVE TISSUE

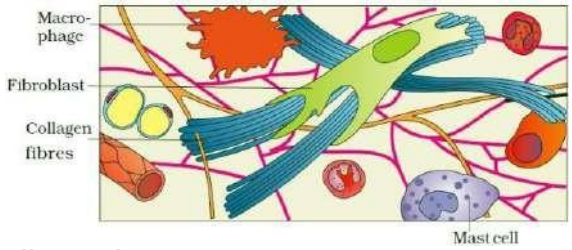
- It links and supports other tissues/organs.
- They are most abundant in complex animals.
- All connective tissues except blood have **fibroblast** cells. They secrete structural fibrous proteins called **collagen** & **elastin.** They give strength, elasticity & flexibility to tissue.
- The cells also secrete modified polysaccharides **(matrix),** which accumulate between cells and fibres.
- Types of connective tissues: **Loose, Dense & Specialised.**

1. Loose Connective Tissues

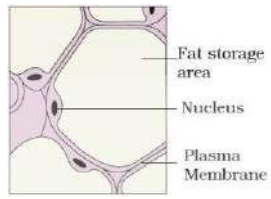
In this, cells **(fibroblasts, macrophages, mast cells etc.)** and fibres are loosely arranged in a semi-fluid matrix.

It is 2 types: Areolar & Adipose.

o **Areolar tissue:**
- Present beneath the skin.
- It serves as a support framework for epithelium.



o Adipose tissue:

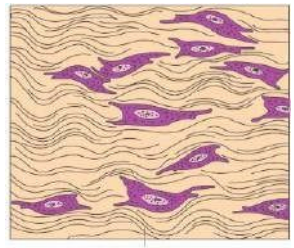


- Seen mainly under skin.
- Its cells **(adipocytes)** store fats.
- Excess nutrients which are converted into fats are stored in this tissue.

2. Dense Connective Tissues

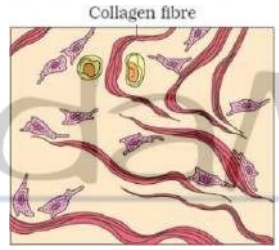
In this, fibres and fibroblasts are compactly packed. 2 types:

o Dense regular connective tissues:



- Show regular pattern of fibres.
- Collagen fibres are present in rows between many parallel bundles of fibres.
- E.g. tendons & ligaments.
  - i. **Tendons:** Attach muscles to bones.
  - ii. **Ligaments:** Attach one bone to another.

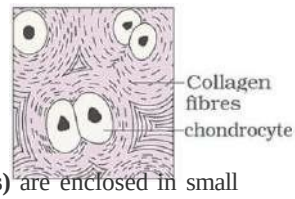
o Dense irregular connective tissues:



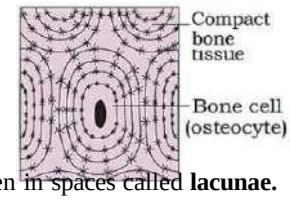
Irregular pattern of fibres.
- Fibroblasts & fibres (mostly collagen) are oriented differently.
- This tissue is present in skin.

3. Specialized Connective Tissues

- **Cartilage**:
  - In this, intercellular material (matrix) is solid and pliable (due to ***chondroitin salts)*** and resists compression.



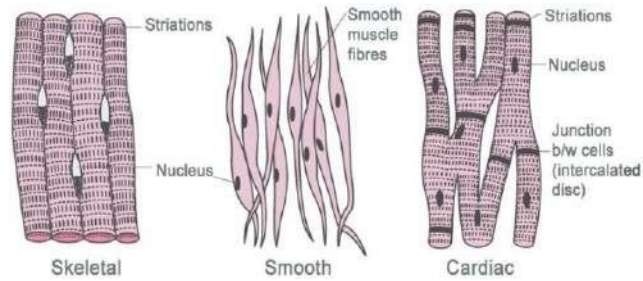
  - Cartilage cells **(chondrocytes)** are enclosed in small cavities within the matrix secreted by them.
  - Most of the cartilages in vertebrate embryos are replaced by bones in adults.
  - Cartilage is present in the **tip of nose, outer ear, joints in the vertebral column, limbs** and **hands in adults.**
- **Bone:**
  - It has hard and non-pliable matrix rich in **calcium salts** and **collagen fibres** which give bone its strength.



  - Bone cells **(osteocytes)** are seen in spaces called **lacunae.**
  - **Functions:**
    - It provides structural frame to the body.
    - Support and protect softer tissues and organs.
    - Limb bones serve weight-bearing functions.
    - Take part in locomotion and movements.
    - Blood cells are produced in bone marrow.
- **Blood:**
  - A fluid connective tissue containing **plasma, red blood cells (RBC), white blood cells (WBC)** and **platelets.**
  - Helps in the circulation of various substances.

III. MUSCLE TISSUE

- The tissues made of many **muscle fibres (muscle cells).**
- Muscle fibres are composed of numerous fine **myofibrils.**
- Muscle fibres can contract (shorten) and relax (lengthen).
- Muscles take part in locomotion and movements.
- Muscles are 3 types: **skeletal, smooth** and **cardiac.**



1. Skeletal (striated or voluntary) muscle

- They are attached to bones. E.g. **Biceps.**
- Striations are present in muscle fibres.
- Muscle fibres are bundled together in a parallel fashion.
- A sheath of tough connective tissue encloses several bundles of muscle fibres.

2. Smooth (non-striated or visceral) muscle

- **Involuntary** and **fusiform** (Fibres taper at both ends).
- No striations.
- Cell junctions hold them together and they are bundled together in a connective tissue sheath.
- They are seen in the wall of internal organs such as the **blood vessels, stomach** and **intestine.**

3. Cardiac muscle

- **Involuntary** muscle seen only in the **heart.**
- Cell junctions fuse the plasma membranes of cardiac muscle cells and make them stick together.
- Communication (gap) junctions **(intercalated discs)** at some fusion points allow cells to contract as a unit, i.e., when a cell receives signal to contract, other cells also contract.

IV. NEURAL TISSUE

- Made up of neurons (unit of neural system).
- Responsible for **control** and **co-ordination** of the body.
- **Neurons** are excitable cells. They carry impulses.
- Neurons are protected and supported by **neuroglial cells.**
- Neuroglia make up more than half the volume of neural tissue.

ORGAN AND ORGAN SYSTEM

- **Cells → tissues → organs → organ systems.**
- This organization is essential for better coordinated activities of cells.
- An organ is made of one or more type of tissues. E.g. Heart has epithelial, connective, muscular & neural tissues.

MORPHOLOGY & ANATOMY OF COCKROACH

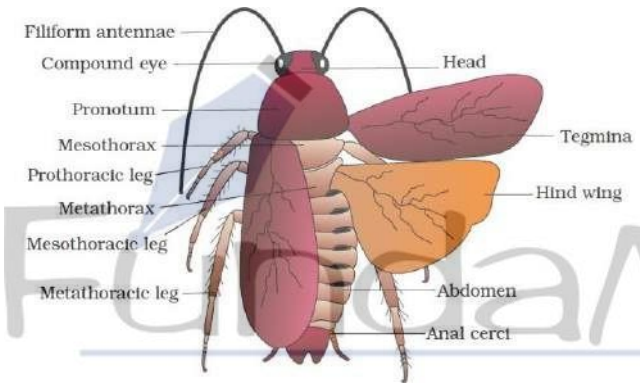
- **Morphology:** Study of external features of organisms.
- **Anatomy:** Study of morphology of internal organs.
- **Cockroach *(Periplaneta americana)*** are nocturnal, omnivores and live in damp places.
- **Colour:** Brown or black. Bright yellow, red & green coloured cockroaches are also seen in tropical regions.
- **Size:** ¼ inches to 3 inches (0.6-7.6 cm).

Systematic position

Phylum	**: Arthropoda**
Class	**: Insecta**
Genus	**: *Periplaneta***
Species	**: *americana***

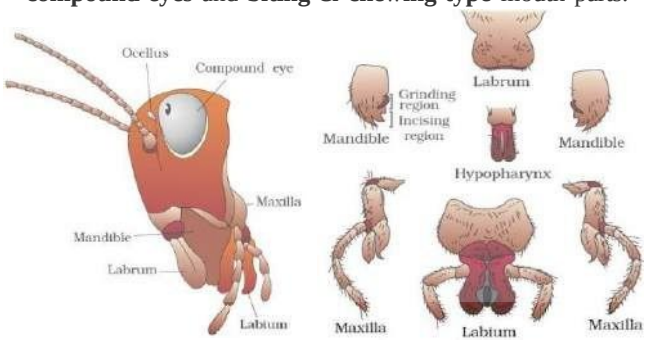
MORPHOLOGY OF COCKROACH

- The adults are about **34-53 mm** long.
- Body is covered by a hard brown **chitinous exoskeleton**.
- In each segment, exoskeleton has hardened plates called **sclerites (dorsal tergites** & **ventral sternites).** They are joined to each other by a thin and flexible **articular membrane (arthrodial membrane).**
- The body has 3 regions – **head, thorax** and **abdomen.**



Head

- Triangular head is formed by 6 fused segments.
- It shows great mobility in all directions due to flexible neck.
- Head bears a pair of thread-like **antennae**, a pair of **compound eyes** and **biting & chewing type** mouth parts.



- **Mouthparts:** a **labrum** (upper lip), 2 **mandibles,** 2 **maxillae, hypopharynx** (tongue) & a **labium** (lower lip).

Thorax

- It has 3 parts: **prothorax, mesothorax** & **metathorax.**
- The head is connected to thorax by a **neck** (short extension of the prothorax).
- Each thoracic segment bears a pair of walking legs.
- 2 pairs of wings: Forewings (2) and Hind wings (2).
  - **Forewings (mesothoracic)** or **tegmina:** Opaque, dark and leathery and cover the hind wings when at rest.
  - **Hind wings (metathoracic):** Transparent, membranous and are used in flight.

Abdomen

- It consists of **10 segments.**
- In females, 7th (boat shaped), 8th & 9th sterna form a **brood (genital) pouch.** It contains female **gonopore, spermathecal pores** & **collateral glands.**
- In males, genital pouch lies at the hind end of abdomen bounded dorsally by 9th & 10th terga and ventrally by the 9th sternum. It contains **dorsal anus, ventral male genital pore (gonopore)** and **gonapophysis.**
- In both sexes, 10th segment bears a pair of jointed **anal cerci.** Males bear a pair of short, threadlike **anal styles.**

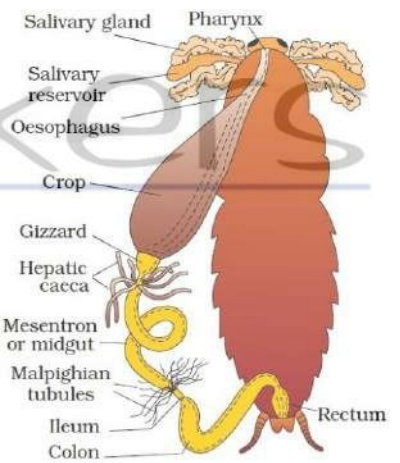
Differences between male & female cockroaches

Male	Female
i. Larger size	Smaller
ii. Wings extend beyond the tip of the abdomen.	Wings do not extend beyond the tip of abdomen.
iii. Narrow abdomen	Broad abdomen
iv. Anal styles present	Absent
v. Brood pouch absent	Present

ANATOMY OF COCKROACH

Digestive system

Alimentary canal has 3 parts: **foregut, mid gut** & **hindgut.**



- **Foregut:** It is lined by **cuticle.** It includes

  Mouth → pharynx → oesophagus → crop (to store food) **→ gizzard (proventriculus).**

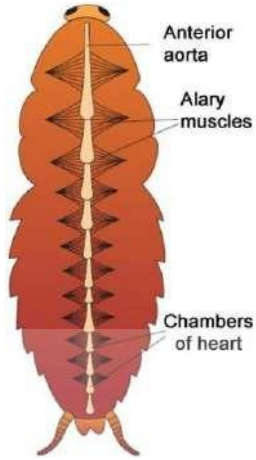
  Gizzard helps in grinding the food. It has an outer layer of thick circular muscles and thick inner cuticle forming **6 chitinous plates (teeth).**
- **Mid gut (Mesenteron):** It is not lined by cuticle. 6-8 tubules **(hepatic** or **gastric caecae)** are seen at the junction of foregut & mid gut. They secrete digestive juice.

  At the junction of mid gut & hindgut, there are **100-150** yellow coloured thin filamentous **Malpighian tubules.**
- **Hindgut**: It is broader than mid gut and lined internally by cuticle. Hindgut includes **ileum, colon** & **rectum.** Rectum opens out through anus.

Circulatory system

- Blood vascular system: **open type.**
- Blood vessels are poorly developed and open into space **(haemocoel).**

- Visceral organs located in the haemocoel are bathed in blood **(haemolymph).**
- **Haemolymph= colourless plasma + haemocytes.**
- **Heart** consists of elongated muscular tube lying along mid dorsal line of thorax and abdomen.
- It has funnel-shaped chambers with **ostia** on either side.
- Blood from sinuses enter heart through ostia and is pumped anteriorly to sinuses again.



Respiratory system

- It consists of a network of **trachea** that open through **10 pairs** of small holes called **spiracles** present on the lateral side of the body.
- The thin branches of **tracheal tubes** are called **tracheoles.** They carry oxygen from the air to all parts.
- The opening of the spiracles is regulated by **sphincters**.
- Gas exchange takes place at the tracheoles by **diffusion.**

Excretory system

- **Uricotelic**. Excretory organ is **Malpighian tubules**.
- Each tubule is lined by glandular and ciliated cells. They absorb nitrogenous wastes and convert them into **uric acid** which is excreted out through the hindgut.
- **Fat body, nephrocytes & urecose glands** also help in excretion.

Nervous system

- It consists of segmentally arranged **ganglia** joined by paired longitudinal connectives on the ventral side.
- 3 ganglia lie in the thorax and 6 in the abdomen.
- The head holds only a bit of nervous system. Remaining part is situated along the ventral part of the body. So, if the head of cockroach is cut off, it will still live for one week.
- The **supra-oesophageal ganglion** (brain) supplies nerves to antennae and compound eyes.
- **Sense organs: Antennae, eyes, maxillary palps, labial palps, anal cerci etc.**
- Sensory receptors of antennae monitor the environment.
- Each compound eye consists of about **2000 hexagonal ommatidia.** Using these, a cockroach can receive several images of an object. This is called **mosaic vision.** It has more sensitivity but less resolution, being common during night (hence called **nocturnal vision).**

Reproductive system

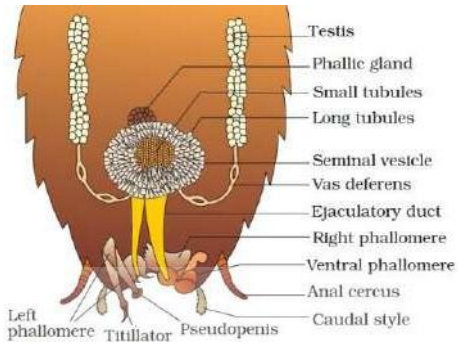
Cockroaches are **dioecious**.

Male reproductive system:

It consists of a pair of **testes, seminal vesicles, accessory glands & external genitalia.**

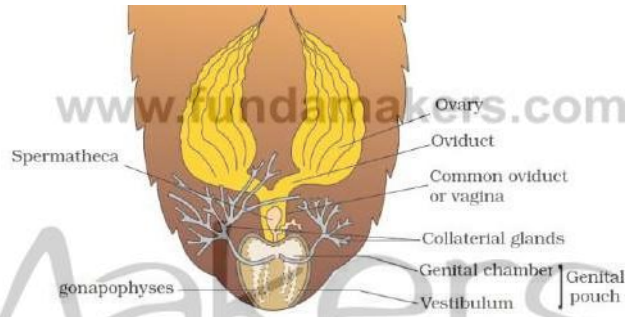
- **Testes:** Lie laterally in the **4th -6th abdominal segments.**

Each **testis** → a thin **vas deferens** → **seminal vesicle** → **ejaculatory duct** → **male gonopore.**



- **Seminal vesicles**: To store sperms. Sperms are glued together to form bundles called **spermatophores.** They are discharged during copulation.
- **Accessory glands:** Include a **mushroom gland** (in **6th-7th abdominal segments)** and **phallic gland**. Their secretions nourish the sperms.
- **External genitalia (male gonapophysis** or **phallomeres):** Chitinous asymmetrical structures, surrounding the **male gonopore.**

Female reproductive system:



- It consists of **2** large **ovaries, oviducts, spermatheca, genital chamber, Colleterial glands etc.**
- **Ovaries** lie laterally in the **2nd – 6th abdominal segments.** Each ovary is formed of **8 ovarian tubules (ovarioles),** containing a chain of developing ova.
- **Oviducts** of each ovary unite into a single **median oviduct (vagina)** which opens into the **genital chamber.**
- A pair of **spermatheca** is present in the **6th segment** which opens into the **genital chamber.**
- Sperms are transferred through spermatophores. Their fertilised eggs are encased in **oothecae.**
- Ootheca is dark reddish to blackish brown capsule, 8 mm long. Females lay **9-10** oothecae, each contain **14-16 eggs.**
- Development of ***P. americana*** is **paurometabolous,** (development through **nymphal stage**).
- **Nymphs** look like adults. They moult **13 times** to reach the adult form. The next to last nymphal stage has **wing pads.** Only adult cockroaches have wings.

ECONOMIC IMPORTANCE OF COCKROACH

They are pests because they destroy food and contaminate it with their smelly excreta. They also transmit bacterial diseases like **cholera, typhoid, tuberculosis** etc.

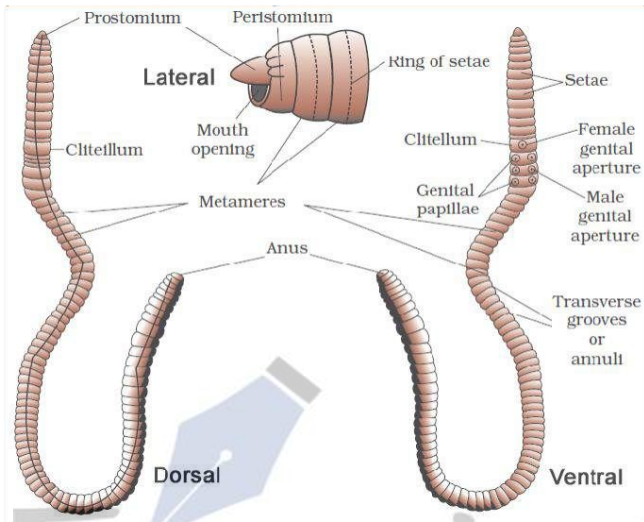
MORPHOLOGY & ANATOMY OF EARTHWORM

Systematic position

Phylum	**: Annelida**
Class	**: Oligochaeta**
Genus	**: *Pheretima***
Species	**: *posthuma***

- Earthworm is a reddish-brown terrestrial invertebrate that inhabits the upper layer of moist soil.
- During day time, they live in burrows made by boring and swallowing the soil.
- Common Indian earthworms: ***Pheretima*** and ***Lumbricus.***

MORPHOLOGY OF EARTHWORM



- Earthworms have long segmented cylindrical body.
- Number of **segments (metameres):** about **100-120**.
- **Dorsal surface** has a **dark median mid dorsal line (dorsal blood vessel)** along the longitudinal axis of the body.
- First segment **(peristomium or buccal segment)** bears the mouth. A lobe called **prostomium** covers the mouth.
- Prostomium is sensory in function and is used to force open cracks in the soil into which the earthworm may crawl.
- In a mature worm, segments **14-16** are covered by a dark band of glandular tissue called **clitellum**.
- Body has 3 regions: **preclitellar, clitellar** & **postclitellar.**
- **4 pairs** of **spermathecal apertures** are found on ventro-lateral sides of **intersegmental grooves (5th -9th segments).**
- A single **female genital pore** is present in the mid-ventral line of **14th segment.**
- A pair of **male genital pores** is present on the ventro - lateral sides of the **18th segment.**
- Many minute **nephridiopores** open on the body surface.
- All segments except the first, last and clitellum bear S-shaped **setae**, embedded in the epidermal pits. Setae can be extended or retracted. Their function is locomotion.

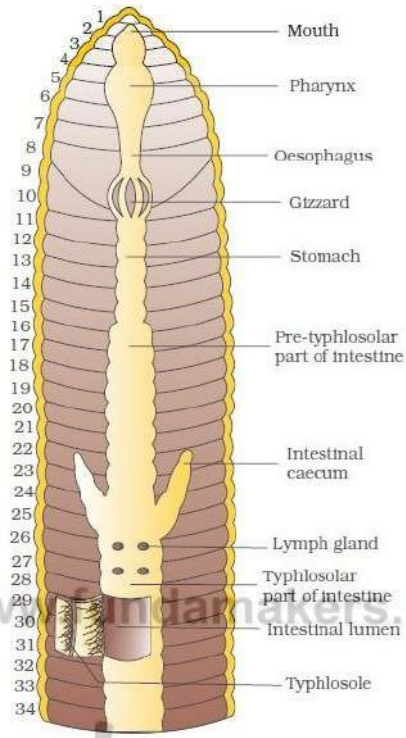
ANATOMY OF EARTHWORM

Body wall

It is composed of

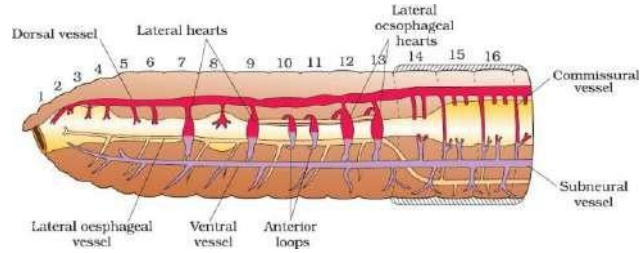
- Outermost thin **non-cellular cuticle.**
- **Epidermis:** Made up of a single layer of columnar epithelial cells which contain secretory gland cells.
- **Two muscle layers (circular and longitudinal).**
- An innermost **coelomic epithelium.**

Digestive system



- The straight **alimentary canal** extends from first to last segment of the body. It has
- **Mouth → buccal cavity (1-3 segments) → muscular pharynx (4th segment) → oesophagus (5-7 segments) → muscular gizzard (8-9 segments) → stomach (9-14 segments) → Intestine (15th segment to last) → anus.**
- Gizzard helps to grind soil particles, decaying leaves, etc.
- **Calciferous glands,** present in the stomach, neutralise the **humic acid** present in humus.
- A pair of short and conical **intestinal caecae** project from the intestine on the **26th segment.**
- The intestinal part between **26-35 segments** has an internal median fold of dorsal wall called **typhlosole**. It increases area of absorption.
- The organic rich soil is digested in the digestive tract by digestive enzymes. Digested nutrients are absorbed through intestinal membranes. Their faecal deposits are known as **worm castings.**

Circulatory system (blood vascular system)

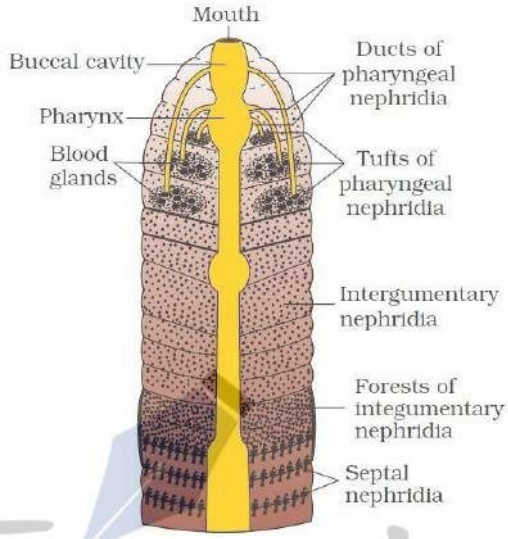


- Circulatory system is **closed type** (blood flows through heart and blood vessels).
- Consists of **blood vessels, capillaries** and **heart.**
- Contractions keep blood circulating in one direction.
- **Blood glands** are present on the **4th, 5th & 6th segments.** They produce **phagocytic blood cells** and **haemoglobin** which is dissolved in blood plasma.

Respiratory system

- No specialized system.
- Gas exchange occurs through moist body surface into the blood stream.

Excretory system



Excretory organs are segmentally arranged tubules called **nephridia.** They are 3 types:

a. **Septal nephridia:** Found on both sides of intersegmental septa (segment 15 to last) that open into intestine.
b. **Integumentary nephridia:** Attached to lining of body wall (segment 3 to last). They open on body surface.
c. **Pharyngeal nephridia:** Present in the **4th, 5th & 6th** segments in the form of paired tufts.

Funnel-shaped part of nephridium collects excess fluid from coelom. The funnel connects with a tubular part of nephridium which delivers the wastes into digestive tube.

Nervous system

- Includes segmentally arranged **ganglia** on the ventral paired and fused **nerve cord.**
- The nerve cord in the anterior region **(3rd & 4th segments)** divides and encircles the pharynx and joins the **cerebral ganglia** dorsally to form a **nerve ring.**
- The nerve ring with cerebral ganglia represents the brain.
- **Sensory system:** Includes
  - Light and touch sensitive **receptor cells**. No eyes.
  - **Chemoreceptors (taste receptors):** React to chemical stimuli.

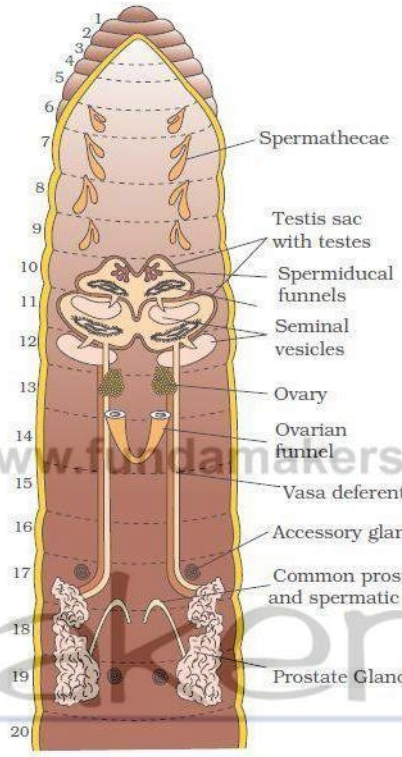
Reproductive system

Earthworm is **hermaphrodite.**

Male reproductive organs:

- **Testes:** 2 pairs. Enclosed in **testis sacs** in **10th** & **11th segments.** The sperms from testes shed into testis sacs. From where, they enter **seminal vesicles** for maturation. Mature sperms move back into testis sacs and enter **spermiducal funnels** which are connected to **vasa deferentia (spermatic ducts).** The vasa deferentia run up to **18th segment** where they join the **prostatic duct.**

  The **common prostate** and **spermatic duct** open to the exterior by a pair of **male genital pores** on the ventro-lateral side of the **18th segment.**
- **Accessory glands:** 2 pairs. Found in the **17th & 19th segments** (one pair in each segment).



Female reproductive organs:

- **Spermathecae:** 4 pairs. Located in **6th-9th segments** (one pair in each segment). They receive and store spermatozoa during copulation.
- **Paired ovaries:** Attached at the inter-segmental septum of the **12th and 13th segments.**
- **Ovarian funnels:** Present beneath the ovaries which continue into **oviduct,** join together and open on ventral side as single median female genital pore on **14th segment.**
- During mating, two worms exchange sperms each other. They mate juxtaposing opposite gonadal openings exchanging **spermatophores** (packets of sperms).
- Mature sperm, ova and nutritive fluid are deposited in **cocoons** produced by gland cells of clitellum. Cocoon with fertilized ova slips off and deposit in the soil. After 3 weeks, cocoon produces 2 to 20 baby worms (no larva).

ECONOMIC IMPORTANCE

- Earthworms are known as **'friends of farmers'** because they make burrows in the soil and make it porous which helps in respiration and penetration of the plant roots. This process of increasing fertility of soil is called **vermicomposting.**
- They are used as **bait** in gamefishing.

MORPHOLOGY & ANATOMY OF FROG

Systematic position

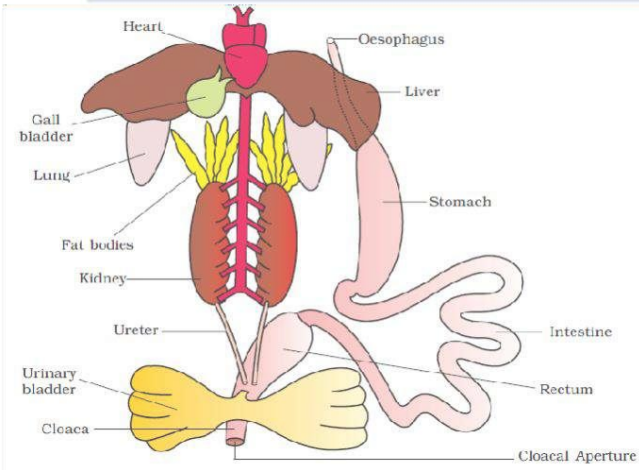
Phylum	**: Chordata**
Class	**: Amphibia**
Genus	**: *Rana***
Species	**: *tigrina***

- ***Rana tigrina*** is the most common species in India.
- They are **poikilotherms (cold blooded).**
- They can change colour to hide them from their enemies **(camouflage).** This protective coloration is called **mimicry.**
- During summer and winter, they undergo **aestivation (summer sleep)** and **hibernation (winter sleep)** respectively to protect them from extreme heat and cold.

MORPHOLOGY OF FROG

- Body is divisible into **head** & **trunk**. Neck and tail absent.
- Skin is moist, smooth and slippery due to the mucus.
- Colour of dorsal side is olive green with dark irregular spots and ventral side is pale yellow.
- The frog never drinks water but absorb it through the skin.
- A **mouth**, paired **nostrils** and bulged **eyes** (covered by nictitating membrane) are present.
- On either side of eyes have a membranous **tympanum(ear)**.
- The **forelimbs (4 digits)** and **hind limbs (5 digits)** help in **swimming, walking, leaping** and **burrowing.** The hind limbs are larger and muscular than fore limbs.
- Feet have webbed digits that help in swimming.
- Frogs exhibit **sexual dimorphism**. Male frogs have sound producing **vocal sac** and also a **copulatory (nuptial) pad** on the first digit of fore limbs which are absent in female frogs.

ANATOMY OF FROG



Digestive system

- Consists of **alimentary canal** and **digestive glands.**
- The alimentary canal is short because frogs are carnivores and hence the length of intestine is reduced.
- **Mouth → buccal cavity → pharynx → oesophagus → stomach → intestine → rectum → cloaca.**
- Liver secretes **bile** that is stored in **gall bladder. Pancreas** produces **pancreatic juice** containing digestive enzymes.
- Food is captured by the bilobed tongue.
- **Digestion**: Gastric juice and HCl secreted from gastric wall digest the food. Partially digested food (**chyme)** is passed from stomach to the **duodenum.**

  Duodenum receives **bile** and **pancreatic juices** through a **common bile duct.**

  Bile emulsifies fat. Pancreatic juice digests carbohydrates and proteins. Digestion completes in the intestine.
- Finger-like **villi** and **microvilli** in intestine absorb digested food. The undigested solid waste moves into the **rectum** and passes out through **cloaca.**

Respiratory system

- **Skin** acts as aquatic respiratory organ **(cutaneous respiration).** Dissolved oxygen in the water is exchanged through the skin by diffusion. During aestivation and hibernation respiration takes place through skin.
- On land, the **buccal cavity, skin** and **lungs (pulmonary respiration)** act as the respiratory organs.
- The lungs are a pair of elongated, pink coloured sac-like structures present in the thorax. Air enters through the nostrils into the buccal cavity and then to lungs.

Circulatory system

- **Closed type.** Includes **Blood vascular system (heart, blood vessels & blood)** and **lymphatic system (lymph, lymph channels & lymph nodes).**
- Heart is **3-chambered, (two atria** and **one ventricle**) and is covered by a membrane called **pericardium.**
- A triangular structure called **sinus venosus** joins the right atrium. It receives blood through major veins **(vena cava).**
- The ventricle opens into a saclike **conus arteriosus** on the ventral side of the heart.
- The blood pumped from the muscular heart is carried to all parts of the body by the **arteries (arterial system).**
- The **veins** collect blood from different parts of body to the heart and form the **venous system.**
- **Hepatic portal system** (venous connection between liver and intestine) and **renal portal system** (between kidney and lower parts of the body) are present in frogs.
- Blood contains **plasma** and **cells (RBC, WBC & platelets).** RBCs are nucleated and contain haemoglobin.
- Blood transports nutrients, gases and water to tissues.

Excretory system

- Includes **kidneys (2), ureters (2), cloaca & urinary bladder.**
- **Kidneys** are dark red and bean-shaped. Found posteriorly in the body cavity on both sides of vertebral column. Each kidney is formed of **uriniferous tubules (nephrons).**
- 2 ureters emerge from the kidneys. In male frogs, the ureters act as **urinogenital duct** which opens into cloaca.

  In females, ureters & oviduct open separately in cloaca.
- The thin-walled **urinary bladder** is present ventral to the rectum which also opens in the cloaca.
- The frog is a **ureotelic** animal (excretes urea). Nitrogenous wastes are carried by blood into the kidney where it is separated and excreted.

Control and co-ordination

Endocrine system

- The **endocrine glands** secrete **hormones**.
- Endocrine glands: **pituitary, thyroid, parathyroid, thymus, pineal body, pancreatic islets, adrenals & gonads.**

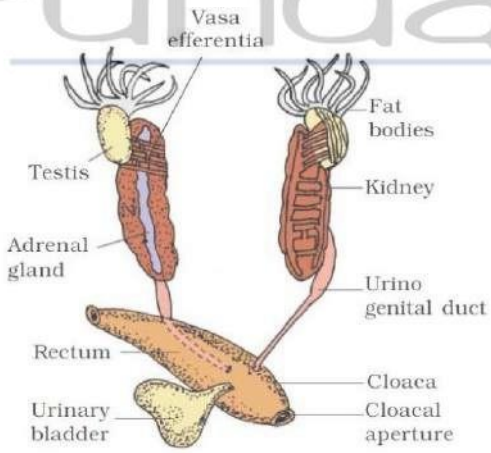
Nervous system

It includes

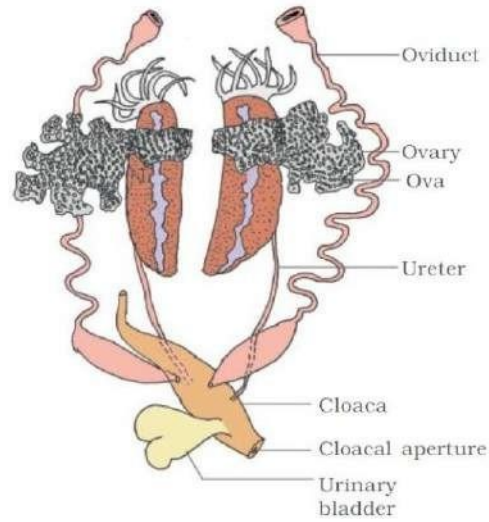
- **Central nervous system (brain** & **spinal cord),**
- **Peripheral nervous system (cranial** & **spinal nerves)**
- **Autonomic nervous system (sympathetic** & **parasympathetic).**

- There are 10 pairs of **cranial nerves** arising from brain.
- Brain is enclosed in a bony **brain box(cranium).**
- The brain is divided into
  - **Fore-brain:** Includes **olfactory lobes, paired cerebral hemispheres** and **unpaired diencephalon.**
  - **Mid-brain:** Includes a pair of **optic lobes.**
  - **Hind-brain:** Includes **cerebellum & medulla oblongata.**
- **Medulla oblongata** passes out through the **foramen magnum** and continues into **spinal cord**, which is enclosed in the vertebral column.
- Sense organs include organs of
  - **Sensory papillae:** For touch
  - **Taste buds:** For taste
  - **Nasal epithelium:** For smell
  - **Simple eyes:** For vision. Paired and situated in orbit
  - **Tympanum with internal ears:** For hearing and balancing (equilibrium).

Reproductive system



- Male reproductive organs consist of a pair of yellowish ovoid **testes**, which are found adhered to the upper part of kidneys by a double fold of peritoneum **(mesorchium).**
- **Vasa efferentia** (10-12 in number) arise from testes. They enter the kidneys on their side and open into **Bidder's canal**. It communicates with urinogenital duct that comes out of the kidneys and opens into cloaca.
- The **cloaca** is a small, median chamber that is used to pass faecal matter, urine and sperms to the exterior.



- The female reproductive organs include a pair of **ovaries.** The ovaries are situated near kidneys and there is no functional connection with kidneys.
- A pair of oviduct arising from the ovaries opens into the cloaca separately.
- A mature female can lay **2500 to 3000 ova** at a time.
- Fertilisation is external and takes place in water.
- Development involves a larval stage called **tadpole.**
- Tadpole undergoes metamorphosis to form the adult.

ECONOMIC IMPORTANCE

- Frogs are beneficial for mankind because they eat insects and protect the crop.
- Maintain ecological balance by serving as an important link of food chain and food web in the ecosystem.
- In some countries the muscular legs of frog are used as food by man.

CELL: THE UNIT OF LIFE

- A cell is the fundamental, structural and functional unit of all living organisms.
- **Robert Hooke:** Discovered cell.
- **Anton Von Leeuwenhoek:** First observed and described a live cell.
- The invention of the **compound** & **electron microscopes** revealed all the structural details of the cell.

CELL THEORY

- **Matthias Schleiden (1838)** observed that all plants are composed of different kinds of cells.
- **Theodore Schwann (1839)** found that cells have a thin outer layer (plasma membrane). He also found that plant cells have cell wall. He proposed a hypothesis that animals and plants are composed of cells and products of cells.
- Schleiden & Schwann formulated the **cell theory.**
- **Rudolf Virchow (1855)** first explained that cells divide and new cells are formed from pre-existing cells (*Omnis cellula-e cellula*). He modified the cell theory.
- Cell theory states that:
  (i) All living organisms are composed of cells and products of cells.
  (ii) All cells arise from pre-existing cells.

AN OVERVIEW OF CELL

- All cells contain
  - **Cytoplasm:** A semi-fluid matrix where cellular activities and chemical reactions occur. This keeps the cell in 'living state'.
  - **Ribosomes:** Non-membrane bound organelles seen in cytoplasm, chloroplasts, mitochondria & on rough ER.
- Cells differ in size, shape and activities.
  - **Smallest cells:** Mycoplasmas (0.3 µm in length).
  - **Largest isolated single cell:** Egg of ostrich.
  - **Longest cells:** E.g. Nerve cell.
  - Size of bacteria: 3 to 5 µm (Typical: 1 to 2 µm).
  - Human RBCs are about 7.0 µm in diameter.
- Based on the functions, shape of cells may be disc-like, polygonal, columnar, cuboid, thread like, or irregular.
- Cells are 2 types: **Prokaryotic cells & Eukaryotic cells.**

PROKARYOTIC CELLS

- They have no membrane bound nucleus and organelles.
- They include **bacteria, blue-green algae, mycoplasma & PPLO (Pleuro Pneumonia Like Organisms).**
- They are generally smaller and multiply more rapidly than the eukaryotic cells.
- They vary in shape & size. E.g. Bacteria have 4 basic shapes: **Bacillus, Coccus, Vibrio** and **Spirillum.**

Cell organelles in prokaryotic cells

1. Cell Envelope

- It is a chemically complex protective covering.
- It is made of 3 tightly bound layers.
  - **Glycocalyx:** Outer layer. Its composition and thickness vary in different bacteria. It may be a **slime layer** (loose sheath) or **capsule** (thick & tough).
  - **Cell wall:** Middle layer. Seen in all prokaryotes except mycoplasma. It gives shape to the cell and provides a structural support to prevent the bacterium from bursting or collapsing.
  - **Plasma membrane:** Inner layer. It is semi-permeable in nature and interacts with the outside. This is structurally similar to that of the eukaryotes.
- Based on the types of the cell envelopes and response to Gram staining (developed by Gram), bacteria are 2 types:
  - **Gram positive:** They take up and retain the gram stain.
  - **Gram negative:** They do not retain the gram stain.

1. Mesosomes & Chromatophores (Membranous structures)

- **Mesosome** is formed by the infoldings of plasma membrane. It includes **vesicles, tubules & lamellae**.
- **Functions:** Mesosomes help
  - In cell wall formation.
  - In DNA (chromosome) replication.
  - In distribution of chromosomes to daughter cells.
  - In respiration and secretion processes.
  - To increase the surface area of the plasma membrane and enzymatic content.
- **Chromatophores** are pigment-containing membranous infoldings in some prokaryotes (e.g. cyanobacteria).

1. Nucleoid

- It is formed of non-membranous (naked) circular **genomic DNA** (single chromosome/ Genetic material) & protein.
- Many bacteria have small circular DNA **(plasmid)** outside the genomic DNA. It gives some unique phenotypic characters (e.g. resistance to antibiotics) to bacteria.

1. Flagella

- These are thin filamentous extensions from the cell wall of motile bacteria. Their number and arrangement are varied in different bacteria.
- Bacterial flagellum has 3 parts – **filament, hook** and **basal body**. The filament is the longest portion and extends from the cell surface to the outside.

1. Pili and Fimbriae

- These are surface structures that have no role in motility.
- **Pili** (sing. Pilus) are elongated tubular structures made of a special protein **(pilin).**
- **Fimbriae** are small bristle like fibres sprouting out of the cell. In some bacteria, they help to attach the bacteria to rocks in streams and to the host tissues.

1. Ribosomes

- They are associated with plasma membrane of prokaryotes.
- They are about 15 nm by 20 nm in size.
- They are made of 2 subunits - **50S** & **30S (Svedberg's unit).** They together form **70S** prokaryotic ribosomes.

(S= sedimentation coefficient; a measure of density & size).
- **Function:** Ribosomes are the site of **translation** (protein synthesis). Several ribosomes may attach to a single mRNA to form a chain called **polyribosomes (polysome)**. Ribosomes translate the mRNA into proteins.

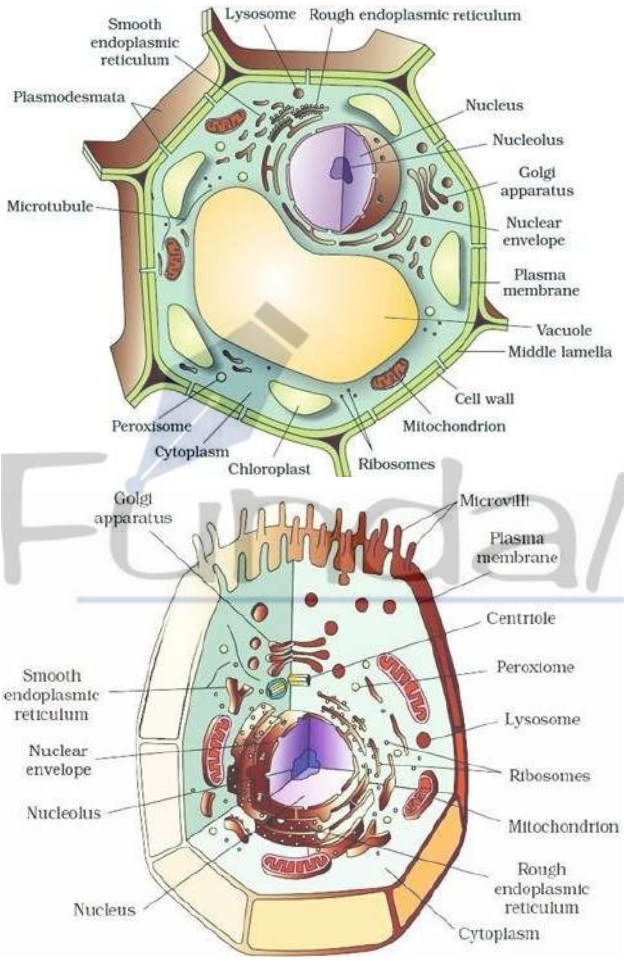
1. Inclusion Bodies

- These are non-membranous, stored reserve material seen freely in the cytoplasm of prokaryotic cells.
- E.g. phosphate granules, cyanophycean granules and glycogen granules, gas vacuoles etc.
- **Gas vacuoles** are found in blue green and purple and green photosynthetic bacteria.

EUKARYOTIC CELLS

- They have well organized **membrane bound nucleus** and **organelles.**
- Presence of membranes gives clear compartmentalization of cytoplasm.
- Their genetic material is organized into chromosomes.
- They have complex locomotory & cytoskeletal structures.

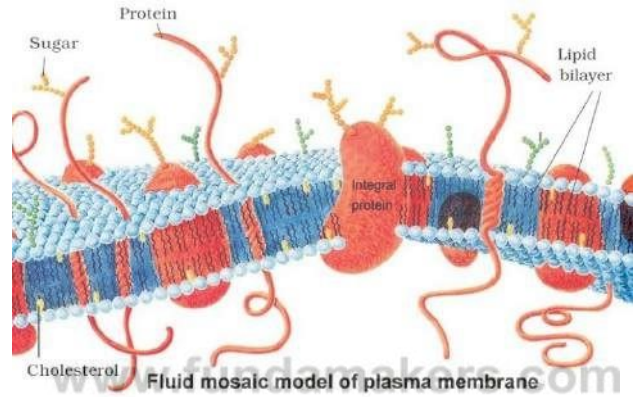
Plant cell and Animal cell



Cell organelles in eukaryotic cells

1. Cell Membrane

- Chemical studies on human RBCs show that cell membrane is composed of a **lipid bilayer, protein & carbohydrate.**
- Lipids (mainly **phosphoglycerides)** have outer **polar head** and the inner **hydrophobic tails.** So the non-polar tail of saturated hydrocarbons is protected from the aqueous environment.
- Ratio of protein and lipid varies in different cells. E.g. In human RBC, membrane has 52% protein and 40% lipids.
- Based on the ease of extraction, membrane proteins are 2 types:
  - **Integral proteins:** Partially or totally buried in membrane.
  - **Peripheral proteins:** Lie on the surface of membrane.
- **Fluid mosaic model of cell membrane:** Proposed by **Singer & Nicolson** (1972). According to this, the quasi-fluid nature of lipid enables lateral movement of proteins within the overall bilayer. This ability to move within the membrane is measured as its fluidity.



Fluid mosaic model of plasma membrane

Functions:
- Transport of the molecules. The membrane is selectively permeable to some molecules present on either side of it.
- Due to the fluid nature, the plasma membrane can help in cell growth, formation of intercellular junctions, secretion, endocytosis, cell division etc.

Types of Transport

1. **Passive transport:** It is the movement of molecules across the membrane along the concentration gradient (i.e., from higher concentration to the lower) without the expenditure of energy. It is 2 types:
   a. **Simple diffusion:** It is the movement of neutral solutes across the membrane.
   b. **Osmosis:** It is the movement of water by diffusion across the membrane.

   Polar molecules cannot pass through the non-polar lipid bilayer. So they require membrane carrier protein for transport.
2. **Active transport:** It is the movement of molecules across the membrane against the concentration gradient (i.e. from lower to the higher concentration) with the expenditure of energy (ATP is utilized). E.g. Na^+/K^+ pump.

2. Cell Wall

- It is a non-living rigid structure found outer to the plasma membrane of fungi and plants.
- Cell wall of Algae is made of cellulose, galactans, mannans and minerals like $CaCO_3$. In other plants, it consists of cellulose, hemicellulose, pectins and proteins.
- Cell wall of a young plant cell **(primary wall)** is capable of growth. It gradually diminishes as the cell matures and

the **secondary wall** is formed on the inner side (towards membrane).

- The **middle lamella** is a layer containing calcium pectate which glues the neighbouring cells together. Cell wall and middle lamellae may be traversed by **plasmodesmata.** It connects the cytoplasm of neighbouring cells.

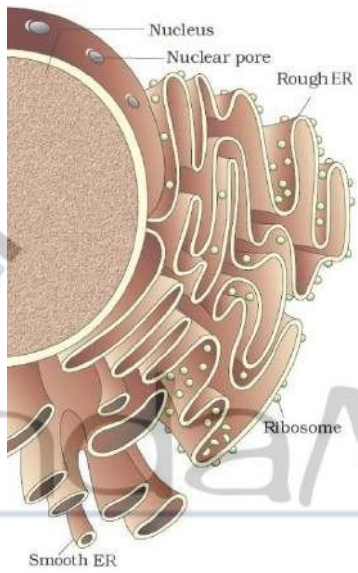
Functions:

a. It gives shape to the cell.
b. It protects the cell from mechanical damage & infection.
c. It helps in cell-to-cell interaction.
d. It acts as barrier to undesirable macromolecules.

3. Endomembrane System

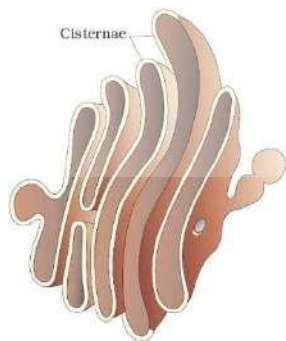
- It is a group of membranous organelles having coordinated functions.
- They include endoplasmic reticulum (ER), Golgi complex, lysosomes and vacuoles.

Endoplasmic Reticulum (ER)



- These are a network of tiny tubular structures scattered in the cytoplasm.
- ER divides the intracellular space into 2 compartments: **luminal** (inside ER) & **extra luminal** (cytoplasm).
- Endoplasmic reticulum is 2 types:
  a. **Rough endoplasmic reticulum (RER):** Bear ribosomes on their surface. RER is frequently observed in the cells actively involved in protein synthesis and secretion. They extend to the outer membrane of the nucleus.
  b. **Smooth endoplasmic reticulum (SER):** Ribosomes are absent. SER is the major site for synthesis of lipid. In animal cells lipid-like steroidal hormones are synthesized in SER.

Golgi apparatus



- Densely stained reticular structures near the nucleus.
- First observed by **Camillo Golgi** (1898).
- They consist of flat, disc-shaped sacs **(cisternae)** of 0.5– 1.0 μm diameter. These are stacked parallelly.
- Cisternae are concentrically arranged with convex ***cis*** (forming) face and concave ***trans*** (maturing) face. *Cis* & *trans* faces are totally different, but interconnected.

Function of Golgi apparatus:

- Secretes materials to intra-cellular targets or outside the cell. Materials to be packaged as vesicles from the ER fuse with the *cis* face and move towards the *trans* face. This is why Golgi apparatus remains in close association with the endoplasmic reticulum.
- Proteins synthesized by ribosomes on the ER are modified in the cisternae of Golgi apparatus before they are released from its *trans* face.
- Formation of glycoproteins and glycolipids.

Lysosomes

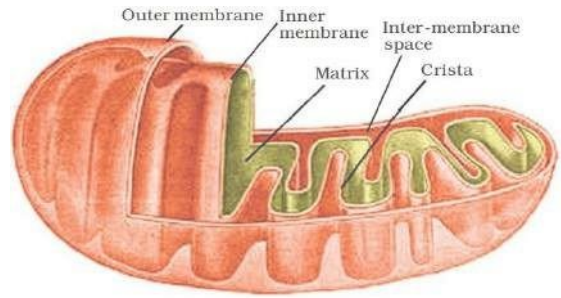
- These are membrane bound vesicular structures formed by the process of packaging in the Golgi apparatus.
- Lysosomal vesicles contain almost all types of hydrolytic enzymes (hydrolases– lipases, proteases, carbohydrases). They are active at acidic pH. They digest carbohydrates, proteins, lipids and nucleic acids.

Vacuoles

- These are the membrane-bound space found in the cytoplasm. It contains water, sap, excretory product and other materials not useful for the cell.
- Vacuole is bound by a single membrane called **tonoplast**.
- In plant cells, the vacuoles can occupy up to 90% of the volume of the cell.
- In plants, the tonoplast facilitates the transport of ions and other materials against concentration gradients into the vacuole. Hence their concentration is higher in the vacuole than in the cytoplasm.
- In *Amoeba*, the **contractile vacuole** helps for excretion.
- In many cells (e.g. protists), **food vacuoles** are formed by engulfing the food particles.

4. Mitochondria

- Mitochondria are clearly visible only when stained.
- Number, shape and size of mitochondria per cell are variable depending on the physiological activity.
- It is sausage-shaped or cylindrical having a diameter of 0.2-1.0 μm (average 0.5 μm) and length 1.0-4.1 μm.



- A mitochondrion is a double membrane-bound structure with the outer membrane and the inner membrane. It divides lumen into 2 aqueous compartments, i.e., the outer compartment and the inner compartment **(matrix)**.
- Inner membrane forms a number of infoldings **(cristae)** towards the matrix. They increase the surface area.
- The two membranes have their own specific enzymes associated with the mitochondrial function.
- Matrix possesses a circular DNA, a few RNA molecules, ribosomes (70S) and components for protein synthesis.
- The mitochondria divide by fission.

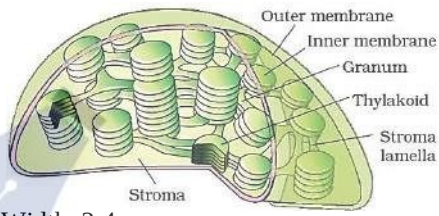
- **Function:** Mitochondria are the sites of aerobic respiration. They produce energy in the form of ATP. So they are called **'power houses'** of the cell.

5. Plastids

- Plastids are found in all plant cells and in euglenoides.
- Large sized. Easily observable under the microscope.
- They contain some pigments.
- Based on the type of pigments, plastids are 3 types:
  a. **Chloroplasts:** Contain **chlorophyll** and **carotenoid** pigments. They trap light energy for photosynthesis.
  b. **Chromoplasts:** Contain fat soluble **carotenoid** pigments like carotene, xanthophylls etc. This gives a yellow, orange or red colour.
  c. **Leucoplasts:** These are colourless plastids of varied shapes and sizes with stored nutrients. They include:
     - **Amyloplasts:** Store starch. E.g. potato.
     - **Elaioplasts:** Store oils and fats.
     - **Aleuroplasts:** Store proteins.

Chloroplasts:

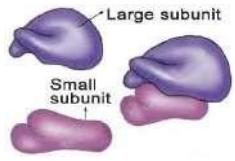
- These are double membrane bound organelles mainly found in the **mesophyll** cells of the leaves.
- These are lens-shaped, oval, spherical, discoid or ribbon-like organelles.



- Length: 5-10 μm. Width: 2-4 μm.
- Their number varies from 1 (e.g. *Chlamydomonas*) to 20-40 per cell in the mesophyll.
- Inner membrane of chloroplast is less permeable.
- The space limited by the inner membrane of the chloroplast is called **stroma**. It contains many organized flattened membranous sacs called **thylakoids**.
- Membrane of thylakoids encloses a space called **lumen**.
- **Chlorophyll** pigments are present in the thylakoids.
- Thylakoids are arranged in stacks called **grana** or the intergranal thylakoids.
- There are flat membranous tubules called the **stroma lamellae** connecting the thylakoids of the different grana.
- The stroma contains small, double-stranded circular DNA molecules, ribosomes and enzymes for the synthesis of carbohydrates and proteins.
- The ribosomes of the chloroplasts are smaller (70S) than the cytoplasmic ribosomes (80S).

6. Ribosomes

- They are non-membranous granular structures composed of **ribonucleic acid (RNA)** & **proteins.**
- It is first observed by **George Palade** (1953).



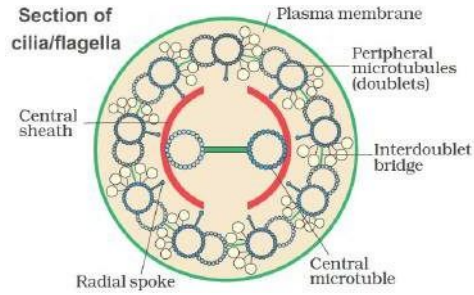
- Eukaryotic ribosome has 2 subunits- **60S** (large subunit) and **40S** (small subunit). They together form **80S.**

7. Cytoskeleton

- It is a network of filamentous proteinaceous structures present in the cytoplasm.
- It provides mechanical support, motility, maintenance of the shape of the cell etc.

8. Cilia and Flagella

- They are hair-like outgrowths of the cell membrane.
- **Cilia**: Small structures which work like oars. Causes the movement of the cell or surrounding fluid.
- **Flagella:** Longer. Responsible for cell movement. Flagella of prokaryotes and eukaryotes are structurally different.



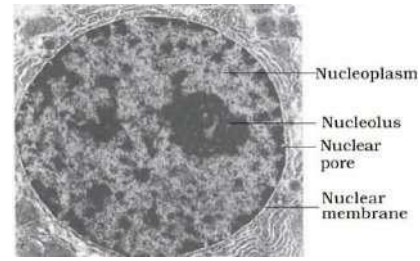
- Cilium and flagellum are covered with plasma membrane. Their core **(axoneme)** has many **microtubules** running parallel to the long axis.
- The axoneme has 9 pairs of doublets of radially arranged peripheral microtubules and a pair of central microtubules. This is called **9+2 array.**
- The central tubules are connected by bridges and are enclosed by a **central sheath.** It is connected to one of the tubules of each peripheral doublet by a **radial spoke.** Thus, there are **9 radial spokes.** The peripheral doublets are also interconnected by linkers.
- Cilium and flagellum emerge from centriole-like structure called the **basal bodies.**

9. Centrosome and Centrioles

- **Centrosome** is an organelle usually containing two non-membrane bound cylindrical structures called **centrioles**.
- They are surrounded by **pericentriolar materials.**
- The centrioles lie perpendicular to each other. They are made up of 9 evenly spaced peripheral fibrils of **tubulin**. Each of the peripheral fibril is a triplet. The adjacent triplets are also linked.
- The central part of the centriole is also proteinaceous and called the **hub**, which is connected with tubules of the peripheral triplets by radial **spokes** made of protein.
- The centrioles form the basal body of cilia or flagella, and spindle fibres that give rise to spindle apparatus during cell division in animal cells.

10. Nucleus

- Nucleus was first described by **Robert Brown** (1831).

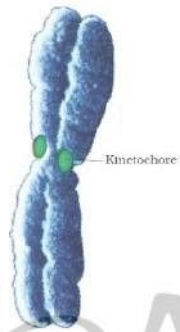


- The material of the nucleus stained by the basic dyes was given the name **chromatin** by **Flemming**.

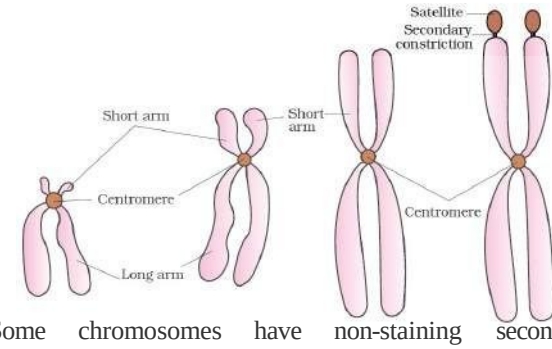
- Normally, a cell has only one nucleus. Some cells have more than one. Some mature cells lack nucleus. E.g. mammalian RBC and sieve tube cells of vascular plants.
- The interphase nucleus contains
  - **Nuclear envelope:** Double layered membrane with a space between (10 - 50 nm) called **perinuclear space.** It is a barrier between the materials present in nucleus & cytoplasm. Outer membrane usually remains continuous with ER and also bears ribosomes on it.
    Nuclear envelope has minute pores formed by the fusion of its two membranes. These are the passages for the movement of RNA and protein between nucleus and cytoplasm.
  - **Nuclear matrix (nucleoplasm)**
  - **Chromatin:** A network of nucleoprotein fibres. It contains DNA and basic proteins **(histones)**, non-histone proteins and RNA. During cell division, chromatins condense to form **chromosomes**.
  - **Nucleolus:** One or more non-membranous spherical bodies. It is continuous with the nucleoplasm. It is a site for ribosomal RNA synthesis.

Chromosomes:

- A human cell has 2 m long thread of DNA distributed among its 46 (23 pairs) chromosomes.
- Every chromosome has a primary constriction **(centromere).** On the sides of centromere, disc shaped structures called **kinetochores** are present.



- Based on position of centromere, chromosomes are 4 types:
  - **Metacentric chromosome:** Middle centromere forming two equal arms of the chromosome.
  - **Sub-metacentric chromosome:** Centromere is nearer to one end forming one shorter arm and one longer arm.
  - **Acrocentric chromosome:** Centromere is close to its end forming one very short and one very long arm.
  - **Telocentric chromosome:** Terminal centromere.



- Some chromosomes have non-staining secondary constrictions at a constant location. It is called **satellite**.

11. Microbodies

- These are membrane bound minute vesicles that contain various enzymes.
- Present in both plant and animal cells.

Differences between Plant and animal cells

Plant cell	Animal cell
1. Cell wall present	Absent
2. Plastids are present	Absent
3. A large central vacuole	Many small vacuoles
4. Centrioles are absent	Present

COMPARISON BETWEEN PROKARYOTIC AND EUKARYOTIC CELLS

Prokaryotic cells	Eukaryotic cells
1. Generally smaller	Larger
2. Genetic material is in the form of nucleoid	Genetic material is in the form of nucleus
3. Nuclear membrane absent	Present
4. Membrane bound organelles absent	Present
5. Circular DNA	Linear DNA
6. Ribosomes 70 S type	80 S type (70 S in plastids and mitochondria)

CELL CYCLE AND CELL DIVISION

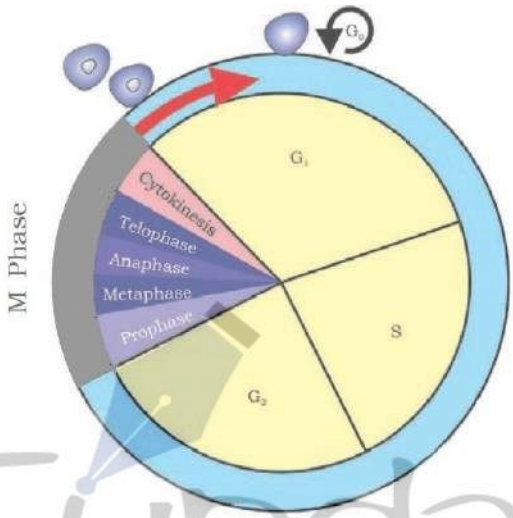
- The growth and reproduction of all organisms depend on the division and enlargement of cells.
- The mechanisms of division and multiplication of cells together constitute **cell reproduction.**

CELL CYCLE

- It is the life period of a cell during which a cell synthesizes DNA (replication), grows & divides into 2 daughter cells.
- Cell growth (cytoplasmic increase) is a continuous process but DNA synthesis occurs only at a specific stage.
- Duration of cell cycle varies in each organism and each cell type. E.g. Duration of a typical eukaryotic cell cycle (e.g. human cell) is about 24 hrs. In Yeasts, it is 90 minutes.

Phases of Cell Cycle

Cell cycle includes 2 basic phases: **Interphase & M Phase.**



1. Interphase (resting phase)

- It is the phase between two successive M phases.
- It includes cell growth and DNA synthesis.
- It lasts more than 95% of the duration of cell cycle.

Interphase has 3 phases:

a. G_1 phase (Gap 1 or Antephase): First growth phase. It is the interval between mitosis and DNA replication.

Main events:

- Continuous growth of cell.
- Cell becomes metabolically active.
- Prepares machinery for the DNA replication.
- Synthesizes RNA and proteins.

b. S (Synthetic) phase:

- In this, DNA replication takes place.
- Amount of DNA per cell doubles. But chromosome number is not increased.
- In animal cells, replication begins in the nucleus, and the centriole duplicates in the cytoplasm.

c. G_2 phase (Gap 2):

- Second growth phase. Cell growth continues.
- Synthesis of RNA and proteins continues.
- Cell is prepared for mitosis.

2. M Phase (Mitosis phase)

- It represents the actual cell division (mitosis).
- In human cell cycle, it lasts for only about an hour.
- M Phase includes **karyokinesis** (nuclear division) and **cytokinesis** (division of cytoplasm).
- Some cells do not show division. E.g. heart cells.
- Many other cells divide only occasionally to replace damaged or dead cells.
- The cells that do not divide further exit G_1 phase and enter an inactive stage called **quiescent stage (G_0).** Such cells remain metabolically active but do not proliferate.

MITOSIS

- It is the cell division occurring in **somatic cells**.
- It is also called as **equational division** as the number of chromosomes in the parent and progeny cells is same.
- Mitosis is generally seen in **diploid cells.** It also occurs in haploid cells of some lower plants and some social insects.
- It involves major reorganization of all cell components.

The karyokinesis of mitosis has 4 stages: **Prophase, Metaphase, Anaphase & Telophase.**

1. Prophase

- It is the longest phase in mitosis.
- It follows the S and G2 phases of interphase.
- In the S & G2 phases, DNA molecules are intertwined.
- **Characteristic events:**
  - Chromosomal materials (chromatin fibres) are untangled and condensed to form mitotic **chromosomes.** They are seen to be composed of **two chromatids** attached together at the **centromere.**
  - **Centrosomes** begin to move towards opposite poles of the cell. Each centrosome radiates out microtubules called **asters.** The two asters together with spindle fibres forms **mitotic apparatus.**
- Cells at the end of prophase do not show Golgi complexes, endoplasmic reticulum, nucleolus & nuclear envelope.

2. Metaphase

- The nuclear envelope completely disintegrates. Hence the chromosomes spread through the cytoplasm of the cell.
- Chromosome condensation is completed. They can be observed and studied easily under the microscope. They will have two sister chromatids.
- Chromosomes come to lie at the equator. The plane of alignment of the chromosomes at metaphase is called the **metaphase plate.**
- The **spindle fibres** from both poles are connected to chromatids by their kinetochores in the centromere.

3. Anaphase

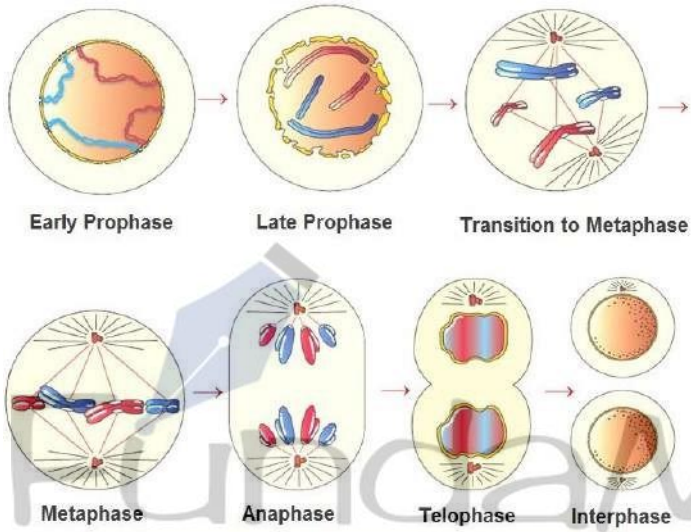
- It is the shortest phase in the mitosis.
- Centromere of each chromosome divides longitudinally resulting in the formation of two daughter chromatids (chromosomes of the future daughter nuclei).
- As the spindle fibres contract, the chromatids move from the equator to the opposite poles.

4. Telophase

- Chromosomes cluster at opposite poles and uncoil into chromatin fibres.
- Nuclear envelope develops around the chromosome clusters at each pole. Thus 2 daughter nuclei are formed.
- Nucleolus, Golgi complex and ER reappear.
- The spindle fibres disappear.

Cytokinesis

- It is the division of cytoplasm to form 2 daughter cells. It starts when telophase is in progress.
- **Cytokinesis in animal cell:** Here, a **cleavage furrow** is appeared in the plasma membrane. It gradually deepens and joins in the centre dividing the cytoplasm into two.
- **Cytokinesis in plant cell:** It is different from the cytokinesis in animal cells due to the presence of cell wall. In plant cells, the vesicles formed from Golgi bodies accumulate at the equator. It grows outward and meets the lateral walls. They fuse together to form the **cell-plate.** It separates the 2 daughter cells. Later, the cell plate becomes the middle lamella.
- During cytokinesis, organelles like mitochondria and plastids get distributed between the daughter cells.
- In some organisms karyokinesis is not followed by cytokinesis. As a result, multinucleate condition (syncytium) arises. E.g. liquid endosperm in coconut.



Significance of Mitosis

- It produces diploid daughter cells with identical genome.
- It helps to retain the same chromosome number in all somatic cells.
- It helps in the body growth of multicellular organisms. Mitosis in the meristematic tissues helps in a continuous growth of plants throughout the life.
- It restores the nucleo-cytoplasmic ratio that disturbed due to cell growth.
- It helps in cell repair & replacement. E.g. cells of the upper layer of the epidermis, lining of the gut & blood cells.

MEIOSIS

- It is the division of diploid germ cells that reduces the chromosome number by half forming haploid daughter cells (gametes). It occurs during gametogenesis.
- It leads to the haploid phase in the life cycle of sexually reproducing organisms. Fertilisation restores diploid phase.

Key features of meiosis

- It involves two cycles **(meiosis I** & **meiosis II)** but only a single cycle of DNA replication.
- It involves **pairing** of homologous chromosomes and **recombination** between their **non-sister chromatids.**
- Meiosis I begins after replication of parental chromosomes to form identical sister chromatids at the S phase.
- 4 haploid cells are formed at the end of meiosis II.

Meiosis I	Meiosis II
Prophase I	Prophase II
Metaphase I	Metaphase II
Anaphase I	Anaphase II
Telophase I	Telophase II

Meiosis I

Prophase I:

- It is typically longer and more complex.
- It includes 5 phases based on chromosomal behaviour: Leptotene, Zygotene, Pachytene, Diplotene & Diakinesis.

▪ **Leptotene (Leptonema):** Chromatin fibres become long slender chromosomes. Nucleus enlarges.

▪ **Zygotene (Zygonema):** Chromosomes become more condensed. Similar chromosomes start pairing together (synapsis) with the help of a complex structure called **synaptonemal complex.** The paired chromosomes are called **homologous chromosomes.** Each pair of homologous chromosomes is called a **bivalent.**

▪ **Pachytene (Pachynema):** Comparatively longer phase. Bivalent chromosomes split into similar chromatids. This stage is called **tetrads**. During this, **recombination nodules** appear at which **crossing over** occurs. It leads to genetic recombination on homologous chromosomes.

Crossing over: The exchange of genetic material between non-sister chromatids of two homologous chromosomes in presence of an enzyme, ***recombinase***.

Recombination is completed by the end of pachytene.

▪ **Diplotene (Diplonema):** Dissolution of the synaptonemal complex occurs. The recombined homologous

chromosomes of the bivalents separate from each other except at the sites of crossovers. These X-shaped structures are called **chiasmata.** In oocytes of some vertebrates, diplotene lasts for months or years.

- **Diakinesis:** Terminalisation of chiasmata. Chromosomes are fully condensed. The meiotic spindle fibres originate from the poles to prepare the homologous chromosomes for separation. Nucleolus & nuclear envelope disappear.

Metaphase I:

Spindle formation is completed. The chromosomes align on the equatorial plate. The microtubules from the spindle attach to the pair of homologous chromosomes.

Anaphase I:

The homologous chromosomes separate, while sister chromatids remain associated at their centromeres.

Telophase I:

- The nuclear membrane and nucleolus reappear and 2 haploid daughter nuclei are formed. This is called **diad**.
- After this, cytokinesis may or may not occur.
- After a short interphase, it is followed by meiosis II.
- This short stage between the two meiotic divisions is called **interkinesis**. DNA replication does not occur in this phase.

Meiosis II

It resembles the mitosis. It has the following phases:

Prophase II:

It is initiated immediately after cytokinesis. The chromosomes again become compact.

Nucleolus and nuclear membrane disappear in both nuclei.

Metaphase II:

The chromosomes align at the equator and the microtubules from opposite poles of the spindle get attached to the kinetochores of sister chromatids.

Anaphase II:

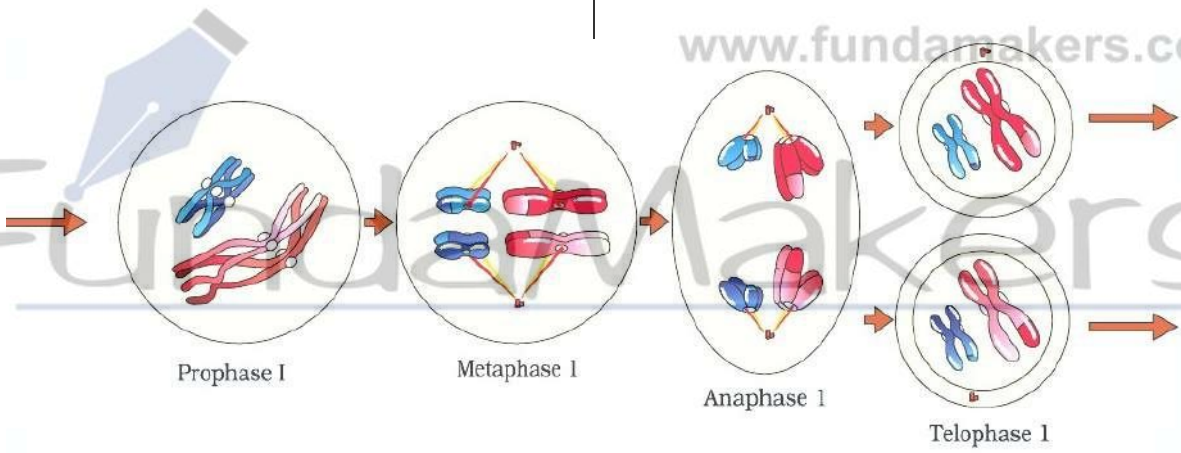
It begins with the simultaneous splitting of the centromere of each chromosome (which was holding sister chromatids together). Thus they move toward opposite poles of the cell by shortening of microtubules attached to kinetochores.

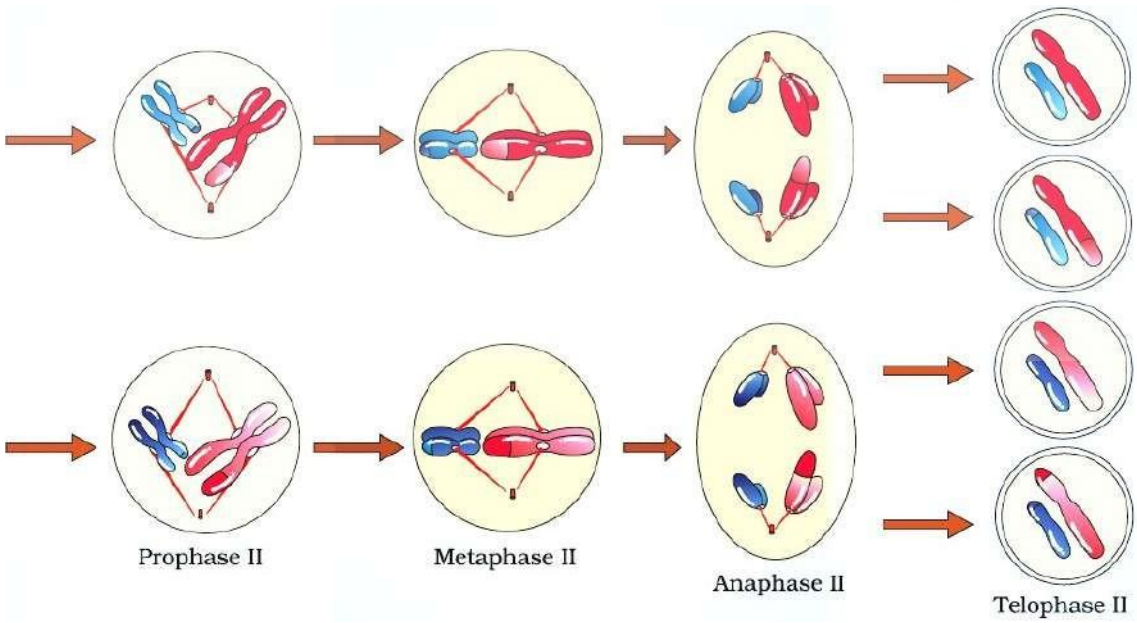
Telophase II:

The two groups of chromosomes once again get enclosed by a nuclear envelope; cytokinesis follows resulting in the formation of tetrad of cells i.e., 4 haploid daughter cells.

Significance of meiosis

- It conserves the chromosome number of each species.
- It causes genetic variation (due to crossing over) in the population of organisms. It is important for evolution.





TRANSPORT IN PLANTS

Plants do not have interstitial fluid and circulatory system. But they need to move various substances (water, minerals, organic nutrients, growth regulators etc.) over long distances.

Direction of transport

- **Unidirectional transport:** E.g. Transport of water and minerals in xylem (from roots to the stems, leaves etc.).
- **Multidirectional transport:** E.g.
  - Transport of photosynthates (organic compounds).
  - Transport of mineral nutrients.
- Sometimes, plant hormones and other chemical stimuli are transported in a polarized or unidirectional manner from where they are synthesized to other parts.

MEANS OF TRANSPORT

1. Diffusion

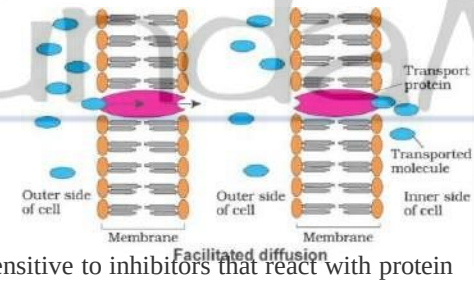
- It is the slow movement of gases, liquids and solutes from higher concentrated region to lower concentrated region without the energy expenditure.
- It may be from one part of the cell to the other or from cell to cell, or over short distances.
- It is not dependent on a 'living system'.
- It is the only means for gaseous movement in a plant body.

Factors affecting diffusion rates:

- Concentration gradient.
- Permeability of the membrane.
- Temperature and pressure.
- Size or density. Smaller substances diffuse faster.
- Solubility in lipids of the membrane. Substances soluble in lipids diffuse through the membrane faster.

2. Facilitated Diffusion

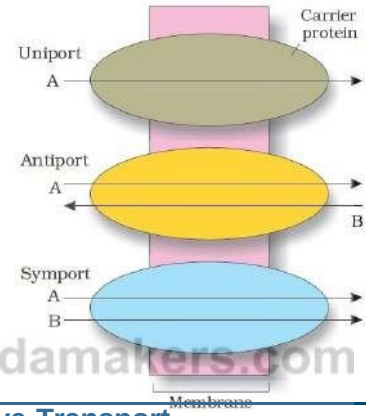
- It is the diffusion of hydrophilic substances with the help of membrane protein channels and without expenditure of energy.
- It also needs a concentration gradient.
- It is very specific. Cell selects substances for uptake. It is sensitive to inhibitors that react with protein side chains.



- Transport rate reaches a maximum when all the protein transporters are being used (saturation).
- Some protein channels are always open; others can be controlled. Some are large sized. E.g. Porins.
- **Porins** form huge pores in the outer membranes of plastids, mitochondria & some bacteria. Molecules having size of small proteins can pass through them.
- An extracellular molecule binds to the transport protein. Then it rotates and releases the molecule inside the cell. E.g. water channels – made up of 8 types of **aquaporins**.

Passive uniports, symports and antiports

- **Uniport:** A molecule alone moves across a membrane through transport or carrier protein.
- **Symport:** Two molecules together cross the membrane in same direction.
- **Antiport:** Two molecules move in opposite directions.



3. Active Transport

- It is the transport of molecules against a concentration gradient (from lower concentrated region to higher concentrated region) with the expenditure of energy.
- It is carried out by **membrane-proteins.**
- Pumps are proteins that use energy to transport substances across cell membrane **('uphill' transport).**
- Transport rate reaches a maximum when all the protein transporters are being used or are saturated.
- The carrier protein is very specific. These are sensitive to inhibitors that react with protein side chains.

Comparison of Different Transport Processes

Property	Simple diffusion	Facilitated transport	Active transport
Requires special membrane proteins	No	Yes	Yes
Highly selective	No	Yes	Yes
Transport saturates	No	Yes	Yes
Uphill transport	No	No	Yes
Requires ATP energy	No	No	Yes

PLANT-WATER RELATIONS

- Water is a **universal solvent.**
- Protoplasm is mainly water in which different molecules are dissolved and suspended.
- Soft plant parts mostly contain water. E.g. watermelon has 92% water.
- Herbaceous plants have only 10 - 15% dry matter.
- Dry seeds and woody parts also contain little water.
- A mature corn plant absorbs 3 litres of water daily.
- A mustard plant absorbs water equal to its own weight in about 5 hours.

Water Potential (Ψw)

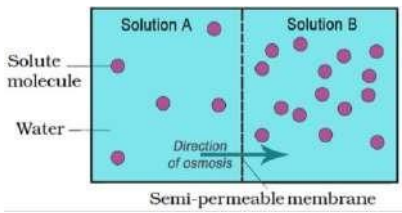
- It is the potential energy of water.
- It is the measure of the ability of water molecules to move freely in solution.
- It is expressed in pressure units such as **Pascals (Pa).**

- Water molecules have kinetic energy. In liquid & gaseous form, they show random, rapid and constant motion.
- As the concentration of water in a system increases, its kinetic energy ('water potential') also increases. Hence, pure water will have the greatest water potential.
- Water molecules move from **higher energy system (higher water potential)** to **lower energy system (lower water potential).** Such movement of substances down a gradient of free energy is called **diffusion**.
- Water potential (Ψw) of **pure water** at standard temperatures, which is not under any pressure, is **zero.**
- If a solute is dissolved in pure water, water potential decreases due to decrease in concentration (free energy) of water. Hence, Ψw of solutions is lower than pure water.
- Magnitude of lowering of water potential due to dissolution of a solute is called **solute potential (Ψs)** or **osmotic potential.**
- **Ψs** is always negative. The more the solute molecules, the lower (more negative) is the Ψs.
- For a solution at atmospheric pressure, **Ψw = Ψs.**
- If a pressure greater than atmospheric pressure is applied to pure water or a solution, its water potential increases. It is equivalent to pumping water from one place to another.
- When water enters a plant cell due to diffusion, it causes a pressure against the cell wall. It makes the cell **turgid.** This increases the **pressure potential (Ψp).**
- Pressure potential is usually positive, though negative potential or tension in the water column in the xylem plays a major role in water transport up a stem.
- Water potential of a cell is affected by **Solute potential** & **pressure potential**. The relationship is:

Ψw = Ψs + Ψp

Osmosis

- It is the spontaneous diffusion of water across a differentially- or semi-permeable membrane.
- Cell membrane and tonoplast (membrane of vacuole) are important determinants of movement of molecules in or out of plant cell. But cell wall is not a barrier to movement as it is freely permeable to water & substances in solution.
- Vacuolar sap in large central vacuole contributes to solute potential of the cell.
- Net direction and rate of osmosis depends on **pressure gradient** & **concentration gradient**.
- Water moves from its region of higher chemical potential (concentration) to its region of lower chemical potential until equilibrium is reached. At equilibrium, the two chambers should have the same water potential.



Solution A: High water potential, high solute potential.

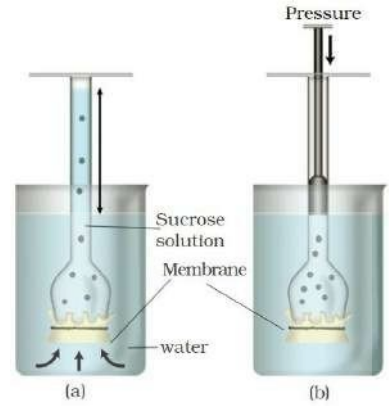
Solution B: Low water potential, low solute potential.

Potato osmometer:

- Make a cavity in a potato tuber. In this, pour concentrated sugar solution. This setup is called potato osmometer.
- If it is placed in water, the cavity containing concentrated sugar solution collects water due to osmosis.

A demonstration of osmosis:

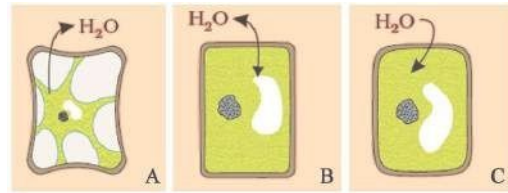
- A thistle funnel filled with sucrose solution is kept inverted in a beaker containing pure water.
- Sucrose solution is separated from water by a semi-permeable membrane (e.g. egg shell membrane).
- Water moves into the funnel. As a result, the level of the solution in the funnel rises. It continues till the equilibrium is reached (figure a).



- If an external pressure is applied from the upper part of the funnel, no water diffuses into the funnel through the membrane (figure b).
- This pressure required to prevent water from diffusing is the **osmotic pressure.** This is the function of the solute concentration. More the solute concentration, greater will be the pressure required to prevent water diffusion.
- Numerically, osmotic pressure is equivalent to the **osmotic potential,** but the sign is opposite. Osmotic pressure is positive, while osmotic potential is negative.

Plasmolysis

- If an external solution balances the osmotic pressure of the cytoplasm, it is called **isotonic**. When a cell (or tissue) is placed in isotonic solution, there is no net flow of water towards inside or outside (water flow is in equilibrium). Such cells are said to be **flaccid**.
- If the external solution is more dilute (higher water potential) than the cytoplasm, it is **hypotonic.** Cells swell (turgid) in hypotonic solution.
- If the external solution is more concentrated (more solutes) than the cytoplasm, it is **hypertonic**.



- When a cell is placed in a hypertonic solution, water moves from the cell (area of high water potential) across the membrane to outside (area of lower water potential) and the cell shrinks. It is called **Plasmolysis**. Water is first lost from the cytoplasm and then from the vacuole.
- During plasmolysis, the cell membrane and protoplast of a plant cell shrinks away from its cell wall. Such cells are said to be **plasmolysed**.
- Plasmolysis is usually reversible. When the cells are placed in a **hypotonic** solution, water diffuses into the cell. As a result, the cytoplasm builds up a pressure against the wall. It is called **turgor pressure**. The pressure exerted by the

protoplasts due to entry of water against the rigid walls is called **pressure potential (Ψ_p).** The cell does not rupture due to the rigidity of cell wall. Turgor pressure causes enlargement and extension growth of cells.

Imbibition

- It is a type of diffusion in which water is absorbed by solids (colloids) causing them to increase in volume. E.g. absorption of water by seeds and dry wood.
- The pressure due to the swelling of wood can split rocks.
- Seedlings are emerged out of the soil due to the **imbibition pressure.**
- Imbibition requires
  - Difference in concentration gradient.
  - Water potential gradient between the absorbent and the liquid imbibed.
  - Affinity between the adsorbent and the liquid.

LONG DISTANCE TRANSPORT OF WATER

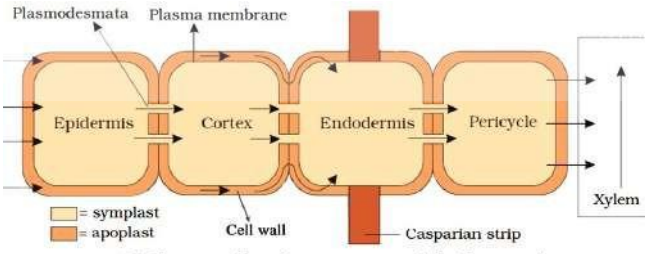
- Diffusion is a slow and short distance movement. E.g. movement of molecules across a typical plant cell (about 50 μm) takes about 2.5 s.
- Long distance transport systems are necessary to move substances faster across long distances.
- Movement of substances in bulk *(en masse)* from one point to another due to pressure differences between two points is called **Mass (bulk) flow**. E.g. movement of water, minerals and food.
- In mass flow, substances (in solution or in suspension) are swept along at the same pace as in a flowing river. But in diffusion, different substances move independently depending on their concentration gradients.
- Bulk flow is achieved either through a +ve hydrostatic pressure gradient (e.g. a garden hose) or a -ve hydrostatic pressure gradient (e.g. suction through a straw).
- Bulk movement of substances in long distance through the conducting tissues (xylem & phloem) is called **translocation.**

Absorption of Water by Plants

- Absorption of water and minerals occurs by diffusion through millions of root hairs present at the root tips.
- Root hairs increase the surface area for absorption.
- The absorbed water is moved deeper into root layers by 2 pathways: **Apoplast pathway** and **Symplast pathway.**

Apoplast pathway:

- It is a system of adjacent cell walls that is continuous except at the **casparian strips** of endodermis in the roots.
- It occurs exclusively through the intercellular spaces and cells walls. It does not cross the cell membrane.
- Water movement through apoplast is dependent on the gradient and occurs through mass flow.
- The apoplast does not provide any barrier to water movement.

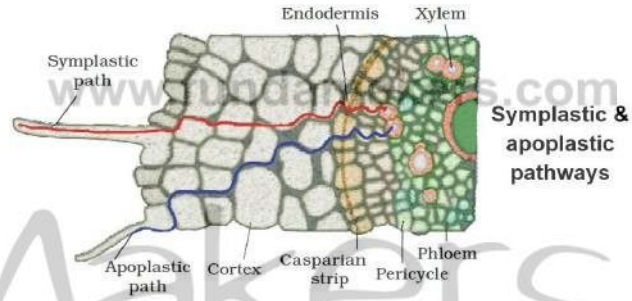


Pathway of water movement in the root

- As water evaporates into the intercellular spaces or the atmosphere, tension develops in the continuous stream of water in the apoplast. Hence mass flow of water occurs due to adhesive and cohesive properties of water.

Symplast pathway:

- It is the system of interconnected protoplasts.
- Here, water travels through cytoplasm; intercellular movement is through the **plasmodesmata** (junction between neighbouring cells through which cytoplasmic strands extend).
- Water has to enter the cells through cell membrane; hence the movement is slower. Movement is again down a potential gradient.
- Symplastic movement may be aided by **cytoplasmic streaming.** E.g. In *Hydrilla* leaf, movement of chloroplast due to cytoplasmic streaming is easily visible.



- Most of the water flow in the roots occurs via the apoplast since the cortical cells are loosely packed. So, water can move without resistance. However, the **endodermis** is impervious to water due to the **casparian strip** (a band of suberised matrix). So water molecules are directed to non-suberised wall regions. The water then moves through the symplast and again crosses a membrane to reach the xylem.
- The water movement through the root layers is ultimately symplastic in the endodermis. This is the only way water and solutes can enter the vascular cylinder.
- In young roots, water enters directly into the xylem vessels and tracheids. These are non-living conduits and so are parts of the apoplast.
- Some plants have additional structures for water and mineral absorption. E.g. **mycorrhiza** is a symbiotic association of a fungus with a root system. The fungal filaments form a network around the young root or they penetrate root cells. The hyphae absorb mineral ions & water from soil. The roots provide sugars & N compounds to mycorrhizae. Some plants have an obligate association with the mycorrhizae. E.g. *Pinus* seeds cannot germinate and establish without mycorrhizae.

Water Movement up a Plant

Water moves up a stem against gravity. So it needs energy.

Root Pressure

- As various ions from the soil are actively transported into the vascular tissues of the roots, water follows (its potential gradient) and increases the **pressure** inside the xylem. This positive pressure is called **root pressure.**
- It helps to push up water to small heights in the stem.

Experiment to prove existence of root pressure:

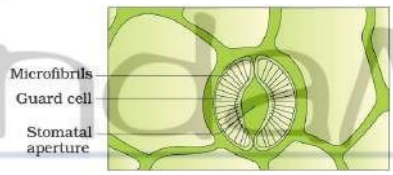
- During early morning, having atmospheric moisture, cut a soft plant stem horizontally near the base. Drops of solution ooze out of the cut stem. This is due to the positive root pressure.
- At night and early morning evaporation is low. So excess water collects in the form of droplets around special openings of veins near the tip of grass blades, and leaves of many herbaceous parts. Such water loss in liquid phase is called **guttation**.
- Root pressure can only provide a modest push in the water transport. They have no major role in water movement up tall trees. Root pressure re-establishes the continuous chains of water molecules in the xylem which often break under the tensions created by transpiration.
- In most plants, majority of water transport occurs by transpiration pull.

Transpiration pull

- In plants, the water flow upward through the xylem achieves high rates (up to 15 m /hr).
- Water is mainly pulled through the plant due to **transpiration pull.** It is a driving force due to transpiration. This is known as **cohesion-tension-transpiration pull model** of water transport.

TRANSPIRATION

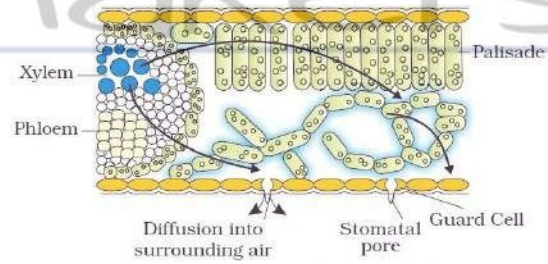
- It is the evaporative loss of water by plants through the **stomata** in the leaves.
- Less than 1% of the water reaching the leaves is used in photosynthesis and plant growth. The remaining is lost by transpiration.
- Transpiration can be studied using **cobalt chloride paper.** It turns colour on absorbing water.
- During transpiration, exchange of O_2 & CO_2 in the leaf also occurs.
- Stomata are open in the day time and close during night.
- Opening or closing of the stomata is due to change in the turgidity of the **guard cells**.



- The inner wall of guard cell lining **stomatal aperture** is thick and elastic and the outer wall is thin.
- When turgidity of guard cells increases, the outer walls bulge out and pull the inner walls into a crescent shape.
- Cellulose microfibrils in the guard cells are oriented radially rather than longitudinally making it easier for the stoma to open.
- The guard cells lose turgidity due to water loss (or water stress) and the inner walls regain their original shape. As a result, the stoma closes.
- Usually lower surface of a dicot leaf has more stomata. In monocot leaf, they are about equal on both surfaces.

Factors affecting transpiration:

- **External factors:** Temperature, light, humidity, wind etc.
- **Plant factors:** Number & distribution of stomata, number of stomata open, water status of plant, canopy structure etc.
- The transpiration-driven ascent of xylem sap depends on the following physical properties of water:
  - **Cohesion:** Mutual attraction between water molecules.
  - **Adhesion:** Attraction of water molecules to polar surfaces (e.g. surface of tracheary elements).
  - **Surface Tension:** Water molecules are more attracted to each other in liquid phase than in gas phase.
- These properties give water high **tensile strength** (ability to resist a pulling force) and **capillarity** (ability to rise in thin tubes). Capillarity is aided by small diameter of the tracheary elements – **tracheids** & **vessel elements**.
- Xylem vessels supply the water from the root to leaf vein. There is a continuous thin film of water over the cells. So as water evaporates through the stomata, water pulls into the leaf from the xylem. Concentration of water vapour in the atmosphere is lower than that in substomatal cavity and intercellular spaces. This also helps water to diffuse into the surrounding air. This creates a 'pull'.
- The forces generated by transpiration can create pressures to lift a xylem sized column of water over 130 m high.



Water movement in the leaf

Transpiration & Photosynthesis – a Compromise

- Photosynthesis is limited by available water which is swiftly depleted by transpiration.
- The humidity of rainforests is mainly due to the cycling of water from root to leaf to atmosphere and back to the soil.
- The evolution of C_4 photosynthetic system is a strategy to maximise the availability of CO_2 and minimise water loss.
- C_4 plants are twice as efficient as C_3 plants in fixing carbon (making sugar). However, C_4 plants lose only half as much water as a C_3 plant for the same amount of CO_2 fixed.

Uses of Transpiration:

- Creates transpiration pull for absorption and transport.
- Supplies water for photosynthesis.
- Transports minerals from soil to all parts of the plant.
- Cools leaf surfaces, sometimes 10 - 15°, by evaporation.
- Maintains shape & structure of plants by keeping cells turgid.

UPTAKE AND TRANSPORT OF MINERAL NUTRIENTS

Uptake of Mineral Ions

- Most minerals are **actively absorbed** by the roots because
  (i) Minerals occur in the soil as charged particles (ions) which cannot move across cell membranes.
  (ii) Concentration of minerals in the soil is lower than that in the root.
- Active uptake of ions is partly responsible for the water potential gradient in roots, and therefore for the uptake of water by osmosis.
- Some ions are absorbed passively.
- The specific membrane proteins of root hair cells actively pump ions from the soil into the epidermal cells.
- Endodermal cell membrane also has transport proteins. They allow only some solutes to cross the membrane. These proteins are control points, where a plant adjusts quantity and types of solutes that reach the xylem.
- The **suberin** in the root endodermis allows the active transport of ions in one direction only.

Translocation of Mineral Ions

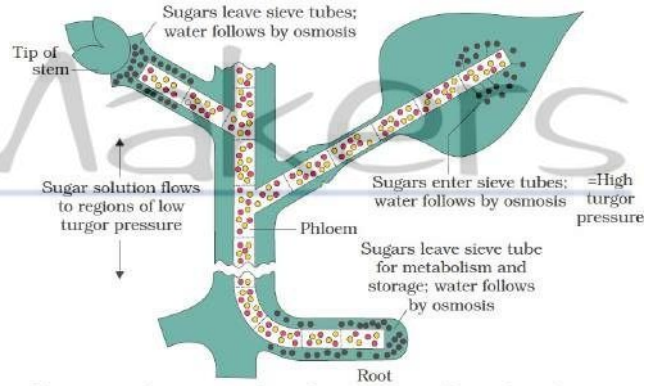
- The ions reached in xylem are further transported to all parts of the plant through the transpiration stream.
- The chief sinks for the mineral elements are
  - Growing regions such as apical and lateral meristems.
  - Young leaves.
  - Developing flowers, fruits and seeds.
  - Storage organs.
- Unloading of mineral ions occurs at the fine vein endings through diffusion and active uptake by these cells.
- Mineral ions are also remobilized, particularly from older, senescing parts (e.g. older dying leaves) to younger leaves.
- Elements most readily mobilized are phosphorus, sulphur, nitrogen and potassium. Some elements that are structural components like calcium are not remobilized.
- Nitrogen is mainly carried in organic forms such as amino acids & related compounds. Some travels as inorganic ions. Some P and S are also carried as organic compounds. There is also exchange of materials between xylem and phloem. So we cannot clearly say that xylem transports only inorganic nutrients while phloem transports only organic materials.

PHLOEM TRANSPORT: FLOW FROM SOURCE TO SINK

- It is the long-distance movement of organic substances (food, primarily sucrose) from a **source** (region of synthesis the food i.e., leaf) to a **sink** (region of storage or utilization of food) through the phloem.
- The source and sink may be reversed depending on the season or the plant's needs. E.g. In early spring, the sugar stored in roots is moved to the tree buds for growth and development of photosynthetic apparatus. Thus root becomes the source and buds the sink.
- The direction of movement in the phloem can be upwards or downwards, **(bi-directional).** In xylem, the movement is always upwards **(unidirectional).** Hence, food in phloem sap can be transported in any direction.
- Phloem sap is mainly **water and sucrose,** but other sugars, hormones and amino acids are also translocated.

The Pressure Flow (Mass Flow) Hypothesis

- It is the hypothesis that explains the mechanism of translocation of sugar (phloem transport).
- The glucose prepared at the source (by photosynthesis) is converted to **sucrose** (a disaccharide).
- Sucrose is moved into the **companion cells** and then into the living **phloem sieve tube** by **active transport (loading).** It produces a hypertonic condition in phloem (water potential decreases). Sieve tube cells form long columns with holes in **sieve plates.** Cytoplasmic strands pass through these holes forming continuous filaments.
- Water in the adjacent xylem moves into the phloem by **osmosis.** As **osmotic pressure/hydrostatic pressure** builds up, the phloem sap moves to areas of lower osmotic pressure (sink).



Diagrammatic presentation of mechanism of translocation

- The sucrose from the phloem sap actively moves into the cells. The cells convert the sugar into energy, starch, or cellulose (complex carbohydrates).
- As sugars are removed, osmotic pressure decreases (water potential increases) and water moves out of the phloem.

Identification of the tissue that transports food (girdling)

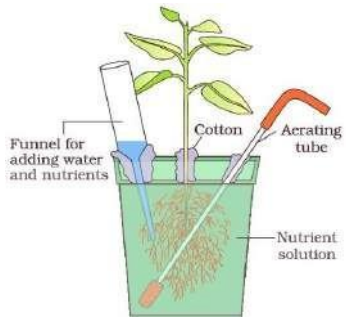
- Carefully remove a ring of bark (including phloem layer) from a tree trunk.
- After a few weeks, the portion of the bark above the ring on the stem becomes swollen. This is due to the absence of downward movement of food.
- This shows that phloem is responsible for translocation of food; and that transport takes place in one direction, i.e., towards the roots.

MINERAL NUTRITION

All organisms require macromolecules (carbohydrates, proteins, fats etc.), water & minerals for growth and development.

METHODS TO STUDY THE MINERAL REQUIREMENTS OF PLANTS

- The technique of growing plants in a defined nutrient solution (without soil) is known as **hydroponics**.
- It is demonstrated by **Julius von Sachs** (Germany, 1860).
- The nutrient solution is aerated for optimum growth.
- Hydroponics is used to identify the essential elements required for plants and their deficiency symptoms.
- In this, plant roots are immersed in nutrient solutions and an element is added / removed or given in varied concentration.



Hydroponics is used for commercial production of vegetables such as tomato, seedless cucumber & lettuce.

ESSENTIAL MINERAL ELEMENTS

- More than **60 elements** are found in different plants.
- Some plant species growing near mining sites accumulate selenium, gold etc. Some plants near nuclear test sites take up radioactive strontium.
- There are techniques to detect the minerals even at a very low concentration (10^{-8} g/mL).

Criteria for Essentiality of an element

- An element must be needed for normal growth and reproduction. In the absence of the element the plants do not complete their life cycle or set the seeds.
- The requirement of an element must be specific. i.e., deficiency of an element cannot be met by another element.
- It must be directly involved in the plant metabolism.

Only **17 elements** are absolutely essential for plant growth and metabolism.

Based on quantitative requirements, essential elements are 2 types: Macronutrients & Micronutrients.

i. Macronutrients

- They are present in plant tissues in large amounts (more than 10 mmole Kg^{-1} of dry matter).
- They include carbon, hydrogen, oxygen, nitrogen, phosphorous, sulphur, potassium, calcium & magnesium.
- C, H & O are mainly obtained from CO_2 & H_2O. Others are absorbed from soil as mineral nutrition.

ii. Micronutrients (trace elements)

- They are needed in very small amounts (less than 10 mmole Kg^{-1} of dry matter).
- They include iron, manganese, copper, molybdenum, zinc, boron, chlorine and nickel.

Higher plants also need sodium, silicon, cobalt, selenium etc. Based on functions, essential elements are 4 categories.

1. **Components of biomolecules & structural elements of cells:** E.g. carbon, hydrogen, oxygen & nitrogen.
2. **Components of energy-related chemical compounds:** E.g. Mg in chlorophyll and phosphorous in ATP.
3. **Elements that activate or inhibit enzymes:** E.g. Mg^{2+} is an activator for *RUBISCO & phosphoenol pyruvate carboxylase* (critical enzymes in photosynthetic carbon fixation). Zn^{2+} is an activator of *alcohol dehydrogenase* and Mo of *nitrogenase* during nitrogen metabolism.
4. **Elements that alter the osmotic potential of a cell:** E.g. Potassium helps in opening & closing of stomata.

Role of Macro- and Micro-nutrients

Essential elements have role in metabolic processes such as

- Permeability of cell membrane.
- Maintenance of osmotic concentration of cell sap.
- Electron transport systems.
- Buffering action.
- Enzymatic activity.
- Constituents of macromolecules and co-enzymes.

Nitrogen:

- This is required by plants in the greatest amount.
- It is absorbed mainly as NO_3^-. Some are also taken up as NO_2^- or NH^{4+}.
- It is essential for all plant parts, particularly the meristematic tissues and the metabolically active cells.
- It is the major constituents of amino acids, proteins, nucleic acids, chlorophyll, vitamins and hormones.

Phosphorus:

- It is absorbed by plants from soil as phosphate ions (as $H_2PO_4^-$ or HPO_4^{2-}).
- It is a constituent of cell membranes, certain proteins, all nucleic acids and nucleotides.
- It is required for all phosphorylation reactions.

Potassium:

- It is absorbed as potassium ion (K^+).
- Essential in meristematic tissues, buds, leaves & root tips.
- It maintains an anion-cation balance in cells.
- It is involved in protein synthesis, opening & closing of stomata, activation of enzymes and in the maintenance of the turgidity of cells.

Calcium:

- It is absorbed from the soil as calcium ions (Ca^{2+}).
- It is required by meristematic and differentiating tissues.
- During cell division, it is used in the synthesis of cell wall, particularly as calcium pectate in middle lamella. It is also needed during the formation of mitotic spindle.

- It accumulates in older leaves.
- It is involved in the functioning of the cell membranes.
- It activates some enzymes and regulates metabolic activities.

Magnesium:

- It is absorbed by plants as divalent Mg^{2+}.
- It activates enzymes of respiration & photosynthesis.
- It is involved in the synthesis of DNA and RNA.
- It is a constituent of the ring structure of chlorophyll.
- It helps to maintain the ribosome structure.

Sulphur:

- Plants obtain it as sulphate $(SO)_4^{2-}$.
- It is present in 2 amino acids (cysteine & methionine).
- It is the constituent of several coenzymes, vitamins (thiamine, biotin, Coenzyme A) and ferredoxin.

Iron:

- Plants obtain iron as ferric ions (Fe^{3+}).
- It is required in larger amounts in comparison to other micronutrients.
- It is a main constituent of proteins involved in the transfer of electrons like ferredoxin and cytochromes.
- It is reversibly oxidized from Fe^{2+} to Fe^{3+} during electron transfer.
- It activates *catalase* enzyme, and is essential for the formation of chlorophyll.

Manganese:

- It is absorbed as manganous ions (Mn^{2+}).
- It activates many enzymes involved in photosynthesis, respiration and nitrogen metabolism.
- The best defined function of manganese is in the splitting of water to liberate O_2 during photosynthesis.

Zinc:

- Plants obtain zinc as Zn^{2+} ions.
- It activates various enzymes, especially *carboxylases.*
- It is needed in the synthesis of auxin.

Copper:

- It is absorbed as cupric ions (Cu^{2+}).
- It is essential for the overall metabolism in plants.
- Like iron, it is associated with some enzymes in redox reactions and is reversibly oxidised from Cu^{+} to Cu^{2+}.

Boron:

- It is absorbed as BO_3^{3-} or $B_4O_7^{2-}$.
- It is required for uptake & utilisation of Ca^{2+}, membrane functioning, pollen germination, cell elongation, cell differentiation & carbohydrate translocation.

Molybdenum:

- Plants obtain it as molybdate ions $(MoO)_2^{2+}$.
- It is a component of many enzymes such as *nitrogenase* & *nitrate reductase.* These enzymes participate in nitrogen metabolism.

Chlorine:

- It is absorbed as chloride anion (Cl^-).
- Along with Na^+ & K^+, it helps in determining the solute concentration and the anion-cation balance in cells.
- It is essential for the water-splitting reaction in photosynthesis that leads to oxygen evolution.

Deficiency Symptoms of Essential Elements

- Deficiency of an essential element causes retarded growth.
- Concentration of an essential element below which plant growth is retarded is called **critical concentration.** The element is said to be deficient when present below the critical concentration.
- The morphological changes due to deficiency or absence of an element are called **deficiency symptoms.**
- Deficiency symptoms vary from element to element.
- The plant parts that show the deficiency symptoms depend on the mobility of the element. For elements that are actively mobilized and exported to young developing tissues, the deficiency symptoms appear first in the older tissues. E.g. deficiency symptoms of nitrogen, potassium and magnesium are visible first in the senescent leaves.
- In older leaves, biomolecules containing these elements are broken down. It makes these elements available for mobilizing to younger leaves.
- If the elements are relatively immobile and are not transported out of the mature organs, the deficiency symptoms appear first in the young tissues. E.g. S and Ca are part of the structural component of the cell and hence are not easily released.
- This aspect of mineral nutrition has great significance in agriculture and horticulture.
- The deficiency symptoms include chlorosis, necrosis, stunted growth, premature fall of leaves & buds and inhibition of cell division.
- **Chlorosis** is the loss of chlorophyll leading to yellowing in leaves. It is due to the deficiency of elements N, K, Mg, S, Fe, Mn, Zn and Mo.
- **Necrosis** is the death of tissue, particularly leaf tissue. It is due to the deficiency of Ca, Mg, Cu, K.
- Lack or low level of N, K, S & Mo inhibits cell division. Low concentration of N, S, Mo etc. delay flowering.
- Deficiency of different elements may cause same symptoms. Hence, to identify the deficient element, all the symptoms are studied. Also, different plants respond differently to the deficiency of the same element.

Toxicity of Micronutrients

- A moderate increase in micronutrients causes toxicity.
- Any mineral ion concentration in tissues that reduces the dry weight of tissues by about 10% is considered toxic. Such critical concentrations vary widely among different micronutrients.
- The toxicity symptoms are difficult to identify. Toxicity levels for an element also vary for different plants.
- Excess of an element may inhibit the uptake of another element. E.g. Excess of Mn induces deficiencies of Fe, Mg & Ca because it competes with Fe & Mg for uptake and with Mg for binding with enzymes. Mn also inhibits Ca translocation in shoot apex. Thus symptoms of Mn toxicity may actually be the deficiency symptoms of Fe, Mg & Ca. Main symptom of manganese toxicity is the appearance of brown spots surrounded by chlorotic veins.

MECHANISM OF ABSORPTION OF ELEMENTS

- The inward movement of ions into the cells is called **influx** and the outward movement is **efflux.**
- The process of absorption includes 2 main phases:
  - **First phase:** Initial rapid and **passive** uptake of ions into the **apoplast** (free space or outer space) of cells. It usually occurs through ion-channels (trans-membrane proteins that function as selective pores).
  - **Second phase:** The ions are taken in slowly into the **symplast** (inner space or cytoplasm) of the cells. It is an **active** process (requires energy).

Translocation of solutes

- Mineral salts are translocated through xylem along with the ascending stream of water.
- Analysis of xylem sap shows the presence of mineral salts in it. Use of radioisotopes of mineral elements also proved that they are transported through the xylem.

Soil as Reservoir of Essential Elements

Weathering and breakdown of rocks enrich the soil with dissolved ions and inorganic salts.

Roles of soil:

- It supplies minerals and holds water.
- It harbours nitrogen-fixing bacteria and other microbes.
- It supplies air to the roots.
- It acts as a matrix that stabilizes the plant.

Deficiency of essential minerals affects the crop-yield. So fertilisers should be supplied. Both macro-nutrients and micro-nutrients form components of fertilisers.

METABOLISM OF NITROGEN

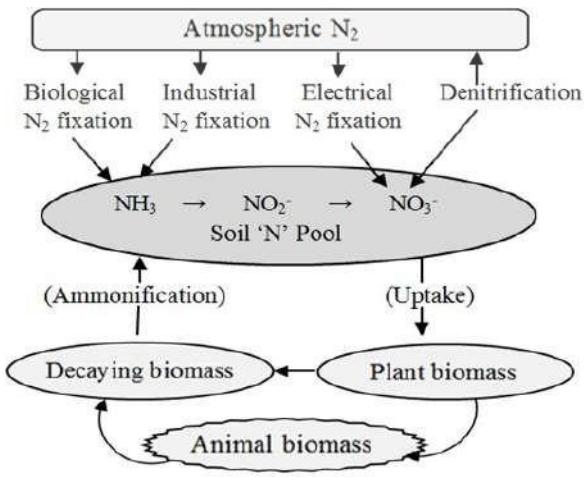
Nitrogen Cycle

- Nitrogen is the most prevalent element in living organisms.
- Plants compete with microbes for the limited nitrogen in soil. Thus, nitrogen is a limiting nutrient for natural and agricultural eco-systems.
- The process of conversion of atmospheric nitrogen (N_2 or N≡N) to ammonia is called **nitrogen fixation.**
- In nature, lightning and UV radiation provide energy to convert nitrogen to nitrogen oxides (NO, NO_2, N_2O). Industrial combustions, forest fires, automobile exhausts and power-generating stations are also sources of atmospheric nitrogen oxides.
- Decomposition of organic nitrogen of dead plants and animals into ammonia is called **ammonification.**
- Some of this ammonia volatilizes and re-enters atmosphere but most of it is oxidised into nitrate by soil **nitrifying bacteria** (*Nitrosomonas, Nitrococcus* & *Nitrobacter*-**chemo-autotrophs).** These steps are called **nitrification**.

$$2NH_3 + 3O_2 \xrightarrow{Nitrosomonas,\ Nitrococcus} 2NO^- + 2H^+ + 2H_2O$$

$$2NO_2^- + O_2 \xrightarrow{Nitrobacter} 2NO_3^-$$

- Plants absorb the nitrate and is transported to the leaves. In leaves, it is reduced to form ammonia that finally forms the amine group of amino acids.



- Nitrate present in the soil is also reduced to nitrogen by the process of **denitrification**. It is carried by bacteria *Pseudomonas* and *Thiobacillus.*

Biological Nitrogen Fixation

- It is the reduction of N_2 to NH_3 by living organisms in presence of ***nitrogenase*** enzyme.

$$N \equiv N \xrightarrow{Nitrogenase} NH_3$$

- Very few organisms can utilize the nitrogen in the form of N_2 in the air.
- Only certain prokaryotic species have *Nitrogenase*enzyme and capability to fix N_2. They are called **N_2- fixers.**
- Nitrogen-fixing microbes are 2 types:
  - **Free-living:** E.g. *Azotobacter* & *Beijerinckia* (aerobic microbes), *Rhodospirillum* & *Bacillus* (anaerobic), cyanobacteria such as *Anabaena* & *Nostoc.*
  - **Symbiotic:** E.g. *Rhizobium* (aerobic).

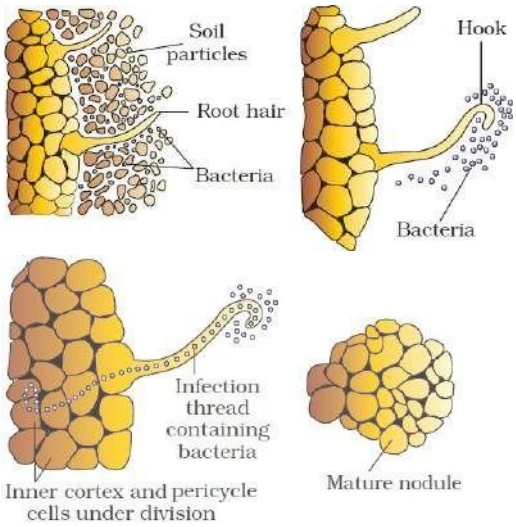
Symbiotic Biological Nitrogen Fixation

- **Legume-bacteria relationship:** Most prominent. E.g. *Rhizobium* species (rod-shaped) seen in the roots of legumes such as alfalfa, sweet clover, sweet pea, lentils, garden pea, broad bean, clover beans etc.
- The most common association on roots is as **nodules.**
- The microbe, *Frankia* also produces N_2 fixing nodules on the roots of non-leguminous plants (e.g. *Alnus*).
- *Rhizobium* & *Frankia* are free-living in soil, but as symbionts, can fix atmospheric nitrogen.
- Central part of a nodule is red or pink coloured due to the presence of **leguminous haemoglobin (leg-haemoglobin).**

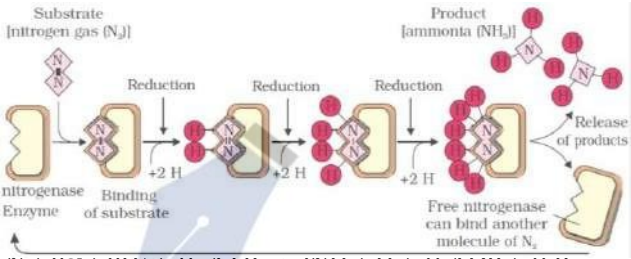
Principal stages in the Nodule formation:

- *Rhizobia* multiply and colonise the surroundings of the roots and get attached to epidermal and root hair cells.
- Root-hairs curl and the bacteria invade the root-hair.
- An infection thread is produced carrying the bacteria into root cortex, where they initiate nodule formation.
- The bacteria are released from thread into cells. It leads to differentiation of specialized nitrogen fixing cells.

- The nodule establishes a direct vascular connection with the host for exchange of nutrients.



- Nodule contains ***nitrogenase*** enzyme & **leg-haemoglobin.**
- *Nitrogenase* (a Mo-Fe protein) catalyzes the conversion of nitrogen to NH_3, the first stable product of N_2 fixation.



$$N_2 + 8e^- + 8H^+ + 16\ ATP \rightarrow 2NH_3 + H_2 + 16ADP + 16P_i$$

- Ammonia synthesis needs high input energy (8 ATP for each NH_3). It is obtained from the respiration of host cells.
- *Nitrogenase* is highly sensitive to the molecular oxygen. So it requires anaerobic conditions to protect from oxygen. For this, **leg-haemoglobin** acts as an **oxygen scavenger.**
- *Rhizobia* are aerobic under free-living conditions (where *nitrogenase* is not operational), but during N_2-fixing events, they become anaerobic (to protect *nitrogenase*).

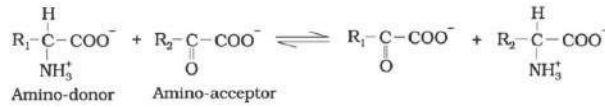
Fate of ammonia:

- At physiological pH, the NH_3 is protonated to form NH_4^+ (ammonium) ion. Most of the plants can assimilate nitrate and NH_4^+. But NH_4^+ is quite toxic to plants and so cannot accumulate in them.
- In plants, NH_4^+ is used to synthesize amino acids by 2 ways:

a. Reductive amination: In this, ammonia reacts with α-ketoglutaric acid to form glutamic acid.

α- ketoglutaric acid + NH_4^+ + NADPH $\xrightarrow{\textit{Glutamate dehydrogenase}}$ Glutamate + H_2O + NADP

b. Transamination: It is the transfer of amino group (NH_2) from one amino acid to the keto group of a keto acid in presence of *transaminase* enzyme. Glutamic acid is the main amino acid from which the transfer of NH_2 takes place and other amino acids are formed through transamination. For example,



- **Asparagine & glutamine** are most important amides found in plants. They are structural part of proteins. They are formed from 2 amino acids **(aspartic acid & glutamic acid)** by addition of another amino group to each. The hydroxyl part of the acid is replaced by another NH_2 radical.
- Since amides contain more nitrogen than the amino acids, they are transported to other parts of the plant via xylem vessels. In addition, along with the transpiration stream the nodules of some plants (e.g. soyabean) export the fixed nitrogen as **ureides.** These compounds also have particularly high nitrogen to carbon ratio.

PHOTOSYNTHESIS

- **Photosynthesis** is a **physico-chemical process** by which green plants use **light energy (solar energy)** to synthesise organic compounds. So they are autotrophs.
- It is the basis of life on earth.
- Ultimately, all living forms depend on sunlight for energy.

Importance of Photosynthesis

- It is the primary source of all food on earth.
- It releases oxygen into the atmosphere.

EXPERIMENTS RELATED WITH PHOTOSYNTHESIS

1. Variegated leaf experiment

- Take a variegated leaf (or leaf partiallycovered with black paper) that was exposed to light.
- Test the leaves for starch. It shows that photosynthesis occurs only in green parts of the leaves in presence of light.

2. Half-leaf experiment

- A part of a leaf is enclosed in a test tube containing KOH soaked cotton (which absorbs CO_2).
- The other half of leaf is exposed to air.
- Place this setup in light for some time.
- Test the leaf for presence of starch. Exposed part shows positive for starch and portion in the tube shows negative. This proves that CO_2 is required for photosynthesis.

EARLY EXPERIMENTS

Experiments by Joseph Priestley (1770)

- Priestley performed experiments to prove the role of air in the growth of green plants.
- He discovered oxygen in 1774.
- He observed that a candle burning in a closed bell jar gets extinguished. Similarly, a mouse suffocated in closed jar. He concluded that a burning candle or a breathing animal damage the air.
- He placed a mint plant in the same bell jar. He found that the mouse stayed alive and the candle continued to burn.
- He hypothesised that plants restore to the air whatever breathing animals and burning candles remove.

Experiments by Jan Ingenhousz (1730-1799)

- He conducted the same experiment by placing in darkness and sunlight.
- He showed that sunlight is essential to the plant for purifying the air fouled by burning candles or animals.
- He repeated this experiment with an aquatic plant. It showed that in bright sunlight, small bubbles were formed around green parts while in the dark they did not.
- Later he identified these bubbles to be of oxygen. Thus he showed that only the green part of plants release O_2.

Experiments by Julius von Sachs (1854)

- He proved that
  - Glucose is produced when plants grow and it is usually stored as starch.
  - **Chlorophyll** is located in special bodies **(chloroplasts)**.
  - Glucose is made in the green parts of plants.

Experiments by T.W Engelmann (1843 – 1909)

- He split the light using a prism into its spectral components and illuminated a green alga *(Cladophora)* placed in a suspension of aerobic bacteria.
- The bacteria were used to detect the sites of O_2 evolution.
- He observed that the bacteria accumulated mainly in the region of blue and red light of the split spectrum.
- It was a first described **action spectrum** of photosynthesis. It resembles the absorption spectra of chlorophyll *a* & *b*.
- By the middle of 19th century, it is discovered that plants use light energy to make carbohydrates from CO_2 & H_2O.
- Empirical equation of the process of photosynthesis is

$$CO_2 + H_2O \xrightarrow{\text{Light}} [CH_2O] + O_2$$

Where, $[CH_2O]$ represents a carbohydrate (e.g. glucose).

Experiments by Cornelius van Niel (1897-1985)

- Van Niel (microbiologist) conducted some studies in purple and green bacteria.
- He demonstrated that photosynthesis is a light-dependent reaction in which hydrogen from an oxidisable compound reduces CO_2 to carbohydrates.

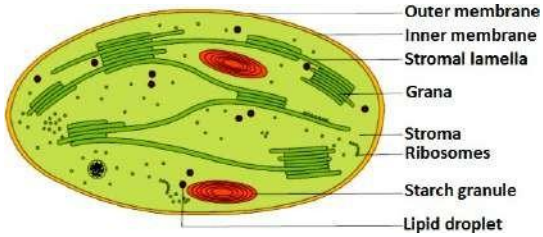
$$2H_2A + CO_2 \xrightarrow{\text{Light}} 2A + CH_2O + H_2O$$

- In plants, H_2O is the hydrogen donor and is oxidised to O_2.
- Purple & green sulphur bacteria use H_2S as H-donor. So the 'oxidation' product is sulphur or sulphate and no O_2 is produced.
- Thus, he inferred that the O_2 evolved by the green plant comes from H_2O, not from CO_2. This was later proved by using radio isotopic techniques.
- Therefore overall correct equation for photosynthesis is:

$$6CO_2 + 12H_2O \xrightarrow{\text{Light}} C_6H_{12}O_6 + 6H_2O + 6O_2$$

PHOTOSYNTHESIS: SITE AND PIGMENTS

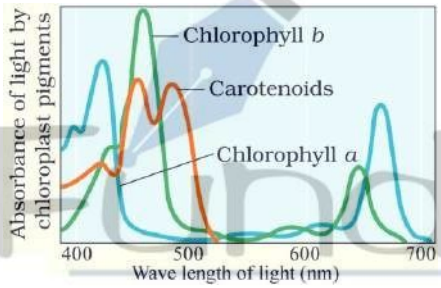
- Photosynthesis occurs in green leaves & other green parts.
- **Chloroplasts** present in the walls of **mesophyll cells** of leaves. It helps to get optimum quantity of incident light.
- Chloroplast contains a **membranous system.** It consists of **grana, stroma lamellae** and **matrix stroma.**
- Each granum is a group of membrane-bound sacs called **thylakoids (lamellae).** They contain leaf pigments.
- The **membrane system** traps light energy and synthesise ATP and NADPH. It is called **light reactions.**
- In **stroma,** enzymatic reactions synthesize sugar, which in turn forms starch. It is called **dark reactions (carbon reactions)**. It does not mean that they occur in darkness or that they are not light dependent.



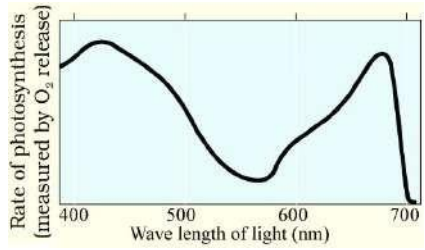
PIGMENTS INVOLVED IN PHOTOSYNTHESIS

- Pigments are substances that have ability to absorb light at specific wavelengths.
- Chromatography shows the following leaf pigments:
  - **Chlorophyll *a*** (bright or blue green in chromatogram)
  - **Chlorophyll *b*** (yellow green)
  - **Xanthophylls** (yellow)
  - **Carotenoids** (yellow to yellow-orange)

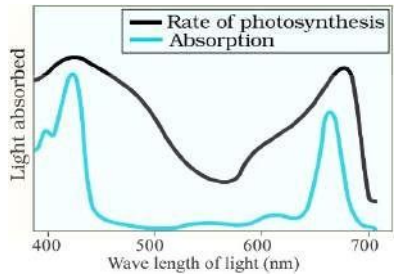
  } **Accessory pigments**
- **Functions of accessory pigments:**
  - They absorb light at different wavelength and transfer the energy to chlorophyll *a*.
  - They protect chlorophyll *a* from photo-oxidation.
- The **absorption spectrum & action spectrum** coincide closely showing that photosynthesis is maximum at the **blue & red regions** of the spectrum.
- The graphs also show that chlorophyll *a* is the chief pigment associated with photosynthesis.



Graph showing absorption spectrum of chlorophyll *a, b* & carotenoids



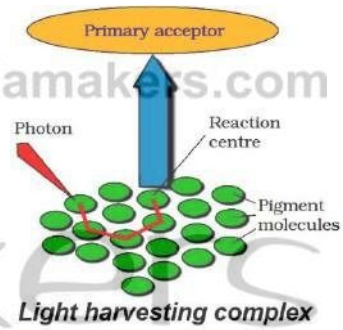
Graph showing action spectrum of photosynthesis



Graph showing action spectrum of photosynthesis superimposed on absorption spectrum of chlorophyll *a*

Photosystems

- Pigments are organised into two **Photosystems** called **Photosystem I (PSI) & Photosystem II (PSII).** These are named in the sequence of their discovery.
- Each photosystem has a **chlorophyll a** and **accessory pigments** bound by proteins.
- All pigments (except one molecule of chlorophyll *a*) form a **light harvesting complex (LHC or antennae).**
- Single chlorophyll a acts as **reaction centre.**
- In **PS I,** the reaction centre absorbs light at **700 nm,** and so called **P700.**
- In **PS II,** the reaction centre absorbs light at **680 nm,** and so called **P680**.

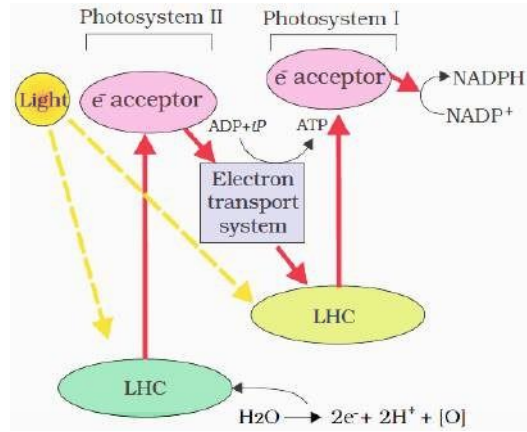


LIGHT REACTION (PHOTOCHEMICAL PHASE)

- Light reactions include **light absorption, water splitting, oxygen release** and **formation of ATP & NADPH** (high-energy chemical intermediates).

The Electron Transport

- When **PS II** absorbs **red light of 680 nm** wavelength, electrons are excited and transferred to an electron acceptor.
- The electron acceptor passes them to a chain of **electrons transport system** consisting of **cytochromes.**
- This movement of electrons is downhill, in terms of redox potential scale.
- The electrons are transferred to the pigments of PS I.
- Simultaneously, electrons in **PS I** are also excited when they receive **red light of 700 nm** and are transferred to another accepter molecule having a greater redox potential.
- These electrons are moved downhill to a molecule of $NADP^+$. As a result, $NADP^+$ is reduced to NADPH + H^+.
- Transfer of electrons from PS II to PS I and finally downhill to $NADP^+$ is called the **Z scheme**, due to its zigzag shape. This shape is formed when all the carriers are placed in a sequence on a redox potential scale.



Z scheme of light reaction

Splitting of Water (Photolysis)

- The **water splitting complex** in PS II is located on the inner side of the thylakoid membrane.
- Water is split into H^+, [O] and electrons.

$$2H_2O \rightarrow 4H^+ + O_2 + 4e^-$$

- So PS II can supply electrons continuously by replacing electrons from water splitting.

- Thus PS II provides electrons needed to replace those removed from PS I.
- The protons (H^+) are used to reduce NADP to NADPH.
- Oxygen is liberated as a by-product of photosynthesis.

Photo-phosphorylation

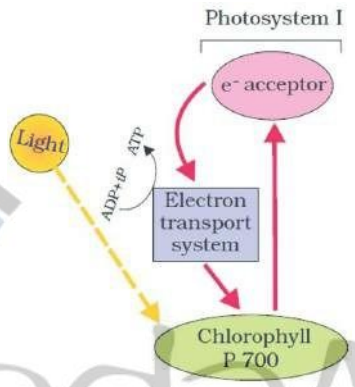
- The synthesis of ATP by cells (in mitochondria & chloroplasts) is called **phosphorylation.**
- **Photo-phosphorylation** is the synthesis of ATP from ADP in chloroplasts in presence of light.
- It occurs in 2 ways: **Non- cyclic** and **Cyclic.**

a) Non-cyclic photo-phosphorylation

- It occurs when the two photosystems work in a series, (first PS II and then PS I) through an electron transport chain as seen in the Z scheme.
- Here, ATP & NADPH + H^+ are synthesised.
- It is a non-cyclic process because the electrons lost by PS II do not come back to it but pass on to $NADP^+$.

b) Cyclic photo-phosphorylation

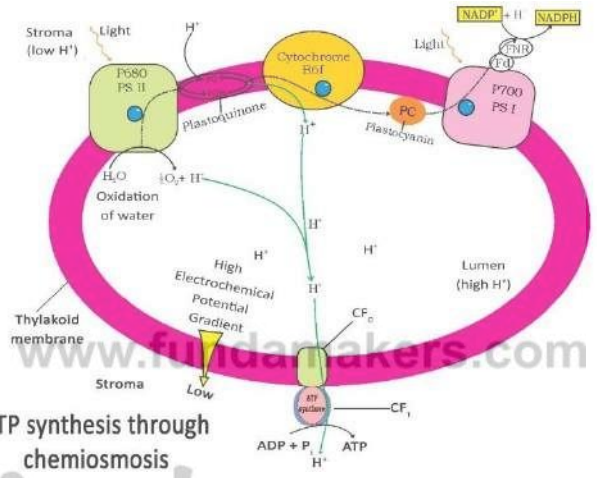
- It occurs in stroma lamellae when only PS I is functional.
- The electron is circulated within the photosystem and the ATP synthesis occurs due to cyclic flow of electrons.
- The lamellae of grana have PS I & PS II. The stroma lamellae membranes lack PS II and *NADP reductase*.



- The electron does not pass on to $NADP^+$ but is cycled back to PS I complex through electron transport chain.
- Here, only ATP is synthesised (no NADPH + H^+).
- Cyclic photophosphorylation also occurs when only light of wavelengths beyond 680 nm are available.

Chemiosmotic Hypothesis

- It explains **mechanism of ATP synthesis** in chloroplast.
- **Chemiosmosis:** Movement of ions across a semipermeable membrane. It occurs in chloroplast and mitochondria.
- Chemiosmosis needs a membrane, a proton pump, a proton gradient (across thylakoid membranes) and *ATP synthase.*
- Splitting of water occurs on the inner side of the membrane. So the protons accumulate in the lumen of thylakoids.
- As electrons move through the photosystems, protons are transported across the membrane. It is due to the removal of protons from the stroma for the following reasons:
  - **Primary electron accepter** is located towards the outer side of the membrane. It transfers its electron to an **H carrier.** So this molecule removes a proton from the stroma while transporting an electron. When this molecule passes on its electron to the **electron carrier** on the inner side of the membrane, proton is released into the lumen of the membrane.
  - The ***NADP reductase*** enzyme is located on the stroma side of the membrane. Along with electrons coming from PS I, protons are necessary to reduce $NADP^+$. These protons are also removed from the stroma.
- Hence, protons in stroma are decreased but in lumen, protons are accumulated. It creates a proton gradient across the thylakoid membrane and decrease in pH in the lumen.



ATP synthesis through chemiosmosis

- Breakdown of proton gradient leads to synthesis of ATP by ***ATP synthase*** enzyme.
- The *ATP synthase* consists of two parts:
  - **CF_0:** It is embedded in the membrane and forms a trans-membrane channel. It carries out facilitated diffusion of protons across the membrane to the stroma. It results in breakdown of proton gradient.
  - **CF_1:** It protrudes on the outer surface of the thylakoid membrane. The energy due to breakdown of gradient causes a conformational change in the CF_1 particle. It makes the enzyme to synthesise ATP molecules.
- Energy is used to pump protons across a membrane, to create a gradient or a high concentration of protons within the thylakoid lumen.
- *ATP synthase* has a channel for the diffusion of protons back across the membrane. This releases energy to activate *ATP synthase* that catalyses formation of ATP.

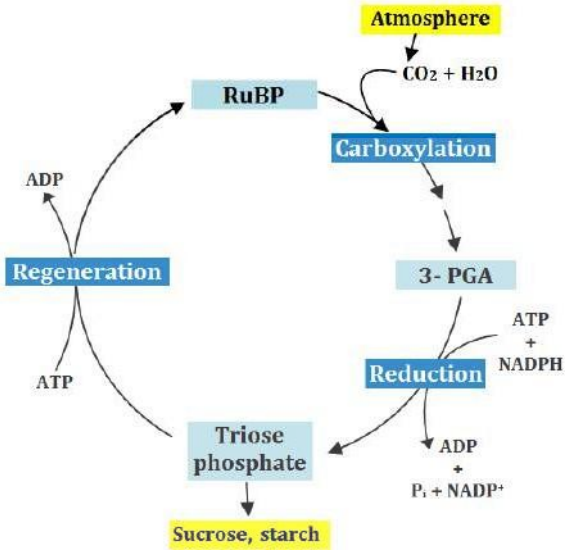
DARK REACTION (BIOSYNTHETIC PHASE) - USE OF ATP & NADPH

- Products of light reaction are ATP, NADPH and O_2.
- **Dark reaction** is the use of ATP and NADPH to drive the processes for the synthesis of food (sugars).
- This phase does not directly depend on the light but is dependent on the products of the light reaction.
- It can be verified as follows: Immediately after light becomes unavailable, the biosynthetic process continues for some time, and then stops. If light is available, the synthesis starts again.
- CO_2 combines with H_2O to form $(CH_2O)_n$ or sugars.
- CO_2 assimilation during photosynthesis is 2 types:
  - **C_3 pathway:** In this, first stable product of CO_2 fixation is a C_3 acid **(3-phosphoglyceric acid - PGA). Melvin Calvin** discovered this using ^{14}C in algal photosynthesis.

- **C_4 pathway:** In this, first stable product is **oxaloacetic acid (OAA),** a 4-carbon (C_4) organic acid.

C_3 PATHWAY (CALVIN CYCLE)

- It occurs in **all photosynthetic plants** (C_3 or C_4 pathways).
- It has 3 stages: carboxylation, reduction and regeneration.



1. Carboxylation of RuBP

- RuBP (**ribulose bisphosphate** - a **5-carbon ketose sugar)** is the primary CO_2 acceptor.
- It is the most crucial step. CO_2 is fixed by **RuBP** to two 3-PGA in presence of the enzyme ***RuBP carboxylase.***
- Since this enzyme also has an oxygenation activity it is called ***RuBP carboxylase-oxygenase (RuBisCO).***
- RuBisCO is the most abundant enzyme in the world.

2. Reduction

- It is a series of reactions leading to the glucose formation.
- Here, 2 ATP molecules for phosphorylation and two of NADPH for reduction per CO_2 molecule are used.
- Fixation of 6 CO_2 molecules and 6 turns of the cycle are needed to remove one glucose molecule from the pathway.

3. Regeneration of RuBP

- It is crucial for continuation of the cycle.
- It requires one ATP for phosphorylation to form RuBP.
- Hence for every CO_2 molecule, 3 ATP molecules and 2 NADPH are required.
- It is probably to meet this difference in number of ATP and NADPH used in the dark reaction that the cyclic phosphorylation takes place.
- To make 1 glucose molecule, 6 turns of the cycle are needed.

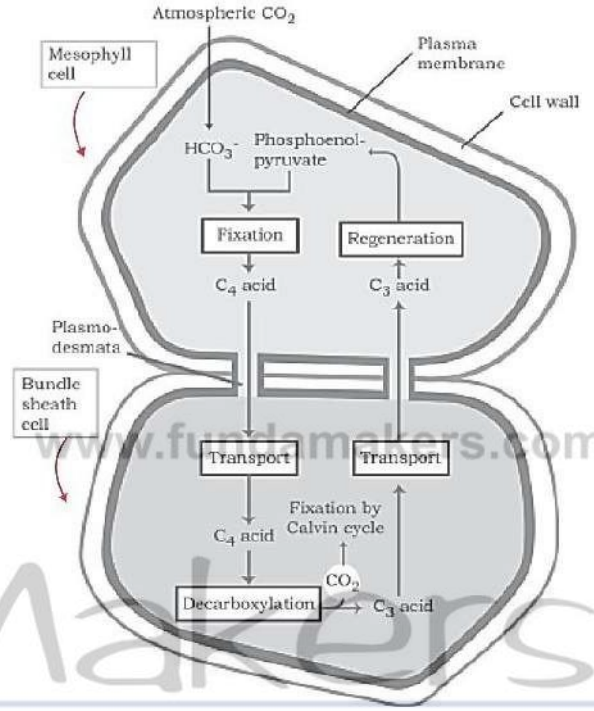
What does go in and come out of the Calvin cycle?	In	Out
	6 CO_2	1 glucose
	18 ATP	18 ADP
	12 NADPH	12 NADP

C_4 PATHWAY (HATCH & SLACK PATHWAY)

- It is present in plants adapted to dry tropical regions.
- They also use C_3 pathway as main biosynthetic pathway.
- The large cells around the vascular bundles of the C_4 plants are called **bundle sheath cells.** Such anatomy is called **'Kranz' anatomy** ('Kranz' = 'wreath').
- The bundle sheath cells may form **several layers** around the vascular bundles.
- They have large number of chloroplasts, thick walls impervious to gas exchange and no intercellular spaces.

Steps of Hatch and Slack Pathway

- Primary CO_2 acceptor is **phosphoenol pyruvate (PEP)** - a 3-carbon molecule seen in mesophyll cells. The enzyme for this fixation is ***PEP carboxylase (PEPcase).***
- The mesophyll cells lack *RuBisCO* enzyme.
- The C_4 acid OAA is formed in the mesophyll cells.
- It then forms other 4-carbon acids like malic acid or aspartic acid. They are transported to bundle sheath cells.



- In the bundle sheath cells, C_4 acids are broken down to release CO_2 and a C_3 molecule.
- The C_3 molecule is transported back to mesophyll where it is converted to PEP again.
- The released CO_2 enters the C_3 pathway.
- Bundle sheath cells are rich in ***RuBisCO,*** but lack *PEPcase.* Thus C_3 pathway is common to C_3 & C_4 plants.

C_4 plants are special because:

- They have a special type of leaf anatomy (Kranz).
- They tolerate higher temperatures.
- They show a response to highlight intensities.
- They lack photorespiration.
- They have greater productivity of biomass.

PHOTORESPIRATION

- In Calvin pathway, RuBP combines with CO_2.

$$RuBP + CO_2 \xrightarrow{\text{Rubisco}} 2\times 3PGA$$

- Active site of RuBisCO can bind to CO_2 & O_2 – so the name.
- RuBisCO has a greater affinity for CO_2 than for O_2. This binding is competitive. Relative concentration of O_2 and CO_2 determines which one will bind to the enzyme.
- In C_3 plants, some O_2 bind to RuBisCO. Hence CO_2 fixation is decreased. Here RuBP binds with O_2 to form one

molecule of phosphoglycerate and phosphoglycolate. This pathway is called **photorespiration.**

- In this, there is no synthesis of sugars, ATP and NADPH. Hence **photorespiration is a wasteful process.** Rather it causes the release of CO_2 by using ATP.
- **In C_4 plants, photorespiration does not occur** because they can increase CO_2 concentration at the enzyme site. This takes place when C_4 acid from the mesophyll is broken down in the bundle cells to release CO_2. This minimises the oxygenase activity of RuBisCO.
- Due to the lack of photorespiration, productivity and yields are better in C_4 plants. Also, these plants show tolerance to higher temperatures.

Differences between C_3 and C_4 plants

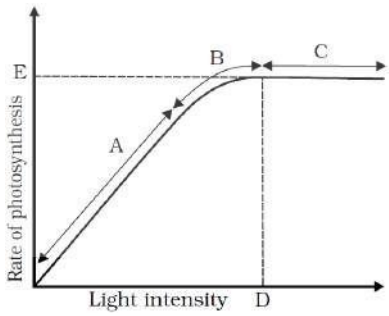
C_3 plants	C_4 plants
1. Photosynthesis occurs in mesophyll cells.	In mesophyll and bundle sheath cells.
2. Kranz anatomy is absent.	Present.
3. RuBP is the primary CO_2 acceptor.	PEP is the primary CO_2 acceptor.
4. 3-PGA, a 3-C compound is the first stable product.	OAA, a 4-C compound is the first stable product.
5. Chloroplasts are of only one type (granal).	Dimorphic (granal in mesophyll and agranal in bundle sheath).
6. Photorespiratory loss is high.	Photorespiration is absent or negligible.
7. High CO_2 compensation point (25-100 µl. CO_2 l^{-1}).	Low CO_2 compensation point (0-10 µl. CO_2 l^{-1}).
8. Optimum temperature for photosynthesis is about 25°C.	About 35°C - 45°C.
9. Photosynthetically less efficient and productivity low.	Photosynthetically more efficient and productivity high.
10. E.g. Rice, wheat, bean, potato.	E.g. Maize, sugarcane, amaranth, sorghum.

FACTORS AFFECTING PHOTOSYNTHESIS

- **Internal (plant) factors:** The number, size, age and orientation of leaves, mesophyll cells and chloroplasts, internal CO_2 concentration and amount of chlorophyll.
  Plant factors depend on the genes and growth of the plant.
- **External factors:** Sunlight, temperature, CO_2 concentration and water.
- **Blackman's Law of Limiting Factors (1905):** *"If a biochemical process is affected by more than one factor, its rate is determined by the factor nearest to its minimal value: it is the factor which directly affects the process if its quantity is changed."*
- E.g. a plant with green leaf, optimal light & CO_2 conditions may not photosynthesize if the temperature is very low. If optimal temperature is given, it will start photosynthesis.

Light

- **Light quality, light intensity** and **duration of exposure to light** influence photosynthesis.
- There is a linear relationship between incident light and CO_2 fixation rates at low light intensities.
- At higher light intensities, the rate does not show further increase because other factors become limiting.



- Light saturation occurs at 10% of the full sunlight. Hence, except for plants in shade or in dense forests, light is rarely a limiting factor in nature.
- High increase in incident light breaks down chlorophyll. It decreases photosynthesis.

Carbon dioxide Concentration

- CO_2 is the major limiting factor for photosynthesis.
- CO_2 concentration is very low in the atmosphere (0.03-0.04%). Increase up to 0.05% cause increase in CO_2 fixation rates. Beyond this level can become damaging over longer periods.
- At low light, C_3 and C_4 plants do not respond to high CO_2. At high light, they show increased rate of photosynthesis.
- C_4 plants show saturation at about 360 μL^{-1}.
- C_3 plants respond to increased CO_2 concentration and saturation is seen only beyond 450 μL^{-1}. Thus, current availability of CO_2 levels is limiting to the C_3 plants.
- Due to response to higher CO_2 concentration, C_3 plants show increased photosynthesis and higher productivity. This fact is used for some greenhouse crops (tomatoes, bell pepper etc). They are grown in CO_2 enriched atmosphere.

Temperature

- Dark reactions, being enzymatic, are temperature controlled. Influence of temperature on Light reactions is very less.
- The C_4 plants respond to higher temperatures and show higher rate of photosynthesis.
- C_3 plants have a much lower temperature optimum.
- The temperature optimum of plants also depends on their habitat. Tropical plants have a higher temperature optimum than the plants adapted to temperate climates.

Water

- Water stress closes the stomata hence reduce the CO_2 availability.
- Water stress also wilts leaves, thus reduce the surface area of the leaves and their metabolic activity.

RESPIRATION IN PLANTS

- **Oxidation of food materials** (breaking of C-C bonds of complex molecules) within the cell to release energy for ATP synthesis is called **cellular respiration**.
- This energy is used for absorption, transport, movement, reproduction, breathing etc.
- Ultimate source of food that is respired is photosynthesis.
- The compounds that are oxidized during respiration are called **respiratory substrates.** E.g. Carbohydrates (most common), proteins, fats and organic acids.
- The energy released is not used directly but is used to synthesize ATP. When energy is needed, ATP is broken down. Hence, **ATP** acts as **energy currency** of the cell.

BREATHING IN PLANTS

- For respiration, plants get O_2 and give out CO_2.
- In plants, gas exchange occurs via **stomata** & **lenticels.**
- Plants need no specialized respiratory organs because
  - Each plant part takes care of its own gas-exchange needs. So **gas transport is very limited.**
  - **Very low gas exchange** as compared to that of animals.
  - Leaves are adapted for maximum **gas exchange during photosynthesis.** During this, O_2 is released within the cell.
  - Most **living cells have contact with air.** They are located close to plant surface. In stems, living cells are organized in thin layers beneath the bark. They also have **lenticels.** In leaves, stems & roots, parenchyma cells are loosely packed that provides interconnected air spaces.
- Complete combustion of glucose yields energy most of which is given out as heat.

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + Energy$$

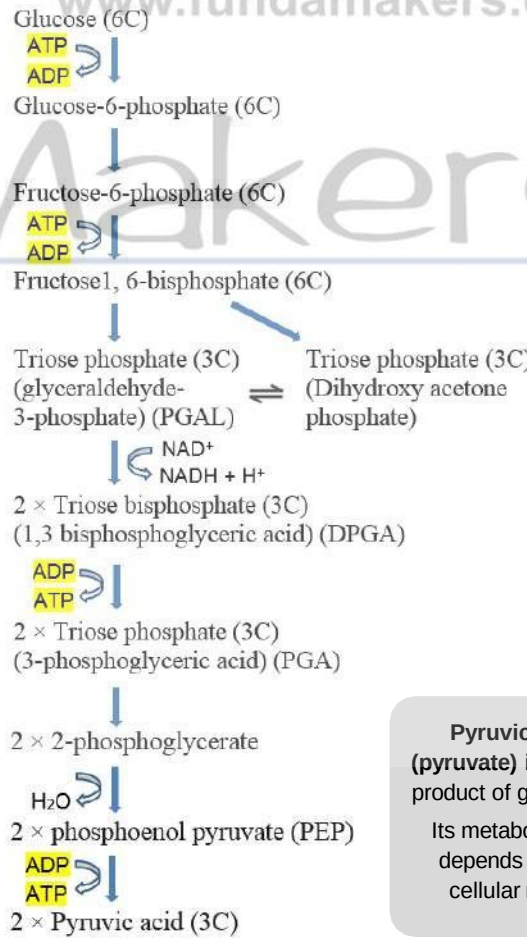
- This energy is utilized to synthesize other molecules.
- During the glucose catabolism, not all the liberated energy goes out as heat. Glucose is oxidised in several small steps. It enables some steps to couple released energy to ATP synthesis.
- During respiration, oxygen is utilized, and CO_2, water & energy are released.
- Certain organisms are adapted to anaerobic conditions. Some are **facultative** anaerobes. Others are **obligate.**

GLYCOLYSIS (EMP PATHWAY)

- It is the partial oxidation (breakdown) of **glucose** to 2 molecules of **pyruvic acid** ($C_3H_4O_3$) in the absence of O_2.
- It occurs in cytoplasm of all living organisms.
- Its scheme was given by **Gustav Embden, Otto Meyerhof & J. Parnas.** So it is also known as **EMP pathway.**
- In anaerobes, it is the only process in respiration.
- In plants, glucose is derived from **sucrose** (end product of photosynthesis) or from storage **carbohydrates.** Sucrose is converted to glucose & fructose by an enzyme, ***invertase.*** These 2 monosaccharides readily enter glycolytic pathway.
- Glucose & fructose are phosphorylated to form glucose-6-phosphate by the enzyme ***hexokinase***. It is then isomerised to produce fructose-6-phosphate. Subsequent steps of metabolism of glucose and fructose are same.

Steps of glycolysis:

- It includes 10 steps under the control of different enzymes.
- ATP is utilized at 2 steps:
  - In the conversion of glucose into glucose 6-phosphate.
  - In the conversion of fructose 6-phosphate to fructose 1, 6-diphosphate.
- Fructose 1, 6-diphosphate is split into dihydroxyacetone phosphate **(DHAP)** & 3-phosphoglyceraldehyde **(PGAL).**
- PGAL is oxidised and with inorganic phosphate get converted to 1, 3-bisphosphoglycerate **(BPGA).** During this, 2 redox-equivalents (2 H-atoms) are removed from PGAL and transferred to NAD^+ forming NADH + H^+.
- BPGA becomes 3-phosphoglyceric acid **(PGA)** yielding energy. This energy is trapped by the formation of ATP.
- ATP is also formed when PEP converts to **pyruvic acid.**
- In glycolysis, **4 ATP molecules** are directly synthesised from one glucose molecule.



Pyruvic acid (pyruvate) is the key product of glycolysis.

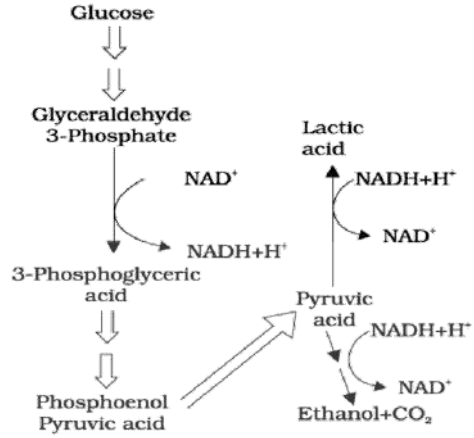
Its metabolic fate depends on the cellular need.

In different cells, pyruvic acid is handled in 3 ways:

- Lactic acid fermentation.
- Alcoholic fermentation.
- Aerobic respiration **(Krebs' cycle)**.

FERMENTATION (ANAEROBIC RESPIRATION)

- It is the **incomplete oxidation** of glucose under anaerobic condition.
- It occurs in many prokaryotes and unicellular eukaryotes.
- It is 2 types:
  - **Alcoholic fermentation:** Here, the **pyruvic acid** formed from glucose is converted to **CO_2** and **ethanol.** The enzymes, ***pyruvic acid decarboxylase*** and ***alcohol dehydrogenase*** catalyse these reactions. E.g. Yeast. Yeasts poison themselves to death when the concentration of alcohol reaches about 13%.
  - **Lactic acid fermentation:** Here, **pyruvic acid** is converted to **lactic acid.** E.g. Some bacteria.
- The reducing agent **($NADH+H^+$)** is reoxidised to **NAD^+** in both the processes.
- In animals, when oxygen is inadequate during exercise, pyruvic acid in muscle cells is reduced to lactic acid by *lactate dehydrogenase.*
- **Net ATP production** from fermentation of one glucose molecule = **2.** (4 ATP from glycolysis – 2 ATP utilized).
- The steps involved in fermentation are shown below:



Drawbacks of fermentation

- **Energy production is limited.** Less than 7% of the energy in glucose is released and not all of it is trapped as high energy bonds of ATP.
- **Hazardous products** (acid or alcohol) are formed.

AEROBIC RESPIRATION

- It is a **complete oxidation** of organic substances in the presence of oxygen releasing CO_2, water & energy.
- It occurs in **mitochondria.**
- For this, the **pyruvate** (final product of glycolysis) is transported from the cytoplasm into the mitochondria.
- The crucial events in aerobic respiration are:
  - **Complete oxidation of pyruvate** by stepwise removal of all the hydrogen atoms, leaving 3 CO_2 molecules. It takes place in the **matrix of mitochondria.**
  - **Passing on of electrons** removed as part of H-atoms to molecular O_2 with simultaneous synthesis of ATP. It occurs on the **inner membrane of mitochondria.**
- Pyruvate (pyruvic acid) enters mitochondrial matrix and undergoes **oxidative decarboxylation** in presence *pyruvic dehydrogenase*. It needs coenzymes, NAD^+ & Coenzyme A.
- During this process, 2 NADH molecules are produced from 2 pyruvic acid molecules.

$$\text{Pyruvic acid} + \text{CoA} + \text{NAD}^+ \xrightarrow[\text{Pyruvate dehydrogenase}]{Mg^{2+}} \text{Acetyl CoA} + CO_2 + \text{NADH} + H^+$$

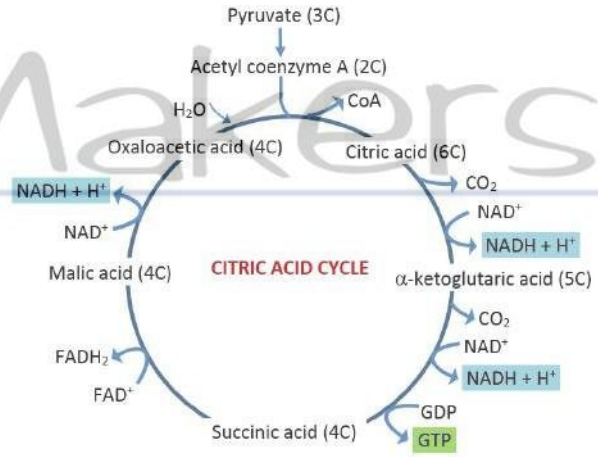
- **Acetyl CoA** then enters **tricarboxylic acid (TCA) cycle.**

Tricarboxylic Acid Cycle
(Krebs' cycle or Citric acid cycle)

TCA cycle was first elucidated by **Hans Krebs.**

Steps:

1. Condensation of **acetyl group** with **oxaloacetic acid (OAA)** & water to form **citric acid** in presence of ***citrate synthase*** enzyme. A **CoA** molecule is released.
2. **Citrate** is isomerised to **isocitrate.**
3. Decarboxylation of isocitrate to **α-ketoglutaric acid.**
4. Decarboxylation of α-ketoglutaric acid to **succinyl-CoA.**
5. Succinyl-CoA is converted to **succinic acid** and a **GTP** molecule is synthesised (substrate level phosphorylation). In a coupled reaction, GTP is converted to GDP with simultaneous synthesis of ATP from ADP.
6. Oxidation of succinate to **Fumarate** and then to **Malate.**
7. Oxidation of malate to **OAA.**



- At 3 points of TCA cycle, NAD^+ is reduced to NADH + H^+. At one point, FAD^+ is reduced to $FADH_2$.
- Continued oxidation of acetyl CoA via TCA cyclerequires continued replenishment of OAA. It also requires regeneration of NAD^+ & FAD^+ from NADH & $FADH_2$.

Summary equation of Krebs' cycle:

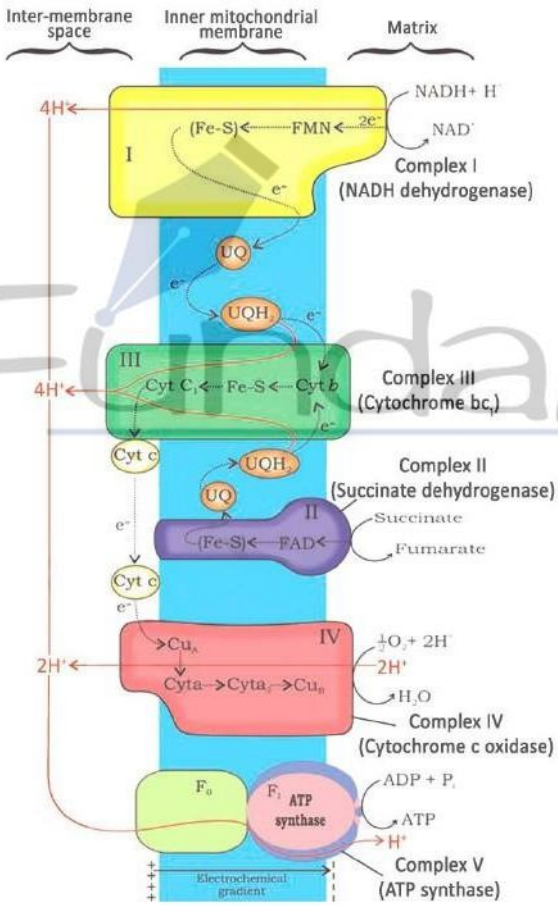
$$\text{Pyruvic acid} + 4NAD^+ + FAD^+ + 2H_2O + ADP + Pi \xrightarrow{\text{Mitochondrial Matrix}} 3CO_2 + 4NADH + 4H^+ + FADH_2 + ATP$$

Thus, **a glucose** is broken down to give **6 CO_2, 8 $NADH+H^+$, 2 $FADH_2$** and **2 ATP.**

Electron Transport System (ETS) & Oxidative Phosphorylation

- **Electron transport system (ETS)** is the metabolic pathway present in the **inner mitochondrial membrane** through which electron passes from one carrier to another.

- This is to release and utilize energy stored in **NADH+H⁺** and **$FADH_2$** (formed during TCA cycle) by oxidation.
- The electrons are passed on to O_2 to form H_2O.
- Electrons from NADH are oxidised by an ***NADH dehydrogenase*** **(complex I).**
- Electrons are then transferred to **ubiquinone (UQ)** located within the inner membrane. Ubiquinone also receives reducing equivalents via **$FADH_2$ (complex II)** that is generated during oxidation of succinate in citric acid cycle.
- The **reduced ubiquinone (ubiquinol or UQH_2)** is then oxidised with the transfer of electrons to **cytochrome *c*** via **cytochrome *bc*$_1$ complex (complex III).** Cytochrome *c* is a small protein attached to the outer surface of the inner membrane. It acts as a mobile carrier of electrons between complex III and IV.
- **Complex IV *(cytochrome c oxidase)*** contains **cytochromes *a* & *a*$_3$,** and 2 copper centres.
- When the electrons pass from one carrier to another via complex I to IV, they are coupled to ***ATP synthase*** **(complex V)** for the ATP production.

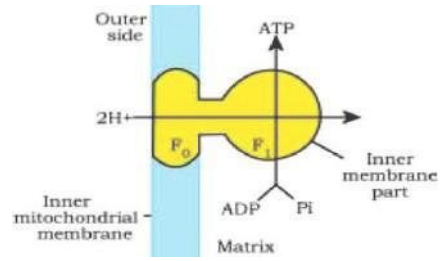


Number of ATP molecules produced depends on nature of electron donor.

Oxidation of **1 NADH → 3 ATP**

Oxidation of **1 $FADH_2$ → 2 ATP**

- In aerobic respiration, the role of oxygen is limited to the terminal stage. Yet, oxygen is vital since it drives the whole process by removing hydrogen from the system. Oxygen acts as the **final hydrogen acceptor.**
- In respiration, energy of **oxidation-reduction** is utilised for the phosphorylation. So this process is called **oxidative phosphorylation.** It is not as photophosphorylation (Here, light energy is utilised to produce proton gradient for phosphorylation).
- The energy released during the ETS is utilized to synthesize ATP by ***ATP synthase*** **(complex V).**
- *ATP synthase* has two major components: **F_1 & F_0.**
- **F_1 headpiece (peripheral membrane protein complex):** Site for ATP synthesis from ADP & inorganic phosphate.
- **F_0 (integral membrane protein complex):** It forms a channel through which protons cross the inner membrane. The passage of protons is coupled to the catalytic site of the F_1 component for ATP production.



Diagrammatic presentation of ATP synthesis in mitochondria

- For each ATP produced, $2H^+$ passes through F_0 from the inter-membrane space to the matrix down the electrochemical proton gradient.

THE RESPIRATORY BALANCE SHEET

- Net gain of ATP from each glucose molecule is calculated based on the following assumptions:
  - All steps in Glycolysis, TCA cycle & ETS occur sequentially and orderly.
  - The NADH synthesised in glycolysis is transferred into mitochondria and undergoes oxidative phosphorylation.
  - Intermediates in the pathway are not used to synthesise other compounds.
  - Only glucose is being respired. Other alternative substrates are not entered in the pathway at any stages.
- Such assumptions are not valid because,
  - All pathways work simultaneously and do not take place one after another.
  - Substrates enter the pathways and are withdrawn from it as and when necessary.
  - ATP is utilized as and when needed.
  - Enzymatic rates are controlled by multiple means.
- Such calculations are useful to appreciate the efficiency of the living system in extraction and storing energy.

Net gain of ATP molecules from one glucose molecule

Glycolysis	2 ATP directly	2 ATP
	2 molecules of NADH	6 ATP
Oxidative decarboxylation	2 NADH	6 ATP
TCA cycle	6 NADH	18 ATP
	2 FADH	4 ATP
	2 GTP	2 ATP
	Total	**38 ATP**

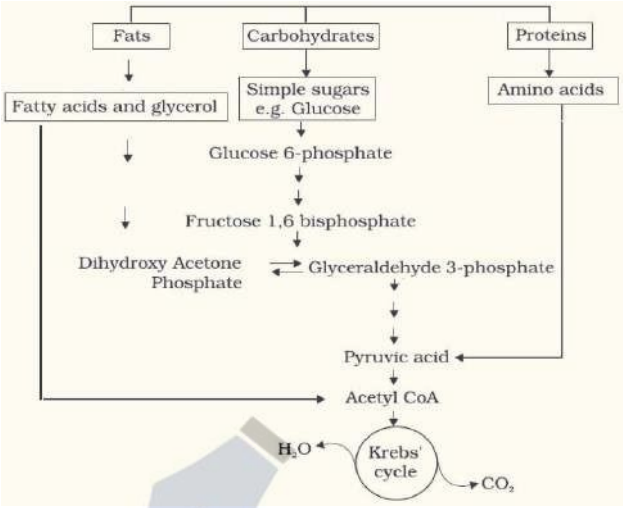
2 ATP molecules are spent for transporting 2 NADH molecules formed during glycolysis to the mitochondria. Hence the **net gain = 36 ATP molecules.**

Comparison b/w fermentation & aerobic respiration

Fermentation	Aerobic respiration
Partial breakdown of glucose.	Complete breakdown of glucose to CO_2 & H_2O.
Net gain of only 2 ATP.	Net gain of 36 ATP.
NADH is oxidised to NAD^+ rather slowly.	NADH is oxidised to NAD^+ very vigorously.

AMPHIBOLIC PATHWAY

- Glucose is the favoured substrate for respiration. So, all carbohydrates are first converted to glucose for respiration.
- Other substrates are also respired.



- Fats breakdown into glycerol & fatty acids. **Fatty acids** are degraded to **acetyl CoA** and enter the pathway. **Glycerol** is converted to **PGAL** and enters the pathway.
- Proteins are degraded by proteases into amino acids. Each amino acid (after deamination) enters the pathway at some stage in the Krebs' cycle or as pyruvate or acetyl CoA.
- The respiratory pathway is generally considered as a catabolic pathway. But it involves both **anabolism** (synthesis) and **catabolism** (breakdown). So it is better called as an **amphibolic pathway.**

  E.g. Fatty acids breakdown to acetyl CoA before entering the respiratory pathway. But when the organism needs to synthesise fatty acids, acetyl CoA withdraw from the respiratory pathway.

  Similarly, during breakdown and synthesis of protein, respiratory intermediates are involved.

RESPIRATORY QUOTIENT (RQ) OR RESPIRATORY RATIO

- It is the ratio of the volume of CO_2 evolved to the volume of O_2 consumed in respiration.

$$RQ = \frac{\text{Volume of } CO_2 \text{ evolved}}{\text{Volume of } O_2 \text{ consumed}}$$

- RQ depends upon the type of respiratory substrate.
- **RQ for carbohydrates= 1**, because equal amounts of CO_2 and O_2 are evolved and consumed, respectively.

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6\,H_2O + \text{energy}$$

$$RQ = \frac{6\,CO_2}{6\,O_2} = 1.0$$

- **RQ for fats = < 1.** Calculations for a fatty acid, (e.g. tripalmitin) are shown:

$$2\,(C_{51}H_{98}O_6) + 145O_2 \rightarrow 102\,CO_2 + 98\,H_2O + \text{energy}$$

$$RQ = \frac{102\,CO_2}{145\,O_2} = 0.7$$

- **RQ for proteins = 0.9.**
- In living organisms, respiratory substances are often more than one. Pure proteins or fats are never used as respiratory substrates.

PLANT GROWTH AND DEVELOPMENT

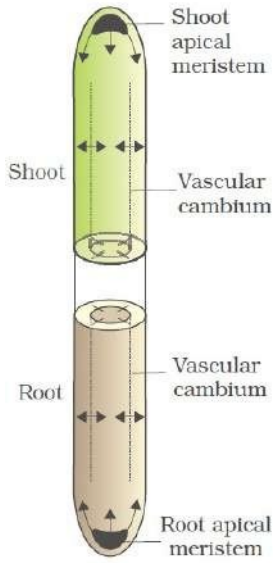
All plant cells are descendants of the zygote (fertilized egg). The zygote develops into a mature plant through growth and differentiation forming roots, leaves, branches, flowers, fruits and seeds. Then they eventually die.

GROWTH

- Growth is an irreversible permanent increase in size of an organ or its parts or an individual cell.
- It involves metabolic processes that consume energy.

Plant Growth Generally is Indeterminate

- Plant growth continues throughout the life due to the presence of **meristems.**
- Meristematic cells have capacity to divide & self-perpetuate.
- The growth where new cells are always added to the plant body by the meristem is called **open form of growth.**
- **Primary growth:** It occurs due to **root apical meristem** & **shoot apical meristem.** It causes the elongation of the plants along the axis.
- **Secondary growth** (In gymnosperms & dicots): It occurs due to **lateral meristems, vascular cambium** & **cork-cambium.** It causes increase in the girth of organs.



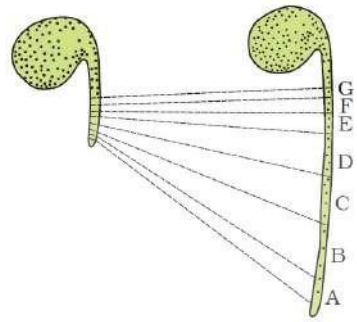
Growth is Measurable

- At cellular level, growth occurs due to increase in the amount of protoplasm.
- Increase in protoplasm is difficult to measure directly. So growth is measured by parameters like increase in fresh weight, dry weight, length, area, volume & cell number. E.g.
  - **Cell number:** E.g. A maize root apical meristem can produce more than 17,500 new cells per hour.
  - **Cell size:** E.g. Cells in a watermelon can increase in size by up to 3,50,000 times.
  - **Length:** E.g. Growth of a pollen tube.
  - **Surface area:** E.g. Growth in a dorsi-ventral leaf.

Phases of Growth

3 phases: **meristematic, elongation & maturation**.

- **Meristematic phase:** It occurs in the meristems at the root apex & the shoot apex. Here, cells have rich protoplasm and large nuclei. Cell walls are primary, thin & cellulosic with abundant plasmodesmata.
- **Elongation phase:** It occurs in cells proximal (just next, away from the tip) to the meristematic zone. The cells have increased vacuolation, size and new cell wall deposition.
- **Maturation phase:** It occurs in the cells further away from the apex, i.e., more proximal to the phase of elongation. The cells attain maximal size in terms of wall thickening and protoplasmic modifications.



Detection of zones of elongation by the parallel line technique.

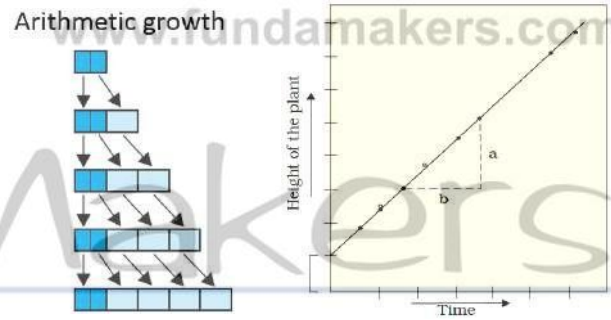
Zones A, B, C, D immediately behind the apex have elongated most.

Growth Rates

- It is the increased growth per unit time.
- The growth rate may be **arithmetic or geometrical.**

Arithmetic growth:

- In this, following mitotic division, only one daughter cell continues to divide while the other differentiates & matures.
- On plotting the length of the organ against time, a linear curve is obtained.

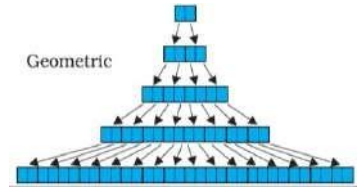


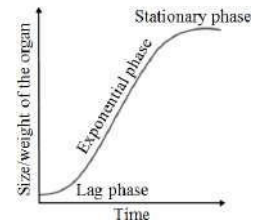
Mathematically, it is expressed as $L_t = L_0 + rt$

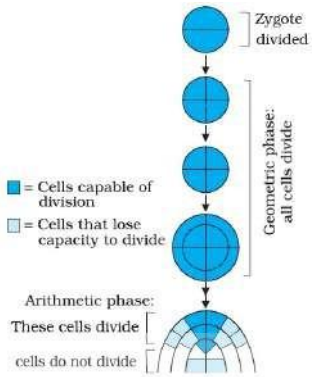
L_t = length at time 't'
L_0 = length at time 'zero'
r = growth rate / elongation per unit time.

Geometrical growth:

- Here, both daughter cells continue mitotic cell division.
- In most systems, the initial growth is **slow (lag phase),** then it increases rapidly **(log or exponential phase).**
- If nutrient supply is limited, the growth slows down leading to a **stationary phase.**
- On plotting the parameter of growth against time, we get a typical **sigmoid (S) curve.**
- A sigmoid curve is a characteristic of living organism growing in a natural environment. It is typical for all cells, tissues and organs of a plant.







Exponential growth is expressed as $W_1 = W_0 e^{rt}$

W_1 = final size (weight, height, number etc.)

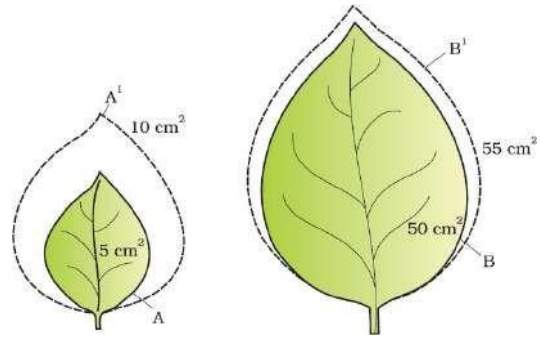
W_0 = initial size at the beginning of period

r = growth rate (relative)

t = time of growth

e = base of natural logarithms

- Here, **r** is **relative growth rate.** It is also the measure of ability of plant to produce new plant material **(efficiency index).** Hence, final size W_1 depends on initial size, W_0.
- Quantitative comparisons between the growth can also be made in 2 ways:
  - **(i) Absolute growth rate:** Measurement & comparison of total growth per unit time.
  - **(ii) Relative growth rate:** Measurement of growth of the given system per unit time expressed on a common basis, e.g., per unit initial parameter.



Diagrammatic comparison of absolute & relative growth rates

Conditions (essential elements) for Growth

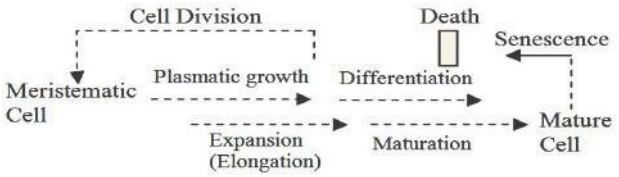
1. **Water:** Essential for cell enlargement. Turgidity of cells helps in extension growth. Water provides medium for enzymatic activities needed for growth.
2. **Oxygen:** It helps to release metabolic energy for growth.
3. **Nutrients:** Macro & micro elements are needed for the synthesis of protoplasm and act as source of energy.
4. **Temperature:** At optimum temperature, growth is maximum. Deviation from this may harm the plants.
5. **Light** & **gravity:** Affect certain phases/stages of growth.

DIFFERENTIATION, DEDIFFERENTIATION & REDIFFERENTIATION

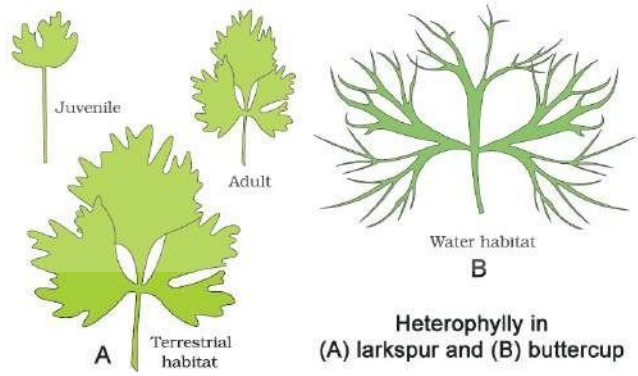
- **Differentiation** is the process in which the cells in meristems (root apical & shoot-apical) and cambium differentiate and mature to perform specific functions.
- In this, cell walls & protoplasm undergo major structural changes. The capacity of cell division is lost.
  E.g. Loss of protoplasm to form a tracheary element. They also develop very strong, elastic, lignocellulosic secondary cell walls to carry water to long distances even under extreme tension.
- Under certain conditions, living differentiated cells regain the capacity of division. This is called **dedifferentiation**.
  E.g. formation of meristems (interfascicular cambium & cork cambium) from differentiated parenchyma cells.
- The dedifferentiated cells can divide and produce cells that again lose the capacity to divide but mature to perform specific functions. It is called **redifferentiation.**
- Plant growth is open, i.e., it can be indeterminate or determinate. Differentiation in plants is also open, because cells/tissues arising out of the same meristem have different structures at maturity.
- Final structure at maturity of cell/tissue is also determined by the location of the cell.
  E.g. cells positioned away from root apical meristems differentiate as root-cap cells, while those pushed to the periphery mature as epidermis.

DEVELOPMENT

- It is a process that includes all changes in the life cycle of an organism from seed germination to senescence.
- It is the sum of growth and differentiation.



- Plants follow different pathways in response to environment or phases of life to form different kinds of structures. This ability is called **plasticity.** E.g.
- **Heterophylly due to phases of life:** E.g. In cotton, coriander and larkspur, the leaves of the juvenile plants and mature plants are different in shape.
- **Heterophylly due to environment:** E.g. Difference in shapes of leaves produced in air and water (e.g. buttercup).



Heterophylly in (A) larkspur and (B) buttercup

Factors controlling the development:

- **Intrinsic factors:** Include intracellular (genetic) or intercellular factors (such as plant growth regulators).
- **Extrinsic factors:** Include light, temperature, water, oxygen, nutrition, etc.

PLANT GROWTH REGULATORS (PLANT HORMONES OR PHYTOHORMONES)

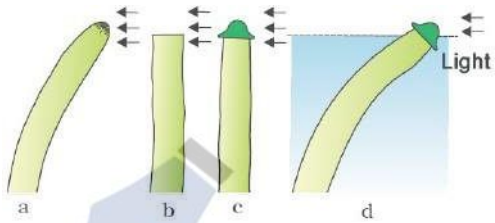
Plant growth regulators (PGRs) are small, simple molecules that regulate plant growth.

Based on the functions, PGRs are 2 groups:

- **Plant growth promoters:** For growth promoting activities like cell division & enlargement, tropic growth, pattern formation, flowering, fruiting & seed formation. E.g. auxins, gibberellins and cytokinins.
- **Plant growth inhibiters:** For growth inhibiting activities like dormancy & abscission. Respond to wounds & stresses of biotic and abiotic origin.
  E.g. abscisic acid & ethylene. (Ethylene fits either of the groups, but it is largely a growth inhibitor).

1. Auxins

- **Charles Darwin** & his son **Francis Darwin** observed that the coleoptiles of canary grass responded to unilateral illumination by growing towards the light source (**phototropism**). It was concluded that the tip of coleoptile caused the bending of the entire coleoptile.



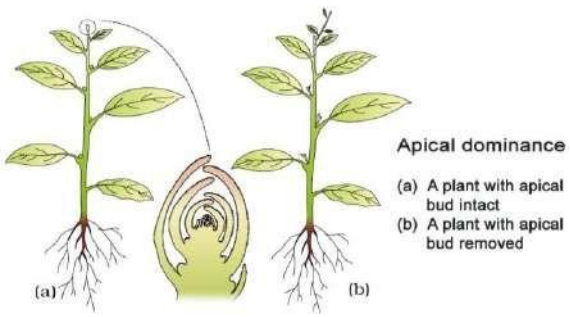
- **F.W. Went** isolated **Auxin** (Greek 'auxein': to grow) from tips of coleoptiles of oat seedlings.
- Auxin was first isolated from human urine.
- Auxins are produced by the growing apices of stems & roots, from where they migrate to regions of their action.

Types of Auxins:

- **Natural:** E.g. **Indole-3-acetic acid (IAA)** and **indole butyric acid (IBA).** They are isolated from plants.
- **Synthetic:** E.g. **NAA (naphthalene acetic acid)** and **2, 4-D (2, 4-dichlorophenoxyacetic).**

Functions of auxins:

- Initiate rooting in **stem cuttings** for plant propagation.
- Promote flowering. E.g. in pineapples.
- Prevent fruit and leaf drop at early stages.
- Promote the abscission of older leaves and fruits.
- Induce **parthenocarpy.** E.g., in tomatoes.
- Used as **herbicides.** E.g. 2, 4-D is used to kill dicot weeds. It does not affect mature monocot plants. It is used to prepare weed-free lawns.
- Controls xylem differentiation and helps in cell division.



In higher plants, the growing apical bud inhibits the growth of lateral (axillary) buds. It is known as **apical dominance**. Removal of shoot tips (decapitation) results in the growth of lateral buds. It is applied in tea plantations & hedge-making.

2. Gibberellins

- These are acidic PGR.
- **E. Kurosawa** treated the sterile filtrates of *Gibberalla fujikuroi* (a fungus that causes 'bakane' disease or foolish seedling in rice) to healthy rice seedlings. As a result, it showed the symptoms of 'bakane' disease. Later, the active substances were identified as **gibberellic acid.**
- There are more than 100 gibberellins (GA_1, GA_2, GA_3 and so on) in fungi and higher plants.
- **Gibberellic acid (GA_3 or Terpenes)** is one of the first discovered and most intensively studied gibberellins.

Functions:

- They cause an increase in length of axis. So they are used to increase the length of grapes stalks.
- To elongate and improve the shape of fruits such as apple.
- They delay senescence. So the fruits can be left on the tree to extend the market period.
- GA_3 is used to speed up malting process in brewing industry.
- Sugarcane stores sugar in stems. Spraying sugarcane crop with gibberellins increases the length of the stem. It increases the yield by as much as 20 tonnes per acre.
- Spraying juvenile conifers with GAs hastens the maturity period. It leads to early seed production.
- For **bolting** (internode elongation just prior to flowering) in beet, cabbages and many plants with rosette habit.

3. Cytokinins

- **F. Skoog** and co-workers observed that from the internodal segments of tobacco stems, the callus (a mass of undifferentiated cells) proliferated only if the nutrients medium was supplemented with extracts of vascular tissues, yeast extract, coconut milk or DNA.
  Skoog & Miller later identified and crystallized the active substance and termed as **kinetin.**
- Cytokinins were discovered as kinetin (N_6-furfurylamino purine - an Adenine derivative) from the autoclaved herring sperm DNA.
- Kinetin does not occur naturally in plants.
- **Zeatin** (from corn-kernels and coconut milk) is the natural substances with cytokinin-like activities.
- There are some synthetic compounds with cell division promoting activity.
- Natural cytokinins are synthesized in regions of rapid cell division (root apices, shoot buds, young fruits etc).

Functions:

- Play a role in cytokinesis.
- Help to produce new leaves, chloroplasts in leaves, lateral shoot growth and adventitious shoot formation.
- Help overcome the apical dominance.

- Promote nutrient mobilization which helps in the delay of leaf senescence.

4. Ethylene (C_2H_4)

- **Cousins** confirmed that ripened oranges released a volatile substance that hastened the ripening of stored bananas. Later this substance was identified as ethylene.
- Ethylene is a simple gaseous PGR.
- It is synthesized in large amounts by tissues undergoing senescence and ripening fruits.

Functions:

- Influences horizontal growth of seedlings, swelling of the axis and apical hook formation in dicot seedlings.
- Promotes senescence and abscission of plant organs especially of leaves and flowers.
- Promotes fruit ripening. It enhances respiration rate during fruit ripening. This is called **respiratory climactic.**
- Breaks seed and bud dormancy, initiates germination in peanut seeds, sprouting of potato tubers.
- Promotes rapid internode/petiole elongation in deep water rice plants. It helps leaves/upper parts of the shoot to remain above water.
- Promotes root growth and root hair formation. It increases absorption surface.
- Used to initiate flowering and for synchronising fruit-set in pineapples. It also induces flowering in mango.
- It is widely used in agriculture.

The most widely used source of ethylene is **ethephon**. Ethephon in an aqueous solution is readily absorbed and transported within the plant and releases ethylene slowly. Ethephon hastens fruit ripening in tomatoes & apples and accelerates abscission in flowers and fruits (thinning of cotton, cherry, walnut). It promotes female flowers in cucumbers thereby increasing the yield.

5. Abscisic acid (ABA)

- During mid-1960s, it was reported 3 kinds of inhibitors: **inhibitor-B, abscisin II** & **dormin**. They were chemically identical and now known as **abscisic acid.**
- ABA is the derivatives of carotenoids.
- It regulates abscission and dormancy.

Functions:

- Inhibitor of plant growth and metabolism.
- Inhibits seed germination.
- Stimulates the closure of stomata in the epidermis.
- Increases the tolerance of plants to various kinds of stresses. Therefore, it is also called the **stress hormone.**
- For seed development, maturation & dormancy (it helps to withstand desiccation and other unfavourable factors).

Interactions of PGRs

- PGRs play individualistic or synergistic role. Such roles may be complimentary or antagonistic.
- PGRs interact to affect dormancy in seeds/ buds, abscission, flowering, senescence, vernalisation, apical dominance, seed germination, plant movements etc.
- In most situations, ABA acts as an antagonist to GAs.

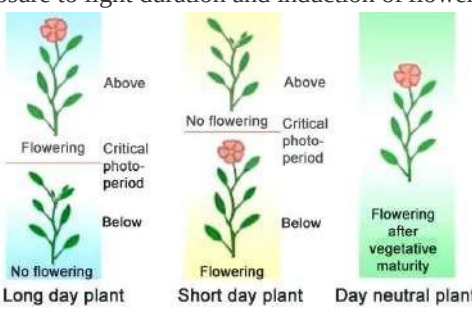
Factors influencing the action of PGR:

- **Intrinsic factor:** Genomic control.
- **Extrinsic factors:** Light and Temperature.

ROLE OF LIGHT AND TEMPERATURE ON FLOWERING

1. PHOTOPERIODISM

- It is the response of plants to periods of day/night.
- Some plants require light to induce flowering.
- Based on light duration, plants are 3 groups:
  - **Long day plants:** They require the exposure to light for a period exceeding a well-defined critical duration.
  - **Short day plants:** They require the exposure to light for a period less than the critical duration before the flowering is initiated in them.
  - **Day-neutral plants:** They have no correlation between exposure to light duration and induction of flowering.



- While shoot apices modify into flowering apices, they by themselves cannot perceive photoperiods. The site of perception of light/dark duration is the leaves.
- It has been hypothesised that there is hormone(s) for flowering. When plants get enough photoperiod, the hormone migrates from leaves to shoot apices to induce flowering.

2. VERNALISATION

- It is the phenomenon in which some plants depend quantitatively or qualitatively on exposure to low temperature for flowering.
- It prevents precocious reproductive development late in the growing season, and enables the plant to have sufficient time to reach maturity.

Examples for vernalisation:

1. Some food plants, wheat, barley & rye have two varieties:
   - **Spring varieties:** These are normally planted in the spring and come to flower and produce grain before the end of the growing season.
   - **Winter varieties:** Winter varieties if planted in spring would normally fail to flower or produce mature grain within a span of a flowering season. Hence, they are planted in autumn. They germinate, and over winter come out as small seedlings, resume growth in the spring, and are harvested usually around mid-summer.
2. **Vernalisation in biennial plants:** Biennials are monocarpic plants that normally flower and die in second season. E.g. Sugar beet, cabbages, carrots etc. Subjecting

the growing of a biennial plant to a cold treatment stimulates a subsequent photoperiodic flowering response.

SEED DORMANCY

- Certain seeds fail to germinate even under favourable external conditions. Such seeds are in **dormancy.**
- Dormancy is caused by endogenous conditions within the seed. E.g. Hard seed coat; chemical inhibitors such as ABA, phenolic acids, para-ascorbic acid; and immature embryos.
- Dormancy can be overcome naturally and artificially. E.g.
  - **Breaking of seed coat barrier:** By mechanical abrasions using knives, sandpaper etc. or vigorous shaking. In nature, abrasions are caused by microbial action, and passage through digestive tract of animals.
  - **Removing inhibitory substances:** By subjecting the seeds to chilling conditions or by application of certain chemicals like gibberellic acid and nitrates.
  - Changing the environmental conditions, such as light and temperature.

DIGESTION AND ABSORPTION

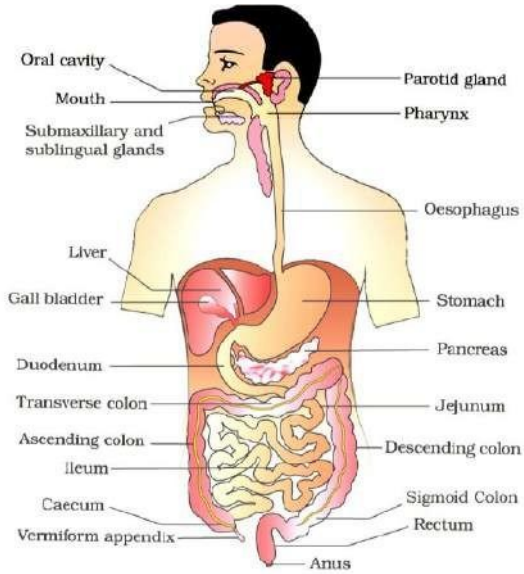
- **Nutrition** is the getting and utilization of energy rich nutrients (food) by an organism.
- Food consists of **carbohydrates, proteins, fats (lipids), vitamins, minerals** and **water.**
- Food provides ***energy for life activities, materials for growth, maintains body temperature*** and ***repairs tissues.***
- The water plays an important role in metabolic processes and prevents dehydration of the body.

HUMAN DIGESTIVE SYSTEM

ALIMENTARY CANAL
- Mouth
- Buccal cavity
- Pharynx
- Oesophagus
- Stomach
- Small intestine
- Large intestine
- Anus

DIGESTIVE GLANDS
- Salivary glands
- Gastric glands
- Liver
- Pancreas
- Intestinal glands

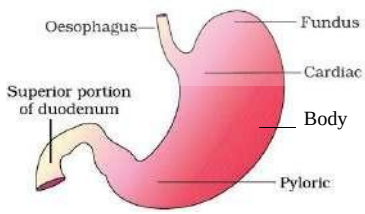
5 Processes of Digestive system
- Ingestion
- Digestion
- Absorption
- Assimilation
- Egestion



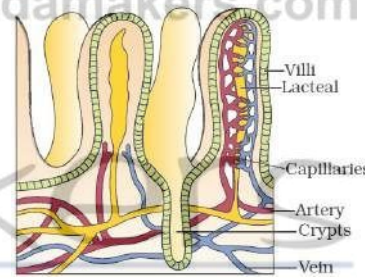
I. ALIMENTARY CANAL (GUT)

It includes the following parts:

- **Mouth:** To receive the food **(ingestion).**
- **Buccal cavity (oral or mouth cavity):**
  - Consists of ***palate (roof), teeth & muscular tongue.***
  - Palate has anterior ***hard palate*** and posterior ***soft palate.***
  - Tongue is a muscular organ attached to the floor of oral cavity by the **frenulum.** Tongue has small projections called **papillae.** Some papillae bear **taste buds.**
  - At the back, on either side of tongue ***tonsils*** present.
- **Pharynx:**
  - Common passage for digestive and respiratory systems.
  - When food materials pass through the pharynx, the cartilaginous ***epiglottis*** closes the ***glottis*** (opening of larynx) and prevents the entry of food into trachea.
- **Oesophagus:**
  - Muscular tube (30 cm) that conducts food into stomach.
  - Posterior part of the oesophagus has ***gastro-oesophageal sphincter*** (a circular muscle). It controls the opening of oesophagus into stomach.
- **Stomach:**
  - 'J' shaped structure for storage and digestion of food.
  - **4 parts:** a **cardiac** portion into which the oesophagus opens, a **fundic** region, **body** (main central region) and a **pyloric** portion (antrum).
  - Pyloric stomach leads to small intestine by an opening called **Pylorus**, guarded by ***pyloric sphincter muscle***.
  - Inner wall of stomach bears **rugae** (longitudinal folds).



- **Small intestine:**
  - Longest part of gut (7 m long and 2.5 cm diameter).
  - Consists 3 parts, namely **duodenum** (C shaped first part), **Jejunum** (middle part) and **Ileum** (terminal part).
  - Finger-like **villi** are seen at the mucosa. Each villus has a brush-bordered columnar epithelial layer provided with ***microvilli***. Villus consists of a capillary network and a small lymph vessel **(lacteal).**



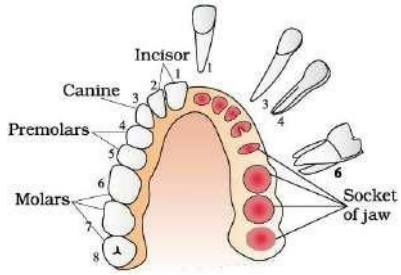
- **Large intestine:**
  - 1.5 m long. Consists of **caecum, colon** and **rectum.**
  - Caecum is well-developed in herbivores but very small in man. Arising from the caecum is a finger-like vestigial organ, the ***vermiform appendix.***
  - The colon consists of ***ascending colon, transverse colon, descending colon*** and ***Sigmoid colon***.
  - Pelvic colon leads to **rectum** that opens out by **anus**. Anus is guarded by ***anal sphincter*** (circular voluntary muscles).
  - In some herbivores, the large intestine consists of several cellulose digesting bacteria.

TEETH

Nature & mode of arrangement of teeth is called **dentition**. **Human dentition** is Thecodont, Heterodont & Diphyodont.

- **Thecodont:** It means teeth are placed in the jaw sockets.
- **Heterodont:** It means different kinds of teeth are present. They are ***incisors (I)*** for cutting, ***canines (C)*** for tearing, ***premolars (PM)*** & ***molars (M)*** for mastication.

Premolars & molars are collectively called as ***cheek teeth*** which have **cusps**.



- **Diphyodont:** It means teeth appear twice in the lifetime. They are ***milk (deciduous) teeth*** and ***permanent teeth***.

  Milk teeth (**20** in number) are erupted at **6-7 months** of birth. They are replaced by permanent teeth (**32** in number) at the age of **6-7.**

  Last 4 molars ***(wisdom teeth)*** appear only at the age of 18.

The hard chewing surface of teeth is made up of **enamel.**

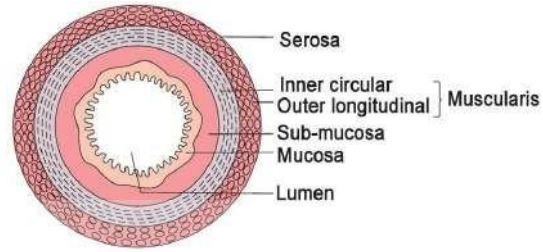
Dental formula: It explains the kinds and number of teeth.

Human dental formula (of permanent teeth):

$$I\ ^{2}/_{2}\ C\ ^{1}/_{1}\ PM\ ^{2}/_{2}\ M\ ^{3}/_{3} \times 2 = 32 \quad (\tfrac{2123}{2123})$$

Dental formula of milk dentition:

Histology of human gut (Transverse section)



Human gut is formed of 4 layers:

1. **Mucosa:** Innermost, moist epithelial layer. Contains secretory and absorptive cells.
2. **Submucosa:** Soft connective tissue layer just outside the mucosa. Nerves and blood vessels are present.
3. **Muscularis:** Outer to submucosa. Smooth muscle layer (inner circular & outer longitudinal muscles).
4. **Serosa:** Outermost fibrous layer.

II. DIGESTIVE (ASSOCIATED) GLANDS

- They secrete **digestive juices.**
- They include **salivary glands, gastric glands, intestinal glands, pancreas & liver.**

a. Salivary glands

- 3 pairs. They are
  - **Parotids (2):** Largest salivary gland. Seen in cheeks.
  - **Submaxillary/submandibular (2):** Seen in lower jaw.
  - **Sublingual (2):** Below the tongue.
- Salivary glands secrete ***saliva***. It contains 99.5% water, ***mucin (mucus)***, enzymes like ***salivary amylase (Ptyalin)*** and ***Lysozyme*** and electrolytes (Na^+, K^+, Cl^-, HCO_3^- etc).

b. Gastric glands

Tubular glands found on the inner wall. They consist of

a. **Mucus neck cells:** Secrete **mucus.** Mucus and **bicarbonates** protect the stomach wall (mucosal epithelium) from HCl and prevents **autodigestion.**

b. **Chief (zymogen or peptic) cells:** Secrete proenzymes like ***pepsinogen & prorennin*** and some ***lipase***.

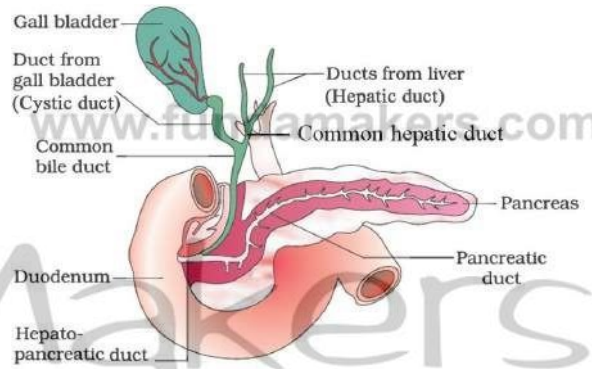
c. **Oxyntic (parietal) cells:** Secrete **HCl** & **Castle's intrinsic factor** (for absorption of vitamin B_{12}).

Gastric glands secrete acidic (pH 1.8-2.0) **gastric juice.**

c. Liver

- Largest gland (1.2 - 1.5 kg). Reddish brown.
- Situated in abdominal cavity, just below the diaphragm.
- Bilobed (large right lobe & small left lobe). Each lobe is formed of ***hepatic lobules*** (structural & functional units).
- A lobule has many ***hepatic cells*** arranged as cords around a ***central vein***. They secrete alkaline ***bile juice***.
- Liver lobule is covered by ***Glisson's capsule***.
- Bile is transported from liver to duodenum as follows:

  Bile → hepatic duct → gallbladder → cystic duct → common bile duct → common hepato-pancreatic duct → duodenum.
- ***Hepato-pancreatic duct*** is guarded by ***sphincter of Oddi***.



- Bile has **no enzymes** but contains ***bile pigments (bilirubin & biliverdin), bile salts, cholesterol*** and ***phospholipids***.

d. Pancreas

- Second largest gland. Seen near **duodenal loop**.
- It is a cream-coloured **heterocrine gland**, i.e. it has both **exocrine** and **endocrine** parts.
- The exocrine part has a **pancreatic duct** that opens into duodenum along with bile duct ***(hepato-pancreatic duct).***
- Exocrine part secretes alkaline ***pancreatic juice.*** It contains inactive protease enzymes ***(trypsinogen, chymotrypsinogen & procarboxypeptidases), amylases, lipases & nucleases.***

e. Intestinal glands

- Simple tubular glands. 2 types:
  1. **Crypts of Lieberkuhn:** Consists of mucus-secreting ***Goblet cells*** and enzyme-secreting ***Paneth cells.***
  2. **Brunner (duodenal) glands:** Confined to submucosa of duodenum. Secrete ***mucus*** only.
- Intestinal glands secrete alkaline ***intestinal juice (succus entericus).*** It contains enzymes ***(maltase, lactase, sucrase, dipeptidase, lipases, nucleotidases, nucleosidases etc).***
- The ***bicarbonate*** and ***mucus*** provide alkaline medium and protect intestinal mucosa.

DIGESTION AND ABSORPTION OF FOOD

Digestion is the conversion of complex insoluble food materials into simple and absorbable form. It includes mechanical processes such as ***mastication*** (chewing), ***deglutition*** (swallowing) & ***peristalsis*** (wave-like movement of food bolus through the gut by muscular contraction).

- **Digestion in buccal cavity:** Only starch digestion.
  Ptyalin converts starch (polysaccharide) into disaccharides. About 30% of starch is digested by ptyalin.

  Starch $\xrightarrow[pH\ 6.8]{Salivary\ amylase}$ Maltose + Isomaltose + limit dextrins

- **Digestion in stomach:** Stomach stores food for 4-5 hrs. It is mixed with gastric juice by the churning movements and is converted into acidic pasty form ***(chyme).***

  Pepsinogen (inactive) $\xrightarrow{HCl}$ Pepsin (active)

  Protein $\xrightarrow{Pepsin}$ Proteoses + Peptones (peptides)

  Prorennin (inactive) $\xrightarrow{HCl}$ Rennin (active)

  Casein (milk protein) $\xrightarrow{Rennin}$ Paracasein

  Paracasein $\xrightarrow{Ca2+}$ Ca paracaseinate (curd)

  Calcium paracaseinate $\xrightarrow{Pepsin}$ Peptones

  (Only in infants)

  The *gastric lipase* hydrolyses a small amount of lipids.

- **Digestion in small intestine (in Duodenum):** Chyme is mixed with ***succus entericus, pancreatic juice*** & ***bile juice***.

a) Action of bile: Bile helps in digestion by ***emulsification*** (conversion of ***fat*** into ***micelles*** or tiny droplets). It provides large surface area for the action of lipase on fat. Bile also activates lipase.

b) Action of pancreatic juice: ***Amylopsin (Pancreatic amylase)*** hydrolyses remaining starch into ***disaccharides***.

Starch $\xrightarrow{Amylopsin}$ Maltose + Isomaltose + limit dextrins

Enterokinase (Enterokinin) secreted by intestinal mucosa activates ***trypsinogen*** to active ***trypsin***. Trypsin activates *chymotrypsinogen & procarboxypeptidase.*

Trypsinogen $\xrightarrow{Enterokinin}$ Trypsin

Chymotrypsinogen $\xrightarrow{Trypsin}$ Chymotrypsin

Procarboxypeptidase $\xrightarrow{Trypsin}$ Carboxypeptidase

Proteins, Peptones, Proteoses $\xrightarrow[Carboxypeptidase]{Trypsin/Chymotrypsin}$ Dipeptides

Fats $\xrightarrow{Lipases}$ Diglycerides $\xrightarrow{Lipases}$ Monoglycerides

Nucleic acids $\xrightarrow{Nucleases}$ Nucleotides

c) Action of intestinal juice: At duodenum region, the intestinal enzymes act on the products of above reactions.

Dipeptides $\xrightarrow{Dipeptidase}$ Amino acids

Maltose $\xrightarrow{Maltase}$ 2 Glucose

Lactose $\xrightarrow{Lactase}$ Glucose + Galactose

Sucrose $\xrightarrow{Sucrase}$ Glucose + Fructose

Nucleotides $\xrightarrow{Nucleotidase}$ Nucleosides

Nucleosides $\xrightarrow{Nucleosidase}$ Sugars + Bases

Diglycerides, monoglycerides $\xrightarrow{Lipases}$ Fatty acid + Glycerol

In large intestine, there is no significant digestive activity.

The functions of large intestine are:

a. Absorption of water, minerals and certain drugs.
b. Secretes mucus for adhering waste (undigested) particles together and lubricating it for an easy passage.

Fully digested semi fluid and alkaline food formed in small intestine is called ***chyle.***

The digestive activities like gastric & intestinal secretions are controlled by **neural** and **hormonal mechanisms**. The **sight, smell or presence of food** in buccal cavity stimulate salivary secretions. Gastric & intestinal mucosa secretes **digestive hormones.** They control secretion of digestive juices.

ABSORPTION OF DIGESTED PRODUCTS

Absorption is the transfer of end products of digestion through the intestinal mucosa into blood & lymph.

It is 2 types- passive and active.

a) Passive absorption (Passive transport): Absorption of nutrients from higher concentrated region to lower concentrated region without the expenditure of energy.

It includes **osmosis** (absorption of water) and **diffusion** (absorption of solute molecules).

Diffusion is 2 types:

i. **Simple diffusion:** In this, molecules alone can be diffused. E.g. Small amounts of monosaccharides like ***glucose, amino acids, vitamins,*** electrolytes like **Cl**$^-$ etc.
ii. **Facilitated diffusion:** Diffusion with the help of carrier proteins. E.g. **glucose, amino acids** etc.

b) Active absorption (Active transport): Absorption of nutrients from lower concentrated region to higher concentrated region (i.e. against concentration gradient). It needs energy. E.g. absorption of ***amino acids, monosaccharides*** like ***glucose***, electrolytes like Na^+ etc.

Absorption of lipids

- ***Monoglycerides, diglycerides*** and ***fatty acids*** cannot be absorbed directly as they are insoluble in water.
- ***Bile salts*** and ***phospholipids*** convert them into small spherical water-soluble droplets called ***micelles***.
- They are reformed into small protein coated fat globules ***(chylomicrons).*** They are transported into ***lacteals*** in the villi. From the lymph, the chylomicrons enter the blood.

Absorption in different parts of alimentary canal

- **Mouth:** Certain drugs.
- **Stomach:** Water, simple sugars, some drugs & alcohol.
- **Small intestine** (mainly Jejunum & Ileum): All nutrients including minerals & vitamins.
  It is the ***chief area of absorption*** due to the presence of villi, its great length and coiled nature.
- **Large intestine:** Water, some minerals & drugs.

The absorbed materials are incorporated into tissues for their activities. It is called ***assimilation.***

The undigested substances like plant fibres, dead bacteria etc. form **faeces.** It enters caecum through the ***ileo-caecal valve,*** which prevents back flow of faeces.

Faeces are temporarily stored in ***rectum*** and are eliminated through anus. It is called ***egestion (defaecation).***

CALORIFIC VALUE OF PROTEIN, CARBOHYDRATE & FAT *(Not for evaluation)*

- Heat is the ultimate source of all energies. So energy content of food is expressed as measure of **heat energy.**
- Its unit is **calorie (cal) or joule (J).**
- **One calorie** is the amount of heat energy required to raise the temperature of **1g of water by 1°C.**
- This value is tiny amount of energy. So physiologists use **kilocalorie (kcal or Cal) or kilo joule (kjl or Joule).**
- **One kilo calorie** is the amount of energy required to raise the temperature of **1kg of water by 1°C.**
- Amount of heat liberated from complete combustion of 1g food in a **bomb calorimeter** (a closed metal chamber filled with O_2) is its **gross calorific (gross energy) value.**
- Actual amount of energy combustion of 1g of food is the **physiologic value of food.**

Food	Gross calorific value	Physiologic value
Carbohydrates	4.1 kcal/g	4.0 kcal/g
Proteins	5.65 kcal/g	4.0 kcal/g
Fats	9.45 kcal/g	9.0 kcal/g

DISORDERS OF DIGESTIVE SYSTEM

1. **Jaundice:** Here, the skin and eye turns yellow due to the deposition of bile pigments. It indicates liver damage.
2. **Vomiting:** Ejection of stomach content through mouth. It is controlled by medulla oblongata.
3. **Diarrhoea:** Frequent elimination of watery faeces. It reduces the absorption of food.
4. **Constipation:** Infrequent elimination of dry stool. It is due to decreased peristalsis in colon.
5. **Indigestion:** Condition leading to feeling of fullness due to improper digestion. It is due to anxiety, inadequate enzyme secretion, food poisoning, spicy food etc.
6. **Protein-Energy malnutrition (PEM):** It is the dietary deficiencies of proteins & food calories.
   PEM causes **Marasmus & Kwashiorkor** in children.

- **Marasmus:** It is due to deficiency of both **proteins and**

Reason: Replacement of mother's milk by foods with poor proteins and caloric value. This often happens if mother has second pregnancy or child birth when the older infant is still too young.

Symptoms: Impaired growth and replacement of tissue proteins; extreme emaciation of the body, thin limbs, dry, thin and wrinkled skin, declined growth rate and body weight, impaired growth and development of brain and mental faculties.

- **Kwashiorkor:** It is due to **protein deficiency** only.

Reason: Replacement of mother's milk by a high calorie-low protein diet in a child more than one year in age.

Symptoms: Like marasmus, it shows wasting of muscles, thinning of limbs, failure of growth & brain development. Unlike marasmus, some fat is still under the skin; extensive

BREATHING AND EXCHANGE OF GASES

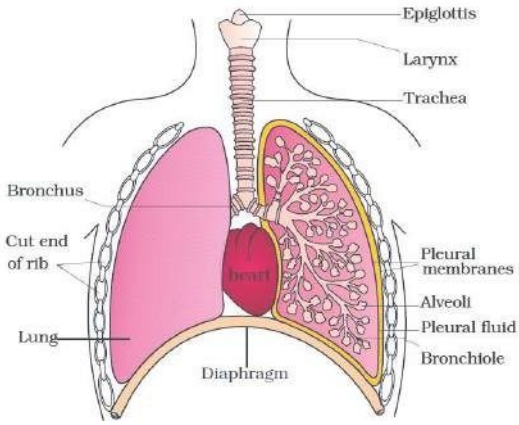
Respiration is the oxidation of nutrients in the living cells to release energy for biological work.
Breathing is the exchange of O_2 from the atmosphere with CO_2 produced by the cells.

RESPIRATORY ORGANS

- **General body surface:** E.g. lower invertebrates (sponges, coelenterates, flatworms etc).
- **Skin or moist cuticle (cutaneous respiration):** E.g. earthworms, leech, amphibians etc.
- **Tracheal tubes:** E.g. insects, centipede, millipede, spider.
- **Gills (Branchial respiration):** E.g. fishes, tadpoles, prawn.
- **Lungs (Pulmonary respiration):** E.g. most vertebrates.

HUMAN RESPIRATORY SYSTEM

It consists of a pair of ***air passages (air tract)*** and ***lungs***.



1. Air passages

- ***Conducting part*** which transports the atmospheric air into the alveoli, clears it from foreign particles, humidifies and brings the air to body temperature.

External nostrils → nasal passage → nasal chamber (cavity) → pharynx → glottis → larynx → trachea → primary bronchi → secondary bronchi → tertiary bronchi → bronchioles → terminal bronchioles → respiratory bronchiole → alveolar duct.

- Each terminal bronchiole gives rise to many very thin and vascularised ***alveoli*** (in lungs).
- A cartilaginous ***Larynx*** (sound box or voice box) helps in sound production.
- During swallowing, ***epiglottis*** (a thin elastic cartilaginous flap) closes ***glottis*** to prevent entry of food into larynx.
- Trachea, all bronchi and initial bronchioles are supported by incomplete cartilaginous half rings.

2. Lungs

- Lungs situate in ***thoracic chamber*** and rest on ***diaphragm***.
- Right lung has 3 lobes and left lung has 2 lobes.
- Lungs are covered by double-layered ***pleura*** (outer **parietal pleura** and inner **visceral pleura).**
- The ***pleural fluid*** present in between these 2 layers lubricates the surface of the lungs and prevents friction between the membranes.
- ***Lungs= Bronchi + bronchioles + alveoli.***
- Alveoli and their ducts form the ***respiratory*** or ***exchange part*** of the respiratory system.
- ***Alveoli are the structural and functional units of lungs.***

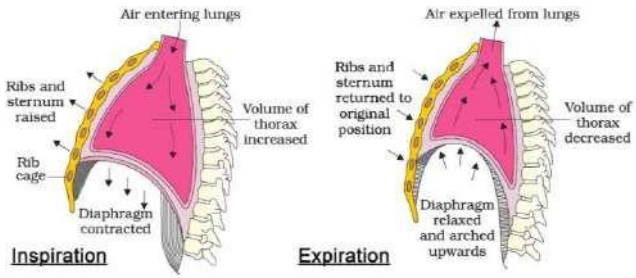
Steps of respiration

1. **Pulmonary ventilation (breathing).**
2. **Gas exchange between lung alveoli & blood.**
3. **Gas transport (O_2 transport & CO_2 transport).**
4. **Gas exchange between blood & tissues.**
5. **Cellular or tissue respiration.**

MECHANISM OF BREATHING (INSPIRATION & EXPIRATION)

a. Inspiration

- **Active** intake of air from atmosphere into lungs.
- During this, the **diaphragm contracts** (flattens) causing an increase in vertical thoracic volume *(antero-posterior axis).*
- Contraction of **external intercostal muscles** (muscles found between ribs) lifts up the ribs and sternum causing an increase in thoracic volume in the ***dorso-ventral axis***.
- Increase in thoracic volume reduces thoracic pressure. So, lungs expand. Thus, pulmonary volume increases resulting in decrease of ***intra-pulmonary pressure*** to less than the atmospheric pressure. So, air moves into lungs.



b. Expiration

- **Passive** expelling of air from the lungs.
- During this, ***intercostal muscles & diaphragm*** relax causing a decrease in thoracic volume and thereby pulmonary volume. So, air moves out.
- During **forceful expiration, abdominal muscles** and **internal inter-costal muscles contract.**

Respiratory volumes and capacities

- **Tidal volume (TV):** Volume of air inspired or expired during a normal respiration. It is about **500 ml.** i.e., **6000-8000 ml** per minute.
- **Inspiratory reserve volume (IRV) or complemental air:** Additional volume of air that can inspire by forceful inspiration. It is **2500-3000 ml.**
- **Expiratory reserve volume (ERV) or supplemental air:** Additional volume of air that can expire by a forceful expiration. It is **1000-1100 ml.**
- **Residual volume (RV):** Volume of air remaining in lungs after a forcible expiration. It is **1100-1200 ml.**

- **Inspiratory capacity (IC):** Total volume of air inspired after a normal expiration (TV + IRV). It is **3000-3500 ml.**
- **Expiratory capacity (EC):** Total volume of air expired after a normal inspiration (TV + ERV). It is **1500-1600 ml.**
- **Functional residual capacity (FRC):** Volume of air remaining in the lungs after a normal expiration (ERV + RV). It is **2100-2300 ml.**
- **Vital capacity (VC):** Volume of air that can breathe in after a forced expiration or Volume of air that can breathe out after a forced inspiration (ERV + TV + IRV). It is **3500-4500 ml.**
- **Total lung capacity (TLC):** Total volume of air in the lungs after a maximum inspiration. (RV + ERV + TV + IRV or VC + RV). It is **5000-6000 ml.**
- Part of respiratory tract (from nostrils to terminal bronchi) not involved in gaseous exchange is called ***dead space***. **Dead air volume** is about **150 ml.**

- ***Respiratory cycle=*** *an inspiration + an expiration*
- ***Normal respiratory (breathing) rate****: 12-16 times/min*
- ***Spirometer (respirometer):*** *To measure respiratory rate.*

GAS EXCHANGE

Gas exchange occurs between

1. Alveoli and blood **2. Blood and tissues**

Alveoli are the primary sites of gas exchange.

O_2 & CO_2 are exchanged by simple diffusion. It depends upon the following factors:

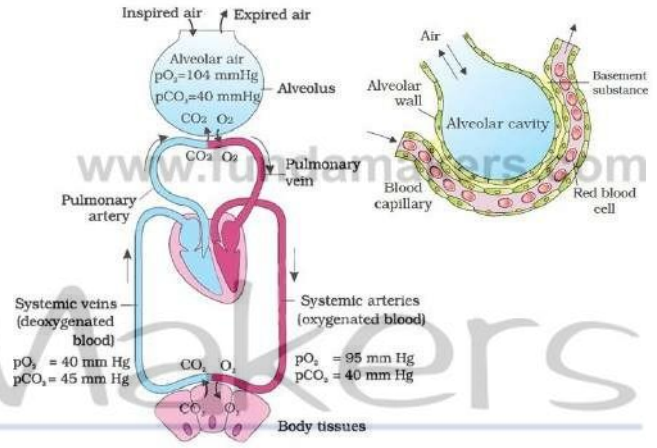
- **Pressure/ concentration gradient:** The ***Partial pressures*** (individual pressure of a gas in a gas mixture) of O_2 and CO_2 (pO_2 and pCO_2) are given below.

Respiratory gas	pO_2 (in mm Hg)	pCO_2 (in mm Hg)
Atmospheric air	159	0.3
Alveoli	104	40
Deoxygenated blood	40	45
Oxygenated blood	95	40
Tissues	40	45

pO_2 in **alveoli** is more **(104 mm Hg)** than that in **blood capillaries (40 mm Hg).** So O_2 diffuses into capillary blood. **pCO_2** in **deoxygenated blood** is more **(45 mm Hg)** than that in alveoli **(40 mm Hg).** So, CO_2 diffuses to alveoli.

- **Solubility of gases:** Solubility of CO_2 is 20-25 times higher than that of O_2. So, the amount of CO_2 that can diffuse through the diffusion membrane per unit difference in partial pressure is higher than that of O_2.
- **Thickness of membranes:** The diffusion membrane is made up of 3 layers:
  - **a) Squamous epithelium** of alveoli.
  - **b) Endothelium** of alveolar capillaries.
  - **c) Basement substance** between them.

  Its total thickness is only 0.5 µm. It enables easy gas exchange.
- **Surface area:** Presence of alveoli increases the surface area of lungs. It increases the gas exchange.



GAS TRANSPORT (O_2 TRANSPORT & CO_2 TRANSPORT)

It is the transport of respiratory gases (O_2 & CO_2) from alveoli to the systemic tissues and vice versa.

1. O_2 TRANSPORT

It is the transport of O_2 from lungs to various tissues.

It occurs in 2 ways:

a. In physical solution (blood plasma): About **3%** of O_2 is carried in a dissolved state through plasma.

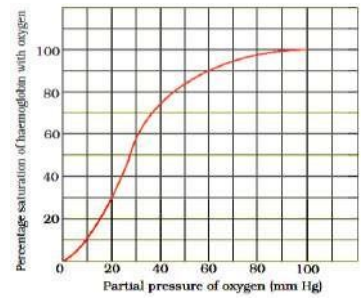
b. As oxyhaemoglobin: About **97%** of O_2 is transported by **haemoglobin** (red coloured iron containing pigment) on RBC. O_2 binds with haemoglobin (Hb) to form **oxyhaemoglobin.** This is called **oxygenation.** Hb has **4 haem units.** So, each Hb molecule can carry 4 oxygen molecules. Binding of O_2 depends upon pO_2, pCO_2, H^+ ion concentration (pH) and temperature.

$$Hb_4 + 4O_2 \underset{\text{Low } pO_2\text{/ High } pCO_2 \text{ (Tissues)}}{\overset{\text{High } pO_2\text{/ Low } pCO_2 \text{ (lungs)}}{\rightleftharpoons}} Hb_4O_8$$

- In the alveoli, high pO_2, low pCO_2, lesser H^+ ion concentration and lower temperature exist. These factors are favourable for the formation of oxyhaemoglobin.
- In tissues, low pO_2, high pCO_2, high H^+ ions and high temperature exist. So Hb_4O_8 dissociates to release O_2.
- Every 100 ml of oxygenated blood can deliver around 5 ml of O_2 to the tissues under normal physiological conditions.

Oxygen-haemoglobin dissociation curve

It is a sigmoid curve obtained when percentage saturation of Hb with O_2 is plotted against the pO_2. It is used to study the effect of factors like pCO_2, H^+ concentration etc., on binding of O_2 with Hb.



2. CO_2 TRANSPORT

It is the transport of CO_2 from tissues to lungs.

In tissues, pCO_2 is high due to catabolism and pO_2 is low. In lungs, pCO_2 is low and pO_2 is high. This favours CO_2 transport from tissues to lungs. It occurs in 3 ways:

a. **As carbonic acid:** In tissues, **7%** of CO_2 is dissolved in **plasma water** to form **carbonic acid** and carried to lungs.

b. **As carbamino-haemoglobin:** In tissues, **20-25%** of CO_2 binds to Hb to form **carbamino-haemoglobin**. In alveoli, CO_2 dissociates from carbamino-haemoglobin.

c. **As bicarbonates: 70%** of CO_2 transported by this method. RBCs contain an enzyme, *carbonic anhydrase*. (It is slightly present in plasma too).

At tissue site, it facilitates the following reactions:

$$CO_2 + H_2O \xleftrightarrow{\text{Carbonic anhydrase}} H_2CO_3 \xleftrightarrow{\text{Carbonic anhydrase}} HCO_3^- + H^+$$

In alveoli, the above reaction proceeds in opposite direction leading to the formation of CO_2 and H_2O.

Every **100 ml of deoxygenated blood** delivers about **4 ml of CO_2** to the alveoli.

REGULATION OF RESPIRATION

In brain, there are the following **Respiratory centres:**

- **Respiratory rhythm centre (Inspiratory & Expiratory centres):** In **medulla oblongata**. It regulates respiratory rhythms.
- **Pneumotaxic centre:** In **Pons**. It moderates functions of respiratory rhythm centre. Impulse from this centre reduces the duration of inspiration and thereby alter respiratory rate.
- **Chemosensitive area:** Seen adjacent to the rhythm centre. Increase in the concentration of CO_2 and H^+ activates this centre, which in turn signals rhythm centre. **Receptors** in **aortic arch** & **carotid artery** also recognize changes in CO_2 & H^+ concentration and send signals to rhythm centre. Role of oxygen in the regulation of respiratory rhythm is quite insignificant.

DISORDERS OF RESPIRATORY SYSTEM

1. **Asthma:** Difficulty in breathing causing wheezing due to inflammation of bronchi and bronchioles.
2. **Emphysema:** Damage of alveolar walls. It decreases respiratory surface. Major cause is cigarette smoking.
3. **Occupational respiratory disorders:** Certain industries produce so much dust. So, the defense mechanism of the body cannot cope with the situation. Long exposure causes inflammation leading to **fibrosis** (proliferation of fibrous tissues). It results in lung damage. Workers in such industries should wear protective masks.

BODY FLUIDS AND CIRCULATION

Circulation is the transport of nutrients, oxygen, CO_2 and excretory products to the concerned tissues or organs.
For circulation, simple organisms **(sponges**, **coelenterates etc.)** use water from their surroundings. Complex organisms use body fluids (**blood & lymph)** for circulation.

CIRCULATORY PATHWAYS

Circulatory system is 2 types- **Open** and **Closed.**

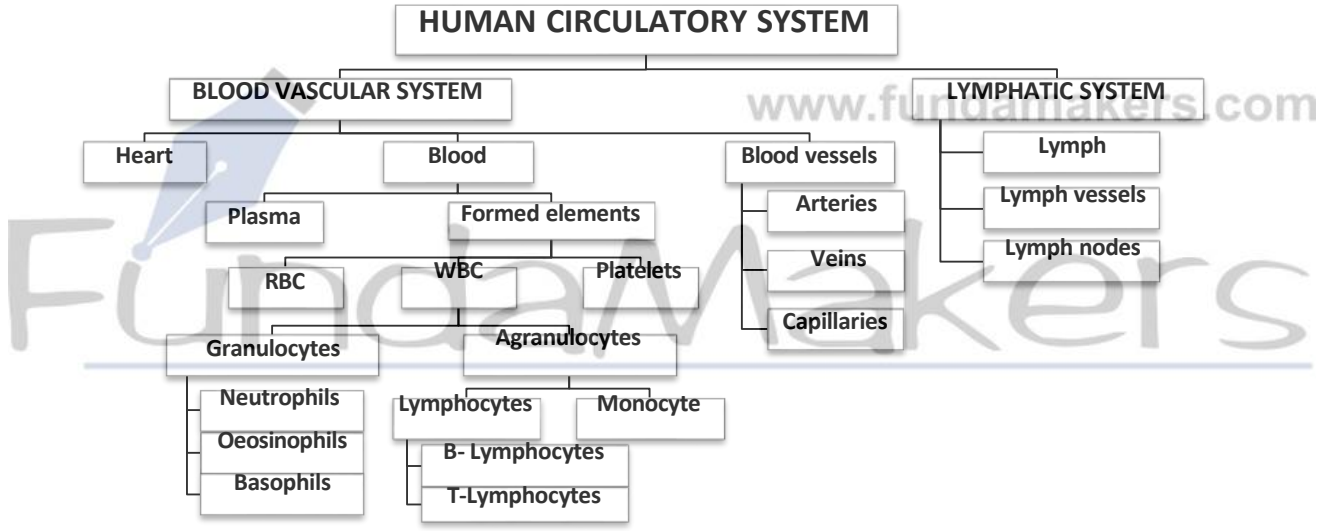
- **Open circulatory system:** Here, the blood pumped by the heart passes through large vessels into open spaces or cavities called **sinuses.** E.g. Arthropods and molluscs.
- **Closed circulatory system:** Here, the blood pumped by the heart is always circulated through blood vessels. This is more advantageous as the flow of fluid can be more precisely regulated. E.g. Annelids and chordates.

All vertebrates have a muscular chambered heart.

- ***Fishes:*** *2-chambered heart (an atrium + a ventricle).*
- ***Amphibians:*** *3-chambered heart (2 atria + a ventricle).*
- ***Reptiles (except crocodiles):*** *3-chambered heart (2 atria + a ventricle). Ventricle is incompletely partitioned.*
- ***Crocodiles, birds & mammals:*** *4-chambered heart.*

Types of circulation

- **Single circulation:** In **fishes**. In this, heart receives impure blood only ***(venous heart).***
  Deoxygenated blood → to heart → to gills → oxygenated blood → to body parts → deoxygenated blood → to heart.
- **Incomplete double circulation:** In amphibians & reptiles. In this, left atrium gets oxygenated blood from gills/ lungs/skin and right atrium gets deoxygenated blood from other body parts. However, they get mixed up in the single ventricle. It pumps out mixed blood.
- **Double circulation:** In birds & mammals. Right atrium gets deoxygenated blood and passes to right ventricle and left atrium gets oxygenated blood and passes to left ventricle. The ventricles pump it out separately without any mixing up.



BLOOD VASCULAR SYSTEM

It includes Heart, Blood & Blood vessels.

1. BLOOD

Formed of **plasma** (55%) & **formed elements** (45%).

A. PLASMA

Straw-coloured, slightly alkaline (pH 7.4) viscous fluid.

Constituents of plasma

- **Water (90-92%):** It is a good solvent.
- **Plasma proteins (6-8 %):** Include
  - **Fibrinogen:** For blood coagulation.
  - **Globulins:** Act as antibodies (for defense of the body).
  - **Albumins:** For osmotic balance. Regulate blood pressure.
- **Glucose, amino acids, lipids & cholesterol.**
- **Inorganic constituents:** Na^+, Ca^{2+}, Mg^{2+}, Cl^-, HCO_3^- etc.
- **Gases** like CO_2, O_2, N_2 etc.

Plasma without clotting factors is known as ***Serum.***

B. FORMED ELEMENTS (RBC, WBC & PLATELETS)

Red Blood Cells (RBC) or Erythrocytes:

- Biconcave non-nucleated cells. No mitochondria, Golgi complex etc. Red colour is due to **Haemoglobin** (iron containing protein). Normal Hb level is 12-16 g/ 100 ml.
- **Count:** 5 - 5.5 millions/ mm^3.
- **Formed in:** Red Bone marrow.
- **Average lifespan:** 120 days. Worn-out RBCs are destroyed in **spleen** (graveyard of RBCs).
- **Function:** CO_2 and O_2 transports.

White Blood Cells (WBC) or Leucocytes:

- Colourless nucleated cells.
- **Count:** 6000-8000 /mm^3.
- **Formed in:** Bone marrow, lymph glands, spleen.
- **Average lifespan:** Generally short lived (1- 15 days).
- **Function:** Part of immune system.

Types of WBC: Granulocytes & Agranulocytes

1. Granulocytes

They are 3 types:

a. **Neutrophils (Heterophils):** 60-65%. Soldier of the body. Function: Phagocytosis.
b. **Eosinophils (Acidophils):** 2-3%. Resist infections. Cause allergic reactions.
c. **Basophils (Cyanophils):** 0.5-1%. Secrete histamine, serotonin, heparin etc. Cause inflammatory reactions.

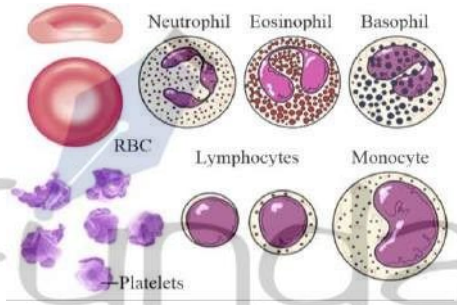
2. Agranulocytes

They are 2 types:

a. **Lymphocytes** (20-25%): Smallest WBC with largest nucleus. Includes **B- lymphocytes & T- lymphocytes.** Cause immune responses. Secrete antibodies.
b. **Monocytes** (6-8%): Largest WBC. Function: Phagocytosis.

Platelets (Thrombocytes):

- Colourless non-nucleated cell fragments.
- **Count:** 1.5 - 3.5 lakhs /mm^3.
- **Formed in:** Megakaryocytes in Bone marrow.
- **Average lifespan:** 7 days.
- **Function:** Blood clotting.



BLOOD COAGULATION

It is a mechanism for **haemostasis** (prevention of blood loss through injuries). At the site of injury, following events occur:

Clumped **platelets & tissues** release ***thromboplastin*** → It forms ***thrombokinase (Prothrombinase)*** enzyme → ***Thrombokinase*** hydrolyses ***prothrombin*** to ***thrombin*** enzyme in presence of Ca^{2+} → ***Thrombin*** converts soluble ***fibrinogen*** to insoluble ***fibrin*** → ***Fibrin*** threads trap dead & damaged blood cells to form ***clot (coagulum).***

BLOOD GROUPS

Blood groups were discovered by **Carl Land Steiner**.

1. ABO grouping

It is based on presence or absence of 2 surface **antigens** (chemicals that induce immune response) on **RBCs** namely **A** & **B**. Similarly, **plasma** contains 2 **antibodies** (proteins produced in response to antigens) namely **anti-A** & **anti-B.**

Blood group	Antigens	Antibodies	Can donate blood to	Can receive blood from (Donor's group)
A	A	Anti-B	A & AB	A, O
B	B	Anti-A	B & AB	B, O
AB	A, B	Nil	AB only	A, B, AB & O
O	Nil	Anti-A & Anti-B	A, B, AB & O	O only

- Antigen A reacts with anti-A. Antigen B reacts with anti-B.
- If bloods with interactive antigens & antibodies are mixed together, it causes **clumping** (**agglutination**) of RBCs**.**
- Persons with **O Group** are called **Universal donors** because they can donate blood to persons with any other blood group. Persons with **AB group** are called **Universal recipients** because they can accept blood from all groups.

2. Rh grouping

- **Rhesus (Rh) factor** is another antigen found on RBC.
- **Rh+ve** means the presence of Rh factor and **Rh-ve** means absence of Rh factor. Nearly **80%** of humans are Rh+ve.
- **Anti-Rh antibodies** are not naturally found. So Rh-ve person can receive Rh+ve blood only once but it causes the development of anti-Rh antibodies in his blood. So, a second transfusion of Rh+ve blood causes ***agglutination.*** Therefore, Rh-group should be matched before transfusion.

Erythroblastosis foetalis

- It is a **Rh incompatibility** between the Rh-ve blood of a pregnant mother and Rh+ve blood of the foetus.
- Rh antigens do not get mixed with maternal blood in first pregnancy because placenta separates the two bloods.
- But during first delivery, the maternal blood may be exposed to small amount of foetal blood (Rh+ve). This induces the formation of Rh antibodies in maternal blood.
- In case of her subsequent pregnancies, the Rh antibodies from the mother leak into the foetal blood (Rh+ve) and destroy the foetal RBCs. This is fatal to the foetus or cause severe ***anaemia*** and ***jaundice*** to the baby. This condition is called ***Erythroblastosis foetalis.***
- It can be avoided by administering **anti-Rh antibodies** to the mother immediately after the first delivery.

2. BLOOD VESSELS

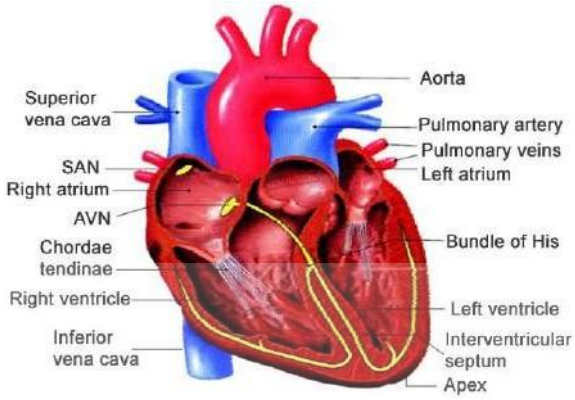
Blood vessels are 3 types: Arteries, Veins & Capillaries.

- **Arteries:** They carry blood from heart to other tissues. They contain oxygenated blood (except pulmonary artery). Their smaller branches are called **arterioles.** Arteries are 3-layered- inner **tunica intima** (squamous endothelium), middle **tunica media** (smooth muscles & elastic fibres) and outer **tunica externa** (fibrous connective tissue).
- **Veins:** They carry blood towards heart. They contain deoxygenated blood (except pulmonary vein). Their smaller branches are called **venules.** Veins are also 3-layered but tunica media is comparatively thin.
- **Capillaries:** In tissues, arterioles divide into thin walled and single layered vessels. They are called capillaries. They unite into venules.

3. HEART

- It is a mesodermally derived organ located in ***mediastinum.***
- It has the size of a clenched fist.
- It is protected by double-layered***pericardium.***
- The ***pericardial space*** (between pericardial membranes) is filled with ***pericardial fluid***. It reduces the friction between the heart walls and surrounding tissues.
- Heart has 4 chambers- two upper ***atria (auricles)*** and two lower ***ventricles***.

- The walls ***(cardiac muscles)*** of the ***ventricles*** are much **thicker** than that of the atria.



- The atria are separated by an ***inter-atrial septum*** and the ventricles are separated by ***inter-ventricular septum.***
- In between atrium and ventricle, there is a thick fibrous ***atrio-ventricular septum*** with an opening.
- A ***tricuspid valve*** (3 muscular flaps or cusps) guards the opening between right atrium & right ventricle. A ***bicuspid (mitral) valve*** guards the opening between left atrium and left ventricle. These valves allow the flow of blood only in one direction, i.e. from atria to ventricles.
- Right ventricle has an opening to ***pulmonary artery*** and left ventricle has an opening to ***aorta.*** These openings have ***semi-lunar valves.*** They prevent backward flow of blood.

CONDUCTING SYSTEM OF HEART

- It includes **nodal tissues, bundles & fibres.**
- ***Nodal tissues*** are specialized cardiac musculature present in heart wall. They are 2 types:
  - ***Sino-atrial node (SAN)*** in the right upper corner of the right atrium.
  - ***Atrio-ventricular node (AVN)*** in the lower left corner of the right atrium close to the ***atrio-ventricularseptum***.
- From the AVN, a bundle of fibrous ***atrio-ventricular bundle (AV bundle)*** passes through ***atrio-ventricular septa*** and divides into right & left branches. Each branch passes through the ventricular walls of its side. In the ventricular wall, it breaks up into minute fibres ***(Purkinje fibres).*** These fibres along with the bundles are known as ***bundle of His.***
- ***Nodal tissues*** generate **action potential** without any external stimuli, i.e. it is **autoexcitable. SAN** initiates and maintains contraction of heart by generating action potentials **(70-75/min).** So, it is called the ***pacemaker.***

CARDIAC CYCLE

It is the cyclic contraction and relaxation of heart for pumping blood. It involves 3 stages:

1. **Joint diastole:** It is the relaxed state of all chambers of heart. When the **tricuspid** and **bicuspid valves** open, blood from **pulmonary vein** and **vena cava** flows into **left** & **right ventricles** respectively through **left** and **right atria. Semilunar valves** are **closed** at this stage.
2. **Atrial (Auricular) systole: SAN** generates an **action potential.** As a result, both the atria contract. It is called *atrial systole.* This increases the flow of blood into the ventricles by about **30%.**
3. **Ventricular systole:** The action potential is conducted to ventricular side by **AVN** & **AV bundle** from where **bundle of His** transmits it through the ***ventricular musculature.*** As a result, ventricles contract. It is called *ventricular systole.* During this, the atria undergo diastole. Ventricular systole increases the **ventricular pressure** causing
   * Closure of **tricuspid** and **bicuspid valves** due to attempted backflow of blood into the atria.
   * Semilunar valves open. So deoxygenated blood enters the ***pulmonary artery*** from ***right ventricle*** and oxygenated blood enters the ***aorta*** from ***left ventricle.***

The ventricles now relax *(ventricular diastole)* and the **ventricular pressure** falls causing

* The closure of the ***semilunar valves*** which prevents the backflow of blood into the ventricles.
* The ***tricuspid*** and ***bicuspid valves*** are opened by the pressure in the atria.

The ventricles and atria again undergo joint diastole and the above processes are repeated.

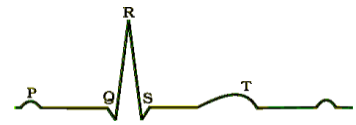
A cardiac cycle is completed in **0.8 seconds.**

- **One heartbeat = a cardiac cycle.**
  So, normal heartbeat: **70-75 times/min (average: 72/min).**
- **Stroke volume:** It is the volume of blood pumped out by each ventricle during a cardiac cycle. It is about **70 ml.**
- **Cardiac output:** It is the volume of blood pumped out by each ventricle per minute, i.e. **stroke volume x heart rate (70 x 72).** It is about **5000 ml (5 litres).**
  Cardiac output of an athlete is very high.
- **Heart sounds:** During each cardiac cycle, 2 sounds are produced. The first sound **(lub)** is due to the closure of *tricuspid* and *bicuspid valves.* The second sound **(dub)** is due to the closure of the *semilunar valves.*

One heartbeat = a lub + a dub.

ELECTROCARDIOGRAPH (ECG)

- It is an instrument used to obtain ***electrocardiogram.***
- Electrocardiogram is the *graphical representation* of the *electrical activity* of the heart during a cardiac cycle.
- To get an ECG, a patient is connected to the machine with 3 ***electrical leads*** (one to each wrist and to left ankle) that monitor heart activity. For a detailed evaluation of heart's function, multiple leads are attached to the chest region.
- An ECG consists of the following waves:
  - **P-wave:** Represents the excitation ***(depolarization)*** of atria during ***atrial systole.***
  - **QRS-complex:** Represents ***depolarization*** of ventricles during ***Ventricular systole.***
  - **T-wave:** Represents the ***repolarisation*** of ***ventricles.***



Deviation in the **ECG** indicates the abnormality or disease. So, ECG has great clinical significance.

DOUBLE CIRCULATION

It is the circulation in which blood flows through the heart twice for completing its circuit.

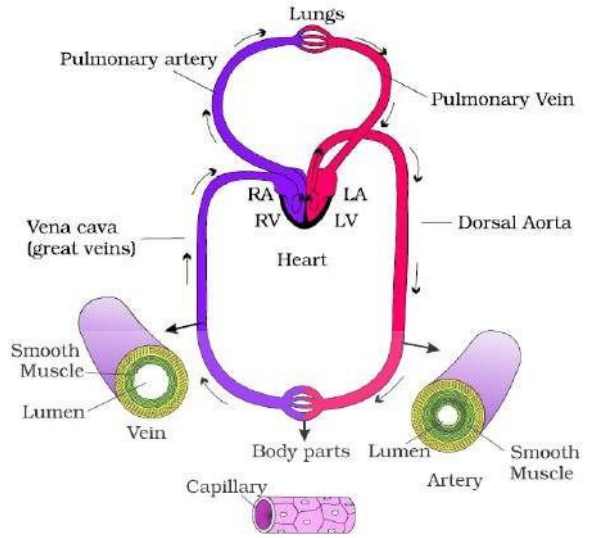
It includes:

1. **Pulmonary circulation:** Circulation b/w lungs and heart. ***Deoxygenated blood*** from right ventricle → to**pulmonary artery** → to **lungs** → ***oxygenated blood*** → to **pulmonary veins** → **left atrium.**
2. **Systemic circulation:** Circulation b/w heart and various body parts.

   Oxygenated blood from left ventricle → to **aorta** → **arteries** → **arterioles** → **capillaries** → **tissues** → ***deoxygenated blood*** from tissues → **venules** → **veins** → **vena cava** → to **right atrium.**

   Systemic circulation provides nutrients, O_2 and other substances to the tissues and takes CO_2 and other harmful substances away for elimination.

- **Hepatic portal system:** It is a system which includes the ***hepatic portal vein*** that carries blood from ***intestine*** to the ***liver*** before it is delivered to the systemic circulation.
- **Coronary circulatory system:** It is a system of ***coronary vessels*** that circulate blood to and from ***cardiac musculature.***



REGULATION OF CARDIAC ACTIVITY

- Normal activities of heart are auto-regulated by ***nodal tissues.*** So, it is called **myogenic heart.**
- ***Medulla oblongata*** regulates cardiac activity through **ANS.**
- ***Sympathetic nerves*** of ANS increase the rate of heartbeat, the strength of ventricular contraction and cardiac output.
- ***Parasympathetic nerves*** of ANS decrease the heartbeat, conduction of action potential and the cardiac output.
- ***Adrenal medullary hormones*** increase the cardiac output.

LYMPHATIC SYSTEM

- Includes ***Lymph, Lymph vessels & Lymph nodes (glands).***
- As the blood passes through the capillaries in tissues, some water and soluble substances are filtered out from plasma to the intercellular spaces, to form **tissue (interstitial) fluid.** It has same mineral distribution as that in plasma.
- Some tissue fluid enters **lymphatic system** and the tissue fluid in them is called **lymph**. It drains back to major veins.
- Lymph is a colourless fluid containing lymphocytes.

Functions of lymph

- It is the middleman between blood & tissues. Tissue fluid helps to exchange nutrients, gases, etc. b/w blood and cells.
- It carries plasma proteins synthesized in liver to the blood.
- Transports digested fats (through lacteals in the intestinal villi), fat soluble vitamins, hormones etc.
- Filtration of bacteria and foreign particles.
- Lymph nodes produce WBC (lymphocytes) & antibodies.

DISORDERS OF CIRCULATORY SYSTEM

- **Hypertension (High Blood Pressure):** The pressure of circulating blood on the walls of blood vessels is called **blood pressure.** Normal BP is **120/80 mm Hg.** It includes ***systolic (pumping) pressure*** (120 mm Hg) and ***diastolic (resting) pressure*** (80 mm Hg).

  When the BP is higher than normal, it is called **hypertension.** If an individual repeatedly has the BP of **140/90 or above,** it shows ***hypertension.*** It leads to ***heart diseases*** and affects ***vital organs*** (brain, kidney etc).
- **Coronary Artery Disease (CAD) or Atherosclerosis:** Here, **Ca, fat, cholesterol** and **fibrous tissue** are deposited in **coronary arteries.** So the lumen of arteries becomes narrower and thereby affects the blood supply.
- **Angina (angina pectoris):** An ***acute chest pain*** due to ***O_2 deficiency*** to heart muscles. It occurs due to improper blood flow. It is common among middle-aged and elderly.
- **Heart Failure (congestive heart failure):** It is the inability of heart to pump blood enough to meet the needs of the body. Congestion of the lungs is the main symptom.
- **Cardiac arrest:** Heart stops beating.
- **Heart attack:** Sudden damage of heart muscle due to inadequate blood supply.

EXCRETORY PRODUCTS & THEIR ELIMINATION

Excretion is the elimination of metabolic wastes like **ammonia, urea, uric acid** etc. from the tissues.

Types of excretion

1. **Ammonotelism:** Process of excretion of **NH_3.**
   Ammonotelic animals: Aquatic invertebrates, aquatic insects, bony fishes, aquatic amphibians etc.
   NH_3 is highly toxic. So, excretion needs excess of water.
   NH_3 is readily soluble in water and is excreted by diffusion through body surface or gill surfaces (in fishes) as ammonium ions.
   Kidneys do not play any significant role in its removal.
2. **Ureotelism:** Process of excretion of **urea.**
   Ureotelic animals: Cartilaginous fishes, terrestrial & semi-aquatic amphibians (frogs, toads etc.), aquatic & semi-aquatic reptiles (alligators, turtles), mammals etc.
   In liver, NH_3 is converted into less toxic urea. So, it needs only moderate quantity of water for excretion.
   Some amount of urea may be retained in the kidney matrix of some animals to maintain a desired osmolarity.
3. **Uricotelism:** Process of excretion of **uric acid.** It is water insoluble & less toxic. So, water is not needed for excretion.
   Uricotelic animals: Insects, some land crustaceans, land snails, terrestrial reptiles & birds.

Ureotelism & uricotelism are needed for water conservation.

Some excretory organs in animals

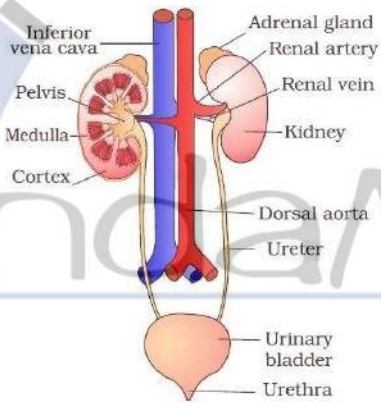
- **Protonephridia (flame cells):** In Flatworms, rotifers, some annelids & cephalochordate (*Amphioxus*). Protonephridia are primarily for osmoregulation.
- **Nephridia:** In Annelids. Help in the removal of nitrogenous wastes and osmoregulation.
- **Malpighian tubules:** In Insects. Help in the removal of nitrogenous wastes and osmoregulation.
- **Antennal or green glands:** In Crustaceans (prawn etc.)
- **Kidneys:** In higher animals.

HUMAN EXCRETORY SYSTEM

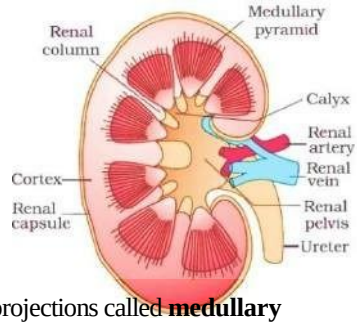
It includes **kidneys, ureters, urinary bladder** & **urethra.**

Structure of Kidney

- Reddish brown, bean-shaped structures situated between the levels of last thoracic & 3rd lumbar vertebra.
- Length: **10-12 cm,** width: **5-7 cm,** thickness: **2-3 cm.** Average weight: **120-170 gm.**



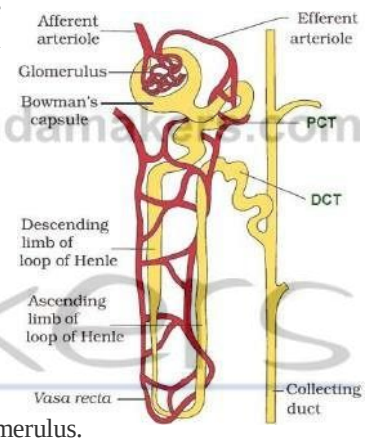
- It is enclosed in a tough, 3-layered **fibrous renal capsule.**
- On the concave side of kidney, there is an opening (**hilum** or **hilus**) through which blood vessels, nerves, lymphatic ducts and ureter enter the kidney.
- Hilum leads to funnel shaped cavity called **renal pelvis** with projections called **calyces.**
- A kidney has outer **cortex** & inner **medulla.**



- Medulla has few conical projections called **medullary pyramids (renal pyramids)** projecting into the calyces.
- Cortex extends in between the medullary pyramids as renal columns **(Columns of Bertini).**
- Each kidney has nearly one million tubular **nephrons**.

Nephron

- Nephrons are the structural & functional units ofkidney.
- Each nephron has 2 parts: **Glomerulus** & **Renal tubule.**



- **Glomerulus:** A tuft of capillaries formed by **afferent arteriole** (a fine branch of renal artery). Blood from glomerulus is carried away by **efferent arteriole.**
- **Renal tubule:** It begins with a double walled cup-like **Bowman's capsule**, which encloses the glomerulus.

Glomerulus + Bowman's capsule = Malpighian body

- The tubule continues with **proximal convoluted tubule (PCT), Henle's loop** & **distal convoluted tubule (DCT).**
- Henle's loop is hairpin-shaped. It has **descending and ascending limbs.**
- The DCTs of many nephrons open into a **collecting duct**. Collecting duct extends from cortex to inner parts of medulla. They converge and open into the **renal pelvis** through **medullary pyramids** in the **calyces.**
- **Malpighian body (Renal corpuscle), PCT** and **DCT** are situated in **renal cortex. Loop of Henle** dips into **medulla.**
- The **efferent arteriole** forms a fine capillary network **(peritubular capillaries)** around the renal tubule. A minute vessel of this network runs parallel to Henle's loop forming a 'U' shaped **vasa recta**.

Types of nephrons

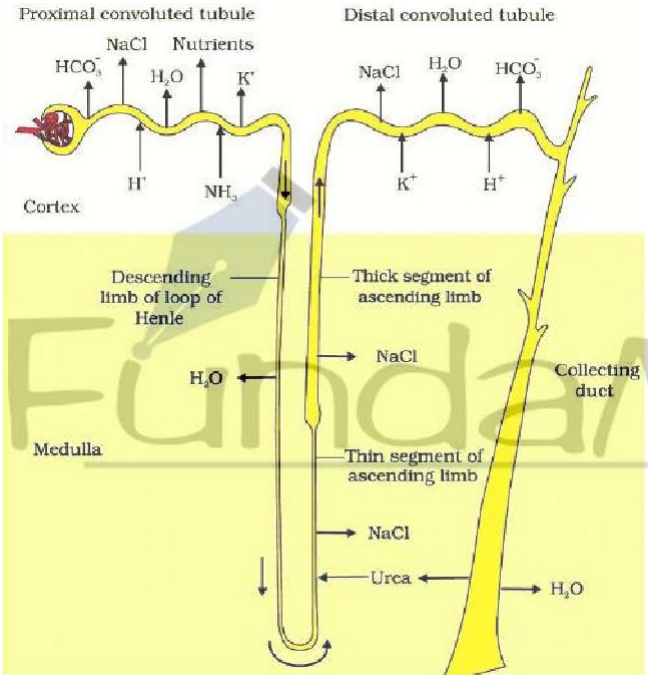
1. **Cortical nephrons** (85%): In this, the Henle's loop is short and extends only very little into the medulla. Vasa recta is absent or highly reduced.
2. **Juxtamedullary nephrons** (15%): In this, Henle's loop is long and runs deep into medulla. Vasa recta present.

URINE FORMATION (PHYSIOLOGY OF KIDNEY)

3 processes: Glomerular filtration, reabsorption & secretion.

1. Glomerular filtration (ultrafiltration)

- The glomerular capillary blood pressure causes filtration of blood through 3 layers, i.e. **endothelium of glomerular blood vessels**, **epithelium of Bowman's capsule** & **a basement membrane** between these 2 layers.
- The epithelial cells **(podocytes)** of the Bowman's capsule are arranged in an intricate manner leaving some minute spaces called **filtration slits (slit pores).**
- Almost all constituents of the blood plasma except the proteins pass onto the lumen of the Bowman's capsule.
- About **1100-1200 ml of blood** is filtered by the kidneys per minute. It constitutes **1/5th** of the blood pumped out by each ventricle of the heart in a minute.
- The amount of glomerular filtrate formed per minute is called **Glomerular filtration rate (GFR).**
- **Normal GFR = 125 ml/minute, i.e., 180 litres/day.**



2. Reabsorption

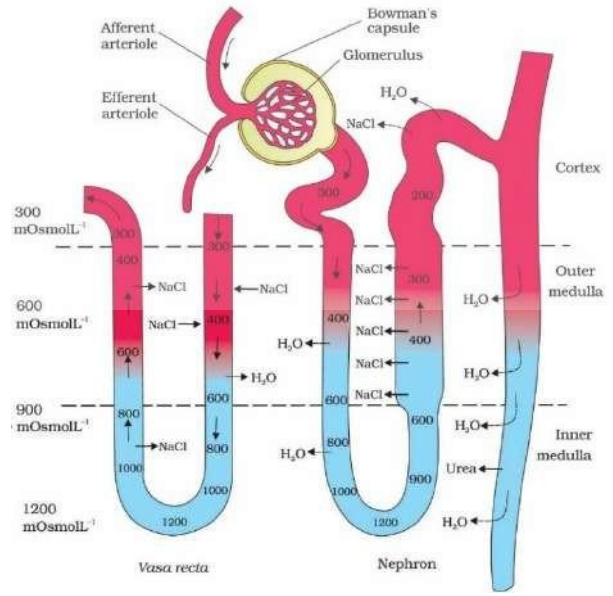
- **180 litres** of glomerular filtrate is produced daily. But about **99%** of this is reabsorbed by the renal tubules.
  So normal volume of urine released is **1.5 litres.**
- From the filtrate, **glucose, amino acids, Na^+,** etc. are reabsorbed **actively** and **nitrogenous wastes** are absorbed **passively**. Passive reabsorption of water occurs in the initial segments of the nephron.
- **PCT** reabsorbs most of the nutrients, and 70-80% of electrolytes & water. Simple cuboidal brush border epithelium of PCT increases surface area forreabsorption.
- **Loop of Henle** maintains high osmolarity of medullary interstitial fluid.
  Descending limb is permeable to water but almost impermeable to electrolytes. This concentrates the filtrate.
  In **ascending limb,** minimum reabsorption occurs. It is impermeable to water but allows transport of electrolytes.
  So, filtrate gets diluted.
- In **DCT,** conditional reabsorption of Na^+ & water takes place.
- **Collecting duct** extends from cortex to inner parts of medulla. It reabsorbs large amount of water to concentrate urine. It also allows passage of small amounts of urea into medullary interstitium to keep up the osmolarity.

3. Tubular Secretion

- Cells of **PCT** & **DCT** maintain **ionic** (Na-K balance) and **acid-base balance (pH)** of body fluids by selective secretion of H^+, K^+ & NH_3 into the filtrate and absorption of HCO_3^- from it.
- **Collecting duct** also maintains pH and ionic balance of blood by the secretion of H^+ and K^+ ions.

Mechanism of concentration of the filtrate

- **Henle's loop** & **vasa recta** help to concentrate the urine.
- The flow of **filtrate** in the 2 **limbs of Henle's loop** and the flow of **blood** through the 2 **limbs of vasa recta** are in opposite directions (counter current pattern). This is called **Counter current mechanism.**
- Due to the counter current and proximity between Henle's loop & vasa recta, **osmolarity** increases from cortex **(300 $mOsmolL^{-1}$)** to the **inner medullary interstitium (1200 $mOsmolL^{-1}$).** This gradient is caused by **NaCl** & **urea.**
- NaCl is transported by ascending limb of Henle's loop that is exchanged with descending limb of vasa recta. NaCl is returned to interstitium by ascending limb of vasa recta. Similarly, small amount of urea enters the thin segment of the ascending limb of Henle's loop which is transported back to the interstitium by the collecting tubule. Thus electrolytes and urea are retained in the interstitium and maintain a **concentration gradient (interstitial gradient)** in medullary interstitium. It enables easy passage of water from collecting tubule to concentrate the filtrate (urine).
- Thus DCT & collecting duct produce urine **four times concentrated** than the initial filtrate formed (i.e. 300 $mOsmolL^{-1}$ to 1200$mOsmolL^{-1}$).



MICTURITION

- Gradual filling of urinary bladder causes stretching. As a result, **stretch receptors** on its wall send impulses to CNS. The CNS passes on **motor messages.** It causes the contraction of **smooth muscles** of the bladder and simultaneous relaxation of the **urethral sphincter.** It results in **micturition** (release of urine).
- The neural mechanism causing micturition is called **micturition reflex.**
- An adult human excretes **1 to 1.5 litres** of urine (**25-30 gm urea)** per day.
- Urine is a **light yellow coloured watery fluid**, slightly **acidic (pH-6.0)** and has a characteristic odour.
- Various conditions affect the characteristics of urine.
- Analysis of urine helps in **clinical diagnosis** of many metabolic disorders and malfunctioning of the kidney.

E.g. **Glycosuria** (presence of glucose) and **Ketonuria** (ketone bodies) in urine indicates **diabetes mellitus.**

Role of Lungs, liver & skin in Excretion

- **Lungs:** Remove CO_2 **(200 mL/minute)** and **water.**
- **Liver:** Secretes bile containing **bilirubin, biliverdin, cholesterol, degraded steroid hormones, vitamins** and **drugs.** Most of them pass out along with digestive wastes.
- **Skin (Sweat glands** & **sebaceous glands): Sweat** contains water, NaCl, small amounts of urea, lactic acid, etc. Primary function of sweat is to give a **cooling effect** on body surface.

  Sebaceous glands eliminate **sterols, hydrocarbons, waxes etc.** through **sebum.** Sebum provides a protective oily covering for the skin.
- **Saliva** eliminates small amounts of nitrogenous wastes.

REGULATION OF THE KIDNEY FUNCTION

- It is done by hormonal feedback mechanisms involving the **hypothalamus, JGA** and the **heart.**
- Changes in **blood volume, body fluid volume** and **ionic concentration** activate **Osmoreceptors** in the body.

1. Regulation by ADH (vasopressin)

- When body fluid level decreases, the **osmoreceptors** stimulate **hypothalamus** to release **antidiuretic hormone (ADH)**. It stimulates water reabsorption from **DCT** & **collecting duct**. Thus, ADH prevents **diuresis** and increases body fluid volume.
- Increase in fluid volume switches off the osmoreceptors and suppresses ADH release to complete the feedback.
- ADH constricts blood vessels resulting in an increase of BP. This increases the glomerular blood flow and GFR.

2. Regulation by JGA (Renin-Angiotensin mechanism)

- **JGA (Juxta glomerular apparatus)** is a sensitive region formed by cellular modification of **DCT** and the **afferent arteriole** at the location of their contact.
- JGA regulates the **GFR.**
- A fall in glomerular blood flow/glomerular blood pressure/GFR activates the **JG cells** to release **renin.**
- Renin converts **angiotensinogen** in blood to **angiotensin I** and further to **angiotensin II** (a **vasoconstrictor**).
- Angiotensin II performs the following functions:
  - ❖ Increases glomerular blood pressure and thereby GFR.
  - ❖ Activates **adrenal cortex** to release **Aldosterone.**
- Aldosterone causes **reabsorption** of Na^+ and **water** from the **distal parts** of the tubule. This also leads to an increase in blood pressure and GFR.

3. Regulation by ANF

- ANF check on the renin- angiotensin mechanism.
- An increase in blood flow to the atria of the heart causes the release of **Atrial Natriuretic Factor (ANF).**
- ANF causes **vasodilation** (dilation of blood vessels) and thereby decreases the blood pressure.

DISORDERS OF EXCRETORY SYSTEM

- **Uremia**: Accumulation of urea in blood due to malfunction of kidney. It may lead to **kidney failure (renal failure).**
- **Renal calculi:** Stone or insoluble mass of crystallized salts (oxalates, etc.) formed within the kidney.
- **Glomerulonephritis:** Inflammation of glomeruli.

Hemodialysis

- It is a process of removal of **urea** in patients withuremia.
- The **dialyzing unit** (artificial kidney) contains a coiled **cellophane tube** surrounded by **dialyzing fluid.** It has same composition of plasma except nitrogenous wastes.
- Blood drained from a convenient artery is pumped into **dialyzing unit** after adding anticoagulant like **heparin.**
- The porous **cellophane membrane** of the tube allows the passage of molecules based on concentration gradient.
- As nitrogenous wastes are absent in dialyzing fluid, these substances freely move out, thereby clearing the blood.
- The purified blood is pumped back to the body through a vein after adding **anti-heparin** to it.

Kidney transplantation

- It is the ultimate method in the correction of **acute renal failures.** A functioning kidney is taken from a donor.
- It is better to receive kidney from a close relative to minimize chances of rejection by immune system of host.

LOCOMOTION AND MOVEMENT

Locomotion is the voluntary movements resulting in a in location. All locomotion are movements but all movements are not locomotion. Both are interlinked. E.g.

- In *Paramoecium*, cilia help in the movement of food through cytopharynx and in locomotion.
- *Hydra* use tentacles to capture prey and for locomotion.
- Limbs help to change body postures and for locomotion.

Types of movement in human being

- **Amoeboid movement:** By **pseudopodia** formed by streaming of protoplasm as in *Amoeba*. Cytoskeletal elements like microfilaments also help for this. E.g. change Macrophages & leucocytes.
- **Ciliary movement:** By **cilia.** E.g. ciliary movements in trachea (to remove dust particles and foreign substances), and oviducts (for the passage of ova).
- **Muscular movement:** By muscles. E.g. movement of limbs.

Flagellar movement helps in the swimming of spermatozoa, maintenance of water current in the canal system of sponges and in locomotion of Protozoans like *Euglena.*

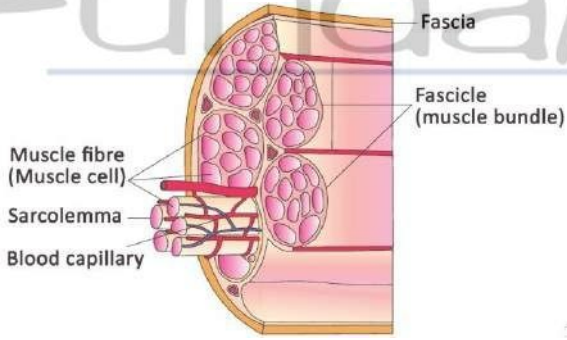
HUMAN MUSCULAR SYSTEM

- It includes muscles which are mesodermal in origin.
- Muscles constitute 40-50% of the body weight.
- Muscles have excitability, contractility, extensibility & elasticity.
- Based on location, muscles are 3 types:

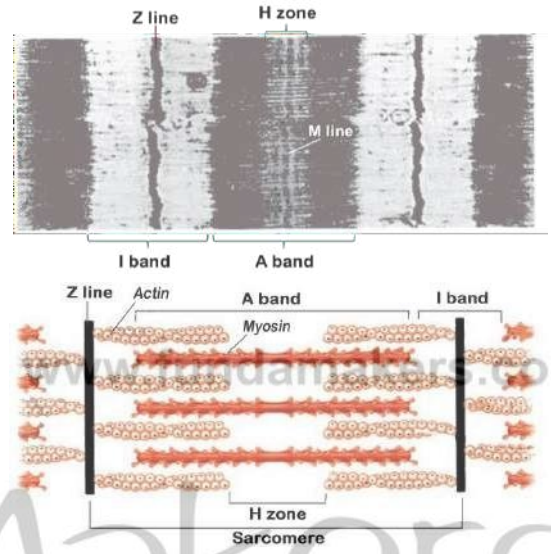
Skeletal (striated) muscles	Visceral (Non-striated) muscles	Cardiac muscles
Attached to skeleton	In visceral organs	In heart wall
Striations present	Absent	Present
Voluntary	Involuntary	Involuntary
Rich blood supply	Poor blood supply	Rich blood supply
Fatigue muscle	Non-fatigue	Non-fatigue
Multinucleate	Uninucleate	Uninucleate
More mitochondria	Less mitochondria	More mitochondria

STRUCTURE OF STRIATED MUSCLE

- Skeletal muscle is made of **muscle bundles (fascicles)** held together by collagenous connective tissue layer **(fascia).**

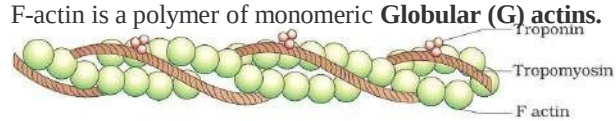


- Each fascicle contains many **muscle fibres (muscle cells).**
- Muscle fibres are lined by **plasma membrane (sarcolemma)** enclosing the **sarcoplasm.**
- Each muscle fibre contains **myofilaments (myofibrils).**
- Each myofibril has alternate **dark (Anisotropic or A-band)** and **light striations (Isotropic or I-band)**. This is due to the presence of 2 fibrous contractile proteins- thin **Actin filament** and thick **Myosin filament**.
- I-bands contain actin. A-bands contain actin and myosin. They are arranged parallel to each other.
- A-band bears a lighter middle region **(H band)** formed of only myosin. A thin dark line (**M-line**) runs through the centre of **H-zone**.
- I-band is bisected by a dense dark band called **Z-line**. Region between two Z-lines is called **sarcomere.** They are the *functional units of muscle contraction.*

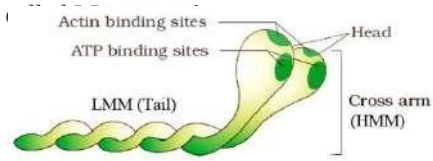


Structure of contractile proteins

- An **actin filament** is made of **2 filamentous (F) actins** which form double helix.
- F-actin is a polymer of monomeric **Globular (G) actins.**



- Actin contains 2 other proteins **(tropomyosin & troponin).**
- Two filaments of **tropomyosin** run along the grooves of the F-actin double helix.
- **Troponin** has 3 subunits. It is seen at regular intervals on tropomyosin. In the resting state, **a subunit of troponin** masks the binding sites for myosin on the actin filaments.
- Each myosin filament is a polymer of many **monomeric proteins**



- A meromyosin has 2 parts:
  - **Heavy meromyosin or HMM or cross arm (globular head + short arm)**: It projects outwards.
  - **Light meromyosin or LMM (tail).**
- The globular head is an active ***ATPase*** **enzyme** and has **binding sites for ATP** and **active sites for actin.**

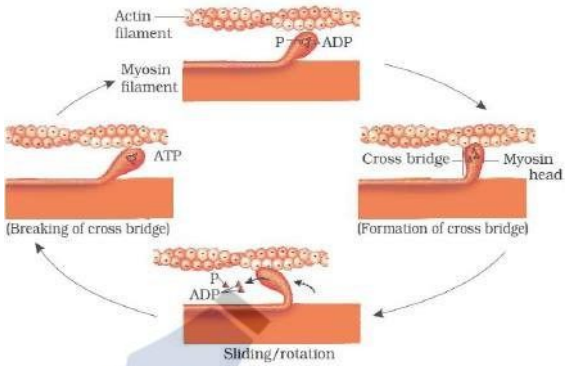
MECHANISM OF MUSCLE CONTRACTION

According to **sliding filament theory,** *contraction of a muscle fibre occurs by the sliding of thin filaments over thick filaments.* The steps are given below:

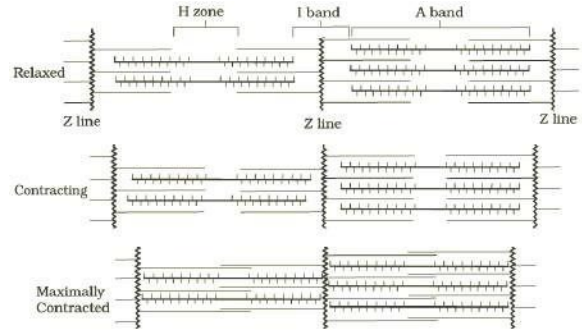
- An **impulse** from the **CNS** reaches the **neuromuscular junction (Motor-end plate)** via **motor neuron**.

> **Neuromuscular junction** is the synapse between a motor neuron and the sarcolemma of the muscle fibre.
> **A motor neuron + muscle fibres = a motor unit.**

- Synaptic vesicles release a neurotransmitter **Acetylcholine.** It generates an **action potential** in the sarcolemma that spreads through the muscle fibre. It causes the release of **Ca^{2+} ions** from sarcoplasmic cisternae into **sarcoplasm.**
- **Ca** binds with a subunit of **troponin** on actin filaments and unmask the active sites for myosin.



- Using energy from **ATP hydrolysis, myosin head** binds to **active sites** on the actin to form **cross bridge.** This pulls actin filaments on both sides towards the centre of **A-band.** Actin filaments partially overlap so that H-zone disappears.
- The **Z- line** attached to actins is also pulled inwards. It causes a shortening **(contraction)** of **sarcomere.**
- I-bands get shortened, whereas A-bands retain the length.
- Myosin releases **ADP** and **Pi** and goes back to its relaxed state. A new ATP binds and the cross-bridge is broken.
- The ATP is again hydrolyzed by the myosin head and the above processes are repeated causing further sliding.
- When Ca^{2+} ions are pumped back to sarcoplasmic cisternae, actin filaments are again masked. As a result, Z-lines return to their original position. It results in **relaxation.**



- The reaction time of the fibres varies in different muscles.
- Repeated activation of muscles leads to the accumulation of the **lactic acid** causing **muscle fatigue**. This is due to **anaerobic breakdown** of **glycogen** in muscles.

Red muscle fibres and white muscle fibres

Red (Aerobic) muscles	White muscle
Red coloured due to myoglobin	White coloured due to lesser myoglobin
More mitochondria	Less mitochondria
Aerobic metabolism	Anaerobic metabolism
Slow & sustained contraction	Fast contraction for short period

HUMAN SKELETAL SYSTEM

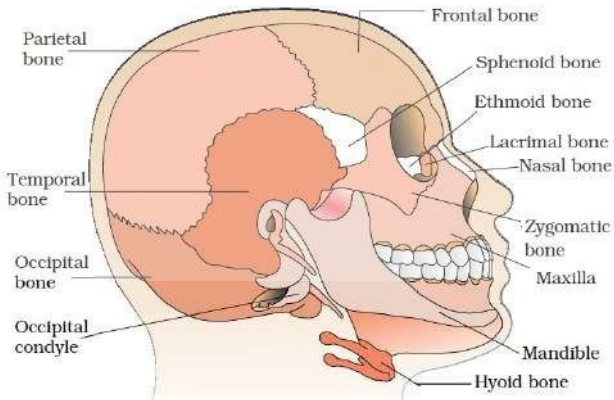
It consists of a framework of **bones (206)** & **few cartilages**. Human skeletal system has 2 parts: **axial & appendicular.**

1. Axial skeletal system (80 bones)

Includes **bones of head, vertebral column, sternum & ribs.**

a. Bones of Head (29 bones)

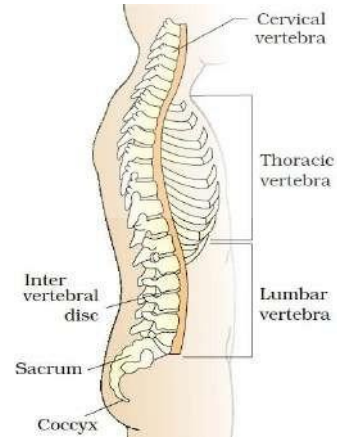
It includes skull, Hyoid and Ear ossicles.



- **Skull (22):** Include cranial bones and facial bones.
  Cranial bones (8): Include *Frontal (1), Parietals (2), Temporals (2), Occipital (1), Sphenoid (1) &Ethmoid (1).*
  Facial bones (14): Include *Nasals (2), Maxillae (2), Zygomatics (2), Lacrimals (2), Palatines (2), Inferior nasals (2), Mandible (1) and Vomer (1).*
  Skull articulates with ***First vertebra (atlas)*** with the help of 2 ***occipital condyles (dicondylic skull).***
- **Hyoid bone (1):** U-shaped bone seen below buccal cavity.
- **Ear ossicles (3 x 2 = 6):** *Malleus (2), Incus (2) & stapes (2).*

b. Vertebral column

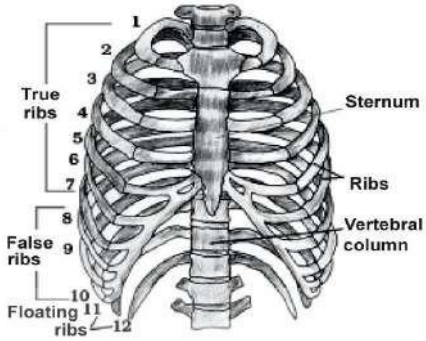
- Formed of **26 vertebrae.** Includes *Cervical vertebrae (7), Thoracic vertebrae (12), Lumbar vertebrae (5), Sacral vertebrae (1-fused) and Coccygeal vertebrae (1-fused).*
- Vertebra has a central hollow portion ***(neural canal)*** through which the ***spinal cord*** passes.
- Number of cervical vertebrae are 7 in almost all mammals.
- The ***vertebral column*** protects the spinal cord, supports the head and serves as the point of attachment for the ribs and musculature of the back.



c. Sternum or Breast bone (1)

- Flat bone on the ventral midline of thorax.

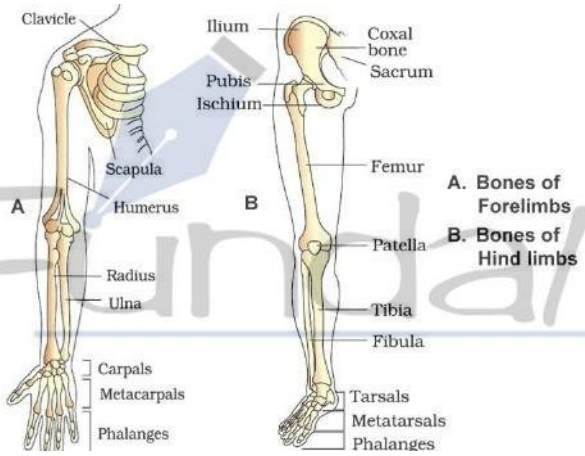
d. Ribs (12 pairs)



- **True ribs** (first 7 pairs): They are attached to ***thoracic vertebrae*** and ventrally connected to sternum with the help of ***Hyaline cartilage.***
- **Vertebrochondral (false) ribs** (8th, 9th & 10th pairs): They do not articulate directly with the sternum but join the ***7th rib*** with the help of ***Hyaline cartilage.***
- **Floating ribs** (11th & 12th pairs): They are not connected ventrally (no connection with sternum or other ribs).

- Each rib has 2 articulation surfaces on its dorsal end and is hence called **bicephalic.**

2. Appendicular skeletal system (126 bones)



a. Bones of fore-limbs (30 x 2 = 60)

Include *Humerus (1), Radius (1), Ulna (1), Carpals (wrist bones-8), Metacarpals (palm bones-5) & Phalanges (digits-14).*

b. Bones of hind-limbs (30 x 2 = 60)

Include *Femur (thigh bone- 1), Patella (knee cap- 1), Tibia (1) & fibula (1), Tarsals (ankle bones-7), Metatarsals (5) & Phalanges (digits-14).*

c. Pectoral girdles (2x2=4)

- Include **clavicle (2) & scapula (2).**
- Scapula is a large *triangular* flat bone situated in the dorsal part of the thorax between ***the second and 7th ribs.***
- **Scapula (shoulder blade)** has a slightly elevated ridge ***(spine)*** which projects as a flat, expanded process ***(acromion).*** The ***clavicle*** **(collarbone)** articulates with this.
- Below the acromion is ***glenoid cavity*** which articulates with the head of ***humerus*** to form the ***shoulder joint.***

d. Pelvic girdles (2)

- Formed of 2 coxal bones. Each coxal bone is formed by the fusion of 3 bones- *Ilium, Ischium & pubis.*
- At the point of fusion of ***Ilium, Ischium*** and ***Pubis*** is a cavity ***(Acetabulum)*** to which the ***thigh bone*** articulates.
- The 2 halves of the ***pelvic girdle*** meet ventrally to form ***pubic symphisis*** containing ***fibrous cartilage.***

JOINTS

Joints are points of contact between bones, or between bones and cartilages. 3 types:

1. **Fibrous (immovable) joints:** E.g. sutures b/w skull bones.
2. **Cartilaginous joints (Slightly movable joints):** Bones are joined together with the help of cartilages. E.g. Joints between the adjacent vertebrae.
3. **Synovial (movable) joints:** They have a fluid filled synovial cavity between articulating surfaces of 2 bones.

Types of synovial joint

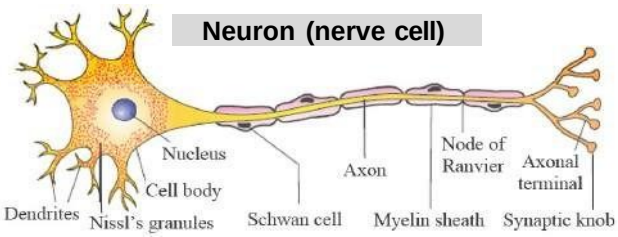
Joint	Examples
Ball & socket	Shoulder joint & hip joints.
Hinge joint	Knee joint, elbow joint, phalanges joints
Pivot joint	Joints b/w atlas & axis.
Gliding joint	Joints b/w carpals
Saddle joint	Joints b/w carpal & metacarpal of thumb

DISORDERS OF MUSCULAR & SKELETAL SYSTEMS

- **Myasthenia gravis:** An auto immune disorder that affects neuromuscular junction. It leads to fatigue, weakening and paralysis of skeletal muscles.
- **Muscular dystrophy:** Progressive degeneration of skeletal muscles. Mostly due to genetic disorder.
- **Tetany:** Rapid muscle spasm due to low Ca^{2+} in body fluid.
- **Arthritis:** Inflammation of joints.
- **Osteoporosis:** Age-related disorder characterized by decreased bone mass and increased chances of fractures. Decreased level of estrogen is a common cause.
- **Gout:** Inflammation of joints due to accumulation of uric acid crystals.

NEURAL CONTROL AND CO-ORDINATION

- Neural (Nervous) system is a system that controls and coordinates the body activities, conducts and integrates the information and responds to stimuli.
- It includes **brain, spinal cord** and **nerves.**
- It is made up of specialized cells known as **neurons.**



Neuron is the **structural** and **functional unit** of neural system. It is composed of

- **Cell body (cyton):** Contains cytoplasm, cell organelles and **Nissl's granules** (granular bodies).
- **Dendron:** Short fibres projecting from the cyton. Their sub branches **(dendrites)** transmit impulses towards the cyton.
- **Axon:** A long fibre which transmit impulses away from the cell body. The branching of axon is called **axonite.** Each axonite ends as a bulb-like structure called **synaptic knob**.

Types of Neurons

- **Unipolar:** One axon. No Dendron. Found in embryo.
- **Bipolar:** One axon and one dendron. Found in the retina.
- **Multipolar:** One axon and 2 or more dendrons. Most common type. Found in the CNS & PNS.

Types of axon

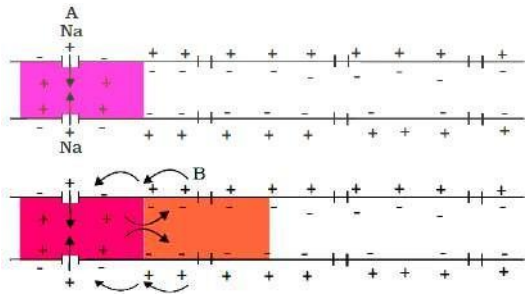
- **Myelinated axon:** It is enveloped with **Schwann cells** that form a **myelin sheath** around the axon. Found in **spinal** & **cranial nerves**. The white coloured area, formed of myelinated nerve fibres is called **white matter**. Gaps b/w 2 adjacent myelin sheaths are called **nodes of Ranvier**.
- **Non-myelinated axon:** Schwann cells present but no myelin sheath. The gray coloured area without myelin sheath is called **gray matter**. Found in **autonomous & somatic neural systems**.

GENERATION & CONDUCTION OF NERVE IMPULSES

Impulse transmission is ***electrochemical.*** It has 3 steps:

1. Maintenance of resting membrane potential

- Neural membrane contains various selectively permeable ion channels.
- In a resting neuron (neuron not conducting impulse), the axonal membrane is more permeable to K^+ ions and nearly impermeable to Na^+ ions. Also, the membrane is impermeable to negatively charged proteins in axoplasm.
- Therefore, concentration of K^+ and –vely charged proteins in axoplasm is high and concentration of Na^+ is low.
- The fluid outside the axon contains low concentration of K^+ and high concentration of Na^+. This forms an ionic or concentration gradient across resting membrane.
- The ionic gradients are maintained by the active transport of ions by the **Na-K pump.** It transports **3 Na^+** outwards for 2 K^+ into the cell. As a result, the outer surface becomes positively charged and inner surface becomes negatively charged (i.e, polarized).
- The electrical potential difference across the resting plasma membrane is called as the **resting potential**.



2. Action Potential

- When a stimulus is applied, the membrane at the site A becomes permeable to Na^+. This causes rapid influx of Na^+ and reversal of the polarity at that site (outer negative and inner positive). It is called **depolarization.**
- The electrical potential difference during depolarization across the plasma membrane is called **action potential** (a **nerve impulse)**.

3. Propagation of action potential

- At sites ahead (site B), outer surface is positive and inner surface is negative. As a result, a current flows on the inner surface from site A to site B.
- On the outer surface, current flows from site B to site A to complete the circuit. Hence, the polarity is reversed and action potential is generated at site B. i.e., action potential at site A arrives at site B.
- The sequence is repeated along the axon and the impulse is conducted.
- The rise in permeability to Na^+ is extremely short lived. It is quickly followed by a rise in permeability to K^+.
- Immediately, K^+ diffuses outside the membrane and restores the resting membrane. Thus the fibre becomes ready for further stimulation.

Synaptic transmission of impulses

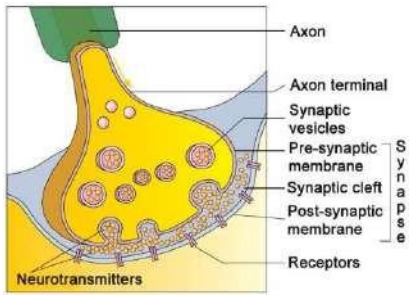
- Synapse is a functional junction between two neurons.
- It is 2 types: **Electrical & Chemical.**

1. Electrical synapses

- In this, the membranes of pre- and post-synaptic neurons are in close proximity. So impulse transmission is similar to the transmission along an axon.
- Impulse transmission is faster than in chemical synapse.
- Electrical synapses are very rare in human system.

2. Chemical synapses

- In this, there is a fluid filled space **(synaptic cleft**) between the presynaptic neuron and postsynaptic neuron.
- The presynaptic regions have swellings called **Synaptic knob (buttons).** They contain **synaptic vesicles** filled with **neurotransmitters (acetylcholine or adrenaline).**



Impulse transmission through chemical synapse:

Impulse reaches at axon terminal → synaptic vesicles bind on plasma membrane → release of neurotransmitter → It diffuses across synaptic cleft → combine with receptors on the post synaptic membrane → opening of ion channels allowing entry of ions → generates action potential.

- This action potential may be excitatory or inhibitory.

HUMAN NERVOUS (NEURAL) SYSTEM

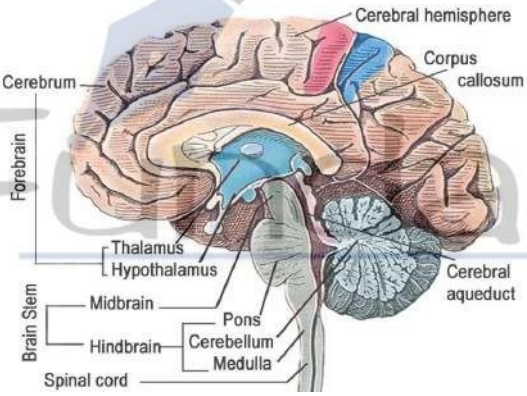
It has 2 parts:

- **Central neural system (CNS):** Brain & spinal cord.
- **Peripheral nervous system (PNS):** All nerves.

CENTRAL NEURAL SYSTEM (CNS)

A. BRAIN

- It is protected in ***cranial cavity***.
- It has 3-layered connective tissue membranes called ***cranial meninges***.
- Meninges consist of outer ***dura mater***, middle ***arachnoid mater*** and inner ***pia mater***.
- The ***subarachnoid space*** (space between pia mater and arachnoid mater) is filled with **cerebrospinal fluid (CSF).** The **ventricles** of brain are also filled with CSF.
- Brain has 3 divisions: Forebrain, Midbrain & Hindbrain.



a. Forebrain (Prosencephalon)

It is the anterior part. Consists of ***cerebrum*** & ***diencephalon.***

Cerebrum

- Largest part. It has 2 **cerebral hemispheres** held together by a tract of nerve fibres **(Corpus callosum).**
- Outer part of cerebrum is called **cerebral cortex.** It has convulsions & depressions and is formed of **gray matter**. Gray colour is due to the presence of neuron cell bodies.
- Inner part of cerebrum is formed of **white matter.**
- Cerebral cortex consists of
  - **Motor area:** Controls voluntary movements of muscles.
  - **Sensory (Somaesthetic) area:** Controls the functioning of sense organs.
  - **Association area:** It is neither clearly sensory nor motor in function. Responsible for intersensory associations, memory and communication.

Integrated activities of different centres of cerebral cortex control intelligence, memory, judgment, learning, thinking and articulate speech.

Diencephalon (Thalamus & Hypothalamus)

- **Thalamus:** It is the structure around which the cerebrum wraps. It is a coordinating centre (relay station) for sensory and motor impulses.
- **Hypothalamus:** Seen below the thalamus. It
  a. Regulates temperature, thirst, hunger and emotions.
  b. Secretes hypothalamic hormones.
  c. Controls pituitary gland.
  d. Controls sleep, wakefulness, blood pressure, heart rate.
- The inner parts of cerebral hemispheres and a group of associated deep structures like ***amygdala***, ***hippocampus,*** ***hypothalamus,*** etc. together constitute ***Limbic system (Limbic lobe).*** It regulates sexual behavior, motivations, emotions (excitement, pleasure, rage, fear etc).

b. Midbrain (Mesencephalon)

- It is located between ***thalamus/hypothalamus*** and ***Pons***.
- A canal ***(cerebral aqueduct)*** passes through the mid brain.
- Mid brain consists of 4 round lobes called ***Corpora quadrigemina***. Their anterior pair is the centre of *visual reflexes* and the posterior pair is a centre of *auditory reflex*.

c. Hindbrain (Rhombencephalon)

It consists of **cerebellum**, **Pons** & **Medulla oblongata.**
Midbrain & hindbrain form the **Brain stem.**

- **Cerebellum ("little cerebrum"):** It has very convoluted surface to accommodate more neurons. It co-ordinates muscular activities and body equilibrium.
- **Pons varoli:** It consists of fibre tracts that interconnect different regions of the brain. It co-ordinates the activities of eye and ear and regulates respiration.
- **Medulla oblongata:** It is connected to spinal cord. It controls respiration, cardiovascular reflexes, gastric secretions, peristalsis etc. It also controls salivation, vomiting, sneezing & coughing.

B. SPINAL CORD

- It is enclosed within the spinal canal of vertebral column.
- It is also protected by meninges.
- Spinal cord has a central canal containing CSF.
- Outer white matter and inner gray matter.

Functions:

a. Conduction of impulses to and from the brain.
b. Centre of spinal reflexes.

PERIPHERAL NEURAL SYSTEM (PNS)

It includes **cranial nerves** and **spinal nerves.**
Nerve fibres of PNS are 2 types:

- **Afferent (sensory) fibres:** Carry impulses from sense organs to CNS.
- **Efferent (motor) fibres:** Carry impulses from CNS to muscles and glands.

PNS has 2 divisions. They are

- **Somatic neural system:** Relays impulses from the CNS to skeletal muscles.
- **Autonomic neural system (ANS):** Transmits impulses from CNS to involuntary organs & smooth muscles. It includes ***sympathetic*** & ***parasympathetic*** nerves. Sympathetic system prepares body to cope with emergencies, stresses & dangers. It increases heartbeat, breathing rate, constricts arteries and elevates BP. Parasympathetic system returns the body to a resting state after stressful situations and slows down heartbeat, dilates arteries, lowers BP etc.

Visceral nervous system is the part of PNS. It includes **nerves, fibres, ganglia & plexus** by which impulses travel from CNS to the viscera and from viscera to CNS.

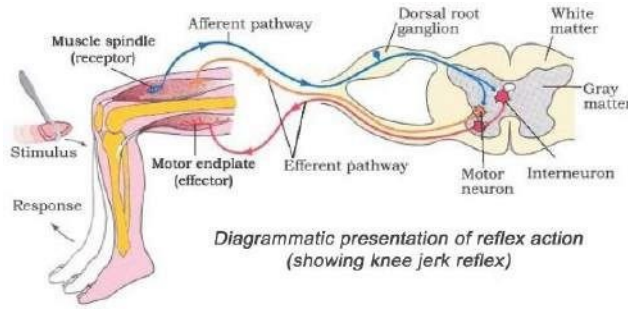
REFLEX ACTION

It is the ***rapid, involuntary*** and ***unconscious actions*** of body in response to a stimulus. E.g.

- Withdrawal of the hand when it touches a hot object.
- Touching lips of a nursing baby evokes sucking reflex.
- Closing of the eyelids when light falls on them.
- Knee jerk phenomenon.
- If a child sees or smells a food unknown to him, he does not salivate. But if he sees or smells that food every time before tasting it, he salivates **(conditioned reflex).**

The pathway of impulses in a reflex action is called **Reflex arc**. It consists of

- A ***receptor organ:*** It receives the stimulus.
- ***Sensory (afferent) neuron:*** It transmits impulses from sense organ to CNS.
- ***Intermediate (connector) neuron***: It connects sensory and motor neurons.
- ***Motor (efferent/effector/excitor) neuron:*** It conducts impulse from the CNS to effector organ.
- An ***effector organ*** (muscle/gland): It responds to impulse.



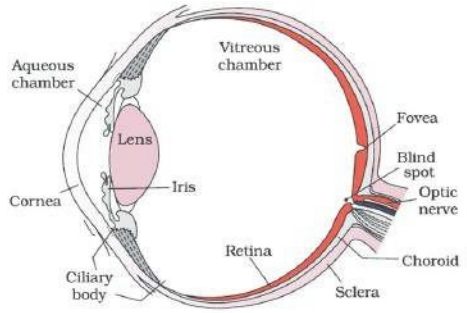
Diagrammatic presentation of reflex action (showing knee jerk reflex)

SENSORY RECEPTION & PROCESSING (SENSE ORGANS)

- These are the organs that detect the changes in the environment and convey the information to the CNS.
- It includes **eye, ear, nose, tongue & skin.**

EYE

- Two eyes are located in sockets of the skull called **orbits**.
- The adult human eyeball is nearly spherical.
- Eyeball has three layers: **Sclera, Choroid & Retina.**



a. Sclera

- The external layer formed of a dense connective tissue.
- Anterior transparent portion of sclera is called **cornea**.

b. Choroid

- Bluish middle layer. Contains many blood vessels.
- Choroid is thin over posterior two-thirds of the eyeball, but it is thick in the anterior part to form **ciliary body**.
- Ciliary body continues forward to form a visible pigmented and opaque portion of the eye called the **iris.**
- Iris has a central opening called **pupil.** The diameter of the pupil is regulated by the muscle fibres of iris. This helps to regulate the amount of light entering the eye.
- The eyeball contains a transparent crystalline **lens.** It is held in place by **ligaments** attached to the ciliary body.

c. Retina

- Inner layer. It contains 3 layers of cells – from inner to outer – **ganglion cells, bipolar cells & photoreceptor cells.**
- Photoreceptor cells are 2 types: **rods** and **cones**. They contain ***photosensitive proteins (photopigments).***
- Photopigments are formed of ***opsin*** (a protein) and ***retinal*** (an aldehyde of vitamin A).

Cone cells:

- **Function: Daylight (photopic)** vision & colour vision.
- There are 3 types of cones containing photopigments **(photopsin)** that respond to red, green and blue lights.
- The sensations of different colours are produced by combinations of these cones and their photopigments.
- When the cones are stimulated equally, a sensation of white light is produced.

Rod cells:

- **Function: Twilight (scotopic) vision.**
- They contain a purplish-red protein called **rhodopsin** (visual purple). It contains a derivative of **Vitamin A.**
- At the region, slightly above the posterior pole of the eyeball, **optic nerves** leave the eye and retinal blood vessels enter it. Here, photoreceptor cells are absent. It is called **blind spot**.
- Lateral to the blind spot, there is a yellowish pigmented spot called **macula lutea** with a central pit **(fovea)**.
- The fovea is a thinned-out portion of the retina where only the cones are densely packed. It is the point of greatest visual acuity (resolution).
- The space between the cornea and lens is called **aqueous chamber.** It contains **aqueous humor** (thin watery fluid).

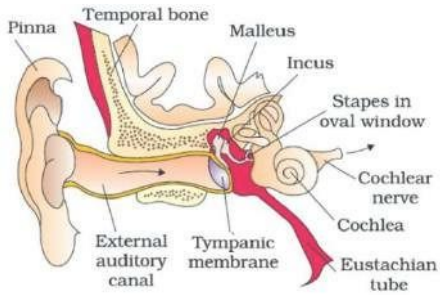
- The space between the lens and retina is called **vitreous chamber.** It contains **vitreous humor** (a transparent gel).

Mechanism of vision

Light reflected from an object → enters the eye through cornea & lens → focus on retina → dissociation of **retinal** from **opsin** → changes in **membrane permeability** → generates potential differences (impulse) in photoreceptor cells → generates action potentials in ganglion cells through bipolar cells → impulses are transmitted by **optic nerves** to brain (**visual cortex)** → impulses are analyzed and the image is recognized based on memory and experience → vision.

EAR (STATO-ACOUSTIC ORGAN)

- It is the organ for hearing & balancing.
- It has 3 divisions: **External ear, middle ear** & **inner ear.**



External ear

- Consists of ***pinna (ear lobe)*** & ***auditory meatus (ear canal).***
- At the opening of ear canal, hairs are seen.
- Ear canal and skin of pinna contains **ceruminous glands** (modified sweat glands). They secrete **wax (cerumen)**.
- Wax and hairs protects ears from foreign objects.
- Ear canal ends in **tympanic membrane (Tympanum** or **ear drum).** It is a semi-transparent membrane covered by a thin layer of skin on its outer surface and by mucous membrane on the inside.

Middle ear

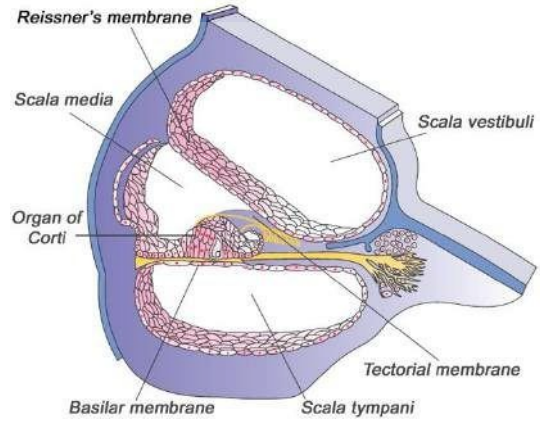
- Consists of **tympanic cavity** and **ear ossicles.**
- Tympanic cavity is an air filled space that separates the external and inner ear portions.
- An **auditory tube (Eustachian canal)** connects middle ear to the pharynx. It maintains an equal pressure on either side of the eardrum.
- **Ear ossicles** include 3 small bones namely **Malleus, Incus** and **stapes.** Malleus is attached to tympanum.
- **Stapes** is the **smallest bone** of the body. It is attached to membrane of **oval window (fenestra ovalis)** of inner ear.

Inner ear

- It consists of **bony labyrinth** & **membranous labyrinth**.
- Bony labyrinth is a cavity filled with **perilymph.**
- The membranous labyrinth consists of **cochlea** and **Vestibular apparatus.**

Cochlea (organ of hearing):

- It is a coiled structure having 3 canals - upper **scala vestibula,** middle **scala media** and lower **scala tympani.**
- Scala vestibula & scala media are separated by **Reissner's membrane.**
- Scala media and scala tympani are separated by **basilar membrane**.
- S. vestibula & S. tympani are filled with **perilymph** and scala media is filled with **endolymph**.
- Resting on the basilar membrane and projecting into scala media is complex receptor organ called **Organ of Corti**. It consists of row of **sensory hair cells**. The hairs (stereo cilia) of these cells project upwards and lie in contact with **tectorial membrane**, which projects above them.



Vestibular apparatus:

- It consists of 3 **semicircular canals** and **otolith organ.**
- 2 semicircular canals are vertical and one is horizontal. One end of each canal has a bulging called **ampulla.** Inside it is a lump called **crista ampullaris.** Long cilia of cells of crista are grouped together in a bundle **(cupula).**
- **Otolith organ** consists of **utricle** and **saccule.**
- Utricle & Saccule have a projecting ridge called **macula.**
- **Crista** and **Macula** are specific receptors in vestibular apparatus. They contain **sensory hair cells.** They are responsible **equilibrium & posture** of body.

Mechanism of hearing

Pinna collects sound waves → waves reach the **tympanic membrane** via ear canal → tympanic membrane vibrates → vibrations transmit to **ear ossicles** & **oval window** → **perilymph** in the **vestibular canal** vibrates → vibrations reach the **scala tympani** and force the **basilar membrane** to vibrate → hair endings of **sensory hair cells** press against **tectorial membrane** → sensory hair cells are excited → **auditory nerve** carries impulses to **auditory centre** of the brain → hearing.

NOSE

- Organ of **smell (olfaction).**
- It contains mucus-coated receptors **(olfactory receptors)** made up of **olfactory epithelium.** They receive sense of smell. It contains 3 kinds of cells.
- The neurons of olfactory epithelium extend from the outside environment directly into a pair of broad bean-sized organs, called **olfactory bulb.** These are extensions of the brain's limbic system.

TONGUE

- Organ of **taste (gustation).**
- 4 primary tastes are **sweet, salt, sour** and **bitter.**

- **Taste buds (Gustatoreceptors + supporting cells)** are seen around the bases of **taste papillae.**

Nose & tongue are **chemoreceptors** (detect dissolved chemicals). Senses of taste & smell are functionally similar and interrelated. The brain integrates different input from taste buds and a complex flavour is perceived.

SKIN (Cutaneous receptors)

- Largest sense organ.
- It contains receptors for **heat, cold, touch, pain** & **pressure.**

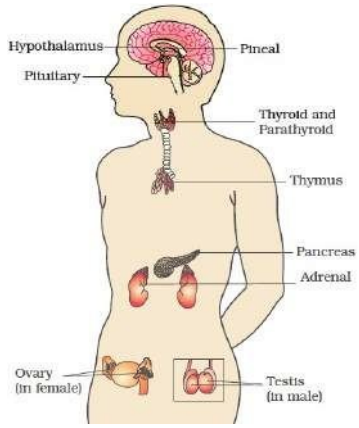
CHEMICAL CO-ORDINATION AND INTEGRATION

Endocrine system includes **endocrine (ductless) glands** and their secretions **(hormones).**
Hormones are **non-nutrient** chemicals that act as **intercellular messengers** and are produced in trace amounts.

HUMAN ENDOCRINE GLANDS

They include

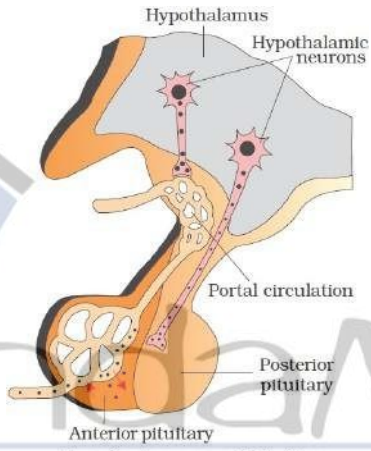
1. **Hypothalamus**
2. **Pituitary**
3. **Pineal**
4. **Thyroid**
5. **Parathyroid**
6. **Thymus**
7. **Adrenals**
8. **Pancreas (Islets of Langerhans)**
9. **Gonads (Testis & Ovary)**



1. HYPOTHALAMUS

Neurosecretory cells (nuclei) of hypothalamus secrete the following types of hormones:

- **Releasing hormones:** Stimulate secretion of **pituitary hormones.** **E.g. gonadotropin releasing hormone (GnRH)** stimulates pituitary to release **gonadotropins (FSH & LH).**
- **Inhibiting hormones:** Inhibit secretion of **pituitary hormones.** E.g. **Somatostatin** inhibits release of growth hormone from pituitary.
- **Oxytocin & vasopressin:** These are transported axonally and stored in pituitary. *(See pituitary gland).*



Hypothalamus and Pituitary

2. PITUITARY GLAND

- It is located in a bony cavity called **sella tursica.**
- It is attached to **hypothalamus** bya stalk.
- It is divided into anterior **Adenohypophysis** & posterior **Neurohypophysis.**

a. Adenohypophysis

It has 2 parts: **Pars distalis** and **Pars intermedia.**

Pars distalis (Anterior pituitary): It produces

- **Somatotropin (Growth hormone, GH):** For body growth. Its **over-secretion** causes **Gigantism** (abnormal growth). **Hyposecretion** causes **Dwarfism** (stunted growth). **Over-secretion** of **GH** in adults (mainly in middle age) causes **Acromegaly** (severe disfigurement especially of face). It leads to serious complications and premature death. Early diagnosis of the disease is difficult. It may be undetected for many years.
- **Prolactin (PRL):** Regulates growth of **mammary glands** and **milk production.**
- **Thyroid stimulating hormone (TSH):** Stimulates **thyroid gland** to secrete **thyroid hormones.**
- **Adrenocorticotrophic hormone (ACTH):** Stimulates **adrenal cortex** to synthesise & secrete **steroid hormones (glucocorticoids).**
- **Follicle stimulating hormone (FSH):** Stimulates gonadal activity. **In males,** FSH & androgens regulate sperm formation **(spermatogenesis). In females, FSH** stimulates growth and development of **ovarian follicles.**
- **Luteinizing hormone (LH):** Stimulates gonadal activity. **In males,** it stimulates synthesis and secretion of androgens from testis. **In females,** it induces ovulation and maintains the corpus luteum.

Pars intermedia: In human, it is almost merged with pars distalis. It produces **Melanocyte stimulating hormone (MSH).** It acts on **melanocytes** to regulate skin pigmentation.

b. Neurohypophysis

It stores **Oxytocin & Vasopressin** from hypothalamus.

i. **Oxytocin:** Contracts **smooth muscles.** In females, it stimulates contraction of uterus during child birth, and milk ejection from the mammary gland.

ii. **Vasopressin or Anti-diuretic hormone (ADH):** Stimulates **reabsorption of water** & **electrolytes** by **DCT** of kidney and thereby reduces **diuresis** (loss of water through urine). Deficiency of ADH results in diminished ability of the kidney to conserve water. It leads to water loss and dehydration. This is called **Diabetes insipidus.**

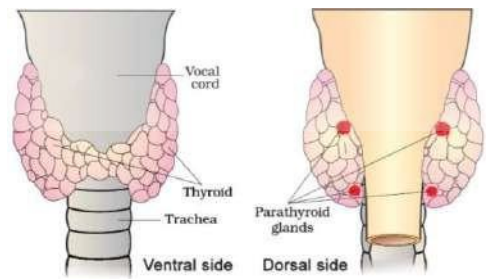
3. PINEAL GLAND

Smallest endocrine gland.
It is located on dorsal side of forebrain. Secretes **melatonin.**

Functions of melatonin:

- Regulates **diurnal (24-hour) rhythm** of body. E.g. sleep-wake cycle, body temperature etc.
- Influences metabolism, pigmentation & menstrual cycle.
- Influences defense capability.

4. THYROID GLAND



- Largest endocrine gland.
- It includes 2 lobes on either side of the trachea. The lobes are interconnected with **isthmus** (a connective tissue).
- Thyroid gland is made of **follicles** & **stromal tissues.**

Follicular cells secrete the following hormones:

- **Thyroxin (tetraiodothyronine, T_4) & Triiodothyronine (T_3):** Their functions are
  - Regulation of **basal metabolic rate (BMR).**
  - Physical, mental and sexual development.
  - Support **RBC formation.**
  - Control **metabolism** of carbohydrates, proteins & fats.
  - Maintain **water** and **electrolyte balance.**
- **Thyrocalcitonin (TCT):** A protein hormone. It regulates (lowers) **blood calcium** levels (Hypocalcaemic hormone).

Iodine is essential for normal hormone synthesis in thyroid.

Hypothyroidism (Goiter):

- Enlargement of thyroid gland due to deficiency of **iodine.**
- In adult women, it causes irregular menstrual cycle.
- Hypothyroidism during pregnancy affects the baby causing stunted growth (cretinism), mental retardation, low intelligence quotient, abnormal skin, deaf-mutism etc.

Hyperthyroidism:

- Abnormal increase of thyroid hormones resulting in adverse effects on the physiological activities.
- It is caused due to development of the nodules or the cancer of thyroid gland.
- **Exophthalmic goiter (Grave's disease):** It is a form of Hyperthyroidism. Symptoms are enlargement of thyroid gland, protruded eyeballs, increased BMR & weight loss.

5. PARATHYROID GLAND

4 parathyroid glands are present on back side of the thyroid gland, one pair each in the two lobes of thyroid gland. They secrete **Parathyroid hormone (PTH) –** a peptide hormone.

Functions of parathyroid hormone:

- Increases **Ca^{2+} level** in blood **(hypercalcaemic hormone).**
- Stimulates the **bone resorption (demineralization).**
- Stimulates the **reabsorption of Ca^{2+}** by the **renal tubules** and increases **Ca^{2+} absorption** from the **digested food.**
- Along with **TCT,** it helps in **calcium balance** in thebody.

6. THYMUS GLAND

It is located between lungs behind sternum on the ventral side of aorta. It secretes **Thymosins** (peptide hormones).

Functions of thymosins:

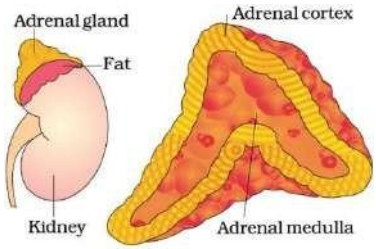
- Differentiation of **T-lymphocytes.** It provides **cell-mediated immunity.**
- Promote **antibody** production for **humoral immunity.**

Thymus is degenerated in old individuals. So, production of thymosins decreases. As a result, immune responses of old persons become weak.

7. ADRENAL GLAND

It has 2 parts: **Adrenal cortex & Adrenal medulla.**

a. Adrenal cortex It has 3 layers: inner **zona reticularis,** middle **zona fasciculata** & outer **zona glomerulosa.**



It produces the following **corticoid hormones:**

- **Glucocorticoids** (mainly **cortisol**):
  - Involved in **carbohydrate metabolism.**
  - Stimulate **gluconeogenesis, lipolysis and proteolysis.**
  - Inhibit cellular uptake and utilization of **amino acids.**
  - Maintain **cardiovascular** system and **kidney** functions.
  - Cortisol stimulates **RBC production.**
  - Produces **anti-inflammatory reactions** and suppress immune response.
- **Mineralocorticoids** (mainly **aldosterone**):
  - Regulate the **water** (body fluid volume), **electrolytic** balance, **osmotic pressure** and **blood pressure.**
  - Aldosterone stimulates **reabsorption of Na^+ & water** from renal tubules and excretion of **K^+ and PO_4^{3-} ions.**
- **Androgenic corticoids:** For growth of **axial hair, pubic hair** and **facial hair** during puberty.

Deficiency of corticoid hormones affects carbohydrate metabolism. It causes acute weakness and fatigue. This condition is called **Addison's disease.**

b. Adrenal medulla

- Produces **catecholamine** hormones such as **Adrenaline (epinephrine) & Noradrenaline (norepinephrine).**
- They are rapidly secreted in response to stress emergency situations so called **emergency hormones (hormones of Fight or Flight).**
- These increase alertness, pupillary dilation, piloerection (rising of hairs), sweating, heartbeat, heart contraction and respiratory rate. Stimulate glycogenolysis to increase glucose in blood. Also stimulate lipolysis and proteolysis.

8. PANCREAS (ISLETS OF LANGERHANS)

- A **composite (heterocrine)** gland i.e. **exocrine + endocrine.**
- **Islets of Langerhans** are the endocrine part. There are about 1-2 million Islets (1-2% of pancreatic tissue).
- **α cells** and **β cells** in the islets secrete peptide hormones such as **Glucagon** and **Insulin** respectively. They maintain **Glucose homeostasis** in blood.

- **Glucagon:** Hyperglycemic factor. It
  - Acts on **hepatocytes** and stimulates **glycogenolysis** resulting in an increased blood sugar **(hyperglycemia).**
  - Stimulates **gluconeogenesis.**
  - Reduces the cellular glucose uptake and utilization.
- **Insulin:** Hypoglycemic factor. It
  - Acts on **hepatocytes** and **adipocytes** to enhance cellular glucose uptake and utilization. So, glucose from blood rapidly moves to hepatocytes and adipocytes. Thus, blood glucose level decreases **(hypoglycemia).**
  - Stimulates **glycogenesis** (glucose converts to glycogen).

Prolonged hyperglycemia leads to **Diabetes mellitus** (loss of glucose through urine and formation of harmful compounds like ketone bodies). Treatment is **insulin therapy.**

9. TESTIS (MALE GONAD)

- It is the male primary sex organ and an endocrine gland.
- A pair of testis is present in the **scrotal sac**.
- It is formed of **seminiferous tubules** and **interstitial (stromal) tissues.**

- **Leydig (interstitial) cells** in the inter-tubular spaces produce hormones called **androgens (**mainly **testosterone).**

Functions of androgens:

- Regulate development, maturation and functions of the **accessory sex organs.**
- **Spermatogenesis** (sperm production).
- Stimulate sexual behavior **(libido),** growth of muscles, hairs, aggressiveness, low pitch voice etc.
- Help in anabolism of protein and carbohydrate.

10. OVARY (FEMALE GONAD)

- It is the female primary sex organ.
- A pair of ovaries is located in the abdomen.
- It produces one ovum during each menstrual cycle.
- Ovary is formed of **ovarian follicles** and **stromal tissues**.
- **Ovarian follicles** produce **Estrogen** (a steroid hormone).
- After ovulation, ruptured follicle forms a structure called **Corpus luteum.** It secretes **progesterone** (a steroid hormone).

Functions of Estrogen:

- Growth and activities of female **secondary sex organs.**
- Development of **ovarian follicles** & **mammary glands.**
- Female **secondary sex characters** (e.g. high pitch voice) and **sexual behavior.**

Functions of Progesterone:

- It supports **pregnancy.**
- It acts on **mammary glands** to stimulate formation of **alveoli** (sacs to store milk) and **milk secretion.**

HORMONES OF HEART, KIDNEY & GASTROINTESTINAL TRACT

1. **Atrial wall of heart:** Produce a peptide hormone called **Atrial natriuretic factor (ANF).** When BP increases, ANF causes dilation of blood vessels to reduce the BP.
2. **JGA of kidney:** Produces **Erythropoietin** (peptide hormone). Stimulates **erythropoiesis** (formation of RBC).
3. **Gastro-intestinal tract:** Produce peptide hormones. E.g.
   - **Gastrin:** Stimulates **gastric glands** to secrete **HCl** and **pepsinogen.**
   - **Secretin:** Stimulates **exocrine pancreas** to secrete **water** and **bicarbonate ions.**
   - **Cholecystokinin (CCK):** Stimulates secretion of **bile** from gall bladder and pancreatic enzymes from pancreas.
   - **Gastric inhibitory peptide (GIP):** Inhibits **gastric secretion.**

Several other **non-endocrine tissues** secrete hormones called **growth factors.** These help for the normal growth of tissues and their repairing or regeneration.

Based on the chemical nature, hormones are various types:

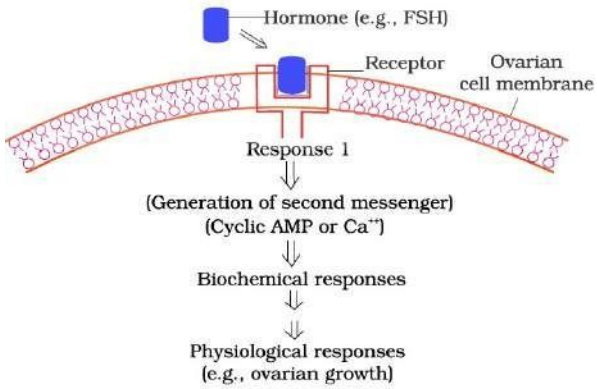
a. **Peptide, polypeptide, protein hormones:** Insulin, glucagon, pituitary hormones, hypothalamic hormones etc.
b. **Steroids:** Cortisol, testosterone, estradiol & progesterone.
c. **Iodothyronines** (thyroid hormones).
d. **Amino-acid derivatives:** Adrenaline, nor-adrenaline etc.

MECHANISM OF HORMONE ACTION

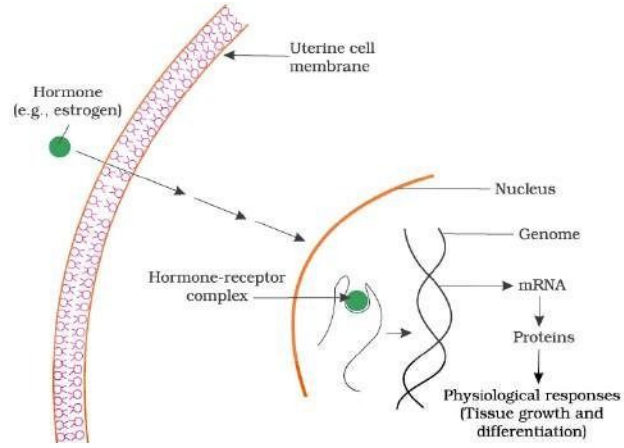
- Hormones produce their effects by binding to the specific proteins **(hormone receptors)** located in **target tissues.**
- A hormone binds to its specific receptor to form **hormone-receptor complex**.
- It leads to biochemical changes in target tissue and thereby regulates metabolism and physiological functions.

Hormone receptors are 2 types:

- **Membrane-bound receptors:** Some hormones (e.g. protein hormone, FSH) interact with membrane-bound receptors (do not enter the target cell). It generates **second messengers** (e.g. cyclic AMP, IP_3, Ca^{2+}). It in turn regulates **cellular metabolism** and causes **physiological effects.**



- **Intracellular receptors** (mostly **nuclear receptors):** Some hormones (e.g. steroid hormones, iodothyronines) interact with intracellular receptors. They mostly regulate **gene expression** or **chromosome function** by the interaction of hormone-receptor complex with the genome. Cumulative biochemical actions result in physiological and developmental effects.



REPRODUCTION IN ORGANISMS

- **Reproduction** is a process in which an organism produces young ones (offspring) similar to itself.
- The period from birth to the natural death of an organism is known as its **lifespan.**
- No individual is immortal, except unicellular organisms. There is no natural death in unicellular organisms.

Life spans of some organisms	Organism	Lifespan	Organism	Lifespan	Organism	Lifespan
	Rose	5-7 years	Butterfly	1-2 weeks	Tortoise	100-150 yrs
	Rice plant	3-7 months	Fruit fly	2 weeks	Crow	15 yrs
	Banyan tree	400+ yrs	Parrot	140 yrs	Cow	22 yrs
	Banana tree	2-3 yrs	Crocodile	60 yrs	Elephant	50-70 yrs
	Dog	22 yrs	Horse	40-50 yrs		

- Based on the number of participants, reproduction is 2 types: **Asexual reproduction & Sexual reproduction.**

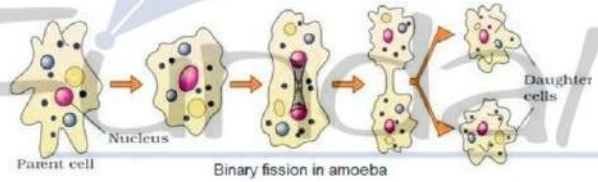
ASEXUAL REPRODUCTION

- It is the production of offspring by a single parent.
- It is seen in unicellular organisms, simple plants & animals.
- The offspring are identical to one another and to their parent. Such morphologically and genetically similar individuals are known as **clone**.

Types of asexual reproduction

a. Fission: In this, the parent cell divides **(cell division)** into two or more individuals. E.g. Protists and Monerans. Fission is 2 types:

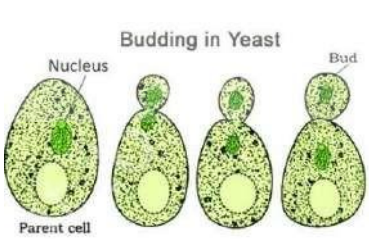
- **Binary fission:** It is the division of parent cell into two individuals. E.g., *Amoeba, Paramecium.*
- **Multiple fission:** It is the division of parent cell into many individuals. E.g. *Plasmodium, Amoeba.*

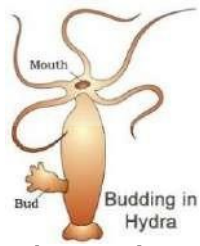


Binary fission in amoeba

Under unfavourable condition, *Amoeba* withdraws its pseudopodia and secretes a 3-layered hard covering (cyst) around itself. It is called **encystation.** Under favourable conditions, encysted *Amoeba* undergoes multiple fission to give many minute amoeba or pseudopodiospores. The cyst wall bursts out and spores are liberated to grow up into many amoebae. This is called **sporulation.**

b. Budding: In this, a bud appears and grows in the parent body. After maturation, it is detached from parent body to form new individual. E.g. *Hydra,* Sponge, Yeast etc.





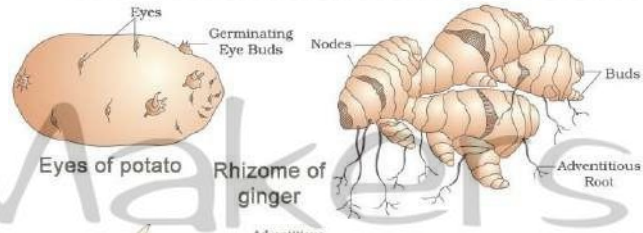
***c.* Fragmentation:** In this, the body breaks into distinct pieces (fragments) and each fragment grows into an adult capable of producing offspring. E.g. *Hydra.*

d. Vegetative propagation: It is the production of offspring from **vegetative propagules** in plants.

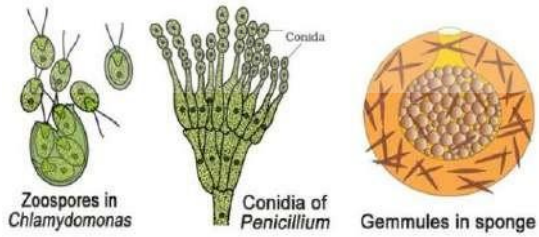
Vegetative propagules are units of vegetative propagation.

Examples for vegetative propagules:

- **Buds ('eyes')** of the potato tuber.
- **Rhizomes** of banana & ginger.
  Buds & Rhizomes arise from the **nodes** of modified stems. The nodes come in contact with damp soil or water and produce roots and new plants.
- **Adventitious buds** of *Bryophyllum.* They arise from the notches at margins of leaves.
- **Bulbil** of *Agave.*
- **Offset** of water hyacinth.
- **Runner, sucker, tuber, bulb etc.**



Other asexual reproductive structures: E.g. **zoospores** (microscopic motile structures in some algae and protists), **conidia** (*Penicillium*) and **gemmules** (*sponge*).



Asexual reproduction is the common method in simple organisms like algae and fungi. During adverse conditions, they can shift to sexual method.

Higher plants reproduce asexually (vegetative) & sexually. But most of the animals show only sexual reproduction.

SEXUAL REPRODUCTION

- It is the reproduction that involves formation of male and female gametes, either by the same individual or by different individuals of the opposite sex.
- It results in offspring that are not identical to the parents or amongst themselves.
- It is an elaborate, complex and slow process as compared to asexual reproduction.
- The period of growth to reach in maturity for sexual reproduction is called the **juvenile phase**. In plants, it is known as **vegetative phase.**
- In higher plants, the flowering indicates the end of vegetative phase (beginning of **reproductive phase).**
- ***Annual & biennial*** plants show clear cut **vegetative, reproductive & senescent phases.** In ***perennial*** plants, these phases are very difficult to identify.
- Some plants exhibit unusual flowering. E.g.
  - Bamboo species flower only once in their lifetime (after 50-100 years), produce large number of fruits and die.
  - *Strobilanthus kunthiana* flowers once in 12 years.
- In animals, juvenile phase is followed by morphological & physiological changes prior to reproductive behaviour.
- Birds living in nature lay eggs only seasonally. However, birds in captivity (e.g. poultry) can be made to lay eggs throughout the year.
- The females of placental mammals exhibit cyclical changes in the ovaries, accessory ducts and hormones during the reproductive phase. It is called **oestrus cycle** in **non-primates** (cows, sheep, rat, deer, dog, tiger etc.) and **menstrual cycle** in **primates** (monkeys, apes & humans).

Based on breeding season, mammals are 2 types:

a. Seasonal breeders: The mammals (living in natural conditions) exhibiting reproductive cycles only during favourable seasons.

b. Continuous breeders: They are reproductively active throughout their reproductive phase.

Senescence (old age):

- It is the last phase of lifespan and end of reproductivephase.
- During this, concomitant changes occur in the body. E.g. slowing of metabolism etc. It ultimately leads to death.

In plants & animals, **hormones** cause transition between **juvenile, reproductive & senescence phases.** Interaction between hormones and environmental factors regulate the reproductive processes and the associated behavioural expressions of organisms.

EVENTS IN SEXUAL REPRODUCTION

3 stages: Pre-fertilisation, Fertilisation & Post-fertilisation events.

1. Pre-fertilisation Events

These are the events prior to the fusion of gametes.
They include **gametogenesis** and **gamete transfer.**

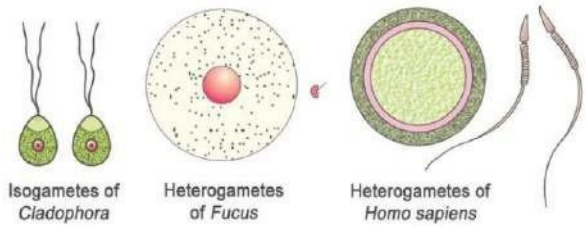
a. Gametogenesis

It is the formation of male and female gametes.

Gametes (haploid cells) are 2 types:

a. Homogametes (isogametes): Similar gametes. They cannot categorize into male & female gametes. E.g. Some algae like ***Cladophora***.

b. Heterogametes: The male and female gametes are distinct types. Male gamete is called **antherozoid (sperm)** and female gamete is called **egg (ovum)**. E.g. ***Fucus*** (an alga), Human beings etc.

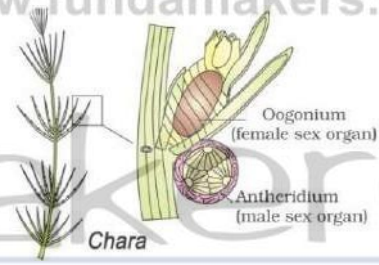


Sexuality (bisexual or unisexual) in organisms:

a. Bisexual: Male & female reproductive structures present in the same individual.

Bisexual plants: E.g. *Hibiscus*, *Pisum.*
In flowering plants, male flower is **staminate** (bears stamens) and female flower is **pistillate** (bears pistils).

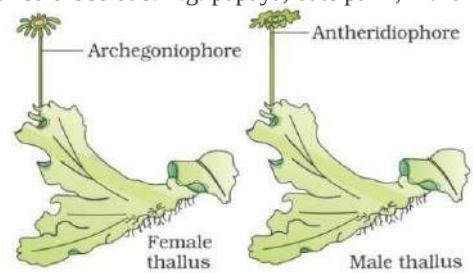
If male & female flowers are present on same plant, it is called **monoecious**. E.g. Cucurbits, coconuts, *Chara.*



Bisexual animals (hermaphrodites): E.g. Earthworms, leech, sponge, tapeworm, etc.

b. Unisexual: Male and female reproductive structures are present on different individuals.

If male & female flowers are present on different plants, it is called **dioecious**. E.g. papaya, date palm, *Marchantia.*



Unisexual animals: E.g. Cockroach, higher animals etc. Fungi may be **homothallic** (bisexual) or **heterothallic** (unisexual).

Cell division during gamete formation:

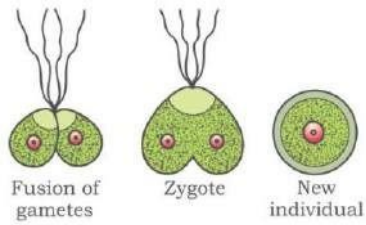
- Many monerans, fungi, algae & bryophytes have **haploid** parental body. They produce haploid gametes by **mitosis.**
- Pteridophytes, gymnosperms, angiosperms & animals have **diploid** parental body. They produce haploid gametes by **meiosis** of **meiocytes** (gamete mother cell).

Name of organism	Chromosome number	
	In meiocytes (2n)	In gametes (n)
Human being	46	23
Housefly	12	6
Rat	42	21
Dog	78	39
Cat	38	19
Fruit fly	8	4
Ophioglossum	1260	630
Apple	34	17
Rice	24	12
Maize	20	10
Potato	48	24
Butterfly	380	190
Onion	16	8

b. Gamete Transfer

- Male gametes need a medium to move towards female gametes for fertilisation.
- In most organisms, male gamete is motile and the female gamete is stationary.

  In some fungi and algae, both types of gametes are motile.



Homogametic contact in alga

- In simple plants (algae, bryophytes & pteridophytes), gamete transfer takes place through water medium. To compensate the loss of male gametes during transport, large number of male gametes is produced.
- In seed plants, **pollen grains** (in anthers) carry male gametes and **ovule** carries the egg. Pollen grains are transferred to the stigma.
- In bisexual self-fertilizing plants (e.g. peas), anthers & stigma are closely located for easy transfer of pollen grains.
- In cross pollinating plants (including dioecious plants), **pollination** helps in transfer of pollen grains. Pollen grains germinate on the stigma and the pollen tubes carrying the male gametes reach the ovule and discharge male gametes near the egg.
- In dioecious animals, the fertilisation helps for successful transfer and coming together of gametes.

2. Fertilisation (syngamy)

- It is the fusion of gametes to form a diploid **zygote**.
- In rotifers, honeybees, some lizards, birds (turkey) etc., female gamete develops to new organisms without fertilisation. This is called **parthenogenesis.**

Types of fertilization:

a. External fertilisation: Syngamy occurs in the external medium (water), i.e. zygote is formed outside the body. E.g. most aquatic organisms (many algae, bony fishes etc.) and amphibians.

Such organisms show synchrony between the sexes and release large number of gametes into the surrounding medium to ensure syngamy.

Disadvantage: The offspring are extremely vulnerable to predators threatening their survival up to adulthood.

b. Internal fertilisation: Syngamy occurs inside the body of the organism. E.g. terrestrial organisms, belonging to fungi, animals (reptiles, birds, mammals) & plants (bryophytes, pteridophytes, gymnosperms & angiosperms). In this, non-motile egg is formed inside the female body to where motile male gamete reaches and fuses.

In seed plants, the non-motile male gametes are carried to female gamete by pollen tubes.

There is large number of sperms produced but the number of eggs is very low.

3. Post-fertilisation Events

These are the events after the formation of zygote.

Zygote

- Development of the zygote depends on the type of life cycle of the organism and the nature of environment.
- In fungi and algae, zygote develops a thick wall that is resistant to desiccation and damage. It undergoes a period of rest before germination.
- In organisms with **haplontic life cycle,** zygote divides by meiosis into **haploid spores** that grow into haploid individuals.
- Sexually reproducing organisms begin life as a zygote.
- Zygote is the vital link between organisms of one generation and the next.

Embryogenesis

- It is the development of **embryo** from the zygote.
- During embryogenesis, zygote undergoes **cell division** (mitosis) and **cell differentiation**.
- Cell divisions increase the number of cells in the embryo. Cell differentiation causes the modifications of groups of cells into various tissues and organs to form an organism.

Based on place of zygote development, animals are 2 types:

a. Oviparous: Here, animals lay fertilized/unfertilized eggs. E.g. Reptiles & birds lay fertilized eggs covered by hard **calcareous shell.** After incubation, young ones hatch out.

b. Viviparous: Here, zygote develops into a young one inside the female body. Later, the young ones are delivered out of the body. E.g. most of mammals.

It shows proper care and protection. So the chances of survival of young ones are greater.

Embryogenesis in flowering plants ***(see next chapter)***

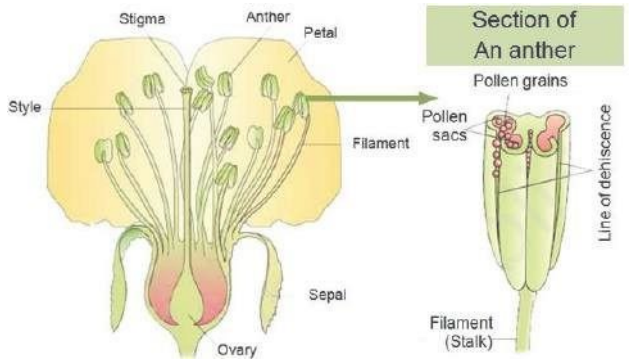
SEXUAL REPRODUCTION IN FLOWERING PLANTS

All flowering plants (angiosperms) show sexual reproduction. **Flowers** are the sites of sexual reproduction.

PRE-FERTILISATION: STRUCTURES & EVENTS

- Several hormonal and structural changes result in differentiation & development of the **floral primordium.**
- Inflorescences bear the floral buds and then the flowers.

STRUCTURE OF A FLOWER



A typical flower has 2 parts: **Androecium & Gynoecium.**

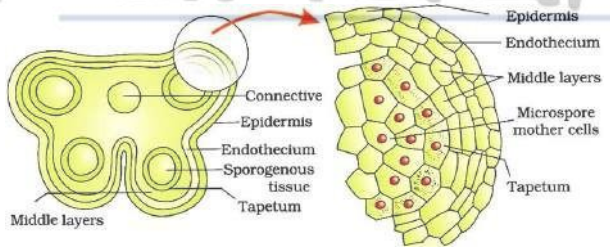
Androecium (male reproductive part)

It consists of a whorl of **stamens.** Their number and length are variable in different species.

A stamen has 2 parts:

a. **Filament:** Long and slender stalk. Its proximal end is attached to the thalamus or the petal of the flower.
b. **Anther:** Terminal and typically **bilobed.** Each lobe has 2 thecae **(dithecous).** Often a longitudinal groove runs lengthwise separating the theca.

Transverse section of anther:



- The anther is a tetragonal structure consisting of four **microsporangia** located at the corners (2 in each lobe).
- The microsporangia develop to **pollen sacs.** They extend longitudinally all through the length of an anther and are packed with pollen grains.

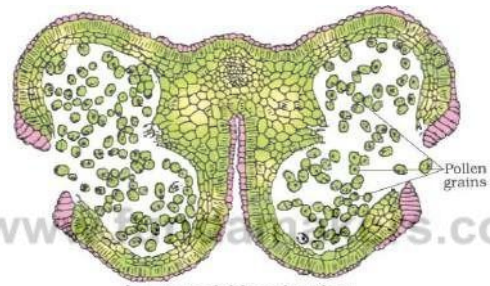
Structure of a microsporangium:

- A typical microsporangium is near circular in outline.
- It is surrounded by 4 wall layers: **epidermis, endothecium, middle layers & tapetum** (innermost layer).
- The outer 3 layers give protection and help in dehiscence of anther to release the pollen.
- The **tapetum** nourishes the developing pollen grains. Cells of the tapetum contain dense cytoplasm and generally have more than one nucleus.
- In young anther, each microsporangium has **sporogenous tissue** at centre. It consists of compactly arranged homogenous diploid cells (sporogenous cells).

Microsporogenesis:


Microspore tetrad

- As the anther develops, each sporogenous cell **(microspore mother cell or pollen mother cell)** undergoes meiotic divisions to form **microspore tetrads** (microspores arranged in a cluster of four cells).
- Formation of microspores from pollen mother cell (PMC) through meiosis is called **microsporogenesis.**
- As the anthers mature and dehydrate, the microspores dissociate from each other and develop into **pollen grains.**
- Each microsporangium contains thousands of pollen grains. They are released with the dehiscence of anther.



A mature dehisced anther

Pollen grain (male gametophyte):

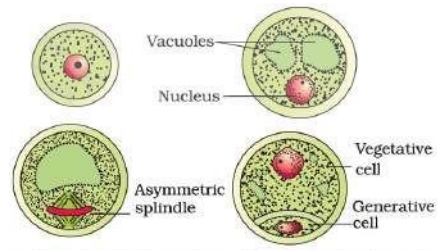
Generally spherical. 25-50 µm in diameter. Cytoplasm is surrounded by a plasma membrane.

A pollen grain has a two-layered wall: **exine** and **intine.**

- **Exine:** Hard outer layer. Made up of **sporopollenin** (highly resistant organic material). It can withstand high temperature and strong acids and alkali. Enzymes cannot degrade sporopollenin.
  Exine has apertures called **germ pores** where sporopollenin is absent.
  Pollen grains are preserved as fossils due to the presence of sporopollenin. Exine exhibits patterns and designs.
- **Intine:** Inner wall. It is a thin and continuous layer made up of **cellulose** and **pectin.**

A matured pollen grain contains 2 cells:

- **Vegetative cell:** It is bigger, has abundant food reserve and a large irregularly shaped nucleus.
- **Generative cell:** It is small and floats in the cytoplasm of the vegetative cell. It is spindle shaped with dense cytoplasm and a nucleus.



Stages of a microspore maturing into a pollen grain

- Over 60% angiosperms shed their pollen grains at 2-celled stage. In others, generative cell divides mitotically to give 2 male gametes. Thus pollen grains are shed at 3-celled stage.

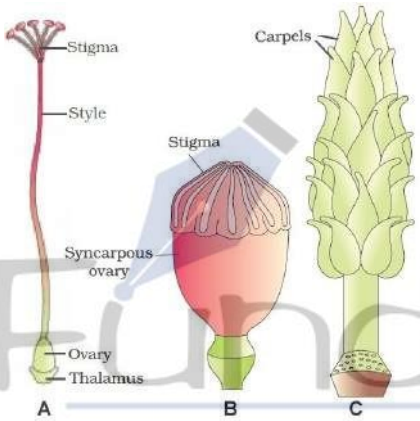
- The shed pollen grains have to land on the stigma before they lose viability. The viability period of pollen grains is variable. It depends on temperature and humidity.
- Viability of pollen grains of some cereals (rice, wheat etc.) is 30 minutes. Some members of *Leguminoseae, Rosaceae & Solanaceae* have viability for months.

Economic importance of pollen grains:

- These are **rich in nutrients.** Pollen tablets are used as food supplements. Pollen tablets & syrups increase performance of athletes and race horses.
- They are stored for years in liquid nitrogen (-196^0 C). They can be used as **pollen banks** in crop breeding programmes.
- Pollen grains of some plants (e.g. *Parthenium* or carrot grass) are allergic for some people. It leads to chronic respiratory disorders (asthma, bronchitis, etc.).

Gynoecium (female reproductive part)

- It may have a single pistil (**monocarpellary**) or more than one pistil **(multicarpellary).**
- In **multicarpellary**, the pistils may be fused together (**syncarpous**) or free (**apocarpous**).



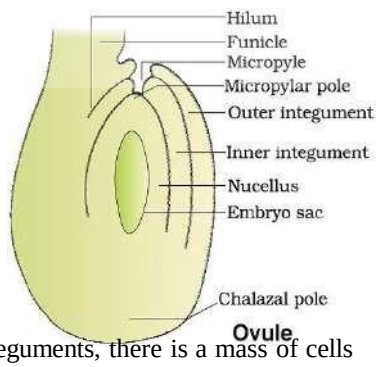
A. *Hibiscus* pistil.
B. Multicarpellary, syncarpous pistil of *Papaver*.
C. Multicarpellary, apocarpous gynoecium of *Michelia*

Each pistil has three parts:

- **Stigma:** Landing platform for pollen grains.
- **Style:** Elongated slender part beneath the stigma.
- **Ovary:** Basal bulged part. It has **ovarian cavity** (**locule)** in which **placenta** is located. Arising from the placenta are the **ovules (megasporangia).** Number of ovules in an ovary may be one (wheat, paddy, mango etc.) to many (papaya, water melon, orchids etc.).

Structure of Megasporangium (Ovule):

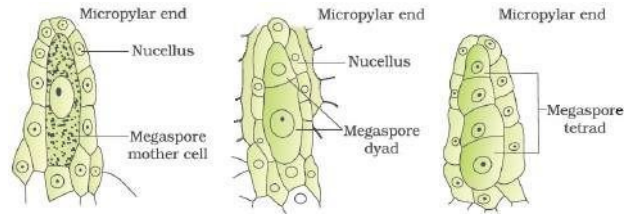
- Ovule is attached to the placenta by a stalk **(funicle)**.
- Junction between the body of ovule and funicle is called **hilum.**
- Each ovule has 1 or 2 protective envelopes (**integuments)** except at the tip where a small opening (**micropyle)** is present.
- Opposite the micropylar end is the **chalaza** (basal part).



- Enclosed within the integuments, there is a mass of cells called **nucellus**. Its cells contain reserve food materials.
- Inside the nucellus is **embryo sac (female gametophyte)**.
- An ovule generally has a single embryo sac formed from a megaspore.

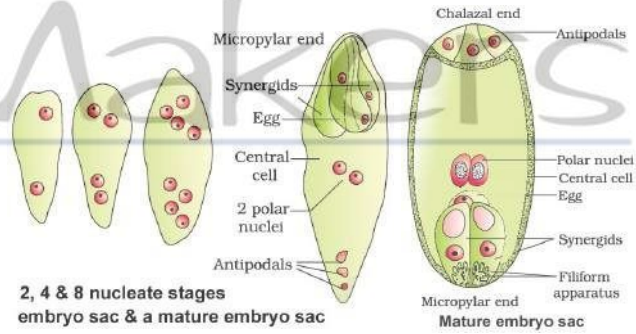
Megasporogenesis:

- It is the formation of megaspores from **megaspore mother cell (MMC).**
- Ovules generally differentiate a single MMC in micropylar region of the nucellus. It is a large cell containing dense cytoplasm and a prominent nucleus.
- MMC undergoes meiosis to produce 4 **megaspores**.



Formation of Female gametophyte (embryo sac):

- In majority of flowering plants, one megaspore is functional while the other three degenerates.
- The **functional megaspore** develops into the **female gametophyte.** The embryo sac formation from a single megaspore is called **monosporic** development.
- Nucleus of the functional megaspore divides mitotically to form two nuclei. They move to the opposite poles, forming **2-nucleate** embryo sac.
- The nuclei again divide two times forming **4-nucleate** and **8-nucleate** stages of the embryo sac.



- These divisions are free nuclear, i.e. nuclear divisions are not followed immediately by cell wall formation.
- After the 8-nucleate stage, cell walls are laid down leading to the organization of the typical **female gametophyte.**
- 6 of the 8 nuclei are surrounded by cell walls and organized into cells. Remaining 2 nuclei (polar nuclei) are situated below the egg apparatus in the large **central cell.**

Distribution of cells within the embryo sac:

A typical mature embryo sac is **8-nucleate** and **7-celled**.

- 3 cells (2 **synergids** + one **egg cell)** are grouped at the **micropylar end** and form **egg apparatus.**
  Synergids have special cellular thickenings at the **micropylar tip** called **filiform apparatus.** It helps to guide the pollen tubes into the synergid.
- 3 cells **(antipodals)** at the **chalazal end.**
- A large **central cell** with two **polar nuclei.**

POLLINATION

It is the transfer of pollen grains from the anther to the stigma of a pistil.

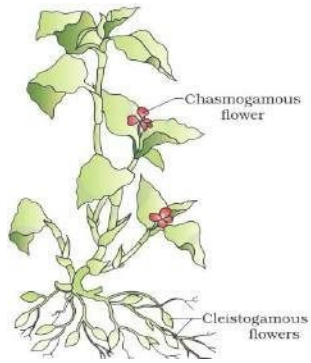
Based on the source of pollen, pollination is 3 types:

a. Autogamy (self-pollination): It is the transfer of pollen grains from the anther to stigma of the **same flower.**

In flowers with exposed anthers & stigma, complete autogamy is rare. Autogamy in such flowers requires synchrony in pollen release and stigma receptivity. Also, anthers & stigma should be close to each other.

Plants like *Viola* (common pansy), *Oxalis* & *Commelina* produce 2 types of flowers:

- **Chasmogamous flowers:** They are similar to flowers of other species with exposed anthers and stigma.
- **Cleistogamous flowers:** They do not open at all. Anthers & stigma lie close to each other. They are autogamous. When anthers dehisce in the flower buds, pollen grains come in contact with stigma for pollination. Cleistogamous flowers produce assured seed-set even in the absence of pollinators. Cleistogamy leads to inbreeding depression.



b. Geitonogamy: It is the transfer of pollen grains from the anther to the stigma of **another flower of the same plant.** It is functionally cross-pollination involving a pollinating agent. But it is genetically similar to autogamy since the pollen grains come from the same plant.

c. Xenogamy: It is the transfer of pollen grains from anther to the stigma of a **different plant.** It brings genetically different pollen grains to the stigma.

Agents of Pollination

1. Abiotic agents (wind & water)

Pollination by wind (anemophily):

- More common abiotic agent.
- Wind pollinated flowers often have a single ovule in each ovary and numerous flowers packed into an inflorescence.
- E.g. Corncob – the tassels are the stigma and style which wave in the wind to trap pollen grains. Wind-pollination is quite common in grasses.
- **Ways for effective pollination:**
  - The flowers produce enormous amount of pollen.
  - Pollen grains are light and non-sticky.
  - They often possess well-exposed stamens (for easy dispersion of pollens into wind currents).
  - Large, feathery stigma to trap air-borne pollen grains.

Pollination by water (hydrophily):

- It is quite rare. It is limited to about 30 genera, mostly monocotyledons. E.g. *Vallisneria* & *Hydrilla* (fresh water), *Zostera* (marine sea-grasses) etc.
- But in lower plants, water is a regular mode of transport for the male gametes. Distribution of some bryophytes & pteridophytes is limited because they need water for the transport of male gametes and fertilisation.
- In *Vallisneria*, the female flower reaches the surface of water by the long stalk and the male flowers or pollen grains are released on to the surface of water. They are carried by water currents and reach the female flowers.
- In sea grasses, female flowers remain submerged in water. Pollen grains are long and ribbon like. They are carried inside the water and reach the stigma.
- The pollen grains of most of the water-pollinated species have a mucilaginous covering to protect from wetting.
- Not all aquatic plants use hydrophily. In most of aquatic plants (water hyacinth, water lily etc.), the flowers emerge above the level of water for entomophily or anemophily.
- Wind and water pollinated flowers are not very colourful and do not produce nectar.

2. Biotic agents (animals)

- Majority of flowering plants use animals as pollinating agents. E.g. Bees, butterflies, flies, beetles, wasps, ants, moths, birds (sunbirds & humming birds) bats, primates (lemurs), arboreal (tree-dwelling) rodents, reptiles (gecko lizard & garden lizard) etc.
- Pollination by insects **(Entomophily),** particularly bees is more common.
- Often flowers of animal pollinated plants are specifically adapted for a particular species of animal.
- **Features of insect-pollinated flowers:**
  - Large, colourful, fragrant and rich in nectar. Nectar & pollen grains are the floral rewards for pollination.
  - Small flowers form inflorescence to make them visible.
  - The flowers pollinated by flies and beetles secrete foul odours to attract these animals.
  - The pollen grains are generally sticky.
- When the animal comes in contact with the anthers and the stigma, its body gets pollen grains. When it comes in contact with the stigma, it results in pollination.
- Some plants provide safe places as floral reward to lay eggs. E.g. *Amorphophallus* (It has the tallest flower of 6 feet). A moth species and the plant *Yucca* cannot complete their life cycles without each other. The moth deposits its eggs in the locule of ovary. The flower gets pollinated by moth. The larvae come out of the eggs as seeds start developing.
- Many insects consume pollen or nectar without bringing about pollination. They are called **pollen/nectar robbers.**

Outbreeding Devices

Hermaphrodite flowers can undergo self-pollination. Continued self-pollination results in inbreeding depression. To avoid **self-pollination (autogamy)** and encourage **cross-pollination,** there are some devices in plants:

a. Avoiding synchronization: Here, the pollen is released before the stigma becomes receptive or stigma becomes receptive before the release of pollen.

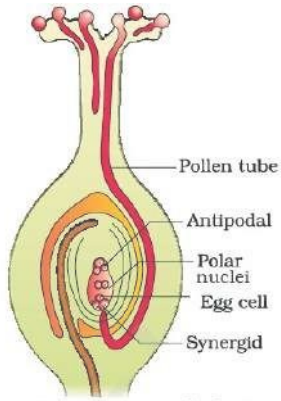
b. Arrangement of anther & stigma at different positions.

c. **Self-incompatibility:** It is a genetic mechanism to prevent self-pollen (from same flower or other flowers of the same plant) from fertilization by inhibiting pollen germination or pollen tube growth in the pistil.

d. **Production of unisexual flowers:** If male & female flowers are present on the same plant (i.e., monoecious, e.g. castor & maize), it prevents autogamy but not geitonogamy. In dioecious plants (e.g. papaya), male and female flowers are present on different plants **(dioecy).** This prevents both autogamy and geitonogamy.

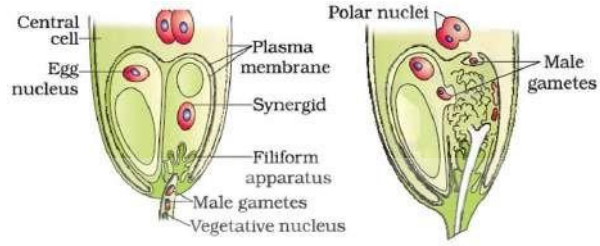
Pollen-pistil Interaction

- It is a process in which pistil recognizes compatible or incompatible pollen through the chemical components produced by them.
- Pistil accepts **compatible pollen** and promotes post-pollination events.
- It rejects **incompatible pollen** by preventing pollen germination or pollen tube growth.
- Pollen grain germinates on the stigma to produce a **pollen tube** through one of the germ pores. The contents of pollen grain move into pollen tube. Pollen tube grows through the tissues of stigma and style and reaches the ovary.
- In plants which shed pollen grains at **2-celled** condition (a vegetative cell & a generative cell), the generative cell divides into two male gametes during pollen tube growth.



Longitudinal section of a flower showing growth of pollen tube

- In plants which shed pollen in **3-celled condition,** pollen tubes carry 2 male gametes from the beginning.
- Pollen tube → **ovary** → **micropyle** → **ovule** → enters one of the **synergids** through **filiform apparatus.** Filiform apparatus guides the entry of pollen tube.



a) Entry of tube into a synergid (b) Discharge of male gametes into a synergid, then to egg & central cell

- A plant breeder can manipulate pollen-pistil interaction, even in incompatible pollinations, to get desired hybrids.

Artificial hybridisation

It is a crop improvement programme in which desired pollen grains are used for pollination.

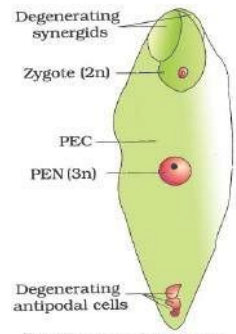
Steps:

- **Emasculation:** Removal of anthers from the bisexual flower bud of female parent before the anther dehisces.
- **Bagging:** Here, emasculated flowers are covered with a bag (butter paper) to prevent contamination of its stigma with unwanted pollen.
- **Pollination:** When stigma attains receptivity, pollen grains collected from male parent are dusted on the stigma.
- **Rebagging** the flowers. It is allowed to develop the fruits.

For unisexual flowers, there is no need for emasculation. Female flower buds are bagged before the flowers open.

DOUBLE FERTILISATION

- After entering the synergid, the pollen tube releases 2 male gametes into the cytoplasm of the synergid. One male gamete moves towards the egg cell and fuses with its nucleus **(syngamy)** to form **zygote** (diploid).
- The other male gamete moves towards the two polar nuclei located in the central cell and fuses with them to produce a triploid **primary endosperm nucleus (PEN).** As it involves fusion of 3 haploid nuclei, it is called **triple fusion.**
- Since 2 types of fusions (syngamy & triple fusion) take place in an embryo sac, it is called **double fertilisation.** It is an event unique to flowering plants.
- The central cell after triple fusion becomes the **primary endosperm cell (PEC)** and develops into the **endosperm** while the zygote develops into an **embryo.**



Fertilized embryo sac

POST- FERTILISATION: STRUCTURES & EVENTS

Post-fertilisation events: Endosperm & embryo development, maturation of ovule(s) into seed(s) & ovary into fruit.

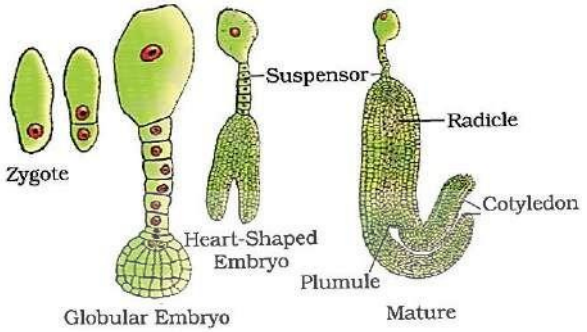
Endosperm development

- **Primary endosperm cell (PEC)** divides repeatedly to form a **triploid endosperm tissue.**
- Endosperm cells are filled with reserve food materials. They are used for **nutrition** of the developing embryo.
- In common endosperm development, PEN undergoes successive nuclear divisions to give free nuclei **(free-nuclear endosperm).** Number of free nuclei varies greatly.
- Endosperm becomes cellular due to cell wall formation.
- **Tender coconut water** is a **free-nuclear endosperm** (made up of thousands of nuclei) and the surrounding **white kernel** is the **cellular endosperm.**

Embryo development

- Embryo develops at the micropylar end of the embryo sac where the zygote is situated.
- Most zygotes divide only after the formation of some endosperm. This provides nutrition to developing embryo.

- In monocots & dicots, seeds differ greatly but **embryogeny** (early embryonic developments) is similar.
- **Zygote → Pro-embryo → Globular → Heart-shaped → Mature embryo.**



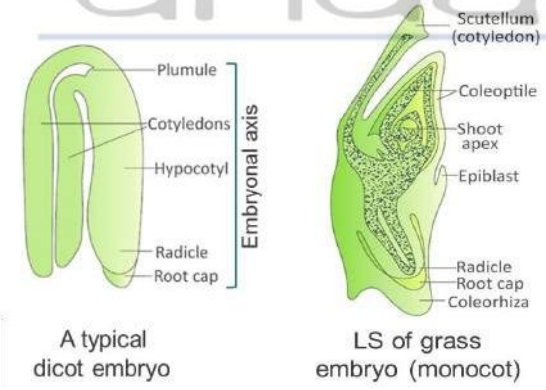
Stages in embryo development in a dicot

Dicotyledonous embryo

- It has an **embryonal axis** and 2 **cotyledons.**
- Portion of embryonal axis above the level of cotyledons is the **epicotyl,** which terminates with **plumule (stem tip).**
- The cylindrical portion below the level of cotyledons is **hypocotyl** that terminates with the **radicle (root tip).** The root tip is covered with a **root cap.**

Monocotyledonous embryo

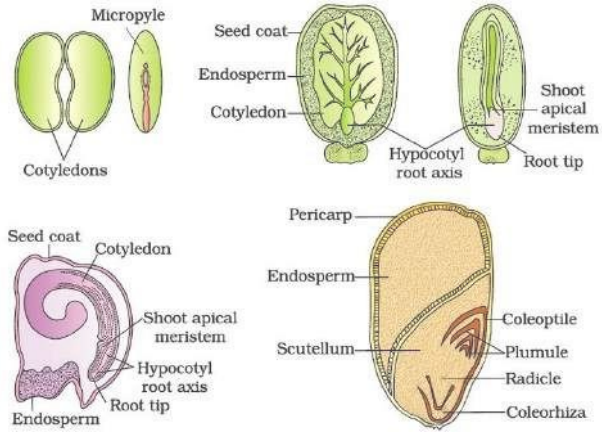
- They possess only **one cotyledon.**
- Cotyledon of the grass family is called **scutellum.**
- It is situated lateral to the embryonal axis. At its lower end, the embryonal axis has the radicle and root cap enclosed in **coleorrhiza** (an undifferentiated sheath).
- Portion of embryonal axis above the level of attachment of scutellum is the epicotyl. It has a shoot apex and a few leaf primordia enclosed in **coleoptile** (a hollow foliar structure).



A typical dicot embryo — LS of grass embryo (monocot)

Seed from Ovule

- Seed is the fertilized ovule formed inside fruits. It is the final product of sexual reproduction.
- It consists of **seed coat(s), cotyledon(s) & an embryo axis.**
- The cotyledons are simple, generally thick and swollen due to storage food (as in legumes).
- Mature seeds are 2 types:
  - **Non-albuminous (Ex-albuminous) seeds:** Have no residual endosperm as it is completely consumed during embryo development. E.g. pea, groundnut, beans.
  - **Albuminous seeds:** Retain a part of endosperm. E.g. wheat, maize, barley, castor, coconut.
- Occasionally, in some seeds (black pepper, beet etc.) remnants of nucellus are also persistent. It is called **perisperm.**
- Integuments of ovules harden as tough protective seed coats. It has a small pore (micropyle) through which O_2 & water enter into the seed during germination.
- As the seed matures, it becomes dry by reducing water content (10-15 % moisture by mass). The metabolic activity of the embryo slows down. It may enter a state of inactivity **(dormancy).** Under favourable conditions (moisture, oxygen & suitable temperature), they germinate.



Structure of some seeds

Advantages of seeds:

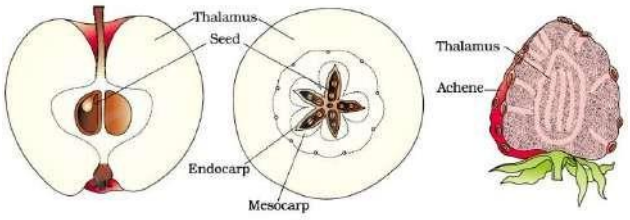
- Since pollination and fertilisation are independent of water, seed formation is more dependable.
- Better adaptive strategies for dispersal to new habitats. It helps the species to colonize in other areas.
- They have food reserves. So seedlings are nourished until they are capable of photosynthesis.
- The hard seed coat protects the young embryo.
- Being products of sexual reproduction, they generate new genetic combinations and variations.
- Dehydration & dormancy helps to store seeds. It can be used as food throughout year and to raise crop in next season.

Viability of seeds after dispersal:

- In a few species, the seeds lose viability within a few months. Seeds of many species live for several years.
- Some seeds can remain alive for hundreds of years. The oldest is that of a lupine (*Lupinus arcticus*) excavated from Arctic Tundra. The seed germinated and flowered after an estimated record of 10,000 years of dormancy.
- 2000 years old viable seed is of the date palm (*Phoenix dactylifera*) discovered during the archeological excavation at King Herod's palace near the Dead Sea.

Fruit from Ovary

- The ovary develops into a fruit. Transformation of ovules into seeds and ovary into fruit proceeds simultaneously.
- The wall of ovary develops into **pericarp** (wall of fruit).
- The fruits may be **fleshy** (e.g. guava, orange, mango, etc.) or **dry** (e.g. groundnut, mustard etc.).
- Fruits are 2 types:
  - **True fruits:** In this, fruit develops **only from the ovary.** Other floral parts degenerate & fall off. E.g. most plants.



False fruits of apple and strawberry

- **False fruits:** In this, the **thalamus** also contributes to fruit formation. E.g. apple, strawberry, cashew etc.
- In some species, fruits develop without fertilisation. Such fruits are called **parthenocarpic fruits.** E.g. Banana.
- Parthenocarpy can be induced through the application of growth hormones. Such fruits are seedless.

APOMIXIS AND POLYEMBRYONY

- **Apomixis** is the production of seeds without fertilisation. E.g. Some species of *Asteraceae* and grasses.
- It is a form of asexual reproduction that mimics sexual reproduction.
- In some species, diploid egg cell is formed without reduction division and develops into the embryo without fertilisation.
- In many species (e.g. many *Citrus* & *Mango* varieties) some **nucellar cells** surrounding the embryo sac divide, protrude into the embryo sac to form embryos. Thus each ovule contains many embryos. Occurrence of more than one embryo in a seed is called **polyembryony**.

Importance of apomixis in hybrid seed industry

- If the seeds collected from hybrids are sown, plants in the progeny will segregate and lose hybrid characters.
- Production of hybrid seeds is costly. So hybrid seeds are also expensive. If the hybrids are made into apomicts, there is no segregation in the hybrid progeny. So farmers can keep on using hybrid seeds to raise new crop.

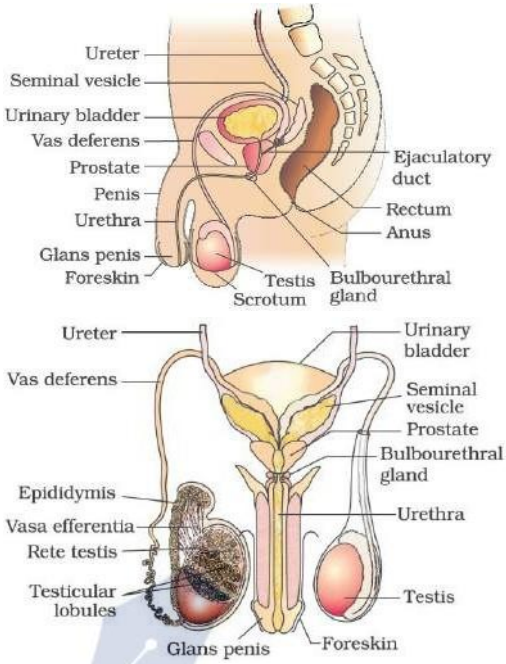
HUMAN REPRODUCTION

Reproduction is the production of young ones by an organism. Humans are sexually reproducing and viviparous.

HUMAN REPRODUCTIVE SYSTEM

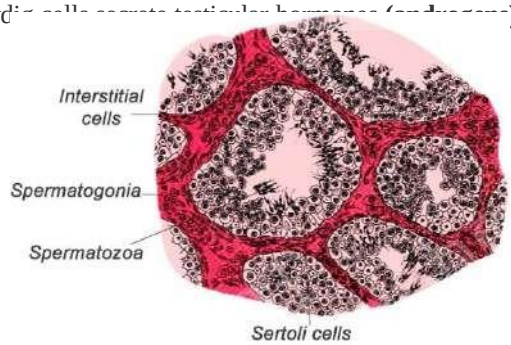
1. Male Reproductive System

- It consists of **paired testes, Accessory ducts, Accessory glands & external genitalia (penis).**



a. Paired testes

- **Primary sex organs** that produce **sperms** & **testosterone.**
- Testes are formed within the abdomen. Soon after the birth or at the 8th month of pregnancy they descent into the **scrotal sac (scrotum)** through **inguinal canal**.
- The low temperature (2-2.5^0 C less than the body temperature) of scrotum helps for proper functioning of testes and for **spermatogenesis.**
- Each testis is oval shaped. Length 4-5 cm, width: 2-3 cm.
- Each testis has about 250 **testicular lobules**.
- Each lobule contains 1-3 coiled **seminiferous tubules.**
- Seminiferous tubule is lined internally with **spermatogonia (male germ cells) & Sertoli cells (supporting cells)**.
- Sertoli cells give shape and nourishment to developing spermatogonia.
- The regions outside the seminiferous tubules (interstitial spaces) contain small blood vessels, **interstitial cells (Leydig cells)** and immunologically competent cells.
- Leydig cells secrete testicular hormones **(androgens).**



b. Accessory ducts (Duct system)

- Include **rete testis, vasa efferentia, epididymis** & **vas deferens.** They conduct sperms from testis as follows:
- Seminiferous tubules → **rete testis** (irregular cavities) → **vasa efferentia** (series of fine tubules) → **epididymis** (stores sperms temporarily) → **vas deferens** → join with duct of **seminal vesicle** to form **ejaculatory duct** → **urethra** → **urethral meatus.**
- Urethra receives ducts of prostate and Cowper's glands.

c. Accessory glands

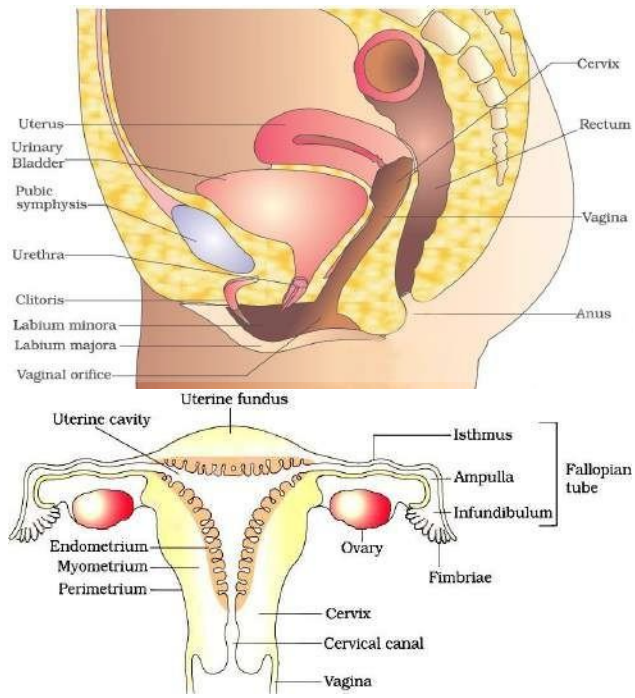
- Include a **prostate gland,** a pair of **seminal vesicles** and a pair of **Cowper's glands (bulbo-urethral glands).**
- Their collective secretion **(seminal plasma)** is rich in fructose, Ca and enzymes.
- Seminal plasma + sperms → **semen.**
- **Functions of seminal plasma:**
  - Helps for transporting sperms.
  - Supplies nutrients to sperms.
  - Provides alkalinity to counteract the acidity of uterus.
  - Secretions of Cowper's glands lubricate the penis.
- Secretions of epididymis, vas deferens, seminal vesicle & prostate help for maturation and motility of sperms.

d. Penis (external genitalia)

- It is a **copulatory organ** made of erectile **spongy tissue.**
- When spongy tissue is filled with blood, the penis erects. It facilitates **insemination**.
- The cone-shaped tip of the penis is called **glans penis.** It is covered by **prepuce (foreskin).**

2. Female Reproductive System

It includes **Ovaries, Accessory ducts** & **External genitalia.**



a. Paired ovaries

- Primary sex organs which produce **ova (female gamete)** & steroid **ovarian hormones (estrogen & progesterone).**
- Each ovary is **2-4 cm** in length.
- They are located on both side of the lower abdomen and connected to the pelvic wall and uterus by ligaments.
- Each ovary is covered by a thin epithelium which encloses the **ovarian stroma.**
- The stroma has outer **cortex** and inner **medulla.**
- Ovary contains groups of cells (**Ovarian follicles).** Each follicle carries a centrally placed **ovum.**

b. Accessory ducts (Duct system)

Include 2 **oviducts (Fallopian tubes), a uterus** & **vagina.**

➢ **Oviducts:** Each oviduct (10-12 cm long) has 3 parts:
- **Infundibulum:** Funnel-shaped opening provided with many finger-like **fimbriae.** It helps to collect the ovum.
- **Ampulla:** Wider part.
- **Isthmus:** Narrow part. It joins the uterus.

The **ciliated epithelium** lined the lumen of the oviduct drives the ovum towards the uterus.

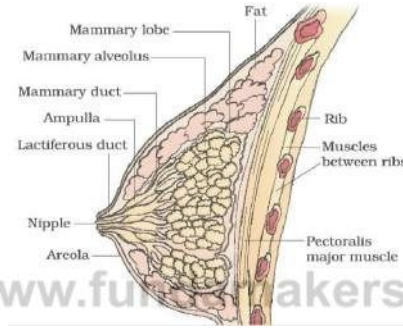
➢ **Uterus (womb)**: It is inverted pear shaped. It is supported by ligaments attached to the pelvic wall.
Uterus has 3 parts- Upper **fundus,** middle **body** and terminal **cervix.** Cervix opens to vagina.
Cervical canal and vagina forms **birth canal.**
The uterine wall has 3 layers:
- **Perimetrium**: External thin membrane.
- **Myometrium**: Middle thick layer of smooth muscle.
- **Endometrium**: Inner glandular and vascular layer.

➢ **Vagina:** It opens to the exterior between **urethra** & **anus.** The lumen of vagina is lined by a glycogen-rich mucous membrane consisting of **sensitive papillae** & **Bartholin's glands.** Bartholin's glands secrete mucus that lubricates the penis during sexual act.

c. External genitalia (vulva or pudendum)

- Consist of **Mons pubis, labia majora, labia minora, hymen & clitoris.**
- **Mons pubis:** A cushion of fatty tissue covered by pubic hair.
- **Labia majora**: Large, fleshy, fatty and hairy outer folds. Surrounds vaginal opening.
- **Labia minora**: Small, thin and hairless inner folds.
- **Hymen (Maiden head):** A membrane which partially cover the vaginal opening. It is often torn during the first coitus. It may also be broken by a sudden fall or jolt, insertion of a vaginal tampon; active participation in some sports items etc. In some women, hymen persists after coitus. So the hymen is not a reliable indicator of virginity or sexual experience.
- **Clitoris:** A highly sensitive organ lying just in front of the urethral opening.

Mammary glands (breasts)



- A pair of mammary glands contains glandular tissue & fat.
- Glandular tissue of each breast has 15-20 **mammary lobes** containing clusters of cells **(mammary alveoli).**
- Cells of alveoli secrete milk. It is stored in lumen of alveoli.
- The alveoli open into **mammary tubules.**
- The tubules of each lobe join to form a **mammary duct.**
- Several mammary ducts join to form a wider **mammary ampulla** which is connected to **lactiferous duct** through which milk is sucked out.

GAMETOGENESIS

- It is the formation of gametes in the gonads.
- It is 2 types: **Spermatogenesis** and **Oogenesis.**

1. Spermatogenesis

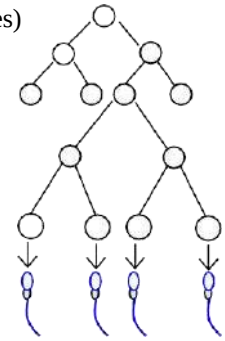
It is the process of formation of sperms (spermatozoa) in seminiferous tubules of testis. It has 2 stages:

a. Formation of spermatids: In this, Sperm mother cells (Spermatogonia or male germ cells) produce spermatids.

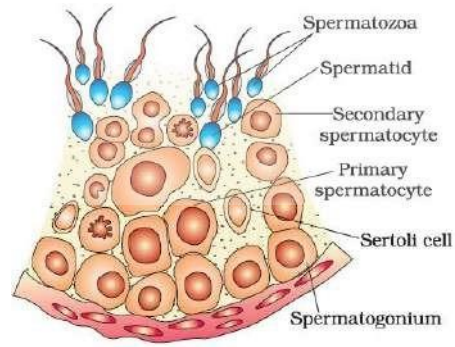
b. Spermiogenesis: Spermatids transform into **sperm.**

Schematic representation of spermatogenesis

Spermatogonia -2n (46 chromosomes)
↓ *Mitosis differentiation*
Primary spermatocytes (2n)
↓ *1st meiotic division*
Sec. spermatocytes -n (23)
↓ *2nd meiotic division*
Spermatids (n)
↓ *Differentiation*
Spermatozoa (n)



- **4 spermatids** are formed from each primary spermatocyte.
- After spermiogenesis, sperm heads are embedded in Sertoli cells to get nourishment. Then they are released to lumen of seminiferous tubules. It is called **spermiation.**



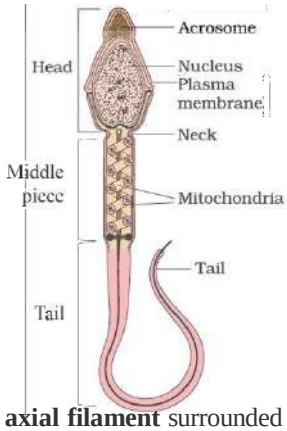
Diagrammatic sectional view of a seminiferous tubule

Role of Hormones in Spermatogenesis

- Hypothalamus releases **Gonadotropin releasing hormone (GnRH)**.

- GnRH stimulates the anterior pituitary gland to secrete 2 **gonadotropins** such as **Luteinizing hormone (LH)** and **follicle stimulating hormone (FSH).**
- LH acts on the **Leydig cells** and stimulates secretion of androgens. Androgens stimulate the spermatogenesis.
- FSH acts on the **Sertoli cells** and stimulates secretion of some factors for the spermiogenesis.

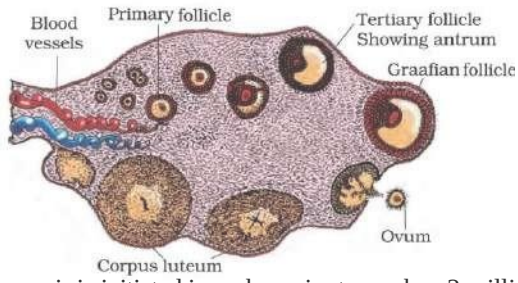
Structure of spermatozoa (Sperm)



- A mature sperm is about **60 µ (0.06 mm)** long.
- A plasma membrane envelops the whole body of sperm.
- A sperm has 3 regions:
  a. **Head:** Oval shaped. Formed of **nucleus** and **acrosome.** Acrosome is formed from **Golgi complex.** It contains **lytic enzymes.** Behind the head is a neck.
  b. **Middle piece:** Composed of **axial filament** surrounded by **mitochondria** & **cytoplasm.** Mitochondria produce energy for the sperm motility.
  c. **Tail:** Consists of a **central axial filament**. The sperm moves in fluid medium and female genital tract by the **undulating movement** of the tail.
- Man ejaculates **200-300 million sperms** during a coitus.
- For normal fertility, at least 60% sperms must have normal shape and size. 40% of them must show vigorous motility.

2. Oogenesis

- It is the process of formation and maturation of **ovum.**
- It takes place in **Graafian follicles.**



- Oogenesis is initiated in embryonic stage when 2 million of **egg mother cells (oogonia)** are formed within each ovary.
- No more oogonia are formed and added after birth.
- Oogonia multiply to form **primary oocytes.** They enter **prophase-I** of the meiosis and get temporarily arrested at that stage.
- Each primary oocyte gets surrounded by a layer of **granulosa cells** to form **primary follicle.**
- Many primary follicles degenerate during the phase from birth to puberty. Therefore, at puberty, only **60,000-80,000** primary follicles are left in each ovary.
- Primary follicles get surrounded by more layers of granulosa cells and a new **theca** to form **secondaryfollicles.**
- The secondary follicles transform into a **tertiary follicle.** It has a fluid filled cavity **(antrum).** The theca layer forms an inner **theca interna** and an outer **theca externa.**
- The primary oocyte in tertiary follicle grows and undergoes first unequal meiotic division to form a large **secondary oocyte (n)** & a tiny first **polar body (n).** So, secondary oocyte retains nutrient rich cytoplasm of primary oocyte.
- It is unknown that whether the first polar body divides further or degenerates.
- The tertiary follicle further changes into the **mature follicle (Graafian follicle).**
- Secondary oocyte forms a new membrane **(zona pellucida).**
- Graafian follicle now ruptures to release the **secondary oocyte (ovum)** from the ovary. This is called **ovulation.**

Schematic representation of oogenesis

Oogonia -2n (46 chromosomes)

↓ *Mitosis differentiation (at foetal stage)*

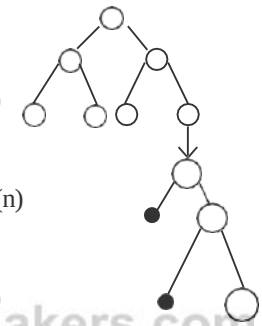
Primary oocyte- 2n (grows in size)

↓ *1st meiotic division (prior to ovulation)*

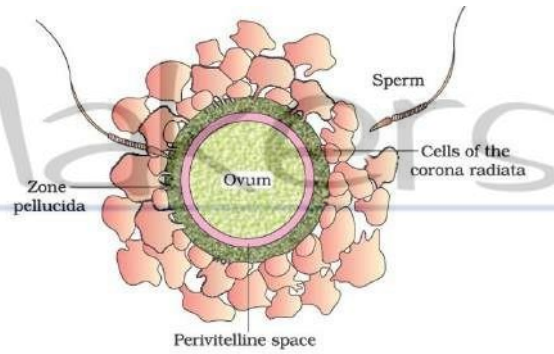
Sec. oocyte (n) & first polar body (n)

↓ *2nd meiotic division (during fertilization)*

Ovum (n) & second Polar body (n)



Structure of ovum (egg)



- Spherical and **non-motile.** About **0.2 mm** in diameter.
- Ovum has 3 membranes:
  a. **Plasma membrane:** Innermost layer.
  b. **Zona pellucida:** Outer to the plasma membrane.
  c. **Corona radiata:** Outer layer formed of follicle cells.

Spermatogenesis & Oogenesis- A comparison

Spermatogenesis	Oogenesis
Occurs in testis.	Occurs in ovary.
Limited growth phase.	Elaborated growth phase
Each primary spermatocyte gives 4 sperms.	Each primary oocyte gives one ovum.
No polar body formation.	Polar bodies are formed.
Begins at puberty and extends up to senility.	Begins at embryonic stage but suspends up to puberty. It ceases around the age of fifty.

MENSTRUAL CYCLE (REPRODUCTIVE CYCLE)

- It is the cyclic events starting from one menstruation till the next during the **reproductive period** (from puberty to menopause) of a woman's life.
- Its duration is **28 or 29 days.**
- Menstrual cycle is also seen in other primates.
- Menstrual cycle includes **Ovarian cycle** (changes in ovary) & **Uterine cycle** (changes in uterus, oviduct & vagina).
- Menstrual cycle has the following phases:

I. Menstrual phase: 1-5th day

- The cycle starts with **menstrual flow (bleeding).**
- It lasts for **3-5 days.**
- Menstruation occurs if the released ovum is not fertilized. It results in breakdown of endometrial lining and uterine blood vessels that comes out through vagina.
- Lack of menstruation indicates pregnancy. It may also be caused due to stress, poor health etc.
- **Menarche:** The first menstruation during puberty.

II. Follicular (Proliferative) phase: 5-13th day

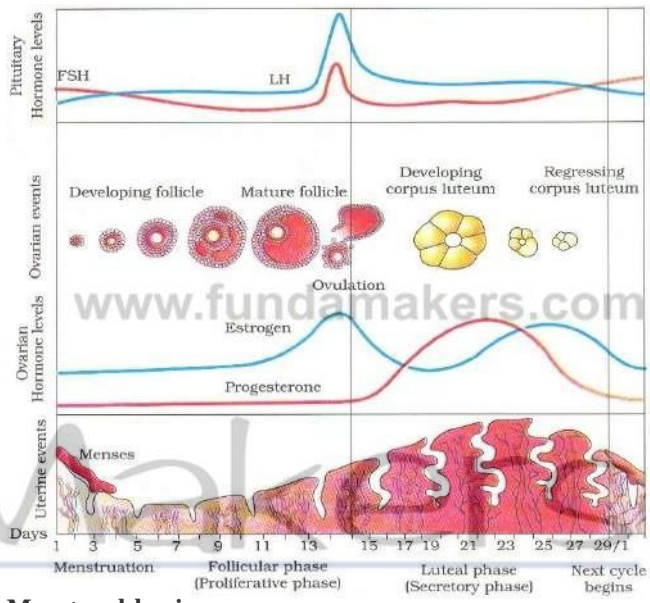
- It starts from **5th day** after menstruation and completed within **8-12 days.**
- In this phase, the action of gonadotropins **(FSH &LH)** from pituitary occurs. FSH stimulates
  - Development of primary follicles into **Graafian follicles.**
  - Secretion of **oestrogens** by **Graafian follicles.**
- Oestrogens stimulate
  - **Proliferation** of **ruptured uterine endometrium** and mucus lining of **oviduct & vagina**.
  - Development of secondary sexual characters.
  - Suppression of FSH secretion.
  - Secretion of LH (Luteinizing hormone).

III. Ovulatory phase: 14th day

- LH & FSH attain a peak level in the middle of cycle.
- Rapid secretion of LH (**LH surge**) induces rupture of Graafian follicle and thereby **ovulation** (on 14th day).

IV. Secretory (Luteal) phase: 15-28th day

- After ovulation, Graafian follicle is transformed to a yellow endocrine mass called **Corpus luteum.** It secretes **progesterone.**
- **Functions of progesterone:**
  - Makes the endometrium **maximum vascular, thick** and **soft.** Thus, the uterus gets ready for implantation.
  - Inhibits the FSH secretion to prevent development of a second ovarian follicle.
- If fertilization does not occur, corpus luteum degenerates. It causes disintegration of endometrium. It leads to next **menstruation** and new cycle.
- If a woman becomes pregnant, all events of menstrual cycle stop and there is no menstruation.
- Menstrual cycle ceases around **50 years** of age. It is called **Menopause.**



Menstrual hygiene:

- Take bath and clean body regularly.
- Use sanitary napkins or clean homemade pads.
- Change them after every 4–5 hrs as per the requirement.
- Dispose the used napkins or pads properly. Do not throw them in the drainpipe of toilets or in the open area.
- After handling the napkin, wash hands with soap.

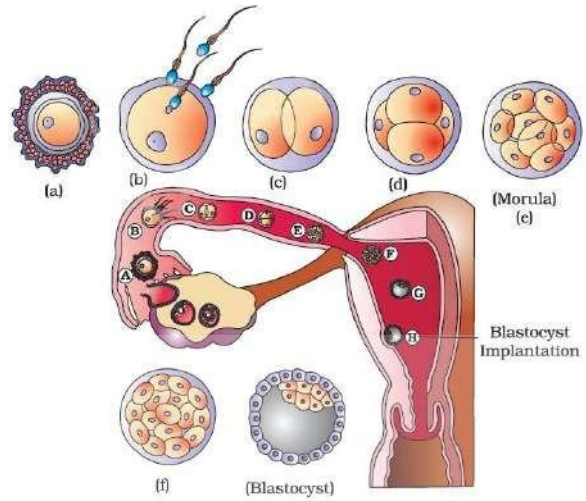
FERTILIZATION AND IMPLANTATION

- During copulation, semen is released by the penis into the vagina. It is called **insemination.**
- Fusion of a sperm with ovum is called **fertilization.** It occurs in **Ampullary region** of fallopian tube.

Sperms → vagina → cervical canal → uterus → isthmus
↓
Fertilization ← Ampullary region
↑
Ovum (from ovary) → fimbriae → infundibulum

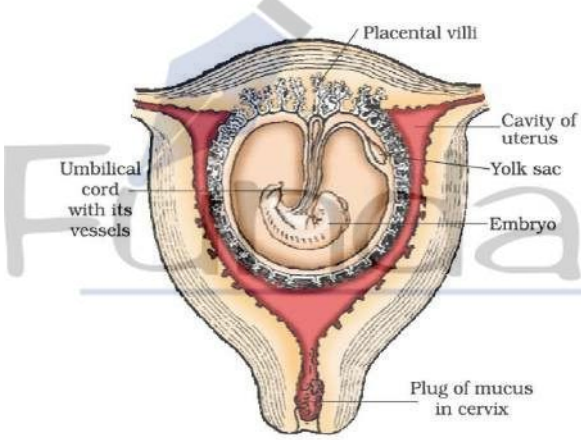
- Fertilization happens only if ovum & sperms are transported simultaneously. So all copulations do not lead to fertilization & pregnancy.
- A sperm contacts with **zona pellucida.** It induces changes in the membrane that block entry of additional sperms.
- The secretions of the **acrosome** help sperm to enter the egg cytoplasm via zona pellucida & plasma membrane. This causes second meiotic division of secondary oocyte to form an **ovum (ootid)** and a **second polar body.**
- The haploid nuclei of the sperm and ovum fuse together to form a **diploid zygote.**
- Zygote undergoes mitotic division **(cleavage)** as it moves through the isthmus towards the uterus and forms 2, 4, 8, 16 daughter cells called **blastomeres.**
- The embryo with 8-16 blastomeres is called a **morula.**
- Morula continues to divide and transforms into **blastocyst.**
- In blastocyst, blastomeres are arranged into **trophoblast** (outer layer) and an **inner cell mass** attached to trophoblast.

- The trophoblast layer gives nourishment to inner cell mass. Also, it gets attached to endometrium.
- After attachment, uterine cells divide rapidly and cover the blastocyst. Thus, the blastocyst becomes embedded in the endometrium. This is called **implantation.**
- The inner cell mass gets differentiated to **3 germ layers** (outer **ectoderm,** middle **mesoderm** & inner **endoderm).** This 3-layered structure **(gastrula)** forms the embryo.



PREGNANCY AND EMBRYONIC DEVELOPMENT

- After implantation, finger-like projections **(chorionic villi)** appear on the trophoblast.
- They are surrounded by uterine tissue and maternal blood.
- The chorionic villi & uterine tissue are interdigitated to form **placenta.** It is a structural and functional unit b/w embryo (foetus) and maternal body.
- Placenta is connected to the embryo by an **umbilical cord.** It transports substances to and from the embryo.



Functions of placenta

- Acts as **barrier** between the foetus and mother.
- Supply **O_2, nutrients** etc. from mother to foetus.
- Remove **CO_2 and excretory wastes** from foetus.
- Acts as an endocrine gland. It secretes **Human chorionic gonadotropin (hCG), human placental lactogen (hPL), oestrogens, progesterone** & **relaxin.** Relaxin is also secreted by ovary.
- During pregnancy, levels of **estrogens, progestogens, cortisol, prolactin, thyroxin** etc. are also increased in maternal blood. They support the fetal growth, metabolic changes in the mother and maintain pregnancy.
- The germ layers give rise to all tissues (organs). The **stem cells** in inner cell mass have the potency to give rise to all the tissues and organs.
- Human pregnancy **(gestation period)** lasts 9 months (for cats: 2 months, dogs: 2 months, elephants: 21 months).

Changes in embryo during pregnancy

- **After one month:** Heart is formed.
- **End of second month:** Limbs and digits are developed.
- **End of 12 weeks (first trimester):** Major organs (limbs, external genital organs etc.) are well developed.
- **During 5th month:** First movement of foetus and appearance of hair on the head.
- **End of 24 weeks (end of 2nd trimester):** Body is covered with fine hair, eyelids separate and eye lashes are formed.
- **End of 9 months:** Ready for delivery.

PARTURITION AND LACTATION

- **Parturition (labour):** Process of giving birth to young ones.
- Parturition is induced by **neuroendocrine mechanism.**
- The signals originating from the foetus and placenta induce mild uterine contractions **(fetal ejection reflex)**. This causes the release of **oxytocin** from **maternal pituitary.**
- Oxytocin causes stronger uterine muscle contractions which in turn stimulate further secretion of oxytocin. This process is continued leading to expulsion of the baby out of the uterus through the **birth canal.**
- After parturition, the **umbilical cord** is cut off.
- The placenta & remnants of umbilical cord are expelled from the maternal body after parturition. It is called **"after birth".**
- The mammary glands produce milk towards the end of pregnancy. It is called **lactation.**
- The yellowish milk produced during the initial few days of lactation is called **colostrum.** It contains several antibodies essential to develop resistance for the new born babies.

REPRODUCTIVE HEALTH

According to **World Health Organisation (WHO),** ***Reproductive health*** *is a total well-being in all aspects of reproduction i.e., physical, emotional, behavioural & social.*

REPRODUCTIVE HEALTH: PROBLEMS & STRATEGIES

India initiated reproductive health programmes **(family planning)** in 1951.

Wider reproduction-related areas are in operation under the **Reproductive & Child Health Care (RCH) programmes.**

Such programmes deal the following:

- Give awareness about reproduction related aspects for creating a reproductively healthy society.
- Educate people about birth control, care of pregnant mothers, post-natal care of mother and child, importance of breast feeding, equal opportunities for male & female child etc.
- Awareness of problems due to population explosion, social evils like sex-abuse and sex-related crimes, etc.

Aims and needs of sex education in schools

- To provide right information about sex-related aspects. It helps to avoid sex-related myths and misconceptions.
- To give proper information about reproductive organs, adolescence and related changes, safe and hygienic sexual practices, sexually transmitted diseases (STD), AIDS etc.

POPULATION STABILIZATION & BIRTH CONTROL

- In **1900,** world population was about **2 billion**. By **2000,** it rocketed to about **6 billion** and **7.2 billion in 2011.**
- In India, population was nearly **350 million** at the time of independence. It reached **1 billion by 2000** and crossed **1.2 billion** in **May 2011.** It means every sixth person in the world is an Indian.
- According to the 2011 census report, our population growth rate was less than **2%** (i.e. 20/1000/year), a rate at which our population could increase rapidly.

Reasons for population explosion

- Increased health facilities and better living conditions.
- Rapid decline in death rate, **maternal mortality rate (MMR)** and **infant mortality rate (IMR).**
- Increase in number of people in reproducible age.

Impacts of population explosion

Scarcity of basic requirements (e.g. food, shelter & clothing).

Control measures

- Motivate smaller families by using **contraceptive methods.**
- Aware peoples about a slogan ***Hum Do Hamare Do*** **(we two, our two).** Many couples have adopted a **'one child norm'.**
- Statutory rising of marriageable age of females (18 years) and males (21 years).

Properties of an ideal contraceptive

- User-friendly, easily available, effective and reversible.
- No or least side-effects.
- It should not interfere with sexual drive, desire & sexual act.

CONTRACEPTIVE METHODS

1. Natural/Traditional methods

Avoid chances of ovum and sperms meeting. It includes

- **Periodic abstinence:** Avoid coitus from day 10 to 17 of the menstrual cycle (**fertile period)** to prevent conception.
- **Coitus interruptus (withdrawal):** Withdraw penis from the vagina just before ejaculation to avoid insemination.
- **Lactational amenorrhea:** It is the absence of menstrual cycle & ovulation due to intense lactation after parturition. Fully breastfeeding increases lactation. This method helps to prevent conception. This is effective up to 6 months following parturition.

  It has no side effect. But chances of failure are high.

2. Barriers

They prevent physical meeting of sperm & ovum. E.g.

- **Condoms (E.g. Nirodh):** Made of rubber/latex sheath.
  Condoms for male: Cover the penis.
  Condoms for female: Cover the vagina & cervix.
  Condoms are used just before coitus. They prevent the entry of semen into female reproductive tract.
  Condoms are very popular because:
  - It protects the user from STDs and AIDS.
  - Easily available and disposable.
  - It can be self-inserted and thereby give privacy to user.
- **Diaphragms, cervical caps** and **vaults:**
  - Made of rubber and are inserted into the female reproductive tract to cover the cervix during coitus.
  - They block the entry of sperms through the cervix.
  - They are reusable.
  - **Spermicidal creams, jellies & foams** are used along with these barriers to increase contraceptive efficiency.

3. Intra Uterine Devices (IUDs)

These are inserted by doctors or nurses in the uterus through vagina. They increase phagocytosis of sperms.

IUDs are ideal method to delay pregnancy or space children.

Types of IUDs:

- **Non-medicated IUDs:** They retard sperm motility. Also have spermicidal effect. E.g. Lippes loop.
- **Copper releasing IUDs:** Cu ions suppress motility and fertilising capacity of sperms. E.g. CuT, Cu7, Multiload 375.
- **Hormone releasing IUDs**: They make the uterus unsuitable for implantation and the cervix hostile to the sperms. E.g. Progestasert, LNG-20.

4. Oral contraceptives

- Oral administration of **progestogens** or **progestogen–oestrogen** combinations in the form of tablets **(pills)**.
- Pills are taken daily for 21 days starting within the first five days of menstrual cycle. After a gap of 7 days (menstruation period), it should be repeated in the same pattern till the female desires to prevent conception.
- They inhibit ovulation and implantation and thicken cervical mucus to prevent entry of sperms.
- Pills are very effective with lesser side effects.

- ***Saheli:*** New oral contraceptive for the females. It is developed by **Central Drug Research Institute(CDRI)** in **Lucknow.** It contains a non-steroidal preparation. It is a 'once a week' pill with very few side effects and high contraceptive value.

5. Injectables

- Progestogens or Progestogens-oestrogen combination are used by females as **injections** or **implants** under skin.
- Their mode of action is like that of pills and their effective periods are much longer.

Progestogens *or* ***progestogen-oestrogen*** *combinations &* ***IUDs*** *are used as* ***emergency contraceptives*** *within 72 hours of coitus. It avoids pregnancy due to rape or casual intercourse.*

6. Surgical methods (sterilization)

- It helps to block gamete transport and thereby prevents conception. It is very effective but reversibility is poor.
- **Vasectomy:** Sterilization procedure in males. In this, a small part of the vas deferens is removed or tied up through a small incision on the scrotum.
- **Tubectomy:** Sterilization procedure in females. In this, a small part of the fallopian tube is removed or tied up through a small incision in the abdomen or through vagina.

Side effects of anti-natural contraceptives:

Nausea, abdominal pain, breakthrough bleeding, irregular menstrual bleeding, breast cancer etc.

MEDICAL TERMINATION OF PREGNANCY (MTP)

- Intentional or voluntary termination of pregnancy before full term is called **MTP** or **induced abortion.**
- **45 to 50 million** MTPs are performed in a year all over the world (i.e. 1/5th of total number of conceived pregnancies).
- MTP helps to decrease the population.
- Many countries have not legalised MTP due to emotional, ethical, religious and social issues.
- Government of India legalised MTP in 1971 with some strict conditions to check illegal female foeticides.

Importance of MTP

- To avoid unwanted pregnancies due to casual intercourse or failure of the contraceptive used during coitus or rapes.
- It is essential in cases where continuation of pregnancy could be harmful to the mother or to the foetus or both.

MTPs are safe during the **first trimester,** (up to 12 weeks of pregnancy). 2nd trimester abortions are very risky.

Problems related with MTPs

- Majority of the MTPs are performed illegally.
- Misuse of **amniocentesis** test for foetal sex determination. If the foetus is female, it is followed by MTP. Such practices are dangerous for the young mother and foetus.

Amniocentesis: In this, some amniotic fluid of the foetus is taken to analyse the foetal cells & dissolved substances. It is used to test the presence of genetic disorders, survivability of the foetus etc.

Government of India enacted **The Medical Termination of Pregnancy (Amendment) Act, 2017** to reduce illegal abortion and consequent maternal mortality and morbidity. According to this Act, a pregnancy may be terminated within the first 12 weeks on the opinion of a registered medical practitioner. If the pregnancy is between 12 - 24 weeks, two registered medical practitioners must be of the opinion.

SEXUALLY TRANSMITTED DISEASES (STDs)

- Diseases or infections transmitted through sexual intercourse are called **Sexually transmitted diseases/infections (STDs or STIs)/Venereal diseases (VD) or Reproductive tract infections (RTI).** E.g. Gonorrhoea, syphilis, genital herpes, genital warts, trichomoniasis, hepatitis-B & HIV leading to AIDS.
- Hepatitis-B & HIV are also transmitted
  - By sharing of injection needles, surgical instruments etc.
  - By transfusion of blood.
  - From infected mother to foetus.
- Except hepatitis-B, genital herpes & HIV, other diseases are completely curable if detected early and treated properly.
- **Early symptoms**: Itching, fluid discharge, slight pain, swellings, etc. in the genital region.
- Absence or less significant early symptoms and the social stigma deter the infected persons to consult a doctor. This leads to **pelvic inflammatory diseases (PID),** infertility, chlamydiasis, ectopic pregnancies, abortions, still births, cancer of the reproductive tract etc.
- All persons are vulnerable to STDs. These are very high among persons in the age group of 15-24 years.
- **Prevention:**
  - i. Avoid sex with unknown partners/multiple partners.
  - ii. Always use condoms during coitus.
  - iii. In case of doubt, go to a qualified doctor for early detection and get complete treatment.

INFERTILITY

- It is the inability to conceive or produce children even after 2 years of unprotected sexual cohabitation.
- The reasons for this may be physical, congenital, diseases, drugs, immunological or even psychological.

ASSISTED REPRODUCTIVE TECHNOLOGIES (ART)

These are the technologies used to correct the infertility problems. Some of them are given below:

1. *In vitro* fertilisation (IVF) or Test tube baby programme

In this method, ova from the wife/donor and sperms from the husband/donor are collected and are induced to form zygote under simulated conditions in the laboratory. This is followed by **Embryo transfer (ET).**

ET is 2 types:

- **Zygote Intra Fallopian Transfer (ZIFT):** Transfer of zygote or early embryo (with up to 8 blastomeres) into fallopian tube.
- **Intra Uterine Transfer (IUT):** Transfer of embryo with more than 8 blastomeres into the uterus.

Embryo formed by ***in vivo*** **fertilisation** (fertilisation within the female) is also used for such transfer to assist those females who cannot conceive.

2. Gamete Intra Fallopian Transfer (GIFT)

Transfer of an ovum from a donor into the fallopian tube of another female who cannot produce ovum, but can provide suitable environment for fertilization and development.

3. Intra cytoplasmic sperm injection (ICSI)

It is a laboratory procedure in which a single sperm (from male partner) is injected directly into an egg (from female partner). After fertilization, the embryo is implanted into the woman's uterus.

4. Artificial insemination (AI) technique

The semen collected from husband or a donor is artificially introduced into the vagina or the uterus of the female.

Artificial insemination into the uterus is known as **intra-uterine insemination (IUI)**.

This technique is useful for the male partner having inability to inseminate female or low sperm counts etc.

Problems of ART

- It requires specialized professionals and expensive instrumentation. Therefore, these facilities are available only in very few centres.
- Emotional, religious and social problems.

Legal adoption is a good method for couples looking for parenthood.

PRINCIPLES OF INHERITANCE AND VARIATION

IMPORTANT TERMS

- **Genetics:** Study of inheritance, heredity and variation of characters or Study of genes and chromosomes.
- **Inheritance:** Transmission of characters from parents to progeny. It is the basis of **Heredity**.
- **Variation:** Difference between parents and offspring.
- **Character:** A heritable feature among the parents & offspring. E.g. Eye colour.
- **Trait:** Variants of a character. E.g. Brown eye, Blue eye.
- **Allele:** Alternative forms of a gene. E.g. T (tall) and t (dwarf) are two alleles of a gene for the character height.
- **Homozygous:** The condition in which chromosome pair carries similar alleles of a gene. Also known as **pure line (True breeding).** E.g. TT, tt, YY, yy etc.
- **Heterozygous:** The condition in which chromosome pair carries dissimilar alleles of a gene. E.g. Tt, Yy etc.
- **Dominant character:** The character which is expressed in heterozygous condition. It indicates with capital letter.
- **Recessive character:** The character which is suppressed in heterozygous condition. It indicates with small letter.
- **Phenotype:** Physical expression of a character.
- **Genotype:** Genetic constitution of a character.
- **Hybrid:** An individual produced by the mating of genetically unlike parents.
- **Punnett square:** A graphical representation to calculate probability of all genotypes of offspring in a genetic cross.

MENDEL'S LAWS OF INHERITANCE

Gregor Mendel is the Father of genetics.
He conducted some hybridization experiments on **garden peas (*Pisum sativum*)** for 7 years (1856-1863).

Steps in making a cross (Deliberate mating) in pea:

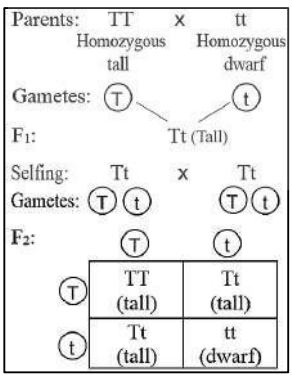
- **Selection** of 2 pea plants with contrasting characters.
- **Emasculation:** Removal of anthers of one plant to avoid self-pollination. This is female parent.
- **Pollination:** Collection of pollen grains from the male parent and transferring to female parent.
- **Collection & germination** of seeds to produce offspring.

Mendel selected 7 pairs of true breeding pea varieties:

7 Characters	Contrasting Traits	
	Dominant	Recessive
1. Stem height	Tall	Dwarf
2. Flower colour	Violet	White
3. Flower position	Axial	Terminal
4. Pod shape	Inflated	Constricted
5. Pod colour	Green	Yellow
6. Seed shape	Round	Wrinkled
7. Seed colour	Yellow	Green

INHERITANCE OF ONE GENE

Monohybrid cross: A cross involving 2 plants differing in one character pair. E.g. Mendel crossed tall and dwarf pea plants to study the inheritance of one gene.



Monohybrid phenotypic ratio:
3 Tall: 1 Dwarf = **3:1**

Monohybrid genotypic ratio:
1 Homozygous tall (TT)
2 Heterozygous tall (Tt)
1 Homozygous dwarf (tt)
= **1:2:1**

Mendel made similar observations for other pairs of traits. He proposed that some **factors** were inherited from parent to offspring. Now it is called as **genes**.

> Do not use ***T*** for tall and ***d*** for dwarf because it is difficult to remember whether ***T*** & ***d*** are alleles of same gene or not.

The F_1 (Tt) when self-pollinated, produces gametes **T** and **t** in equal proportion. During fertilization, pollen grains of **T** have **50%** chance to pollinate eggs of **T** & **t**. Also, pollen grains of **t** have **50%** chance to pollinate eggs of **T** and **t.**
1/4th of the random fertilization leads to TT (¼ TT).
1/2 (2/4) of the random fertilization leads to Tt (½ Tt).
1/4th of the random fertilization leads to tt (¼ tt).

Tt x Tt

Binomial expression = $(ax + by)^2$

Hence $(½\ T + ½\ t)^2$ $= (½\ T + ½\ t)\ (½\ T + ½\ t)$

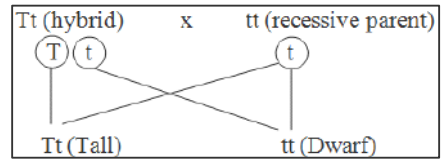
$= ¼\ TT + ¼\ Tt + ¼\ Tt + ¼\ tt$

$= ¼\ \underline{TT} + ½\ \underline{Tt} + ¼\ tt$

Mendel self-pollinated the F_2 plants. He found that dwarf F_2 plants continued to generate dwarf plants in F_3 & F_4. He concluded that genotype of the dwarfs was homozygous- ***tt***.

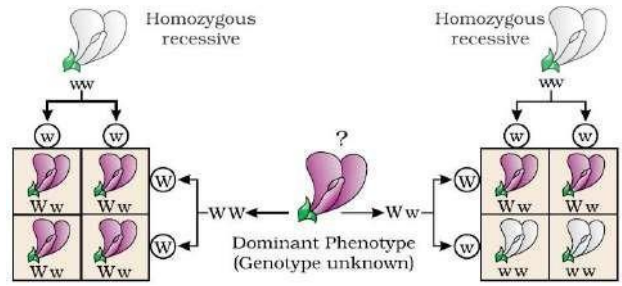
Backcross and Testcross

- **Backcross:** Cross between a hybrid and its any parent.
- **Testcross:** Crossing of an organism with dominant phenotype to a recessive individual. E.g.



Hence monohybrid test cross ratio= **1:1**

Test cross is used to find out the unknown genotype of a character. E.g.



All violet: Unknown flower is homozygous dominant

50% violet, 50% white: Unknown flower is heterozygous

Mendel conducted **test cross** to determine the F_2 genotype.

Mendel's Principles or Laws of Inheritance

1. First Law (Law of Dominance)

- *Characters are controlled by discrete units called* ***factors.***
- *Factors occur in pairs.*
- *In a dissimilar pair of factors, one member of the pair dominates* ***(dominant)*** *the other* ***(recessive).***

2. Second Law (Law of Segregation)

"During gamete formation, the factors (alleles) of a character pair present in parents segregate from each other such that a gamete receives only one of the 2 factors".

Homozygous parent produces similar gametes. Heterozygous parent produces two kinds of gametes.

INHERITANCE OF TWO GENES

Dihybrid cross: It is a cross between two parents differing in 2 pairs of contrasting characters. E.g. Cross b/w pea plant with homozygous round shaped & yellow coloured seeds (RRYY) and wrinkled shaped & green coloured seeds (rryy).

Parents: RRYY X rryy

Gametes: (RY) (ry)

F_1: RrYy (Round yellow)

Selfing: RrYy X RrYy

Gametes: (RY) (Ry) (rY) (ry) (RY) (Ry) (rY) (ry)

F_2:

	(RY)	(Ry)	(rY)	(ry)
(RY)	RRYY *Ro. Yel*	RRYy *Ro. Yel*	RrYY *Ro. Yel*	RrYy *Ro. Yel*
(Ry)	RRYy *Ro. Yel*	RRyy *Ro. Gr*	RrYy *Ro. Yel*	Rryy *Ro. Gr*
(rY)	RrYY *Ro. Yel*	RrYy *Ro. Yel*	rrYY *Wri. Yel*	rrYy *Wri. Yel*
(ry)	RrYy *Ro. Yel*	Rryy *Ro. Gr*	rrYy *Wri. Yel*	rryy *Wri. Gr*

On observing the F_2, Mendel found that yellow and green colour segregated in a 3:1 ratio.

Round & wrinkled seed shape also segregated in a 3:1 ratio.

Dihybrid Phenotypic ratio= 9 Round yellow: 3 Round green: 3 Wrinkled yellow: 1 Wrinkled green = **9:3:3:1**

The ratio of 9:3:3:1 can be derived as a combination series of 3 yellow: 1 green, with 3 round: 1 wrinkled.

i.e. **(3: 1) (3: 1) = 9: 3: 3: 1**

Dihybrid genotypic ratio: 1:2:1:2:4:2:1:2:1

RRYY	=1	RRYy	=2	RrYY	=2
RrYy	=4	RRyy	=1	Rryy	=2
rrYY	=1	rrYy	=2	rryy	=1

Mendel's 3rd Law: Law of Independent Assortment

- It is based on the results of dihybrid crosses.
- It states that *"When two pairs of traits are combined in a hybrid, segregation of one pair of characters is independent of the other pair of characters".*

The concept of dominance

- Every gene contains information to express a particular trait.
- In heterozygotes, there are 2 types of alleles:
  - ***Unmodified (normal or functioning) allele:*** It is generally dominant and represents original phenotype.
  - ***Modified allele:*** It is generally recessive.
- E.g. Consider a gene that contains information for producing an enzyme. Normal allele of that gene produces a normal enzyme. Modified allele is responsible for production of
  - (i) Normal/less efficient enzyme or
  - (ii) A non-functional enzyme or
  - (iii) No enzyme at all

In the first case: The modified allele will produce the same phenotype like unmodified allele. Thus, modified allele is equivalent to unmodified allele.

In 2nd and 3rd cases: The phenotype will dependent only on the functioning of the unmodified allele. Thus the modified allele becomes recessive.

OTHER PATTERNS OF INHERITANCE (NON-MENDELIAN INHERITANCE)

1. Incomplete Dominance

- It is an inheritance in which heterozygous offspring shows intermediate character b/w two parental characteristics.
- E.g. Flower colour in **snapdragon (dog flower or *Antirrhinum sp.*)** and ***Mirabilis jalapa*** **(4'O clock plant).**

Parents: RR x rr (Red flowered, White flowered)

Gametes: (R) (r)

F_1: Rr (Pink)

Selfing: Rr x Rr

Gametes: (R) (r) (R) (r)

F_2:

	(R)	(r)
(R)	RR (Red)	Rr (Pink)
(r)	Rr (Pink)	rr (White)

Here, cross between homozygous **red** & **white** produces **pink** flowered plant. Thus phenotypic & genotypic ratios are same.

Phenotypic ratio=
1 Red: 2 Pink: 1 White

Genotypic ratio=
1 (RR): 2 (Rr): 1(rr)

This means that **R** was not completely dominant over **r**.

- Pea plants also show incomplete dominance in other traits.

2. Co-dominance

- It is the inheritance in which both alleles of a gene are expressed in a hybrid. E.g. ABO blood grouping in human.
- ABO blood groups are controlled by the gene **I**.
- This gene controls the production of **sugar polymers (antigens)** that protrude from plasma membrane of RBC.
- The gene **I** has three alleles I^A, I^B & **i**.
- I^A and I^B produce a slightly different form of the sugar while allele **i** doesn't produce any sugar.

Alleles from parent 1	Alleles from parent 2	Genotype of offspring	Blood types (phenotype)
I^A	I^A	$I^A I^A$	A
I^A	I^B	$I^A I^B$	AB
I^A	i	I^Ai	A
I^B	I^A	$I^A I^B$	AB
I^B	I^B	$I^B I^B$	B
I^B	i	I^Bi	B
i	i	ii	O

When I^A and I^B are present together, they both express their own types of sugars. This is due to **co-dominance.**

3. Multiple allelism

- It is the presence of **more than two alleles** of a gene to govern same character.
- E.g. ABO blood grouping (3 alleles: I^A, I^B & i).
- In an individual, only two alleles are present. Multiple alleles can be found only in a population.

4. Polygenic inheritance

- It is the inheritance in which some traits are controlled by several genes **(multiple genes).**
- E.g. human skin colour, human height etc.
- It considers the influence of environment.
- In a polygenic trait, the phenotype reflects the contribution of each allele, i.e., the effect of each allele is additive.

Human skin colour:

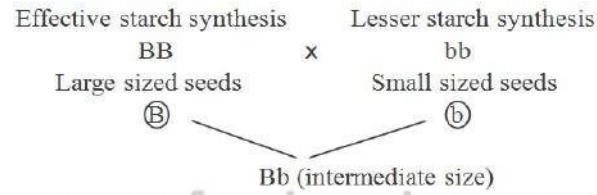
- Assume that 3 genes A, B, C control human skin colour. The dominant forms **A, B & C** responsible for **dark skin** colour and recessive forms **a, b & c** for **light skin** colour.
- Genotype with all the dominant alleles **(AABBCC)** gives **darkest skin** colour.
  Genotype with all the recessive alleles **(aabbcc)** gives **lightest skin** colour.
  Therefore, genotype with **3 dominant alleles and 3 recessive alleles** gives **an intermediate skin** colour.
- Thus, number of each type of alleles determines the darkness or lightness of the skin.

5. Pleiotropy

- Here, a single gene exhibits multiple phenotypic expressions. Such a gene is called **pleiotropic gene.**
- In most cases, the mechanism of pleiotropy is the effect of a gene on metabolic pathways which contributes towards different phenotypes.
- E.g. Starch synthesis in pea, sickle cell anaemia, phenylketonuria etc.
- In Phenylketonuria & sickle cell anaemia, the mutant gene has many phenotypic effects. E.g. Phenylketonuria causes mental retardation, reduction in hair and skin pigmentation.

Starch synthesis in pea plant:

- Starch is synthesized effectively by **BB** gene. Therefore, large starch grains are produced. **bb** have lesser efficiency in starch synthesis and produce smaller starch grains.
- Starch grain size also shows **incomplete dominance.**



CHROMOSOMAL THEORY OF INHERITANCE

Mendel's work remained unrecognized till 1900 because,

- Communication was not easy.
- His mathematical approach was new and unacceptable.
- The concept of genes (factors) as stable and discrete units could not explain the continuous variation seen in nature.
- He could not give physical proof for the existence of factors.

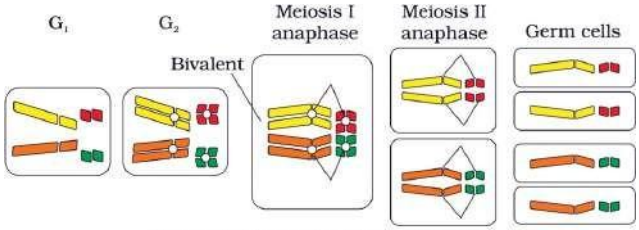
In 1900, **de Vries, Correns** & **von Tschermak** independently rediscovered Mendel's results.

Chromosomal Theory of Inheritance (1902):

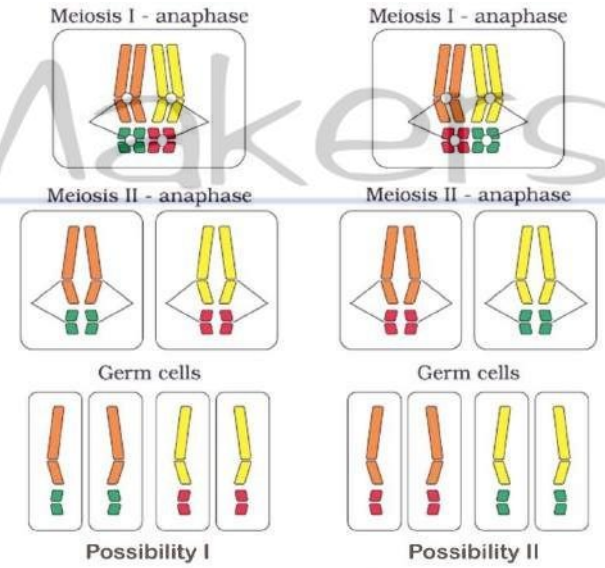
- Proposed by **Walter Sutton** & **Theodore Boveri.**
- They said that pairing & separation of a pair of chromosomes lead to segregation of a pair of factors they carried.
- **Sutton** united chromosomal segregation with Mendelian principles and called it the **chromosomal theory of inheritance**. It states that,

- Chromosomes are **vehicles of heredity.**
- Two identical chromosomes form a **homologous pair.**
- Homologous pair **segregates** during gamete formation.
- Independent pairs **segregate independently** of each other.

Genes (factors) are present on chromosomes. Hence genes and chromosomes show similar behaviours.



Segregation of chromosomes



Independent assortment of chromosomes

Thomas Hunt Morgan proved chromosomal theory of inheritance using fruit flies (***Drosophila melanogaster)***.

It is the suitable material for genetic study because,

- They can grow on simple synthetic medium.
- Short generation time (life cycle: 12-14 days).
- Breeding can be done throughout the year.
- Hundreds of progenies per mating.
- Male and female flies are easily distinguishable. E.g. Male is smaller than female.
- It has many types of hereditary variations that can be seen with low power microscopes.

LINKAGE AND RECOMBINATION

Linkage is the physical association of two or more genes on a chromosome. They do not show independent assortment. **Recombination** is the generation of non-parental gene combinations. It occurs due to independent assortment or crossing over.

Morgan carried out several dihybrid crosses in ***Drosophila*** to study sex-linked genes. E.g.

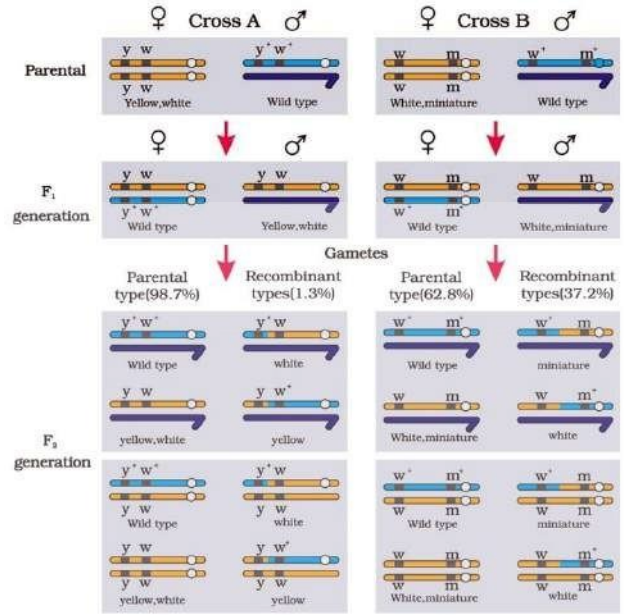
Cross 1: Yellow-bodied, white-eyed females
X
Brown-bodied, red-eyed males (wild type)

Cross 2: White-eyed, miniature winged
X
Red eyed, large winged (wild type)

Morgan intercrossed their F_1 progeny. He found that

- The two genes did not segregate independently and the F_2 ratio deviated from the 9:3:3:1 ratio.
- Genes were located on the X chromosome.
- When two genes were situated on the same chromosome, the proportion of parental gene combinations was much higher than the non-parental type. This is due to **linkage.**
- Genes of white eye & yellow body were very tightly linked and showed only **1.3%** recombination.
- Genes of white eye & miniature wing were loosely linked and showed **37.2%** recombination.

- **Tightly linked genes** show **low recombination**. **Loosely linked** genes show **high recombination.**



Alfred Sturtevant used the recombination frequency between gene pairs for measuring the distance between genes and 'mapped' their position on the chromosome.

Genetic maps are used as a starting point in the sequencing of genomes. E.g. **Human Genome Project.**

SEX DETERMINATION

- The chromosomes that are involved in sex determination are called **sex chromosomes (allosomes).** They include X & Y chromosomes.
- Autosomes are chromosomes other than sex chromosomes. Number of autosomes is same in males and females.
- **Henking (1891)** studied spermatogenesis in some insects and observed that 50 % of sperm received a nuclear structure after spermatogenesis, and other 50 % sperm did not receive it. Henking called this structure as the **X body** (now it is called as **X-chromosome)**.

Mechanism of sex determination

a. XX-XO mechanism: Here, male is heterogametic, i.e. XO (Gametes with X and gametes without X) and female is homogametic, i.e. XX (all gametes are with X-chromosomes). E.g. Many insects such as grasshopper.

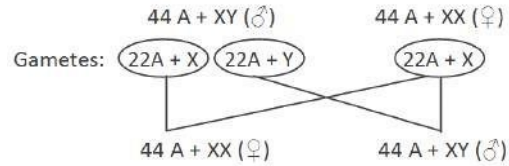
b. XX-XY mechanism: Male is heterogametic (X & Y) and female is homogametic (X only). E.g. Human & *Drosophila.*

c. ZZ-ZW mechanism: Male is homogametic (ZZ) and female is heterogametic (Z & W). E.g. Birds.

XX-XO & XX-XY mechanisms show **male heterogamety**. ZZ-ZW mechanism shows **female heterogamety**.

Sex Determination in Humans (XX-XY type)

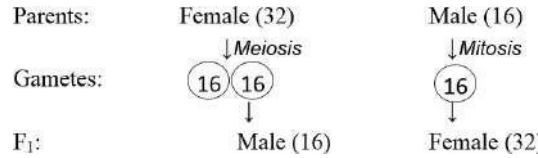
- Human has 23 pairs of chromosomes (22 pairs of autosomes and 1 pair of sex chromosomes).
- A pair of X-chromosomes (XX) is present in the female, whereas X and Y chromosomes are present in male.
- During spermatogenesis, males produce 2 types of gametes: 50 % with X-chromosome and 50 % with Y-chromosome.
- Females produce only ovum with an X-chromosome.
- There is an equal probability of fertilization of the ovum with the sperm carrying either X or Y chromosome.



The sperm determines whether the offspring male or female.

Sex determination in honeybee

- It is based on the number of sets of chromosomes an individual receives.
- Fertilised egg develops as a female (queen or worker).
- An unfertilised egg develops as a male (drone). It is called **parthenogenesis.**
- Therefore, the females are diploid (32 chromosomes) and males are haploid (16 chromosomes). This is called as **haplodiploid sex determination system.**
- In this system, the males produce sperms by mitosis. They do not have father and thus cannot have sons, but have a grandfather and can have grandsons.



MUTATION, PEDIGREE ANALYSIS AND GENETIC DISORDERS

MUTATION

It is a sudden heritable change in DNA sequences resulting in changes in the genotype and the phenotype of an organism.
Mutation is 2 types:

- ✓ **Point mutation**: The mutation due to change (substitution) in a single base pair of DNA. E.g. sickle cell anaemia.
- ✓ **Frame-shift mutation:** It is the deletion or insertion of base pairs resulting in the shifting of DNA sequences.

- Loss (deletion) or gain (insertion/ duplication) of DNA segment cause Chromosomal abnormalities (aberrations).
- Chromosomal aberrations are seen in **cancer cells.**
- The agents which induce mutation are called **mutagens.** They include
  - **Physical mutagens:** UV radiation, α, β, γ rays, X-ray etc.
  - **Chemical mutagens:** Mustard gas, phenol, formalin etc.

PEDIGREE ANALYSIS

- In human, control crosses are not possible. So the study of family history about inheritance is used.
- Such an analysis of genetic traits in several generations of a family is called **pedigree analysis**.
- The representation or chart showing family history is called **family tree (pedigree).**
- In human genetics, pedigree study is utilized to trace the inheritance of a specific trait, abnormality or disease.

Symbols used in pedigree analysis

Male: □ Female: ○ Sex unspecified: ◇

Affected individual: ■ ● ◆ Mating: □—○

Mating b/w relatives (consanguineous mating): □=○

Parents above & children below

Parents with affected male child

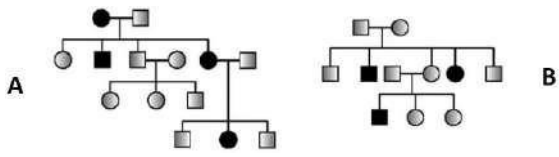
Five unaffected offspring

GENETIC DISORDERS

The disorders due to change in genes or chromosomes.
2 types: **Mendelian disorders & Chromosomal disorders.**

1. Mendelian Disorders

- It is caused by alteration or mutation in the single gene.
- E.g. **Haemophilia, Colour blindness, Sickle-cell anaemia, Phenylketonuria, Thalassemia, Cystic fibrosis etc.**
- The pattern of inheritance of Mendelian disorders can be traced in a family by the pedigree analysis.
- Mendelian disorders may be dominant or recessive.
- Pedigree analysis helps to understand whether the trait is dominant or recessive.



Pedigree analysis of
(A) Autosomal dominant trait (E.g. Myotonic dystrophy)
(B) Autosomal recessive trait (E.g. Sickle-cell anaemia)

Haemophilia (Royal disease):

- It is a sex linked (X-linked) recessive disease.
- In this, a protein involved in the blood clotting is affected.
- A simple cut results in non-stop bleeding.
- The disease is controlled by 2 alleles, **H** & **h**. **H** is normal allele and **h** is responsible for haemophilia.

X^HX^H	Normal female
X^HX^h	Heterozygous female (carrier). She may transmit the disease to sons.
X^hX^h	Hemophilic female
X^HY	Normal male
X^hY	Hemophilic male

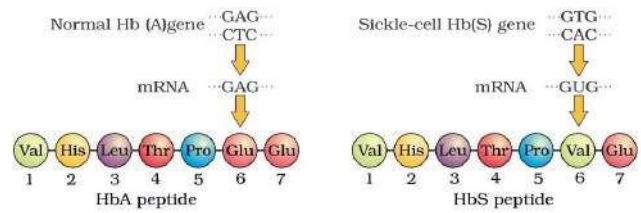
- In females, haemophilia is very rare because it happens only when mother is at least carrier and father haemophilic (unviable in the later stage of life).
- Queen Victoria was a carrier of hemophilia. So her family pedigree shows many haemophilic descendants.

Colour blindness:

- It is a sex-linked (X-linked) recessive disorder due to defect in either red or green cone of eye. It results in failure to discriminate between red and green colour.
- It is due to mutation in some genes in X chromosome.
- It occurs in 8% of males and only about 0.4% of females. This is because the genes are X-linked.
- Normal allele is dominant (C). Recessive allele (c) causes colour blindness.
- The son of a heterozygous woman (carrier, X^CX^c) has a 50% chance of being colour blind.
- A daughter will be colour blind only when her mother is at least a carrier and her father is colour blind (X^cY).

Sickle-cell anaemia:

- This is an autosome linked recessive disease.
- It can be transmitted from parents to the offspring when both the partners are carrier (heterozygous) for the gene.
- The disease is controlled by a pair of allele, Hb^A and Hb^S.
  Homozygous dominant (Hb^AHb^A): normal
  Heterozygous (Hb^AHb^S): carrier; sickle cell trait
  Homozygous recessive (Hb^SHb^S): affected
- The defect is caused by the substitution of **Glutamic acid (Glu)** by **Valine (Val)** at the **sixth position** of the **β-globin chain** of the haemoglobin (Hb).



- This is due to the single base substitution at the sixth codon of the **β-globin gene** from **GAG** to **GUG.**
- The mutant Hb molecule undergoes polymerization under low oxygen tension causing the change in shape of the RBC from biconcave disc to elongated sickle like structure.

Phenylketonuria:

- An inborn error of metabolism.

- Autosomal recessive disease.
- It is due to mutation of a gene that codes for the enzyme ***phenyl alanine hydroxylase*****.** This enzyme converts an amino acid ***phenylalanine*** into ***tyrosine.***
- The affected individual lacks this enzyme. As a result, phenylalanine accumulates and converts into ***phenyl pyruvic acid*** and other derivatives.
- They accumulate in brain resulting in mental retardation. These are also excreted through urine because of poor absorption by kidney.

Thalassemia:

- An autosome-linked recessive blood disease.
- It is transmitted from unaffected carrier (heterozygous) parents to offspring.
- It is due to mutation or deletion.
- It results in reduced synthesis of α or β globin chains of haemoglobin. It forms abnormal haemoglobin and causes anaemia.
- Based on the chain affected, thalassemia is 2 types:
  - α **Thalassemia:** Here, production of α **globin** chain is affected. It is controlled by two closely linked genes **HBA1 & HBA2** on **chromosome 16** of each parent. Mutation or deletion of one or more of the four genes causes the disease. The more genes affected, the less α globin molecules produced.
  - β **Thalassemia:** Here, production of β **globin** chain is affected. It is controlled by a single gene **HBB** on **chromosome 11** of each parent. Mutation of one or both the genes causes the disease.
- Thalassemia is a **quantitative problem** (synthesise very less globin molecules). Sickle-cell anaemia is a **qualitative problem** (synthesise incorrectly functioning globin).

2. Chromosomal disorders

They are caused due to absence or excess or abnormal arrangement of one or more chromosomes. 2 types:

a. Aneuploidy: The gain or loss of chromosomes due to failure of segregation of chromatids during cell division.

b. Polyploidy (Euploidy): It is an increase in a ***whole set of chromosomes*** due to failure of cytokinesis after telophase stage of cell division. This is very rare in human but often seen in plants.

Examples for chromosomal disorders

- **Down's syndrome:** It is the presence of an additional copy of chromosome number 21 **(trisomy of 21).**

  Genetic constitution: 45 A + XX or 45 A + XY (i.e. **47** chromosomes).

  Features:
  - They are short statured with small round head.
  - Broad flat face.
  - Furrowed big tongue and partially open mouth.
  - Many "loops" on finger tips.
  - Broad palm with characteristic palm simian crease.
  - Retarded physical, psychomotor & mental development.
  - Congenital heart disease.
- **Klinefelter's Syndrome**: It is the presence of an additional copy of X-chromosome in male (trisomy).

  Genetic constitution: 44 A + XXY (i.e. **47** chromosomes).

  Features:
  - Overall masculine development. However, the feminine development is also expressed. E.g. Development of breast **(Gynaecomastia).**
  - Sterile.
  - Mentally retarded.
- **Turner's syndrome**: This is the absence of one X chromosome in female (monosomy).

  Genetic constitution: 44 A + X0 (i.e. **45** chromosomes).

  Features:
  - Sterile, Ovaries are rudimentary.
  - Lack of other secondary sexual characters.
  - Dwarf.
  - Mentally retarded.

EVOLUTION

Evolution is an orderly change from one form to another.

Evolutionary Biology is the study of evolutionary history of life forms.

ORIGIN OF LIFE

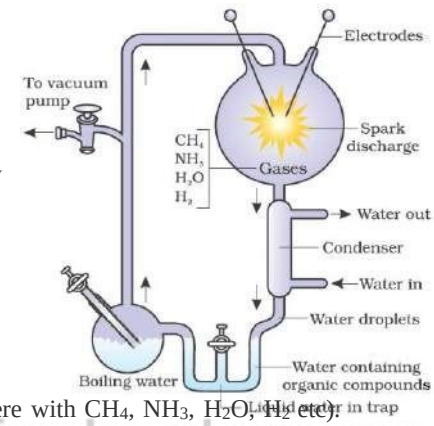
- **Big Bang Theory** states that universe originated about 20 billion years ago by a singular huge explosion.
- The earth was formed about **4.5 billion years** ago.
- There was no atmosphere on early earth. Water vapour, CH_4, CO_2 & NH_3 released from molten mass covered the surface.
- The UV rays from the sun broke up water into H_2 and O_2.
- Oxygen combined with NH_3 & CH_4 to form water, CO_2 etc.
- The ozone layer was formed. As it cooled, the water vapour fell as rain to form oceans.
- Life appeared almost **four billion years** ago.

THEORIES OF ORIGIN OF LIFE

1. **Theory of spontaneous generation (Abiogenesis):** states that, life came out of decaying and rotting matter like straw, mud etc.
   Louis Pasteur disproved this theory. He demonstrated that life comes only from pre-existing life.
   He showed that life did not come from killed yeast in a closed pre-sterilized flask. But in an opened flask, life (microbes) appeared.
2. **Biogenesis:** Proposed by **Francisco Redi, Spallanzani** & **Louis Pasteur**. It states that, life originates from pre-existing life. But it does not explain origin of first life.
3. **Cosmic theory (Theory of Panspermia):** It states that, the units of life (spores) were transferred to different planets including earth.
4. **Theory of special creation:** It states that, living things were created by some supernatural power (God).
5. **Theory of chemical evolution:** Proposed by **Oparin** & **Haldane.** It states that, the first form of life was originated from non-living inorganic & organic molecules such as CH_4, NH_3, H_2O, sugars, proteins, nucleic acids etc. i.e. *"Abiogenesis first, but biogenesis ever since".*

Urey-Miller experiment

- **Harold Urey** & **Stanley Miller** experimentally proved theory of chemical evolution. They created a condition like that of primitive earth (i.e. high temperature, volcanic storms, reducing atmosphere with CH_4, NH_3, H_2O, H_2 etc):



- They made electric discharge in a closed flask containing CH_4, NH_3, H_2 and water vapour at 800° C. As a result, some amino acids are formed.
- In similar experiments, others observed formation of sugars, nitrogen bases, pigment and fats.

First **non-cellular forms** of life originated 3 billion years ago. They were **self-replicating metabolic capsule** containing RNA, proteins, Polysaccharides etc.

EVIDENCES FOR EVOLUTION

1. Paleontological evidences

Paleontology is the study of fossils.

Fossils are remnants of life forms found in rocks (earth crust). *They are written documents of evolution.*

Significance of fossils:

a. To study ***phylogeny*** (evolutionary history or race history). E.g. Horse evolution.
b. To study the ***connecting link*** between two groups of organisms. E.g. *Archaeopteryx.*
c. To study about ***extinct animals***. E.g. Dinosaurs.
d. To study about ***geological period*** by analysing fossils in different ***sedimentary rock layers.*** The study showed that life forms varied over time and certain life forms are restricted to certain geological time spans.

2. Morphological & Anatomical evidences

Comparative anatomy and morphology shows that different forms of animals have some common structural features. This can be explained as follows:

a. Homologous organs

- **Homologous organs** are the organs having fundamentally similar structure and origin but different functions. This phenomenon is called **Homology.**
- E.g. Human hand, Whale's flippers, Bat's wing & Cheetah's foot. These forelimbs have different functions but similar anatomical structures such as bones (e.g. humerus, radius, ulna, carpals, metacarpals & phalanges).
- Homology is also seen in heart, brain etc.
- **Homology in plants:** E.g. Thorns of *Bougainvillea* and tendrils of *Cucurbita*.
- The origin of homologous organs is due to ***Divergent evolution.*** It is the evolution by which **related species** become **less similar** to survive and adapt in different environmental condition.
- Homology indicates common ancestry.

b. Analogous organs

These are the organs having similar function but different structure & origin. This phenomenon is called **Analogy.** E.g.

- **Wings of insects** (formed of a thin flap of chitin) and **wings of birds** (modified forelimbs).
- **Eyes of Octopus** (retina from skin) and **mammals** (retina from embryonic brain).

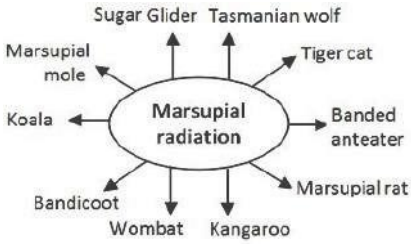
- **Flipper of Penguins** and **Dolphins**.
- **Sweet potato** (modified root) & **Potato** (modified stem).
- **Trachea of insects** (from ectoderm) and **lungs of vertebrates** (from endoderm).

Origin of analogous organs is due to ***Convergent evolution.*** It is the evolution by which **unrelated species** become more **similar** to survive and adapt in similar environmental condition.

3. Adaptive radiation (Biogeographical evidences)

Adaptive radiation (evolution by adaptation) is the evolution of different species from an ancestor in a geographical area starting from a point. It is a type of divergent evolution. E.g.

- Darwin's finches in Galapagos Islands.
- Australian marsupials (Marsupial radiation).



- Placental mammals in Australia.

When more than one adaptive radiation is appeared in an isolated geographical area, it results in ***convergent evolution.*** E.g. Australian Marsupials and Placental mammals.

Placental mammals	Australian Marsupials
Mole	Marsupial mole
Ant eater	Numbat (Ant eater)
Mouse	Marsupial mouse
Lemur	Spotted cuscus
Flying squirrel	Flying phalanger
Bobcat	Tasmanian tiger cat
Wolf	Tasmanian wolf

4. Biochemical evidences

- Organisms show similarities in proteins, genes, other biomolecules & metabolism. It indicates common ancestry.

5. Embryological evidences

- Proposed by **Ernst Haeckel.**
- He observed that all vertebrate embryos have some common features that are absent in adult.
- E.g. all vertebrate embryos (including human) develop vestigial gill slits just behind the head. But it is functional only in fish and not found in other adult vertebrates.
- However, **Karl Ernst von Baer** rejected this proposal. He noted that embryos never pass through the adult stages of other animals.

6. Evidences for evolution by natural selection

Natural selection is the process in which organisms with better favourable & heritable variation are survived and reproduced.

Some evidences are given below:

- **Industrial melanism:** In England, before industrialization (1850s), there were more white-winged moths (*Biston betularia*) on trees than dark winged or melanised moths (*Biston carbonaria*). After industrialization (1920), more dark-winged moths and less white winged moths were developed.

  Reason:

  Before industrialization: There was white lichens covered the trees. In that background, white winged moths survived but dark winged moths were picked out by predators.

  After industrialization: The tree trunks became dark due to industrial smoke and soot. No growth of lichens. So white winged moths did not survive because the predators identified them easily. Dark winged moth survived because of suitable dark background.
- Development of resistant varieties in organisms against ***herbicides, pesticides, antibiotics*** or ***drugs*** etc.

These are the examples for natural selection by **anthropogenic action** (evolution due to human activities).

THEORIES OF BIOLOGICAL EVOLUTION

Lamarckism (Theory of Inheritance of Acquired characters)

It is proposed by Lamarck. It states that evolution of life forms occurred by the inheritance of acquired characters.

Acquired characters are developed by use & disuse of organs.

- **Evolution by use of organs:** E.g. Long neck of giraffe is due to continuous elongation to forage leaves on trees. This acquired character was inherited to succeeding generations.
- **Evolution by disuse:** E.g. Disappearance of limbs in snakes.

This theory was eliminated out because it is proved that the characters are inherited only through genes.

Darwinism (Theory of Natural selection)

- Proposed by **Charles Darwin.**
- It was based on observations during a sea voyage in a sail ship called **H.M.S. Beagle.**
- **Alfred Wallace** (a naturalist worked in **Malay Archepelago)** had also come to similar conclusions.
- Work of **Thomas Malthus** on populations influenced Darwin.

Darwinism is based on 2 key concepts:

- **Branching descent:** It explains that all organisms are modified descendants of previous life forms.
- **Natural selection:** Consider a bacterial colony **A** growing on a given medium. If the medium composition is changed, only a part of the population can survive under new condition. This variant population (B) outgrows the others and appears as new species, i.e. **B is better than A under new condition.** Thus, nature selects for fitness.

Natural selection is based on the following facts:

- **Heritable minor variations:** It is either beneficial or harmful to the organisms.
- **Overproduction:** Population size grows exponentially due to maximum reproduction (E.g. bacterial population).
- **Limited natural resources:** Resources are not increased in accordance with the population size.
- **Struggle for existence:** It is the competition among organisms for resources so that population size is limited.
- **Survival of the fittest:** In struggle for existence, organisms with beneficial variations can utilize resources better. Hence, they survive and reproduce. This is called

Survival of the fittest. It leads to a change in population characteristics and new forms appear.

Darwin ignored about origin of variation and mechanism of evolution or speciation.

MECHANISM OF EVOLUTION

- **Hugo de Vries** proposed **Mutation Theory** of evolution.
- He conducted experiments on *Oenothera lamarckiana* (evening primrose) and believed that evolution takes place through mutation and not by minor variation.
- **Darwinian variation** is minor, slow and directional. It results in **gradual evolution.**
- **Mutational variation** is sudden, random & directionless. Here, speciation is by **saltation** (single step, large mutation).
- Mutation is the origin of variation for evolution.

HARDY-WEINBERG PRINCIPLE

- It states that *allele frequencies in a population are stable and is constant from generation to generation in the absence of disturbing factors.*
- The **gene pool** (total genes and their alleles in a population) remains a constant. This is called **genetic equilibrium (Hardy-Weinberg equilibrium).**
- Sum total of all the allelic frequencies = 1
- E.g. Consider, in a diploid, **p** & **q** are the frequencies of alleles **A & a** respectively.

  Frequency of AA = p^2
  Frequency of aa = q^2
  Frequency of Aa = 2pq
  Hence $p^2 + 2pq + q^2 = 1$ [binomial expansion of $(p+q)^2$]

Change of frequency of alleles in a population disturbs Hardy-Weinberg equilibrium. This change is due to evolution.

Factors affecting Hardy-Weinberg equilibrium

a. Gene migration: Gene flow from one population to another. Here gene frequencies change in both populations. Gene flow occurs if migration happens multiple times.

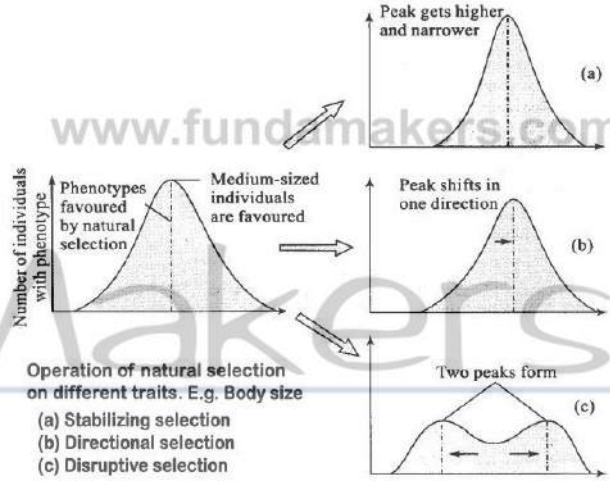
b. Genetic drift: The gene flow by chance causing change in frequency. Sometimes, the change in frequency is so different in the new sample of population that they become a different species. The original drifted population becomes founders and the effect is called **founder effect.**

c. Mutation: It results in formation of new phenotypes. Over few generations, this leads to speciation.

d. Genetic recombination: Reshuffling of genecombinations during crossing over resulting in genetic variation.

e. Natural selection: It is 3 types.

- **Stabilizing selection:** Here, more individuals acquire mean character value and variation is reduced.
- **Directional selection:** Individuals of one extreme (value other than mean character value) are more favoured.
- **Disruptive selection:** Individuals of both extremes (peripheral character value at both ends of the distribution curve) are more favoured.



A BRIEF ACCOUNT OF EVOLUTION

The geological time scale includes 4 eras: **Proterozoic, Palaeozoic, Mesozoic & Cenozoic.**

1. Proterozoic era: 2500 - 541 million yrs ago(mya)

- **2000 mya:** First cellular forms of life appeared.
- Some of the cells had the ability to release O_2 as the light reaction in photosynthesis.
- Single celled organisms became multicellular organisms.

2. Palaeozoic era (540 - 252 mya)

- It has 6 periods: **Cambrian** (540 - 490 mya), **Ordovician** (490 - 443 mya), **Silurian** (425 mya), **Devonian** (405 mya), **Carboniferous** (360 mya) **& Permian** (285 mya).
- **500 mya:** Invertebrates were formed.
- **450 mya:** First land organisms (plants) appeared.
- **400 mya:** Arthropods invaded the land.
- **350 mya:** Jawless fishes were evolved.
  Lobefins (stout & strong finned fishes) could move on land and go back to water. They evolved to first amphibians (ancestors of modern day frogs & salamanders).

In 1938, a lobe-fin called **coelacanth** fish was caught in South Africa which was thought to be extinct.

- **320 mya:** Sea weeds and few plants were existed.
- Amphibians evolved to reptiles. They lay thick-shelled eggs (do not dry up in sun).
- **Giant ferns (Pteridophytes)** were present but they all fell to form coal deposits slowly.

3. Mesozoic era (252 - 66 mya)

- Age of reptiles and gymnosperms.
- It has 3 periods: **Triassic (230 mya), Jurassic (208 mya) & Cretaceous (144 mya).**
- **200 mya:** Some of the land reptiles went back into water to evolve into fish-like reptiles (E.g. *Ichthyosaurs*).
- The land reptiles were **dinosaurs (*Tyrannosaurus rex, Triceratops, Stegosaurus, Brachiosaurus* etc.)**
  T. rex was the largest dinosaur (20 feet in height, huge fearsome dagger-like teeth).
- Toothed birds were emerged.

4. Cenozoic era (66 - 0 mya)

- Age of Mammals & Angiosperms.
- It has 2 periods: **Tertiary (66 mya)** & **Quaternary (2 mya** - Age of man).
- **65 mya:** Dinosaurs suddenly disappeared. Some say climatic changes killed them. Some say most of them evolved into birds.
- First mammals were shrew-like. Their fossils are small sized.
- In South America, there were mammals resembling horse, hippopotamus, bear, rabbit etc. Due to continental drift, when South America joined North America, these animals were overridden by North American fauna.
- Due to continental drift, Australian marsupials survived because of lack of competition from any othermammals.

ORIGIN AND EVOLUTION OF MAN

- **15 mya:** ***Dryopithecus*** *&* ***Ramapithecus.***
  Hairy. Walked like gorillas & chimpanzee.
  Dryopithecus: ape-like.
  Ramapithecus: man-like.
- **3-4 mya: Man-like primates** walked up right in eastern Africa. Height up to 4 feet. This belief is based on fossils of man-like bones found in Ethiopia & Tanzania.
- **2 mya:** ***Australopithecus.*** Lived in East African grass lands. Hunted with stone weapons. Ate fruits.
  Homo habilis: First human-like being (hominid).
  Brain capacity: 650-800 cc. Did not eat meat.
- **1.5 mya:** ***Homo erectus*** **(Java man).** Large brain (900 cc). Ate meat.
- **1 lakh - 40,000 yrs ago:** ***Homo neanderthalensis*** **(Neanderthal man).**
  Brain capacity: 1400 cc. Lived in East & Central Asia. Used hides to protect their body. Buried their dead.
- **75,000 - 10,000 yrs ago (ice age)*: Homo sapiens* (Modern man).**
  Pre-historic cave art developed about 18,000 years ago. E.g. Cave paintings at Bhimbetka rock shelter in Raisen district of Madhya Pradesh.
  Agriculture & settlements: 10,000 years ago.

Sequence of Human evolution:

Dryopithecus → Ramapithecus → Australopithecus → Homo habilis → H. erectus → H. neanderthalensis → H. sapiens

HUMAN HEALTH AND DISEASES

- **Health** is a state of complete *physical, mental & social well-being.* It is affected by genetic disorders, infections, change in life style (food, water, rest, exercise, habits etc).
  - Mind influences immune system (through neural and endocrine systems) and thereby health.
- When the functioning of organs or systems of the body is adversely affected, it is called a **disease**.
  - Diseases may be **infectious** (transmits from one person to another) or **non-infectious** (do not transmit. E.g. cancer).
- Disease causing organisms are called **Pathogens.** Parasites are pathogens as they harm the host.

Good humour hypothesis (by **Hippocrates** & **Indian Ayurveda system):** It states that health is a state of body & mind where there is a balance of certain humours. Persons with 'black bile' belong to hot personality and would have fevers.

William Harvey disproved this hypothesis. He discovered blood circulation and demonstrated normal body temperature in persons with black bile using thermometer.

COMMON INFECTIOUS DISEASES IN MAN

1. BACTERIAL DISEASES

a. Typhoid: Pathogen is ***Salmonella typhi.***

- **Mode of transmission:** It enters small intestine through food & water and migrates to other organs via blood.
- **Symptoms:** Sustained high fever (39º-40º C), headache, weakness, stomach pain, constipation & loss of appetite. Intestinal perforation and death may occur.

Widal test is used for confirmation of the disease.

Mary Mallon **(Typhoid Mary)** was a professional cook. She was a typhoid carrier who spread typhoid for several years through the food she prepared.

b. Pneumonia: Pathogen is ***Streptococcus pneumoniae* & *Haemophilus influenzae.***

It infects lung alveoli. The alveoli get filled with fluid leading to respiratory problems.

- **Mode of transmission:** Inhaling the droplets/aerosols released by an infected person. Sharing glasses and utensils with an infected person.
- **Symptoms:** Respiratory problems, fever, chills, cough, headache. In severe cases, lips and finger nails turn grey to bluish colour.

Other bacterial diseases: Dysentery, plague, diphtheria, etc.

2. VIRAL DISEASES

a.* Common cold:** Pathogen is ***Rhinoviruses.

It infects nose & respiratory passage but not lungs.

- **Mode of transmission:** Inhaling droplets resulting from cough or sneezes. Through contaminated objects (pens, books, cups, doorknobs, computer accessories) etc.
- **Symptoms:** Nasal congestion & discharge, fever, headache, sore throat, cough, hoarseness, tiredness etc. Common cold lasts for 3-7 days.

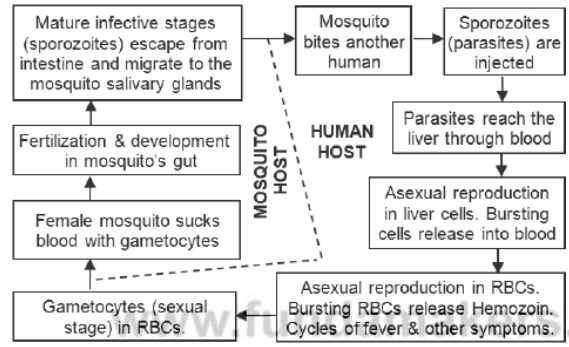
3. PROTOZOAN DISEASES

a.* Malaria:** Pathogen is ***Plasmodium sp. *(P. vivax, P. malariae* & *P. falciparum).*

Most serious (malignant) malaria is caused by *P. falciparum.*

- **Mode of transmission:** By female *Anopheles* mosquito.
- **Symptoms:** Haemozoin (toxin released by *Plasmodium)* causes chill and high fever recurring every 3-4 days.

Life cycle of Plasmodium



b. Amoebiasis (Amoebic dysentery): Pathogen is ***Entamoeba histolytica.***

- **Mode of transmission:** Houseflies (mechanical carriers) transmit parasites from faeces to food & water.
- **Symptoms:** Constipation, abdominal pain and cramps, stools with excess mucus and blood clots.

4. HELMINTH DISEASES

a. Ascariasis: Pathogen is ***Ascaris*** (Intestinal parasite).

- **Mode of transmission:** Soil, water, vegetables, fruits etc. contaminated with faeces containing eggs of parasites.
- **Symptoms:** Internal bleeding, muscular pain, fever, anaemia and blockage of intestinal passage.

b. Filariasis (Elephantiasis): Pathogen is **Filarial worms or *Wuchereria*** *(W. bancrofti & W. malayi).*

- **Mode of transmission:** Bite of female *Culex* mosquito.
- **Symptoms:** Filarial worms live in lymphatic vessels (usually of lower limbs). It causes chronic inflammation of the organs in which they live for many years. Limbs and genital organs may be deformed.

5. FUNGAL DISEASES

a.* Ring worms:** Pathogens are ***Microsporum, Trichophyton* & *Epidermophyton. They are seen in groin, b/w toes etc.

- **Mode of transmission:** From soil or by using towels, cloths, comb etc. Heat and moisture help fungi to grow.
- **Symptoms:** Dry, scaly lesions on skin, nails, scalp etc. Intense itching.

PREVENTION AND CONTROL OF DISEASES

Personal hygiene

Keep the body clean. Use clean drinking water, food etc.

Public hygiene

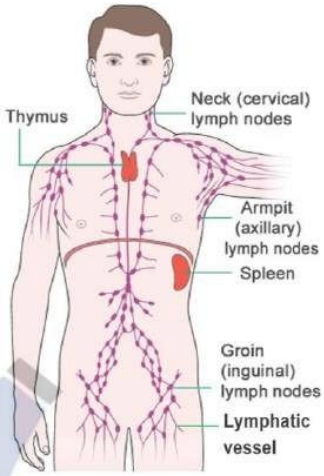
a. Proper disposal of wastes and excreta.
b. Periodic cleaning and disinfection of water reservoirs, pools, cesspools and tanks.
c. Avoid contact with infected persons or their belongings (to control air-borne diseases).
d. Standard practices of hygiene in public catering.
e. Control and eliminate the vectors (e.g. mosquitoes).
   - Avoid stagnation of water.
   - Regular cleaning of household coolers.
   - Use of mosquito nets.
   - Introduce larvivorous fishes like *Gambusia* in ponds.
   - Spraying insecticides in ditches, drainage and swamps.
   - Provide doors and windows with wire mesh.

These precautions can avoid vector-borne diseases like Malaria, Filariasis, Dengue & *Chikun gunya.*

Vaccines & **immunisation** helped to control diseases like smallpox, polio, diphtheria, pneumonia & tetanus. Drugs like **antibiotics** also helped to treat infectious diseases.

HUMAN IMMUNE SYSTEM

- It is the **system that gives immunity to the body** by recognizing, responding and remembering foreign antigens.
- It plays role in allergic reaction, auto-immune disease and organ transplantation.
- It includes **lymphoid organs, tissues, cells** & **antibodies.**



LYMPHOID ORGANS

These are the organs where origin/maturation & proliferation of lymphocytes occur. 2 types: Primary & Secondary.

a. Primary lymphoid organs

The organs where lymphocytes are matured & differentiated to antigen-sensitive lymphocytes. It is 2 types:

1. **Bone marrow:** The site of formation of all blood cells including B & T-lymphocytes.
2. **Thymus:** A bilobed organ seen near the heart and beneath the breastbone. It is large during birth but gradually reduces in size and becomes very small size in puberty. Immature T-lymphocytes from bone marrow is migrated to thymus and matured.

b. Secondary lymphoid organs

- The organs, to which matured lymphocytes migrate from primary lymphoid organs, interact with antigens and then proliferate to become **effector cells.**
  E.g. Spleen, lymph nodes, tonsils, Peyer's patches, Mucosa-associated lymphoid tissue (MALT) & appendix.
- **Spleen:** Bean-shaped organ. Contains lymphocytes and phagocytes. It removes worn-out RBCs & microorganisms from blood. It is a reservoir of erythrocytes in foetus.
- **Lymph nodes:** Found in lymphatic system. They trap microorganisms or other antigens. Trapped antigens activate lymphocytes and cause immune response.
- **MALT:** Located within the lining of respiratory, digestive & urinogenital tracts. It constitutes 50% of lymphoid tissue.

IMMUNITY

It is the ability of the immune system to fight the pathogens. It is 2 types: Innate and Acquired.

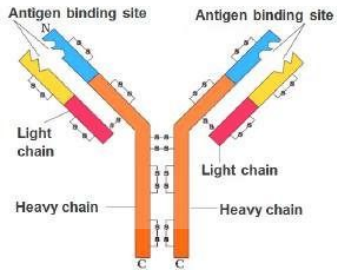
1. Innate (inborn) immunity

- It is the *non-specific* immunity present at the time of birth.
- It includes 4 types of **Barriers:**

a. **Physical barriers:** Prevents entry of microbes. E.g. ***Skin***, ***Mucus coating*** of the respiratory, gastro-intestinal and urino-genital tracts. Mucus traps microbes.
b. **Physiological barriers:** They prevent microbial growth. E.g. gastric HCl, saliva, tear etc.
c. **Cellular barriers: Phagocytes** like *WBC* [*Polymorpho-nuclear leukocytes (PMNL)* or *neutrophils*, *monocytes* and natural killer *lymphocytes]*, *macrophages* etc.
d. **Cytokine barriers:** Virus infected cells secrete a cytokine protein called ***interferon.*** It protects non-infected cells from further viral infection.

2. Acquired (adaptive) immunity

- It is *pathogen specific* immunity developed during lifetime.
- It is characterized by *memory*, i.e. during first encounter of a pathogen, body produces *primary response* in low intensity. Second encounter of the same pathogen causes a *secondary (anamnestic) response* in high intensity.
- Primary and secondary immune responses are carried out with *B-lymphocytes (B-cells)* and *T-lymphocytes (T-cells)*.
  a. **B-lymphocytes:** Produce *antibodies*. These are the proteins to fight the pathogens.
  b. **T-lymphocytes:** Help B-cells to produce antibodies.



Structure of an antibody molecule

An antibody has **4 polypeptide chains:** 2 **light chains** and 2 **heavy chains** (H_2L_2).

Types of antibodies:

IgG, IgA, IgM, IgE & IgD.

Types of Acquired immune response

1. **Humoral immune response/ Antibody mediated immunity (AMI):** It is the immune response mediated by ***antibodies.*** Antibodies are found in blood plasma. So called as Humoral immune response.

2. **Cell-mediated response / cell-mediated immunity (CMI):** It is the immune response mediated by ***T-lymphocytes (T-cells).*** The body can differentiate 'self' and 'non-self' and the CMI causes Graft rejection.

   Tissue matching & blood group matching are essential before undertaking any graft/ transplant. After this, the patient should take immuno-suppressants all his life.

Types of Acquired immunity

Acquired immunity is 2 types: Active and passive.

1. **Active immunity:** It is the immunity in which antibodies are produced in a host body when the host is exposed to *antigens* (e.g. living or dead microbes or other proteins). It is a slow process. It is produced by 2 ways:
   a. **Natural Active Immunity:** It is developed during natural infection by microbes.
   b. **Artificial Active Immunity:** It is developed by injecting the microbes deliberately during immunization.
1. **Passive immunity:** Here, readymade antibodies are directly given to the body. It is 2 types:
   a. **Natural Passive Immunity:** E.g.
      - Antibodies (IgG) from mother → Placenta → Foetus
      - Antibodies (IgA) in colostrum → infants
   b. **Artificial Passive Immunity:** E.g.
      - Anti-tetanus serum (ATS)

Immunization

This is based on 'memory' of the immune system. 2 types:

1. Active Immunization (Vaccination)

- In this, a preparation of **vaccine** (antigenic proteins of pathogen or inactivated pathogen) is introduced into the body. It results in the development of antibodies.
- During actual infection, the antibodies neutralize antigens.
- The vaccines also generate memory B and T-cells. They recognize the pathogen quickly.
- E.g. Polio vaccine, Hepatitis B vaccine, DPT vaccine etc.
- Vaccines are produced using DNA recombinant technology (E.g. Hepatitis B vaccine produced from Yeast).

2. Passive Immunization

- It is the direct injection of **pre-formed antibodies or antitoxin.** It is required for quick immune response.
- E.g. Immunization against Tetanus, snake venom etc.

Allergies

- It is the exaggerated response of the immune system to certain antigens present in the environment.
- **Allergens:** Substances causing allergy. E.g. mites in dust, pollens, animal dander, fur etc.
- Antibodies produced against the **allergens** are **IgE type.**
- IgE binds on **mast cells** to release chemicals like ***histamine*** and ***serotonin*** from them. It results in allergic reactions.
- **Symptoms:** Sneezing, watery eyes, running nose, difficulty in breathing, wheezing, skin rashes etc.
- **Determination of cause of allergy:** The patient is exposed to or injected with very small doses of possible allergens, and the reactions studied.
- **Treatment:** Drugs like *anti-histamine*, *adrenaline* and *steroids* quickly reduce the symptoms of allergy.
- **Asthma** is a respiratory disease due to allergy.
- Modern-day life style and protected environment provided early in life result in low immunity and more sensitivity to allergens. So, many children in metro cities suffer from allergies and asthma.

Autoimmunity

- In higher vertebrates, memory-based acquired immunity evolved based on the ability to differentiate foreign organisms from self-cells.
- Sometimes, due to genetic and other unknown reasons, the body attacks self-cells resulting in damage to the body. It is called **auto-immune disease.** E.g. *Rheumatoid arthritis.*

AIDS (Acquired Immuno Deficiency Syndrome)

- It is the deficiency of immune system.
- Syndrome means a group of symptoms.
- It is caused by **HIV (Human Immunodeficiency Virus),** a **retrovirus** having RNA genome.
- AIDS was first reported in America (1981).
- In the last 25 years, it killed over 25 million persons.

Transmission:

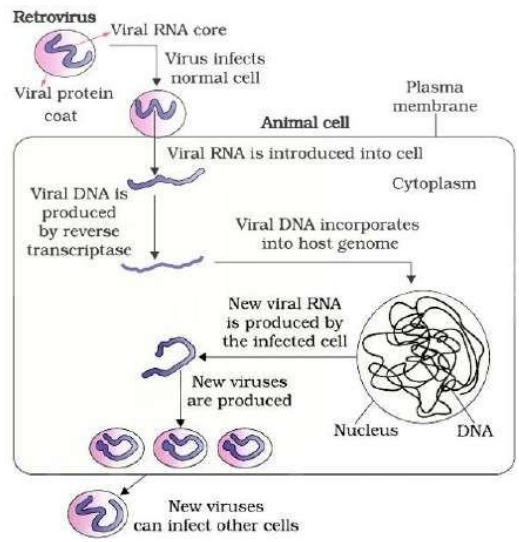
- Sexual contact with infected person.
- Transfusion of contaminated blood & blood products.
- Sharing of infected needles.
- From infected mother to her child through placenta.

High risk people of getting HIV:

- Individuals with multiple sexual partners.
- Drug addicts who take drugs intravenously.
- Individuals who require repeated blood transfusion.
- Children born to an HIV infected mother.

HIV does not spread by touch or physical contact. It spreads only through body fluids.
There is a time-lag (from few months to 5-10 years) between the infection and appearance of symptoms.

Replication of retrovirus:



Life cycle of HIV:

HIV enters body → To macrophages (acts as HIV factory) → RNA genome replicates in presence of *Reverse transcriptase* to form viral DNA → Viral DNA incorporates into host DNA→ Infected cells produce virus particles → HIV enters into helper T-cells (T_H lymphocytes) → Replicates & produce progeny viruses → Attack other T_H cells → T_H cells decrease → Weaken immunity.

- During this period, the person suffers from fever, diarrhoea and weight loss.
- Due to deficiency of T_H cells, he may be infected with *Mycobacterium*, viruses, fungi & parasites like *Toxoplasma*.
- **Diagnosis: ELISAtest** (Enzyme-linkedimmuno-sorbentAssay).
- **Treatment:** Anti-retroviral drugs are partially effective. They can only prolong the life of the patient.

Prevention of AIDS:

- Educate people about AIDS through organisations like **National AIDS Control Organisation (NACO), non-governmental organisations (NGOs), WHO** etc.
- Make blood (from blood banks) safe from HIV.
- Use disposable needles and syringes.
- Advocate safe sex and free distribution of condoms.
- Control drug abuse.
- Regular check-ups for HIV in susceptible population.

CANCER

- Cancer is an abnormal and uncontrolled multiplication of cells resulting in the formation of tumour (masses of cells).
- Normal cells show a **contact inhibition** (contact with the other cells inhibits their uncontrolled growth). Cancer cells do not have this property.

Types of Tumours

- **Benign tumours:** Confined to the place of its origin. They do not spread to other parts. Cause little damage.
- **Malignant tumours:** Mass of proliferating cells **(neoplastic or tumour cells)** that grow rapidly, invade and damage the surrounding normal tissues. Due to active division and growth, they starve normal cells by competing for nutrients. Cells sloughed from tumours reach other sites via blood where they form a new tumour. This is called **metastasis**.

Causes of cancer (Carcinogens)

- **Physical agents:** E.g. Ionizing radiations like X-rays and gamma rays and non-ionizing radiations like UV.
- **Chemical agents:** Tobacco smoke (major cause of lung cancer), vinyl chloride, caffeine, nicotine, mustard gas etc.
- **Biological agents:** E.g. **oncogenic viruses, c-onc (cellular oncogenes or proto oncogenes)** etc. When C-onc in normal cells is activated, the cells become oncogenic.

Cancer detection and diagnosis

- **Biopsy:** A thin piece of the suspected tissue is stained and examined under microscope (histopathological studies).

In case of leukemia: Biopsy & histopathological studies. Blood & bone marrow tests for increased cell counts.

- **Imaging techniques:**
  - **Radiography:** Use of X-rays.
  - **CT (Computerized tomography) scan:** Uses X-rays to generate a 3D image of the internals of an object.
  - **MRI (Magnetic Resonance Imaging):** Uses magnetic fields and non-ionising radiations to detect pathological and physiological changes in the living tissue.
- Use of **Antibodies** against cancer-specific antigens.
- **Molecular biology technique:** To detect cancer related genes. Such individuals should avoid carcinogens (e.g. tobacco smoke).

Treatment of cancer

- **Radiotherapy:** Tumour cells are irradiated lethally, without damaging surrounding normal tissues.
- **Chemotherapy:** Use of chemotherapeutic drugs. Many drugs have side effects like hair loss, anaemia etc.
- **Immunotherapy:** The patients are given **biological response modifiers** (e.g. α- interferon) which activates their immune system and helps in destroying the tumour.
- **Surgery.**

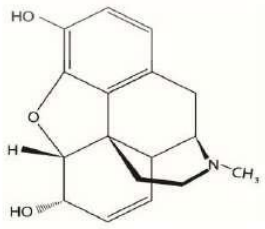
Most cancers are treated by combination of surgery, radiotherapy and chemotherapy.

DRUGS, SMOKING AND ALCOHOL ABUSE

DRUGS

1. Opioids:

- They bind to specific **opioid receptors** in CNS and gastrointestinal tract. E.g. morphine, heroin, brown sugar.



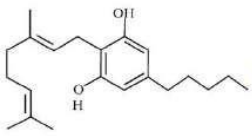
Chemical structure of Morphine


Opium poppy

- **Morphine** is extracted from latex of ***Papaver somniferum*** **(poppy plant).** It is a sedative & painkiller. Used in surgery.
- **Heroin** (*smack* or diacetylmorphine) is a white, odourless, bitter crystalline compound. It is obtained by acetylation of morphine. It is taken by snorting and injection. Heroin is a depressant and slows down body functions.

2. Cannabinoids:

- They interact with **cannabinoid receptors** in the brain.
- Generally taken by inhalation and oral ingestion.
- Natural cannabinoids are obtained from inflorescences of ***Cannabis sativa*** **(Hemp plant).** Its flower tops, leaves & resin are used to make *marijuana, hashish, charas & ganja.*
- They affect cardiovascular system.
- Cannabinoids are abused by some sportspersons.



Skeletal structure of cannabinoid molecule


Leaves of *Cannabis sativa*


Flowering branch of *Datura*

3. Coca alkaloid or cocaine (coke or crack):

- It is obtained from coca plant ***Erythroxylum coca.***
- It interferes with transport of neurotransmitter dopamine.
- Cocaine is usually snorted.
- It stimulates CNS producing euphoria & increased energy.
- Excessive dosage of cocaine causes hallucinations.
- *Atropa belladona* & *Datura* are also hallucinogenic plants.

Drugs like barbiturates, amphetamines, benzodiazepines, etc. are used as medicines to treat mental illnesses like depression & insomnia. But their abuse causes impairment of physical, physiological or psychological functions.

SMOKING

- Tobacco has been used by human beings for over 400 years.
- It is smoked, chewed or used as a snuff.
- It contains many chemical substances like **nicotine** (an alkaloid). It stimulates adrenal gland to release adrenaline and nor-adrenaline, causing high BP and heart rate.
- Smoking causes cancers of lung, urinary bladder and throat, bronchitis, emphysema, coronary heart disease, gastric ulcer etc. Tobacco chewing causes oral cancer.
- Smoking increases CO content in blood and reduces oxyhaemoglobin. This causes O_2 deficiency in the body.

ADOLESCENCE & DRUG/ALCOHOL ABUSE

- **Adolescence** is 'a period' and 'a process' during which a child becomes mature in terms of his/her attitudes and beliefs for effective participation in society.
- Adolescence is a bridge linking childhood and adulthood (period of 12-18 years of age). It is very vulnerable phase of mental and psychological development.

Causes of drug/alcohol use in Adolescence

- Curiosity and Experimentation.
- Need for adventure and excitement.
- To escape facing problems.
- Stress from pressure to excel in academics or examination.
- Television, movies, newspapers, internet etc.
- Unstable or unsupportive family structures & peer pressure.

Addiction and Dependence

- **Addiction:** It is a psychological attachment (euphoria and a temporary feeling of wellbeing) with drugs and alcohol. With repeated use of drugs, the tolerance level of the receptors increases. Thus the receptors respond only to higher doses leading to greater intake and addiction.
- **Dependence:** It is the tendency of the body to manifest a characteristic and unpleasant ***withdrawal syndrome*** if regular dose of drugs/alcohol is abruptly discontinued. This results in anxiety, shakiness, nausea and sweating. Dependence leads to social adjustment problems.

Effects of Drug/alcohol abuse

- Reckless behaviour, vandalism and violence.
- Coma and death due to respiratory failure, heart failure or cerebral haemorrhage.
- Drugs mixed with alcohol may cause death.
- Damage of nervous system and liver cirrhosis.
- Mental and social distress to family and friends.
- Social problems like stealing and spread of infectious diseases (e.g. AIDS, hepatitis B).
- Use of drugs and alcohol by pregnant woman affect the foetus (Foetal alcohol syndrome or FAS).
- Loss of sexual drive and necrospermia.
- Misuse of drugs by athletes (e.g. narcotic analgesics, anabolic steroids, diuretics & certain hormones to increase muscle strength and bulk and to promote aggressiveness).

Warning signs of drug/alcohol abuse in Adolescence period

- Drop in academic performance and absence from school.
- Lack of interest in personal hygiene.
- Withdrawal and isolation.
- Depression, fatigue, aggressive and rebellious behaviour.
- Change in sleeping and eating habits.
- Fluctuations in weight, appetite etc.
- Loss of interest in hobbies.
- Deteriorating relationships with family and friends.

Side effects of anabolic steroid abuse

In males:

- Acne.
- Mood swings & depression.
- Increased aggressiveness.
- Reducedtesticles.
- Decreased sperm.
- Kidney & liver dysfunction.
- Breast enlargement.
- Premature baldness
- Enlargement of prostate gland.

In females:

- Masculinisation
- Mood swings & depression
- Increased aggressiveness
- Excessive hair growth
- Abnormal menstrual cycle
- Deepening of voice
- Enlargement of clitoris

In adolescent male & female: Severe facial and body acne, premature closure of the growth centres of the long bones resulting in stunted growth.

Prevention and control

1. Avoid undue peer pressure.
2. Education and counselling.
3. Seeking help from parents and peers.
4. Looking for danger signs.
5. Seeking professional and medical help.
   a. Psychologists and psychiatrists.
   b. De-addiction and rehabilitation programs.

STRATEGIES FOR ENHANCEMENT IN FOOD PRODUCTION

I. ANIMAL HUSBANDRY

- It is the scientific agricultural practice of breeding and raising livestock.
- It deals with the care & breeding of **livestock** (buffaloes, cows, pigs, horses, cattle, sheep, camels, goats etc.), **poultry farming** and **fisheries.**
- More than **70%** of the world livestock population is in **India** & **China.** However, the contribution to the world farm produce is only **25%,** i.e., the productivity per unit is very low. Hence new technologies should be applied to achieve improvement in quality and productivity.

Management of Farms & Farm Animals

1. Dairy Farm Management (Dairying)

- It is the management of animals for increasing yield and quality of milk and its products.
- Milk yield depends on the quality of breeds in the farm.
- It is important to select good breeds having high yielding potential and resistance to diseases.
- **Ways for the yield potential:**
  - Look after the cattle (housing well, give adequate water and maintain disease free).
  - Feeding of cattle in a scientific manner – emphasis on the quality and quantity of fodder.
  - Stringent cleanliness and hygiene of cattle & handlers while milking, storage and transport of the milk.
- Nowadays, these processes have mechanized. It reduces chance of direct contact of the produce with the handler.
- To ensure these stringent measures there should be
  - Regular inspections to identify and rectify problems.
  - Regular visits by a veterinary doctor.

2. Poultry Farm Management

- Poultry is the domesticated birds used for food or eggs. E.g. chicken, ducks, turkey and geese.
- **Components of poultry farm management:**
  - Selection of disease free and suitable breeds.
  - Proper and safe farm conditions.
  - Proper feed and water.
  - Hygiene and health care.

Animal Breeding

- A **breed** is a group of organisms related by descent and similar general appearance, features, size etc.
- **Breeding** is the modification of genotype of an organism to make that organism more useful to humans. E.g. Jersey (improved cattle breed), Leghorn (improved chickenbreed).
- Animal breeding aims at increasing the yield of animals and improving the desirable qualities of the produce.
- Breeding is 2 types: **Inbreeding** and **out-breeding.**

a. Inbreeding

It is the mating of more closely related individuals within the same breed for 4-6 generations. This strategy is as follows:

- Identify and mate superior males & females of same breed.
- Evaluate the progeny obtained and identify superior males and females among them for further mating.

In cattle, a superior female produces more milk per lactation. A superior male (bull) gives rise to superior progeny.

Advantages of Inbreeding:

- It increases **homozygosity** to evolve a pure line animal.
- It exposes **harmful recessive genes** that are eliminated by selection.
- It helps in accumulation of **superior genes** and elimination of less desirable genes. This increases the productivity of inbred population.

Continued inbreeding, especially close inbreeding, may reduce fertility and productivity. This is called **inbreeding depression**. To solve this problem, selected animals should be mated with unrelated superior animals of the same breed.

b. Out-breeding

It is the breeding of the unrelated animals. It includes out-crossing, cross-breeding and inter-specific hybridization.

i) Out-crossing:

- It is the mating of animals within the same breed, but having no common ancestors on either side of their pedigree up to 4-6 generations.
- The offspring of such a mating is known as **out-cross.**
- It is the best method for animals having low milk productivity, growth rate in beef cattle, etc.
- It helps to overcome inbreeding depression.

ii) Cross-breeding:

- It is the mating of superior males of one breed with superior females of another breed.
- The desirable qualities of 2 different breeds are combined.
- The progeny hybrid animals may be used for commercial production or may be subjected to inbreeding and selection to develop new stable superior breeds.
- E.g. **Hisardale** (sheep) developed in Punjab by crossing **Bikaneri ewes** and **Merino rams.**

iii) Interspecific hybridization:

- It is the mating of male and female of two different species.
- In some cases, the progeny may combine desirable features of both the parents, and may be of considerable economic value. E.g. Mule (male ass x female horse).

Controlled breeding experiments

1. Artificial insemination

- The semen collected from male parent is injected into the reproductive tract of selected female by the breeder.
- Semen is used immediately or is frozen and used later. Frozen semen can also be transported.
- Success rate of crossing mature male & female is low even though artificial insemination is carried out.

2. Multiple Ovulation Embryo Transfer Technology (MOET)

- It is a programme for herd improvement. It improves chances of successful production of hybrids.

- In this, a cow is administered hormones such as **FSH** to induce **follicular maturation & super ovulation** (production of 6-8 eggs per cycle instead of one egg).
- The animal is either mated with an elite bull or artificially inseminated. Fertilised eggs at 8–32 cells stage are recovered non-surgically and transferred to surrogate mothers.
- MOET has been demonstrated for cattle, sheep, rabbits, buffaloes, mares, etc.
- High milk yielding breeds of females and high quality (lean meat with less lipid) meat-yielding bulls have been bred successfully to increase herd size in a short time.

Bee-keeping (apiculture)

- It is the maintenance of hives of honeybees to produce honey and beeswax.
- Most common species that can be reared is ***Apis indica*.**
- Honey is a food of high nutritive and medicinal value.
- Beeswax is used in preparation of cosmetics, polishes etc.
- Apiculture can be practiced in an area having **bee pastures** of some wild shrubs, fruit orchards and cultivated crops.
- **Important points for successful bee-keeping:**
  (i) Knowledge of the nature and habits of bees.
  (ii) Selection of suitable location for keeping beehives.
  (iii) Catching and hiving of swarms (group of bees).
  (iv) Management of beehives during different seasons.
  (v) Handling and collection of honey and beeswax.
- Bees are the pollinators of crop species such as sunflower, *Brassica*, apple and pear.
- Keeping beehives in crop fields during flowering period increases pollination. It improves crop and honey yield.

Fisheries

- Fishery is an industry of catching, processing or selling of fish, shellfish or other aquatic animals (prawn, crab, lobster, edible oyster etc.).
- **Freshwater fishes:** *Catla*, *Rohu*, common carp etc.
  Marine fishes: *Hilsa*, Sardines, Mackerel, Pomfrets etc.
- Fisheries provide income and employment to millions of fishermen and farmers.
- **Aquaculture** (farming of aquatic organisms) & **pisciculture** (farming of fishes) are the techniques to increase the production of aquatic plants and animals.
- **Blue Revolution:** The development and flourishing of the fishery industry.

II. PLANT BREEDING

- It is the manipulation of plant species to create desired plant types suitable for better cultivation, better yields and disease resistance.
- **Green Revolution:** The development and flourishing of the agriculture. It was dependent on plant breeding.
- **Classical plant breeding** involves hybridization of pure lines and artificial selection to produce desirable traits.
- Now molecular genetic tools are used for plant breeding.

Desirable traits for plant breeding:

- Increased crop yield and quality.
- Increased tolerance to environmental stresses (salinity, extreme temperatures & drought).
- Increased resistance to insect pests and pathogens.

Steps of Plant breeding

(i) Collection of genetic variability

- In wild relatives of many crops, pre-existing genetic variability is available.
- Collection and preservation of wild varieties, species and relatives of the cultivated species is a pre-requisite for effective exploitation of natural genes.
- The entire collection of plants/seeds having all the alleles for all genes in a given crop is called **germplasmcollection.**

(ii) Evaluation and selection of parents

- The germplasm is evaluated for identifying plants with desirable characters.
- Selected plants are multiplied and used for hybridisation.
- Pure lines are created wherever desirable and possible.

(iii) Cross hybridisation of the selected parents

- In this, desired characters are genetically combined from 2 different parents to produce hybrid plant.
- E.g. high protein quality of one parent is combined with disease resistance from another parent.
- **Limitations:**
  - Very time-consuming and tedious process.
  - Hybrids may not combine the desirable characters. Usually only hundreds to a thousand crosses show the desirable combination.

(iv) Selection & testing of superior recombinants

- It is crucial to the success of the breeding objective and requires careful scientific evaluation of the progeny.
- It yields plants that are superior to both parents.
- These are self-pollinated for several generations till they reach a state of uniformity (homozygosity), so that the characters will not segregate in the progeny.

(v) Testing, release & commercialization

- The newly selected lines are evaluated for their yield and other agronomic traits of quality, disease resistance, etc.
- This is done by growing them in research fields and recording their performance under ideal fertiliser application irrigation and other crop management practices.
- The evaluation is followed by testing the materials in farmers' fields, for at least 3 growing seasons at several locations in the country, representing all the agro-climatic zones. The material is evaluated in comparison to the best available local crop cultivar (a check or reference cultivar).

Wheat and Rice:

- In India, food production has increased by the development of high yielding varieties of wheat and rice in the mid-1960s **(Green Revolution)**.
- During 1960-2000, wheat production increased from 11 million tons to 75 million tons. The rice production increased from 35 million tons to 89.5 million tons.

- Nobel laureate **Norman E. Borlaug** (International Centre for Wheat & Maize Improvement, Mexico) developed semi-dwarf wheat.
- In 1963, high yielding and disease resistant wheat varieties like ***Sonalika*** & ***Kalyan Sona*** were introduced in India.
- **Semi-dwarf rice varieties** were derived from **IR-8,** (developed at International Rice Research Institute (IRRI), Philippines) and **Taichung Native-1** (from Taiwan). Later better-yielding semi dwarf varieties ***Jaya*** and ***Ratna*** were developed in India.

Sugar cane: ***Saccharum barberi*** (grown in north India, but poor sugar content & yield) was crossed with ***Saccharum officinarum*** (tropical canes in south India, thicker stems and higher sugar content but do not grow well in north India) and got a hybrid sugar cane having desirable qualities like high yield, thick stems, high sugar and ability to grow in north India.

Millets: **Hybrid maize, jowar** & **bajra** developed in India. It includes high yielding varieties resistant to water stress.

Plant Breeding for Disease Resistance

- Plant diseases cause crop losses up to 20-30% or even total.
- Disease-resistant cultivars enhance food production and helps to reduce the use of fungicides and bactericides.
- Resistance of the host plant is the genetic ability to prevent the pathogens from disease.
- **Some plant diseases:**
  - **Fungal: Rusts.** E.g. brown rust of wheat, red rot of sugarcane and late blight of potato.
  - **Bacterial:** Black rot of crucifers.
  - **Viral:** Tobacco mosaic, turnip mosaic, etc.

Methods of breeding for disease resistance

1. Conventional breeding: The steps are:

- Screening germplasm for resistance sources.
- Hybridisation of selected parents.
- Selection and evaluation of the hybrids.
- Testing and release of new varieties.

Some crop varieties bred by Conventional method:

Crop	Variety	Resistance to
Wheat	Himgiri	Leaf & 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 virus and leaf curl.

- Conventional breeding is constrained by the availability of limited number of disease resistance genes.
- Inducing mutations in plants and screening them for resistance help to identify desirable genes. Such plants can be multiplied directly or can be used in breeding.
- Other breeding methods are selection amongst **somaclonal variants** and **genetic engineering.**

2. Mutation breeding:

Mutation (sudden genetic change) can create new desirable characters not found in the parental type.

Mutation breeding is the breeding by mutation using chemicals or radiations (e.g. gamma rays) to produce plants with desirable characters. Such plants are selected and multiplied directly or used as a source in breeding.

E.g. In **mung bean,** resistance to **yellow mosaic virus** and **powdery mildew** were induced by mutations.

- **Resistant genes** from wild species have introduced into the high-yielding cultivated varieties. E.g. In ***bhindi (Abelmoschus esculentus),*** resistance to yellow mosaic virus was transferred from a wild species. It resulted in a new variety of ***A. esculentus*** called ***Parbhani kranti.***
- Resistance genes can be transferred by **sexual hybridisation** between the **target** and the **source plant.**

Plant Breeding for Developing Resistance to Insect Pests

- Morphological, biochemical or physiological characteristics give insect resistance in host crop plants. E.g.
  - **Hairy leaves**: E.g. resistance to jassids in cotton and cereal leaf beetle in wheat.
  - **Solid stems in wheat** lead to non-preference by the stem sawfly.
  - **Smooth leaved and Nectar-less cotton varieties** do not attract bollworms.
  - **High aspartic acid, low nitrogen** and **sugar content in maize** leads to resistance to maize stem borers.
- Sources of resistance genes for breeding are cultivated varieties, germplasm collections of crop or wild relatives.

Some crop varieties bred for insect pest resistance:

Crop	Variety	Insect pests
Brassica (rapeseed mustard)	Pusa Gaurav	Aphids
Flat bean	Pusa Sem 2, Pusa Sem 3	Jassids, aphids & fruit borer
Okra (Bhindi)	Pusa Sawani, Pusa A-4	Shoot and Fruit borer

Plant Breeding for Improved Food Quality

- More than 840 million people in the world do not have adequate food. 3 billion people suffer from micronutrient, protein and vitamin deficiencies **('hidden hunger').**
- Breeding crops with higher levels of nutrients is called **Biofortification.** It helps to improve public health.

Objectives of breeding for improved nutritional quality:

- To improve Protein content and quality.
- To improve Oil content and quality.
- To improve Vitamin content.
- To improve Micronutrient and mineral content.

Examples for hybrids with improved nutritional quality:

- **Maize hybrids** having twice the amount of amino acids, **lysine & tryptophan** compared to existing maize hybrids.
- **Wheat** variety, **Atlas 66**, having high protein content.
- **Iron-fortified rice variety** containing over five times as much iron as in common varieties.
- **Vitamins & mineral rich vegetable crops:** Released by Indian Agricultural Research Institute, New Delhi.
  - Vitamin A enriched carrots, spinach, pumpkin.
  - Vitamin C enriched bitter gourd, *bathua*, mustard, tomato.
  - Iron & calcium enriched spinach & *bathua*.
  - Proteinenrichedbeans(broad, lablab, French & gardenpeas).

III. SINGLE CELL PROTEIN (SCP)

- It is the protein derived from single-celled organisms.
- It is an alternate source of proteins for animal and human nutrition. E.g. ***Spirulina*** (a blue green alga), ***Methylophilus methylotrophus*** (a bacterium).
- ***Spirulina*** is rich in protein, minerals, fats, carbohydrate & vitamins. It is grown on materials like waste water from potato processing plants, straw, molasses, animal manure & sewage. This also reduces environmental pollution.
- A 250 Kg cow produces only 200 g protein/day. But 250 g ***Methylophilus methylotrophus*** produces **25 tonnes** protein. It is due to high rate of biomass production and growth.

IV. TISSUE CULTURE

- A technique of growing plant cells/tissues/organs in sterile culture medium under controlled aseptic conditions.
- The ability to generate a whole plant from any cell/explant is called **totipotency**. An **explant** is any part of a plant that is grown in a test tube under sterile nutrient media.
- The nutrient medium must provide a carbon source (such as sucrose), inorganic salts, vitamins, amino acids and growth regulators like auxins, cytokinins etc.
- The method of producing thousands of plants in very short time through tissue culture is called **micropropagation**.
- These plants will be genetically identical to original plant, i.e., they are **somaclones**.
- Tomato, banana, apple etc. are produced by this method.
- Tissue culture is also used to recover healthy plants from diseased plants. The **meristem** (it will be virus-free) from infected plant is removed and grown *in vitro* to obtain virus-free plants. Scientists have cultured meristems of banana, sugarcane, potato, etc.
- **Somatic hybridization:** It is the fusion of protoplasts from two different varieties of plants (with desirable characters) to get hybrid protoplasts. It can be grown to form a new plant called **somatic hybrids.** Protoplasts can be isolated after digesting the cell walls of plant cells.
  E.g. Protoplast of tomato + protoplast of potato → **pomato.** This hybrid plant has the characteristics of tomato & potato. But it has no all desired characteristics for its commercial utilization.

MICROBES IN HUMAN WELFARE

Several microbes such as bacteria, viruses, fungi etc. are useful to man in many ways. Some of them are given below:

1. MICROBES IN HOUSEHOLD PRODUCTS

- **Lactobacillus or Lactic acid bacteria (LAB):**
  - It converts milk to curd by producing acids that coagulate and partially digest the milk proteins.
  - Fresh milk can be converted to curd by adding some curd containing LAB. It also increases vitamin B_{12} in curd.
  - In stomach, LAB helps to check pathogens.
- **Bacterial fermentation (anaerobic respiration)** in dough is used to make foods such as *dosa*, *idli* etc. The puffed-up appearance of dough is due to the production of CO_2.
- **Baker's Yeast (*Saccharomyces cerevisiae*):** It is used to make bread by fermenting dough.
- **Toddy** is made by fermenting sap from palms.
- Microbes are used to ferment fish, soya bean & bamboo-shoots and to produce cheeses.
- **Swiss cheese** has large holes due to production of CO_2 by ***Propionibacterium sharmanii*** (a bacterium).
  Roquefort cheese is ripened by growing a fungus (*Penicillium roqueforti*) on them.

2. MICROBES IN INDUSTRIAL PRODUCTS

Production of beverages, antibiotics etc. on an industrial scale, requires growing microbes in very large vessels **(fermentors).**

Fermented beverages

- ***Saccharomyces cerevisiae (Brewer's yeast)*** is used in the production of beverages by fermenting malted cereals and fruit juices to produce ethanol.
- Wine & Beer are produced without distillation.
- Whisky, Brandy, Rum, Gin, Arrack etc. are produced by distillation of fermented broth.

Antibiotics

- Chemical substances produced by some microbes and can kill or retard the growth of pathogens.
- They are used to treat plague, whooping cough, diphtheria, leprosy etc.
- **Penicillin:** First antibiotic discovered by **Alexander Fleming**. He observed that *Staphylococci* could not grow around a mould (*Penicillium notatum*) growing in unwashed culture plates. He extracted penicillin from it.
- **Earnest Chain** and **Howard Florey** established its full potential as an effective antibiotic.
- Fleming, Chain &Florey were awarded Nobel Prize (1945).

Chemicals, enzymes & other bioactive molecules

1. **Organic acids:** Acid producer microbes include

Aspergillus niger (a fungus)	:	Citric acid
Acetobacter aceti (a bacterium)	:	Acetic acid
Clostridium butylicum (a bacterium)	:	Butyric acid
Lactobacillus (a bacterium)	:	Lactic acid

2. **Alcohol:** Yeast (*S. cerevisiae*) is used to produceethanol.
3. **Enzymes:**
   - **Lipases:** Used in detergent formulations. Help to remove oily stains from the laundry.
   - **Pectinases & Proteases:** To clarify bottled juices.
   - **Streptokinase:** Produced by ***Streptococcus.*** Used as a '**clot buster**' to remove clots from the blood vessels of patients who have **myocardial infarction.**
4. **Cyclosporine A:** Produced by ***Trichoderma polysporum*** (fungus). Used as an **immunosuppressive agent** in organ transplant patients.
5. **Statins:** Produced by ***Monascus purpureus*** (a yeast).
   Used as **blood-cholesterol lowering agents**. It inhibits the enzymes responsible for synthesis of cholesterol.

3. MICROBES IN SEWAGE TREATMENT

Sewage (municipal waste-water) contains large amount of organic matter and microbes.
Sewage is treated in **Sewage Treatment Plants (STPs)** to make it less polluting. It includes 2 stages.

1. Primary treatment

It is the physical removal of particles. It includes
a. Removal of floating debris by sequential **filtration.**
b. Removal of the grit (soil & pebbles) by **sedimentation.**
The settled solids form the **primary sludge** and the supernatant form the **primary effluent.**

2. Secondary treatment (Biological treatment)

Primary effluent is passed into large aeration tanks and constantly agitated. This allows vigorous growth of useful aerobic microbes into **flocs** (bacteria associated with fungal filaments to form mesh-like structures). These microbes consume the organic matter in the effluent. This reduces the **BOD (Biochemical Oxygen Demand)** of the effluent.

> **BOD:** Amount of O_2 consumed by bacteria to oxidize all organic matter in one litre of water. It is a measure of organic matter present in the water. The greater the BOD more is its polluting potential.

The effluent is then passed into a **settling tank** where the bacterial **'flocs'** are sediment. This sediment is called **'activated sludge'.**
A small part of the activated sludge is pumped back into the aeration tank to serve as the **inoculum.**
The remaining sludge is pumped into large tanks called **anaerobic sludge digesters.** Here, some anaerobic bacteria digest the bacteria and fungi in the sludge by producing gases like CH_4, H_2S and CO_2. These gases form the biogas.
The effluent is released into natural water bodies like rivers and streams.
The Ministry of Environment & Forests initiated **Ganga Action Plan & Yamuna Action Plan** to save from water pollution.

4. MICROBES IN THE PRODUCTION OF BIOGAS

- **Biogas** is a mixture of gases (mainly CH_4) produced bythe microbial activity. It is used for cooking & lighting.
- **Methanogens** grow anaerobically on cellulosic material and produce CH_4. **E.g. *Methanobacterium.***
- ***Methanobacterium*** is found in the **anaerobic sludge** and **rumen of cattle** (for cellulose digestion).
- The cattle dung **(gobar)** is rich in these bacteria. Dung can be used for generation of biogas **(Gobar gas).**
- **The Biogas plant** consists of
  - A **concrete tank** (10-15 feet deep) to collect bio-wastes and slurry of dung. A floating cover is placed over the slurry, which keeps on rising as the biogas is produced.
  - An outlet which is connected to a pipe to supply biogas.
  - An outlet to remove spent slurry (used as fertilizer).

> **Indian Agricultural Research Institute (IARI)** and **Khadi and Village Industries Commission (KVIC):** Developed technology of biogas production in India.

5. MICROBES AS BIOCONTROL AGENTS

- **Biocontrol** is the use of biological methods for controlling plant diseases and pests. E.g. **Lady bird (beetle)** controls aphids. **Dragon flies** control mosquitoes.
- **Chemical pesticides** and **insecticides** kill both useful and harmful organisms and cause pollution. Biocontrol method has no such problems.

Microbial biocontrol agents

- ***Bacillus thuringiensis (Bt):*** To control butterfly caterpillar. The dried spores of Bt (available in sachets) are mixed with water and sprayed on to vulnerable plants such as brassicas and fruit trees. These are eaten by the caterpillar. In their gut, the toxin is released and the larvae get killed.
  The scientists have introduced *B. thuringiensis* toxin genes into plants. E.g. Bt cotton.
- ***Trichoderma sp*** (fungus): These are free livings present in the root ecosystems. They control several plant pathogens.
- ***Baculoviruses*** (Especially genus ***Nucleopolyhedro-virus):*** Attacks insects and other arthropods.
  It is suitable for *species-specific*, narrow spectrum insecticidal applications and desirable in **IPM** (Integrated Pest Management) program to conserve beneficial insects.

6. MICROBES AS BIOFERTILISERS

- **Biofertilisers** are organisms that enrich nutrient quality of the soil. E.g. Bacteria, fungi, cyanobacteria etc.
- **Rhizobium** (symbiotic bacteria in root nodules of **leguminous plants)** fix atmospheric N_2.
- Free-living bacteria in the soil (E.g. *Azospirillum* and *Azotobacter)* enrich the nitrogen content of the soil.
- **Mycorrhiza:** Symbiotic association of fungi (E.g. genus of *Glomus*) with plants. The fungus gets food from plant.
  The fungal symbiont performs the following:
  - Absorb phosphorous from soil and passes it to the plant.
  - Give resistance to root-borne pathogens and tolerance to salinity and draught.
  - Give overall increase in plant growth and development.
- **Cyanobacteria (Blue green algae):** Autotrophic microbes. They fix atmospheric nitrogen. E.g. *Anabaena, Nostoc, Oscillatoria etc*. In paddy fields, Cyanobacteria serve as an important biofertilisers. It also adds organic matter to the soil and increases its fertility.

BIOTECHNOLOGY: PRINCIPLES & PROCESSES

- **Biotechnology** is the technique of using live organisms or their enzymes for products & processes useful to humans.
- The **European Federation of Biotechnology (EFB)** defines Biotechnology as *'the integration of natural science and organisms, cells, parts thereof, and molecular analogues for products and services'*.

Biotechnology deals with:
- Microbe-mediated processes (making curd, bread, wine etc).
- *In vitro* fertilization (test-tube baby programme).
- Synthesis and using of a gene.
- Preparation of DNA vaccine.
- Correcting a defective gene.

PRINCIPLES OF BIOTECHNOLOGY

Core techniques of modern biotechnology

- **Genetic engineering:** The technique in which genetic material (DNA & RNA) is chemically altered and introduced into host organisms to change the phenotype.
- **Bioprocess engineering:** Maintenance of sterile ambience in chemical engineering processes for growing desired microbe/eukaryotic cell for the manufacture of antibiotics, vaccines, enzymes etc.

Basic steps in genetically modifying an organism

a) Identification of DNA with desirable genes: Traditional hybridisation leads to inclusion and multiplication of undesirable genes along with desired genes. In genetic engineering, only desirable genes are introduced.

b) Introduction of the identified DNA into the host: A vector DNA such as plasmid is used to deliver an alien piece of DNA into the host organism.

c) Maintenance of introduced DNA in the host and transfer of the DNA to its progeny: A piece of alien DNA has no the sequence called *Origin of replication (ori)* needed for starting replication. So, it cannot multiply itself in the progeny cells of the organism. Hence alien DNA is integrated into the recipient genome (it has *ori*). It multiplies & inherits along with host DNA.

- The process of joining and inserting a foreign piece of DNA into a host organism to produce new genetic combinations is called **recombinant DNA technology.**
- First **recombinant DNA (rDNA)** was produced by **Stanley Cohen & Herbert Boyer** (1972).
- They isolated an antibiotic resistance gene (piece of DNA) from a plasmid of *Salmonella typhimurium*. It was linked with a plasmid vector and transferred into *E. coli*. As a result, the gene was expressed & multiplied in *E. coli*.

TOOLS OF RECOMBINANT DNA TECHNOLOGY

1. Restriction Enzymes ('molecular scissors')

- The enzymes that cut DNA at specific sites into fragments.
- They belong to a class of enzymes called ***nucleases***.
- In 1963, two enzymes responsible for restricting growth of bacteriophage in *E. coli* were isolated. One enzyme added methyl groups to DNA. The other ***(restriction endonuclease)*** cut DNA.
- More than **900 restriction enzymes** have been isolated from over **230 strains** of bacteria.

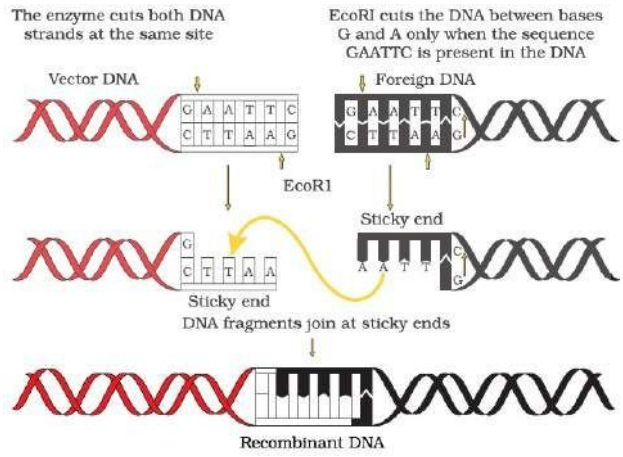
Naming of the restriction enzymes:

- First letter indicates genus. The second two letters indicate species of prokaryotic cell from which they were isolated. E.g. ***EcoRI*** comes from *E. coli* RY 13 (R = the strain. Roman numbers = the order in which the enzymes were isolated from that strain of bacteria).

Types of Restriction enzymes:

- **Exonucleases:** They remove nucleotides from the ends of the DNA.
- **Endonucleases:**
- They cut at specific positions within the DNA. E.g. EcoRI.
- They bind to specific recognition sequence of the DNA and cut the two strands at specific points.
- The first restriction endonuclease is **Hind II.** It cuts DNA molecules by recognizing a specific sequence of 6 base pairs. This is called the **recognition sequence** for Hind II.
- Restriction endonuclease recognizes a specific **palindromic nucleotide sequences** in the DNA. It is a sequence of base pairs that read the same on the two strands in 5′ → 3′ direction and in 3′ → 5′ direction. E.g. Palindromic nucleotide sequence for EcoRI is

5′ —— GAATTC —— 3′
3′ —— CTTAAG —— 5′

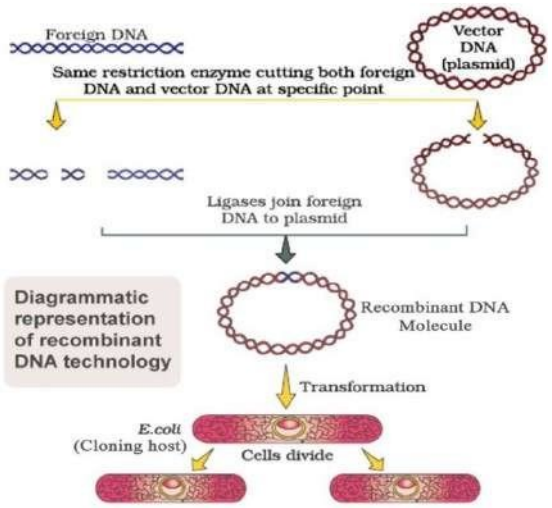


Steps in formation of recombinant DNA by EcoRI

- Restriction enzymes cut the strand a little away from the centre of the palindrome sites, but between the same two bases on the opposite strands. This leaves single stranded overhanging stretches at the ends. They are called **sticky ends**. They form H-bonds with their complementary cut

counterparts. This stickiness facilitates action of the enzyme ***DNA ligase.***

- When cut by the same restriction enzyme, the resultant DNA fragments have the same kind of sticky-ends and these are joined together by *DNA ligases.*



2. Cloning Vector

- It is a DNA molecule that can carry a foreign DNA segment and replicate inside the host cells.
  E.g. Plasmids, bacteriophages etc.
- **Plasmids** are autonomously replicating circular extra-chromosomal DNA of bacteria. Some plasmids have only 1-2 copies per cell. Others have 15-100 copies per cell.
- **Bacteriophages** (high number per cell) have very high copy numbers of their genome within the bacterial cells.
- When the cloning vectors are multiplied in the host, the linked piece of DNA is also multiplied to the numbers equal to the copy number of the vectors.

Features required for cloning into a vector

a. Origin of replication (*ori*)

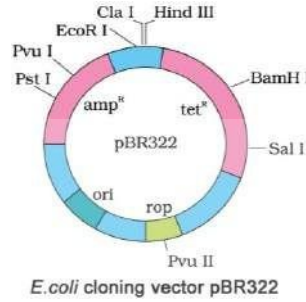
- This is a sequence where replication starts.
- A piece of DNA linked to *ori* can replicate within the host cells. This also controls the copy number of linked DNA. So, for getting many copies of the target DNA, it should be cloned in a vector whose origin support high copy number.

b. Selectable marker (marker gene)

- It is a gene that helps to select the **transformants** and eliminate the **non-transformants.**
- If a piece of DNA is introduced in a host bacterium, it is called **transformation.** Such bacterium is transformant. If transformation does not take place, it is non-transformant.
- Selectable markers of *E. coli* include the genes encoding resistance to antibiotics like *ampicillin, chloramphenicol, tetracycline, kanamycin* etc. Normal *E. coli* cells have no resistance against these antibiotics.

c. Cloning sites

- These are the **recognition sites** for restriction enzymes.
- To link the alien DNA, the vector needs a single or very few **recognition sites.**
- More than one recognition sites generate several fragments. It complicates the gene cloning.
- Ligation of alien DNA is carried out at a restriction site present in one of the two **antibiotic resistance** genes.
  E.g. In vector **pBR322,** foreign DNA is ligated at Bam H I site of tetracycline resistance gene. As a result, **recombinant plasmid** is formed. If ligation does not occur, it is called **non-recombinant plasmid.**



E.coli cloning vector pBR322

- **Restriction sites:** *Hind* III, *Eco*R I, *Bam*H I, *Sa*l I, *Pvu* II, *Pst* I, *Cla* I.
- ***ori***
- **Antibiotic resistance genes:** ampR and tetR.
- **Rop:** codes for the proteins involved in the replication of plasmid.

- When a foreign DNA is inserted within a gene of bacteria, that gene is inactivated. It is called **insertional inactivation.** Here, the recombinant plasmids lose **tetracycline resistance** due to insertion of foreign DNA.
- When the plasmids are introduced into *E. coli* cells, 3 types of cells are obtained:
  - **Non-transformants:** They have no plasmid. So they are not resistant to either tetracycline or ampicillin.
  - **Transformants with non-recombinant plasmid:** They are resistant to both tetracycline & ampicillin.
  - **Transformants with recombinant plasmid:** They are resistant only to ampicillin.
- Recombinant plasmids can be selected out from non-recombinant ones by plating transformants on **ampicillin** medium. Then the transformants are transferred on **tetracycline** medium.
- The **recombinants** grow in **ampicillin** medium but **not on tetracycline** medium. But, non-recombinants grow on the medium containing both the antibiotics.
- Thus, one antibiotic resistance gene helps to select the transformants. The inactivated antibiotic resistance gene helps to select recombinants.
- But this type of selection of recombinants is a difficult procedure because it needs simultaneous plating on 2 plates having different antibiotics. So, alternative **selectable markers** have developed based on their ability to produce colour in presence of a **chromogenic substrate.**
- In this, a recombinant DNA is inserted into the coding sequence (gene) of an enzyme, β-***galactosidase.*** So, the gene is inactivated (insertional inactivation). Such colonies do not produce any colour. These are identified as recombinant colonies.
- If the plasmid in bacteria have no an insert, it gives **blue coloure**d colonies in presence of chromogenic substrate.

d. Vectors for cloning genes in plants & animals

Genetic tools of some pathogens can be transformed into useful vectors for delivering genes to plants & animals. E.g.

- ***Agrobacterium tumefaciens*** (a pathogen of many dicot plants) can deliver a piece of DNA (T-DNA) to transform normal plant cells into a **tumor.** These tumor cells produce the chemicals required by the pathogen.

The **tumor inducing (Ti) plasmid** of *A. tumefaciens* is modified into a cloning vector which is not pathogenic but can use mechanisms to deliver genes of interest into plants.

- **Retroviruses** in animals can transform normal cells into **cancerous** cells. So, they are used to deliver desirable genes into animal cells.

3. Competent Host (For Transformation with Recombinant DNA)

- Since **DNA is a hydrophilic** molecule, it cannot pass through cell membranes. So bacterial cells are made 'competent' to take up alien DNA or plasmid as follows:
- Treat bacterial cells with a specific concentration of a divalent cation (e.g. calcium) → DNA enters the bacterium through pores in cell wall → Incubate the cells with recombinant DNA on ice → Place them briefly at **42^{0}C (heat shock)** → Put them back on ice → Bacteria take up recombinant DNA.

Other methods to introduce alien DNA into host cells

- **Micro-injection:** In this, recombinant DNA is directly injected into the nucleus of an animal cell.
- **Biolistics (gene gun):** In this, cells are bombarded with high velocity micro-particles of gold or tungsten coated with DNA. This method is suitable for plants.
- **'Disarmed pathogen' vectors:** They infect the cell and transfer the recombinant DNA into the host. E.g. *A. tumefaciens.*

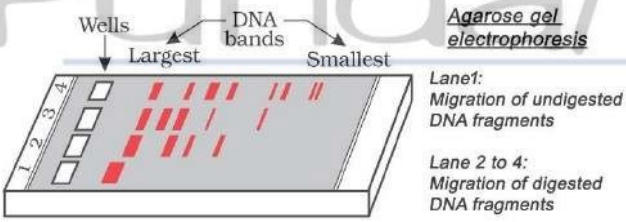
PROCESSES OF RECOMBINANT DNA TECHNOLOGY

1. Isolation of the Genetic Material (DNA)

- Treat the bacterial cells/plant or animal tissue with enzymes like ***lysozyme*** (bacteria), ***cellulase*** (plants), ***chitinase*** (fungus) etc. The cell is broken releasing DNA & other macromolecules (RNA, proteins, polysaccharides & lipids).
- RNA is removed by treating with ***ribonuclease.*** Proteins are removed by treatment with ***protease.*** Other molecules are removed by appropriate treatments.
- When chilled ethanol is added, purified DNA precipitates out as a collection of fine threads in the suspension.

2. Cutting of DNA at Specific Locations

- Purified DNA is incubated with the **restriction enzyme.** As a result, **DNA digests.** These DNA fragments are separated by a technique called **gel electrophoresis**.



- **Agarose gel electrophoresis** is employed to check the progression of a restriction enzyme digestion. DNA is negatively charged. So it moves towards the anode. DNA fragments are separated according to their size through sieving effect of the agarose gel (a polymer extracted from sea weeds). The smaller sized fragment moves farther.
- The process is repeated with the vector DNA also.
- DNA fragments can be seen as bright orange coloured bands when they are stained with **ethidium bromide** and exposed to UV radiation.
- DNA bands are cut out from agarose gel. It is called **elution.** The cut-out **gene of interest** and cut **vector** are mixed and ***ligase*** is added. It creates **recombinant DNA.**

3. Amplification of Gene of Interest using PCR

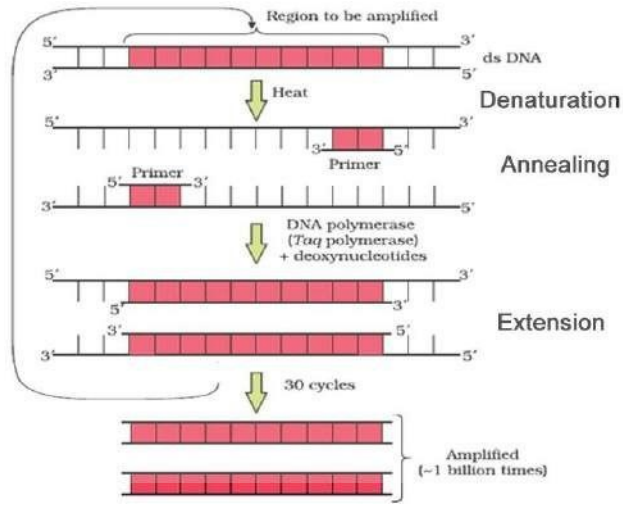
- **Polymerase Chain Reaction (PCR)** is the synthesis of multiple copies of the gene of interest *in vitro* using 2 sets of **primers** & the enzyme ***DNA polymerase.***
- Primers are small chemically synthesized oligonucleotides that are complementary to the regions of DNA.

Steps of PCR:

- **Denaturation:** It is the heating of target DNA (gene of interest) at high temperature (94^{0}C) to separate the strands. Each strands act as template for DNA synthesis.
- **Annealing:** It is the joining of the two primers (at 52^{0}C) at the 3' end of the DNA templates.
- **Extension:** It is the addition of nucleotides to the primer using a thermostable *DNA polymerase* called ***Taq polymerase.*** It is isolated from a bacterium, ***Thermus aquaticus.*** It remains active in high temperature during the denaturation of double stranded DNA.

  Through continuous replication, the DNA segment is amplified up to 1 billion copies.

  The amplified fragment can be used to ligate with a vector for further cloning.



4. Insertion of Recombinant DNA into Host Cell

- Using any methods, the ligated DNA is introduced into recipient (host) cell / organism. They take up DNA from its surrounding.
- If a recombinant DNA bearing **ampicillin resistant gene** is transferred into *E. coli* cells, the host cells become ampicillin-resistant cells.

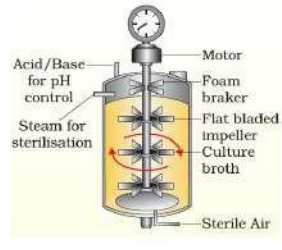
- If the transformed cells are spread on agar plates containing ampicillin, only transformants will grow. Untransformed recipient cells will die.

5. Obtaining the Foreign Gene Product

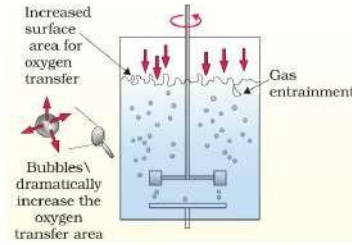
- The aim of recombinant DNA technology is to produce a desirable protein.
- If a protein encoding foreign gene is expressed in a heterologous host, it is called a **recombinant protein**.
- The cells with foreign genes can be grown in laboratory. The cultures are used to extract the desired protein and purify it by using separation techniques.
- The cells can also be multiplied in a **continuous culture system.** Here, the used medium is drained out from one side while fresh medium is added from the other. It maintains the cells more physiologically active and so produces a larger biomass. It yields more desired protein.

Bioreactors

- These are the vessels in which raw materials are biologically converted to specific products, enzymes etc., using microbial, plant, animal or human cells.
- Bioreactors are used to produce large quantities of products. They can process 100-1000 litres of culture.
- A bioreactor provides the optimal growth conditions (pH, temperature, substrate, salts, vitamins, oxygen) to get desired product.
- The most commonly used bioreactors are of stirring type **(stirred-tank bioreactor).**



Simple stirred-tank bioreactor



Sparged stirred-tank bioreactor through which sterile air bubbles are sparged

It is usually cylindrical or with a curved base to facilitate the mixing of the reactor contents. The stirrer facilitates even mixing and oxygen availability. Alternatively, air can be bubbled through the reactor.

The bioreactor has

- An agitator system
- An oxygen delivery system
- A foam control system
- A temperature control system
- pH control system
- Sampling ports (for periodic withdrawal of the culture).

6. Downstream Processing

- It is a series of processes such as **separation and purification of products** after the biosynthetic stage.
- The product is formulated with suitable preservatives. Such formulation undergoes thorough clinical trials and strict quality control testing.

MODEL QUESTIONS

1. Identify the tools.
   a) Separation of DNA b) Amplification of DNA
   c) Large scale purification of product d) Isolation of separated DNA fragments
2. Draw & label the parts of pBR322.
3. Some processes of recombinant DNA technology are given below. Arrange them in correct order.
   a. Amplification of gene of interest using PCR b. Cutting of DNA at specific locations
   c. Obtaining the foreign gene product d. Insertion of recombinant DNA into the host cell
   e. Isolation of the genetic material (DNA) f. Downstream processing
4. Observe the following and answer to the questions.
   5'_____GAATTC_____3'
   3'_____CTTAAG_____5'
   a) Identify the above sequence.
   b) What is the significance of this kind of sequence in recombinant DNA technology?
5. Restriction enzymes & ligases opened the doorway for recombinant DNA technology. Do you agree with this?Justify.
6. Electrophoresis is the migration of charged particles in solution under the influence of an electric field.
   a) Who developed this technique? b) Name the supporting media in AGE and PAGE.
7. A plasmid is a circular double-stranded extra chromosomal DNA in a bacterial cell.
   a) Name the naturally occurring plasmids in *E. coli* and in Agrobacterium.
   b) Name an artificially reconstructed plasmid.
8. PCR is meant for making multiple copies of a gene of interest. Mention the major steps involved in PCR. Name an organism form which a thermostable DNA polymerase is isolated.

BIOTECHNOLOGY AND ITS APPLICATIONS

Biotechnology has many applications such as **biopharmaceuticals, therapeutics, diagnostics, genetically modified crops, processed food, bioremediation, waste treatment and energy production.**

Biotechnology has 3 critical research areas:

a. **Providing the best catalyst** in the form of improved organism usually a microbe or enzyme.
b. **Creating optimal conditions** through engineering for a catalyst to act.
c. **Downstream processing technologies** to purify the protein/organic compound.

APPLICATIONS IN AGRICULTURE

3 options for increasing food production:

a. **Agro-chemical based agriculture:** It uses fertilizers & pesticides. Expensive. Causes environmental pollution.
b. **Organic agriculture:** Expensive.
c. **Genetically engineered crop-based agriculture:** It uses genetically modified crops. **Genetically Modified Organisms** (**GMO**) are the plants, bacteria, fungi & animals whose genes are altered by manipulation.

Advantages of genetic modification in plants:

- It makes crops more tolerant to abiotic stresses (cold, drought, salt, heat etc.).
- Pest-resistant crops reduce the use of chemical pesticides.
- It reduces post-harvest losses.
- It increases efficiency of mineral usage by plants (it prevents early exhaustion of soil fertility).
- It enhances nutritional value of food. E.g. Golden rice (Vitamin A enriched rice).
- To create tailor-made plants to supply alternative resources (starches, fuels, pharmaceuticals etc.) to industries.

Pest Resistant Plants

- They act as **bio-pesticide.**
- It reduces the need for insecticides.
- E.g. Bt cotton, Bt corn, rice, tomato, potato, soyabean etc.

Bt Cotton:

- Some strains of *Bacillus thuringiensis* have proteins that kill insects like coleopterans (beetles), lepidopterans (tobacco budworm, armyworm) & dipterans (flies, mosquitoes).
- *B. thuringiensis* forms an insecticidal protein **(Bt toxin)** crystal during a phase of their growth. It does not kill the *Bacillus* as it exists as inactive *protoxins.*
- When an insect ingests the toxin, it becomes active due to alkaline pH of the gut which solubilise the crystals. Toxin binds to surface of mid-gut epithelial cells creating pores. It causes cell swelling and lysis and death of the insect.
- **Bt toxin genes** were isolated from *B. thuringiensis* and incorporated into crop plants such as cotton.
- Most Bt toxins are insect-group specific. They are coded by **cry genes**. E.g. proteins encoded by *cryIAc* & *cryIIAb* genes control cotton bollworms. Protein of *cryIAb* gene controls corn borer.

Nematode resistance in tobacco plants:

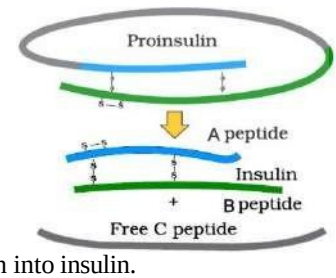
- A nematode *Meloidogyne incognita* infects the roots of tobacco plants causing a reduction in yield.
- It can be prevented by **RNA interference** (RNAi) strategy.
- **RNAi** is a method of cellular defense in all eukaryotic organisms. It prevents translation of a specific mRNA (silencing) due to a complementary dsRNA molecule.
- The source of this complementary RNA is from an infection by RNA viruses or mobile genetic elements (transposons) that replicate via an RNA intermediate.
- Isolate Nematode-specific genes (DNA). It is introduced into host plant using *Agrobacterium* vectors. It produces both sense & anti-sense RNA in host cells. These RNAs are complementary. So they form double stranded (ds) RNA. It initiates RNAi and silences the specific mRNA of nematode. Thus the parasite cannot survive in a transgenic host expressing specific interfering RNA.

APPLICATIONS IN MEDICINE

- Recombinant DNA technology helps for mass production of safe and more effective **therapeutic drugs.**
- Products from non-human sources cause unwanted immunological responses. But recombinant therapeutics does not have such problems.
- At present, about 30 recombinant therapeutics have been approved. Of these, 12 are being marketed in India.

1. Genetically Engineered Insulin

- Insulin is used to manage adult-onset diabetes.
- Insulin from the pancreas of animals (cattle & pigs) causes allergy or other types of reactions to the foreign protein.
- Now, it is possible to produce human insulin using bacteria.
- Insulin consists of two short **polypeptide chains (chain A & chain B)** that are linked by disulphide bridges.
- In mammals, insulin is synthesized as a **pro-hormone (pro-insulin).** It is processed to become mature and functional hormone.



- The pro-hormone contains an extra stretch called **C peptide**. This is removed during maturation into insulin.
- In 1983, **Eli Lilly** (an American company) prepared two DNA sequences corresponding to A & B chains of human insulin and introduced them in plasmids of *E. coli* to produce insulin chains. Chains A & B were combined by creating disulfide bonds to form human insulin ***(Humulin).***

2. Gene Therapy

- It is a method to correct a gene defect in a child/embryo.
- Here, genes are inserted into a person's cells and tissues to treat a hereditary disease. It compensates for the non-functional gene.
- First clinical gene therapy (1990) was given to a 4-year old girl with **adenosine deaminase (ADA) deficiency.**
- This is caused due to the deletion of a gene of ***adenosine deaminase*** (an enzyme for the functioning of immune system). It can be cured by **bone marrow transplantation** or by **enzyme replacement therapy** (injection of ADA). But these are not completely curative.
- **Gene therapy for ADA deficiency:** Collect **lymphocytes** from the patient's blood and grow in a culture → Introduce a functional **ADA cDNA** into lymphocytes (using a retroviral vector) → They are returned to the patient.
  This should be periodically repeated as lymphocytes are not immortal.
- If the **ADA gene** from marrow cells is introduced into cells at early embryonic stages, it could be a permanent cure.

3. Molecular Diagnosis

- Conventional methods (serum & urine analysis) are not suitable for early diagnosis of diseases.
- It is possible by techniques such as **Recombinant DNA technology, PCR & ELISA.**

PCR (Polymerase Chain Reaction):

- Presence of a pathogen is normally suspected only based on symptoms. By this time, the concentration of pathogen is already very high in the body.
- However, very low concentration of a bacteria or virus can be detected by amplification of their nucleic acid by PCR.
- **Uses of PCR:**
  - To detect HIV in suspected patients.
  - To detect gene mutations in suspected cancer patients.
  - To identify many other genetic disorders.
- A single stranded DNA or RNA, tagged with a radioactive molecule (probe) is hybridized to its complementary DNA in a clone of cells. It is detected by autoradiography. The clone having mutated gene will not appear on photographic film, because the probe will not have complementarity with mutated gene.

ELISA (Enzyme Linked Immuno-Sorbent Assay):

- It is based on **antigen-antibody interaction.**
- Infection by pathogen can be detected by the presence of **antigens** (proteins, glycoproteins, etc.) or by detecting the **antibodies** synthesized against the pathogen.

TRANSGENIC ANIMALS

- These are the animals whose genome has been altered by introduction of a foreign gene by manipulation.
- E.g. Transgenic rats, rabbits, pigs, sheep, cows and fish.
- Over 95% of the transgenic animals are mice.

Benefits of transgenic animals

- **To study regulation of genes and their action on normal physiology & development:** E.g. Study of **insulin-like growth factor.** Genes (from other species) that alter formation of this factor are introduced and the biological effects are studied. This gives information about biological role of the factor.
- **To study the contribution of genes in the development of a disease and thereby new treatments:** E.g. transgenic models for human diseases such as cancer, cystic fibrosis, rheumatoid arthritis & Alzheimer's.
- **Biological products:** Some medicines contain expensive biological products. Transgenic animals can be used to produce biological products by introducing genes which codes for a particular product.
  They are used to treat diseases such as emphysema, phenylketonuria (PKU), cystic fibrosis etc. E.g. **human protein (α-1-antitrypsin)** used to treat emphysema.
  In 1997, **Rosie** (first transgenic cow) produced human protein-enriched milk (2.4 gm per litre). It contains **human α-lactalbumin.** It is nutritionally more balanced product for human babies than natural cow-milk.
- **Vaccine safety testing:** Transgenic mice are used to test the safety of the polio vaccine. If it is reliable, they can replace the use of monkeys to test the safety of vaccines.
- **Chemical safety testing (toxicity testing):** Some transgenic animals carry genes which make them more sensitive to toxic substances than non-transgenic animals. They are exposed to the toxic substances and the effects studied. It gives immediate results.

ETHICAL ISSUES

- **Problem of unpredictable results:** Genetic modification may cause unpredictable results.
  Indian Government has set up organizations like **GEAC** (Genetic Engineering Approval Committee) to make decisions about the validity of GM research and the safety of GM-organisms for public services.
- **Bio-piracy:** It is the use of bio-resources by multinational companies and other organizations without proper authorization from the countries and people concerned. Certain companies have got patents for products and technologies that make use of the genetic materials, plants etc. that have been identified, developed and used by farmers and indigenous people of a country. E.g. Basmati rice, herbal medicines (turmeric, neem etc.).
  Basmati rice has unique aroma & flavour. India has 27 varieties of Basmati. In 1997, an American company got patent rights on Basmati rice through the **US Patent and Trademark Office.** This allowed the company to sell a 'new' variety of Basmati. This was actually derived from Indian farmer's varieties. Indian Basmati was crossed with semi-dwarf varieties and claimed as a novelty. Other people selling Basmati rice could be restricted by patent.

Generally, industrialized nations are poor in biodiversity and traditional knowledge. The developing and underdeveloped world have rich biodiversity and traditional knowledge related to bio-resources.

It has to develop laws to prevent unauthorized exploitation of bio-resources and traditional knowledge.

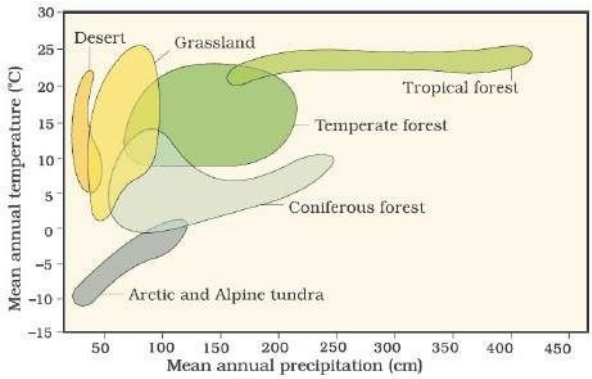
Indian Parliament has cleared the second amendment of the **Indian Patents Bill** that has considered patent terms emergency provisions and research and development initiative.

ORGANISMS AND POPULATIONS

Ecology is the study of interactions among organisms and between the organism and its physical (abiotic) environment. Ecology is concerned with 4 levels of biological organization: Organisms, Populations, Communities & Biomes.

ORGANISM AND ITS ENVIRONMENT

- **Physiological ecology** (Ecology at the organismic level) is the study of adaptation of an organism to environments in terms of survival and reproduction.
- The rotation of earth and the tilt of its axis cause annual variations in temperature & seasons. Major biomes (desert, rain forest, tundra etc.) are formed due to these variations & precipitation (rain & snow).



Biome distribution with respect to annual temperature and precipitation

- Regional and local variations within a biome lead to the formation of different habitats.
- Life exists even in extreme & harsh habitats. E.g. Rajasthan desert, rain-soaked Meghalaya forests, deep ocean trenches, torrential streams, permafrost (snow laden) polar regions, high mountain tops, thermal springs & compost pits.
  Our intestine is a habitat for many microbes.
- **The physico-chemical (abiotic) components** (water, light, temperature, soil etc.) & **biotic components** (pathogens, parasites, predators, competitors etc.) lead to variation of different habitats.
- The distinct role and position of an organism in its environment is called its **niche.** By this, each organism tolerates various conditions, utilises various resources etc.

Abiotic Factors

a. Temperature

- The most ecologically relevant environmental factor.
- Temperature on land varies seasonally. It gradually decreases from equator to the poles and from plains to mountain tops. It ranges from subzero levels (in polar areas & high altitudes) to >50^{0}C (in tropical deserts).
- Average temperature in thermal springs & deep-sea hydrothermal vents is above 100^0 C.
- Mango trees cannot grow in temperate countries (Canada, Germany etc.). There is no Snow leopard in Kerala forests. Tuna fishes are rare beyond tropical latitudes in the ocean.
- Temperature affects kinetics of enzymes, basal metabolism and other physiological functions of the organism.
- Based on range of thermal tolerance, organisms are 2 types:
  - **Eurythermal:** They can tolerate a wide range of temperatures.
  - **Stenothermal:** They can tolerate only a narrow range of temperatures.

b. Water

- It is the second most important factor.
- Desert organisms have special adaptations to limited water.
- Productivity & distribution of plants is dependent on water.
- For aquatic organisms, water quality (pH, chemical composition) is important. The salt concentration (salinity in parts per thousand) is less than 5 in inland waters, 30-35 in the sea and > 100 in some hypersaline lagoons.
- Based on the tolerance to salinity, organisms are 2 types:
  - **Euryhaline:** Tolerate a wide range of salinities.
  - **Stenohaline:** Tolerate only a narrow range of salinity.

  Many freshwater animals cannot live for long in sea water and vice versa because of the osmotic problems.

c. Light

- Plants need sunlight for photosynthesis.
- Small forest plants (herbs & shrubs) are adapted to photosynthesize optimally under very low light because they are overshadowed by tall, canopied trees.
- Many plants depend on sunlight for photoperiodism (e.g. flowering).
- Many animals use diurnal and seasonal variations in light intensity and photoperiod for timing their foraging, reproductive & migratory activities.
- Sun is the ultimate source for light & temperature on land. Deep (> 500m) in the oceans, the environment is dark and there is no energy available from sun.
- The spectral quality of solar radiation is also important for life. The UV spectrum is harmful to many organisms. Not all the colour components of the visible spectrum are available for marine plants.

d. Soil

- Nature & properties of soil is differed due to climate, weathering, sedimentation, method of soil development etc.
- **Soil composition, grain size & aggregation** determine the percolation and water holding capacity of the soils.
- These characteristics and parameters like **pH, mineral composition & topography** determine the vegetation and animals in an area.
- In aquatic environment, the sediment-characteristics determine the type of **benthic animals.**

Responses to Abiotic Factors

- Organisms maintain a stable internal environment ***(homeostasis)*** despite varying external environmental conditions. This is possible by following processes.

a. Regulate

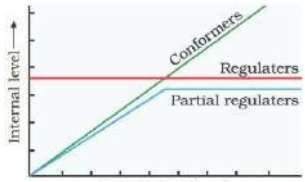
- It is the maintenance of homeostasis by physiological & behavioural means. It ensures constant body temperature

(thermoregulation), constant osmotic concentration (osmoregulation) etc. E.g. All birds & mammals, very few lower vertebrates and invertebrates.

- **Thermoregulation in mammals:** The success of mammals is mainly due to their ability to maintain a constant body temperature.
  In summer, when outside temperature is more than body temperature (37^0C), sweating occurs. This results in evaporative cooling and brings down body temperature.
  In winter, when the temperature is below 37^0C, shivering occurs. It produces heat and raises the body temperature.
- Most of the organisms are not regulators or are partial regulators because thermoregulation is **energetically expensive** especially for small animals (shrews, humming birds etc.). They have a larger surface area relative to their volume. So they lose body heat very fast when it is cold outside. Then they have to expend much energy to generate body heat. So, very small animals are rare in Polar Regions.

b. Conform

- 99% of animals and nearly all plants cannot maintain a constant internal environment. Their body temperature or osmotic concentration change with the surrounding conditions. They are called **conformers.**



Diagrammatic representation of organismic response

- In aquatic animals, osmotic concentration of body fluids changes with that of the ambient osmotic concentration.

c. Migrate

- Many animals like birds move away temporarily from stressful habitat to a more hospitable area and return when stressful period is over.
- E.g. During winter, Keolado National Park (Bhartpur, Rajasthan) hosts migratory birds coming from Siberia and other extremely cold northern regions.

d. Suspend

- In bacteria, fungi & lower plants, thick walled spores help to survive unfavourable conditions. Under suitable conditions, they germinate.
- In higher plants, seeds and some vegetative reproductive structures serve to tide over periods of stress by reducing their metabolic activity. They germinate under favourable moisture and temperature.

In animals: Examples are

- *Hibernation* of bears during winter.
- *Aestivation* of some snails and fishes during summer.
- *Diapause* (a stage of suspended development) of many zooplanktons in lakes & ponds.

Adaptations

- **Adaptation** is the morphological, physiological & behavioural attribute that enables an organism to survive and reproduce in its habitat.
- Many adaptations have evolved over a long evolutionary time and are genetically fixed.

Adaptations of kangaroo rat in North American deserts:

- Internal **fat oxidation** gives water as byproduct if there is no external source of water.
- Ability to **concentrate urine** so that minimal volume of water is used to remove excretory products.

Adaptations of desert plants:

- Presence of **thick cuticle** on leaf surfaces.
- **Sunken stomata** minimise water loss due to transpiration.
- **CAM photosynthetic pathway** enables their stomata to remain closed during day time.
- Desert plants like *Opuntia* have **no leaves** (they are reduced to spines). Photosynthesis is done by stems.

Adaptations of mammals:

- Mammals from colder climates have shorter ears and limbs to reduce heat loss. This is called **Allen's Rule.**
- Aquatic mammals like seals have a thick layer of fat (blubber) below their skin that acts as an insulator and reduces loss of body heat.

Physiological and biochemical adaptations:

- ***Archaebacteria*** are found in hot springs & deep-sea hydrothermal vents where temperature is **>100^{0}C.** Many fish thrive in Antarctic waters (temperature is below 0^0C).
- Many marine invertebrates & fishes live at great depths in the ocean where the pressure is >100 times the normal atmospheric pressure.
- At a high-altitude place (>3,500 m) we feel ***altitude sickness.*** Its symptoms are nausea, heart palpitations & fatigue. This is due to low atmospheric pressure. So the body does not get enough O_2. Gradually, we acclimatize the situation and the body compensates low O_2 availability by increasing RBC & breathing rate and decreasing the binding capacity of hemoglobin.

Behavioural adaptations:

- Desert lizards bask in the sun and absorb heat when their body temperature is low, but move into shade when the ambient temperature starts increasing.
- Some species burrow into the soil to hide and escape from the above-ground heat.

POPULATIONS

- A **population** is a group of individuals of same species that live in a given geographical area, share or compete for similar resources and potentially reproduce.
- E.g. All the cormorants in a wetland, rats in an abandoned dwelling, teakwood trees in a forest tract, bacteria in a culture plate and lotus plants in a pond etc.
- Population ecology is an important area of ecology as it links ecology to population genetics & evolution.

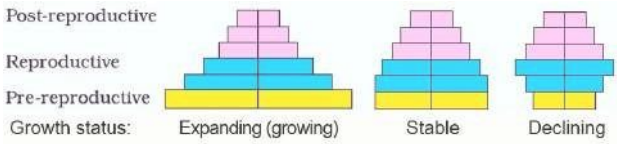
Population Attributes

- **Birth rates:** Refer to *per capita* births.
  E.g. In a pond, there are 20 lotus plants last year and through reproduction 8 new plants are added.

Hence, the current population = 28

The birth rate = 8/20 = 0.4 offspring per lotus per year.

- **Death rates:** Refer to *per capita* deaths.
  E.g. 4 individuals in a laboratory population of 40 fruit flies died during a week.
  Hence, the death rate = 4/40 = 0.1 individuals per fruit fly per week.
- **Sex ratio:** A population has a sex ratio.
  E.g. 60% of the population is females and 40% males.
- **Age pyramid:** It is the structure obtained when the age distribution (% individuals of a given age or age group) is plotted for the population.
  For human population, age pyramids generally show age distribution of males and females in a combined diagram.



Representation of age pyramids for human population

- **Population size or population density (N):** It is the number of individuals of a species per unit area or volume.
  E.g. population density of Siberian cranes at Bharatpur wetlands in any year is <10. It is millions for *Chlamydomonas* in a pond.
  Population size is also measured in **% cover or biomass.**
  E.g. In an area, 200 *Parthenium* plants and a huge banyan tree are seen. In such cases, measuring % cover or biomass is meaningful to show importance of banyan tree.
  Total number is a difficult measure for a huge population. In such cases, **relative population density** (without knowing absolute population density) is used. E.g. Number of fish caught per trap indicates its total population density in the lake.
  In some cases, indirect estimation of population sizes is performed. E.g. Tiger census in national parks & tiger reserves based on pug marks & fecal pellets.

POPULATION GROWTH

The population size changes depending on factors like food availability, predation pressure & weather.

Changes in population density give some idea about the population – whether it is flourishing or declining.

4 basic processes that fluctuate the population density:

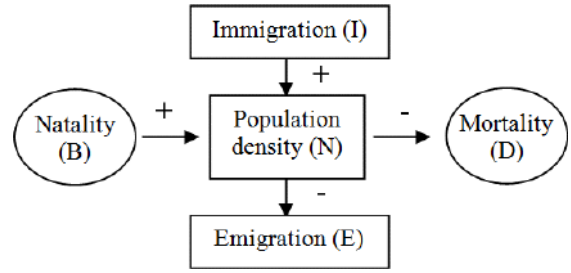
a. Natality (B): It is the number of births in a population during a given period.

b. Mortality (D): It is the number of deaths in a population during a given period.

c. Immigration (I): It is the number of individuals of the same species that have come into the habitat from elsewhere during a given time period.

d. Emigration (E): It is the number of individuals of the population who left the habitat and gone elsewhere during a given time period.

Natality & immigration increase the population density and mortality & emigration decrease the population density.



- If N is the population density at time t, then its density at time t +1 is

$$N_{t+1} = N_t + [(B + I) - (D + E)]$$

Population density increases if B+I is more than D+E. Otherwise it will decrease.

- Under normal conditions, births & deaths are important factors influencing population density. Other 2 factors have importance only under special conditions. E.g. for a new colonizing habitat, immigration may be more significant to population growth than birth rates.

Growth Models

a. Exponential growth

- Resources (food & space) are essential for the unimpeded population growth.
- If resources are unlimited, each species shows its full innate potential to grow in number. Then the population grows in an exponential or geometric fashion.
- If population size = N, birth rates (*per capita* births) = *b* and death rates (*per capita* deaths) = *d*, then the increase or decrease in N during a unit time period t (dN/dt) will be

$$dN/dt = (b - d) \times N$$

Let (b–d) = r, then

$$dN/dt = rN$$

The r ('intrinsic rate of natural increase') is an important parameter for assessing impacts of any biotic or abiotic factor on population growth.

r value for the Norway rat = 0.015

r value for the flour beetle = 0.12

r value for human population in India (1981) = 0.0205

The integral form of the exponential growth equation is

$$N_t = N_0 e^{rt}$$

Where,

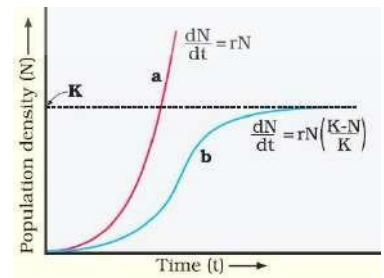
N_t = Population density after time t

N_0 = Population density at time zero

r = intrinsic rate of natural increase

e = the base of natural logarithms (2.71828)

Population growth curves



a = exponential growth (J-shaped curve)

b = logistic growth (Sigmoid curve)

b. Logistic growth

- There is no population in nature having unlimited resources for exponential growth. This leads to competition among individuals for limited resources.
- Eventually, the 'fittest' individuals survive and reproduce.
- In nature, a given habitat has enough resources to support a maximum possible number, beyond which no further growth is possible. It is called **carrying capacity (K)**.
- A population with limited resources shows initially a **lag phase, phases of acceleration & deceleration** and finally an **asymptote**. This type of population growth is called **Verhulst-Pearl Logistic Growth.** It is described by following equation:

$$dN/dt = rN\left(\frac{K-N}{K}\right)$$

Where N = Population density at time t
r = Intrinsic rate of natural increase
K = Carrying capacity

- Since resources for growth for most animal populations are limited, the logistic growth model is more realistic.

Life History Variation

- Populations evolve to maximise their reproductive fitness or Darwinian fitness (high r value). Under a particular set of selection pressures, organisms evolve towards the most efficient reproductive strategy.
- Some organisms breed only once in their lifetime (Pacific salmon fish, bamboo) while others breed many times (most birds and mammals).
- Some produce a large number of small-sized offspring (Oysters, pelagic fishes) while others produce a small number of large-sized offspring (birds, mammals).
- These facts indicate that life history traits of organisms have evolved due to limited abiotic and biotic components of the habitat.

Population Interactions

- Organisms interact in various ways to form a biological community.
- Interaction between two species is called **Interspecific interactions.** They include

Name of interaction	Species A	Species B
Mutualism: Both species are benefitted (+)	+	+
Competition: Both species are harmed (-)	-	-
Predation: One (predator) is benefitted. Other (prey) is harmed	+	-
Parasitism: One (parasite) is benefitted. Other (host) is harmed	+	-
Commensalism: One is benefitted. Other is unaffected (0)	+	**0**
Amensalism: One is harmed. Other is unaffected	-	**0**

- In predation, parasitism & commensalisms, the interacting species live closely together.

a. Predation

- In a broad ecological context, all carnivores, herbivores etc. are predators. About 25 % insects are *phytophagous.*
- If a predator overexploits its prey, then the prey might become extinct. It results in the extinction of predator. Therefore, predators in nature are 'prudent'.

Importance of predators:

- **Predators control prey populations.**
  When certain exotic species are introduced into a geographical area, they spread fast due to the absence its natural predators. E.g. Prickly pear cactus introduced into Australia (1920's) caused havoc by spreading. Later, it was controlled by introducing a cactus-feeding predator moth.
- Predators are used in **Biological control** methods.
- Predators **maintain species diversity** in a community by reducing competition among prey species.
  E.g. the predator starfish *Pisaster* in the rocky intertidal communities of American Pacific Coast. In an experiment, all these starfishes were removed from an enclosed intertidal area. It caused extinction of over 10 invertebrate species within a year, due to interspecific competition.

Defenses of prey species to lessen impact of predation:

- ***Camouflage*** (cryptic colouration) of some insects & frogs.
- Some are **poisonous** and so avoided by the predators.
- Monarch butterfly is highly distasteful to its predator bird. It is due to a special chemical in its body. It is acquired during its caterpillar stage by feeding on a poisonous weed.
- **Thorns** (*Acacia*, *Cactus etc.*) are the most common morphological means of defense of plants.
- Many plants produce chemicals that make the herbivore sick, inhibit feeding or digestion, disrupt its reproduction or kill it. E.g. *Calotropis* produce highly poisonous **cardiac glycosides.** Therefore cattle or goats do not eat it. **Nicotine, caffeine, quinine, strychnine, opium,** etc. are defenses against grazers and browsers.

b. Competition

- It is a process in which fitness of one species ('r' value) is significantly lower in presence of another species.
- Interspecific competition is a potent force in organic evolution.
- Competition occurs when closely related species compete for the same limited resources.
- Unrelated species can also compete for the resource. E.g. Flamingoes & fishes in some shallow South American lakes compete for zooplankton.
- Competition occurs in abundant resources also. E.g. In **interference competition,** the feeding efficiency of one species is reduced due to the interfering and inhibitory presence of other species, even if resources are abundant.

Evidences for competition:

- The Abingdon tortoise in Galapagos Islands became extinct within a decade after goats were introduced on the island, due to greater browsing efficiency of the goats.

- **Competitive release:** It is the expansion of distributional range of a species when the competing species is removed.

  Connell's field experiments: On the rocky sea coasts of Scotland, there are 2 barnacle species: *Balanus* (larger & competitively superior) & *Chthamalus* (smaller). *Balanus* dominates intertidal area and excludes *Chthamalus.*

  When Connell experimentally removed *Balanus, Chthamalus* colonized the intertidal zone.

Gause's 'Competitive Exclusion Principle':

- It states that *two closely related species competing for the same resources cannot co-exist indefinitely and the competitively inferior one will be eliminated eventually*. This may be true in limited resources, but not otherwise.
- Species facing competition may evolve mechanisms for co-existence rather than exclusion. E.g. resource partitioning.
- **Resource partitioning**: It is the division of limited resources by species to avoid competition. For this, they choose different feeding times or different foraging patterns. E.g. MacArthur showed that five closely related species of **warblers** living on a tree could avoid competition and co-exist due to behavioural differences in their foraging activities.

c. Parasitism

- Many parasites are **host-specific** (they can parasitize only a single host species). They tend to **co-evolve.** i.e., if the host evolves special mechanisms against the parasite, the parasite also evolves mechanisms to counteract them to remain with the same host species.
- **Adaptations of parasites:** Loss of sense organs, presence of adhesive organs or suckers to cling on to the host, loss of digestive system, high reproductive capacity etc.
- Life cycles of parasites are often complex. E.g.
  - Human liver fluke depends on 2 intermediate hosts (a snail & a fish) to complete its life cycle.
  - Malarial parasite needs mosquito to spread to other hosts.
- Parasites harm the host. They may reduce the survival, population density, growth and reproduction of the host. They may make the host physically weak and more vulnerable to predation.

Types of parasites:

1. Ectoparasites

- Parasites that feed on the external surface of host. E.g.
  - Lice on humans.
  - Ticks on dogs.
  - Ectoparasitic Copepods on many marine fishes.
  - *Cuscuta* plant on hedge plants.
- *Cuscuta* has no chlorophyll and leaves. It derives its nutrition from the host plant.
- Female mosquito is not considered a parasite, because it needs our blood only for reproduction, not as food.

2. Endoparasites

- Parasites that live inside the host body at different sites (liver, kidney, lungs, RBC etc).
- The life cycles of endoparasites are more complex.
- They have simple morphological & anatomical features and high reproductive potential.

Brood parasitism in birds:

- Here, the parasitic birds lay eggs in the nest of its host and lets the host incubate them.
- During evolution, eggs of the parasitic bird have evolved to resemble the host's egg in size and colour. So the host bird cannot detect and eject the foreign eggs easily.
- E.g. Brood parasitism between **cuckoo and crow.**

d. Commensalism

Examples:

- Orchid (+) growing as *epiphyte* on a mango branch (0).
- Barnacles (+) growing on the back of a whale (0).
- Cattle egret (+) & grazing cattle (0). The egrets forage close to where the cattle are grazing. As the cattle move, the vegetation insects come out. Otherwise it is difficult for the egrets to find and catch the insects.
- Sea anemone (0) & clown fish (+). Stinging tentacles of sea anemone gives protection to fish from predators.

e. Mutualism

Examples:

- **Lichen:** It is a mutualistic relationship between a fungus & photosynthesizing algae or cyanobacteria.
- **Mycorrhizae:** Associations between fungi & the roots of higher plants. The fungi help the plant in the absorption of essential nutrients from the soil while the plant provides the fungi with carbohydrates.
- **Mutualism b/w plant & animal through pollination and seed dispersion:**

  Examples:

  1. **Fig trees & wasps.** The fig species is pollinated only by its 'partner' wasp species. Female wasp pollinates the fig inflorescence while searching for suitable egg-laying sites in fruits. The fig offers the wasp some developing seeds, as food for the wasp larvae.
  2. **Orchids** show diversity of floral patterns. They can attract the right pollinator insect **(bees & bumblebees)** to ensure pollination. Not all orchids offer rewards.
  3. **'Sexual deceit' of *Ophrys*** (Mediterranean orchid). One petal of its flower resembles female bee in size, colour & markings. So male bee 'pseudocopulates' with the flower and is dusted with pollen. When this bee 'pseudocopulates' with another flower, it transfers pollen to it.

     If the female bee's colour patterns change slightly during evolution, pollination success will be reduced unless the orchid flower co-evolves to maintain the resemblance of its petal to the female bee.

ECOSYSTEM

An ecosystem is a functional unit of nature, where living organisms interact each other and with the physical environment.

ECOSYSTEM – STRUCTURE & FUNCTION

Types of ecosystems

- **Terrestrial ecosystem:** Forest, grassland, desert etc.
- **Aquatic ecosystem:** Pond, lake, wetland, river & estuary.
- **Man-made ecosystem:** Crop fields and aquarium.

- Entire biosphere is regarded as **global ecosystem.**
- In an ecosystem, biotic and abiotic components interact and function as a unit.
- Vertical distribution of different species occupying different levels is called **stratification**. E.g. in a forest, trees occupy top strata (layer), shrubs the second and herbs & grasses the bottom layers.

Pond (Aquatic ecosystem)

A pond is a shallow, simple, self-sustainable water body that exhibits all basic components of an ecosystem.

- **Abiotic components:** Water and soil deposit.
- **Climatic conditions:** Solar input, cycle of temperature, day-length etc.
- **Autotrophic components:** Phytoplankton, some algae and the floating, submerged and marginal plants.
- **Consumers (heterotrophs):** Zooplankton, free swimming and bottom dwelling forms.
- **Decomposers:** Fungi, bacteria and flagellates.

Pond performs all the functions of an ecosystem. E.g.

- Autotrophs convert inorganic into organic material using solar radiant energy.
- Heterotrophs consume the autotrophs.
- Decomposition and mineralization of the dead matter to release them back for reuse by the autotrophs.

4 basic components of functioning of an ecosystem:

1) Productivity
2) Decomposition
3) Energy flow
4) Nutrient cycling

1. PRODUCTIVITY

- Solar energy is the basic requirement for an ecosystem to function and sustain.
- Amount of biomass (organic matter) produced per unit area over a time period by plants during photosynthesis is called **primary production.** It is expressed in weight (g^{-2}) or energy (kcal m^{-2}).
- The rate of biomass production is called **productivity**. It is expressed in $g^{-2}\ yr^{-1}$ or (kcal m^{-2}) yr^{-1}.
- It is divided into gross primary productivity (GPP) and net primary productivity (NPP).
- **Gross primary productivity (GPP):** It is the rate of production of organic matter during photosynthesis. A considerable amount of GPP is used by plants in respiration.
- **Net primary productivity (NPP):** It is the available biomass for the consumption to heterotrophs (herbivores & decomposers). i.e., NPP is the Gross primary productivity minus respiration losses (R).

NPP = GPP – R

- **Secondary productivity:** It is the rate of formation of new organic matter by consumers.
- Primary productivity varies in different ecosystems because it depends on
  - The plant species inhabiting an area.
  - Environmental factors.
  - Availability of nutrients.
  - Photosynthetic capacity of plants.
- **Annual net primary productivity** of whole biosphere is about **170 billion tons** (dry weight) of organic matter. Of this, despite occupying about 70 % of the surface, the productivity of the oceans is only 55 billion tons.

2. DECOMPOSITION

- It is the breakdown of complex organic matter by decomposers into inorganic substances like CO_2, water and nutrients. It is largely an oxygen-requiring process.
- Raw material for decomposition is called **Detritus.** E.g. dead plant remains (leaves, bark, flowers etc.), dead remains of animals, fecal matter etc.

Steps of decomposition

a. Fragmentation: It is the breakdown of detritus into smaller particles by **detritivores** (e.g. earthworm).

b. Leaching: Water soluble inorganic nutrients go down into soil horizon and precipitate as unavailable salts.

c. Catabolism: Degradation of detritus into simpler inorganic substances by bacterial and fungal enzymes.

The above three processes occur simultaneously.

d. Humification: Accumulation of **humus** (dark amorphous substance) in soil. Humus is resistant to microbial action and so decomposes very slowly. Being colloidal, it serves as a reservoir of nutrients.

e. Mineralization: It is the release of inorganic nutrients due to the degradation of humus by some microbes.

Factors influencing decomposition

- **Chemical composition of detritus:**
  - Decomposition is slow in detritus rich in lignin & chitin.
  - It is quicker in detritus rich in nitrogen and water-soluble substances like sugars.
- **Climatic factors (temperature & soil moisture):**
  - Warm and moist environment favour decomposition.
  - Low temperature & anaerobiosis inhibit decomposition resulting in buildup of organic materials.

3. ENERGY FLOW

- Sun is the only source of energy for all ecosystems (except deep sea hydro-thermal ecosystem).
- Of the incident solar radiation, less than 50% is **photosynthetically active radiation (PAR).**
- Plants and photosynthetic bacteria (autotrophs), fix solar radiant energy to make food.
- Plants capture only **2-10%** of the PAR. This energy sustains the entire living world.
- Ecosystems obey 2nd Law of thermodynamics. They need a constant supply of energy to synthesize the molecules. It helps to counteract the entropy.

Producers (Autotrophs):

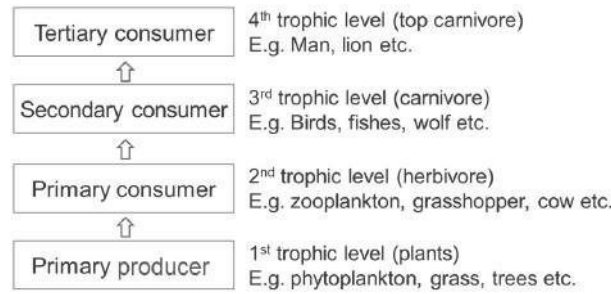
- These are organisms that synthesize food.
- In a terrestrial ecosystem, major producers are herbaceous and woody plants. Primary producers in an aquatic ecosystem are phytoplankton, algae and higher plants.
- The energy trapped by the producer is passed on to a consumer or the organism dies.

Consumers (heterotrophs):

- These are animals that directly or indirectly depend on plants for food. They include:
  - **Primary consumers (herbivores):** Feed on plants. E.g. insects, birds, mammals, molluscs etc.
  - **Secondary consumers (primary carnivores):** Feed on herbivores. E.g. frog, fox, man etc.
  - **Tertiary consumers (secondary carnivores):** Feed on primary carnivores. E.g. tiger, lion etc.
- The chain of feeding relationship between different organisms is called a **food chain.** It is 2 types:
  - **Grazing Food Chain (GFC):** Here, primary consumer feeds on living plants (producer). E.g.

Grass ⟶ Goat ⟶ Man
(Producer) (Primary Consumer) (Secondary consumer)

  - **Detritus Food Chain (DFC):** Here, primary consumer feeds on dead organic matter (detritus). Death of organism is the beginning of the DFC.
- Detritus is made up of **decomposers (saprotrophs**) such as fungi & bacteria. They secrete digestive enzymes that breakdown detritus into simple, inorganic materials, which are absorbed by them. Thus, they get energy & nutrients.
- In an aquatic ecosystem, GFC is the major conduit for energy flow.
- In a terrestrial ecosystem, a much amount of energy flows through the DFC than through the GFC.
- DFC may be connected with GFC at some levels. Some organisms of DFC are prey to the GFC animals. Some animals (cockroaches, crows, human etc.) are omnivores. Such interconnections of food chains are called **food web**.
- A specific place of organisms in the food chain is known as their **trophic level**.

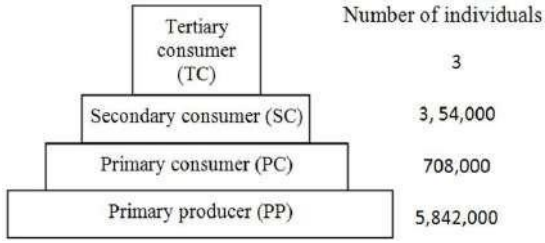


- The amount of energy decreases at successive trophic levels. When an organism dies it becomes **dead biomass (detritus).** It is an energy source for decomposers.
- Organisms at each trophic level depend on those at the lower trophic level for their energy.
- The amount of living material in a trophic level at a given time is called **standing crop**. It is measured as the **biomass** (mass of living organisms) or the **number in a unit area.**
- Biomass of a species is measured in terms of **fresh or dry weight.** Dry weight is more accurate because it is the exact mass of body which remains constant.
- Number of trophic levels in GFC is restricted as it follows **10% law** (only 10% of energy is transferred to each trophic level from the lower trophic level).

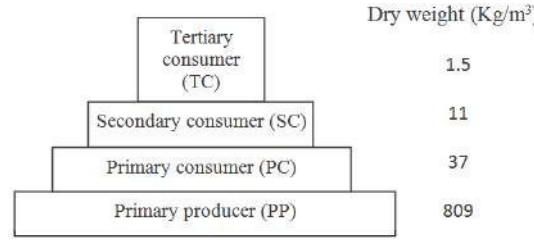
ECOLOGICAL PYRAMIDS

- The representation of a food chain in the form of a pyramid is called **ecological pyramid.**
- The base of a pyramid represents producers (first trophic level). The apex represents tertiary or top-level consumer.
- Ecological pyramids are 3 types: Pyramid of number, Pyramid of biomass and Pyramid of energy.

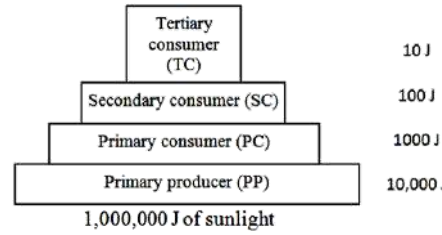
a) Pyramid of number: E.g. grassland ecosystem.



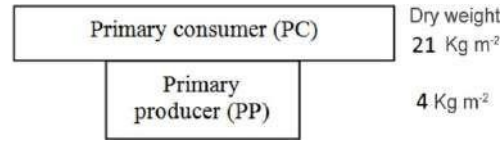
b) Pyramid of biomass: It shows a sharp decrease in biomass at higher trophic levels.



c) Pyramid of energy: Primary producers convert only 1% of the energy in the sunlight available to them into NPP.



- Any calculations of energy content, biomass, or numbers has to include all organisms at that trophic level.
- A trophic level represents a functional level, not a species as such. A species may occupy more than one trophic level in the same ecosystem at the same time. E.g. A sparrow is a primary consumer when it eats seeds, fruits, peas. It is a secondary consumer when it eats insects & worms.
- In most ecosystems, all the pyramids are upright, i.e., producers are higher in number, biomass and energy than the herbivores, and herbivores are higher in number, biomass and energy than the carnivores.
- But in some cases, inverted pyramids for number and biomass are present.
- **Inverted pyramid of number:** E.g. Insects feeding on a tree.
- **Inverted pyramid of biomass:** E.g.
  - Small standing crop of phytoplankton supports large standing crop of zooplankton.
  - Pyramid of biomass in sea is inverted because the biomass of fishes far exceeds that of phytoplankton.



- Pyramid of energy is always upright because some energy is always lost as heat at each trophic level. So energy at a lower trophic level is always more than at a higher level.

Limitations of ecological pyramids

- It does not consider the **same species** belonging to **twoor more trophic levels.**
- It assumes a **simple food chain** that never exists in nature. It does not accommodate a **food web.**
- **Saprophytes** are not included.

ECOLOGICAL SUCCESSION

- It is a gradual, slow and predictable change in the species composition of an area leading to a **climax community** (community that is in equilibrium with the environment).
- In this, some species colonize an area and increase in number, whereas other species decline and disappear.
- The entire sequences of communities that successively change in an area are called **sere**. Individual transitional communities are termed **seral stages (seral communities).**
- The species invading a bare area are called **pioneer species**.
- During succession, there is a change in species diversity, increase in number of species and organisms and an increase in total biomass.
- Present-day communities are due to succession of millions of years. Succession and evolution were parallel processes.
- Succession is 2 types:
  - **Primary:** The succession taking place in areas where no living organisms ever existed. E.g. newly cooled lava, bare rock, newly created pond or reservoir.
    To establish a biotic community, fertile soil must be formed. So primary succession is a very slow process.
  - **Secondary:** The succession taking place in an area after the existed organisms are lost. E.g. abandoned farm lands, burned or cut forests, lands that are flooded.
    Since some soil or sediment is present, succession is faster than primary succession.
    The species that invade depend on the nature of the soil, availability of water etc.
- In succession, changes in vegetation affect food & shelter of animals. Thus, succession leads to change in number and types of animals & decomposers.
- Natural or human induced disturbances (deforestation, fire etc.) convert a particular seral stage to an earlier stage. They create new conditions that encourage some species and discourage or eliminate other species.

Succession of Plants

- Based on the nature of the habitat, succession of plants is 2 types: hydrarch and xerarch.
  - **Hydrarch succession:** It takes place in wetter areas. It progresses from **hydric to mesic** conditions.
  - **Xerarch succession:** It takes place in dry areas. It progresses from **xeric to mesic** conditions.
- Hence, both hydrarch & xerarch successions lead to medium water conditions **(mesic,** the climax community).
- **Primary succession on rocks (xerophytic habitat):**
  Lichens (pioneer species. They secrete acids to dissolve rock, helping in weathering & soil formation) → small plants like **bryophytes** (they need only small amount of soil) → **bigger plants** → **forest** (mesophytic).
  The **climax community (forest)** remains stable if the environment remains unchanged.
- **Primary succession in water:**
  Phytoplankton (pioneers) → rooted-submerged plants → rooted-floating angiosperms → free-floating plants → reed-swamp → marsh-meadow → scrub → trees (climax community is a forest).
  With time, the water body is converted into land.

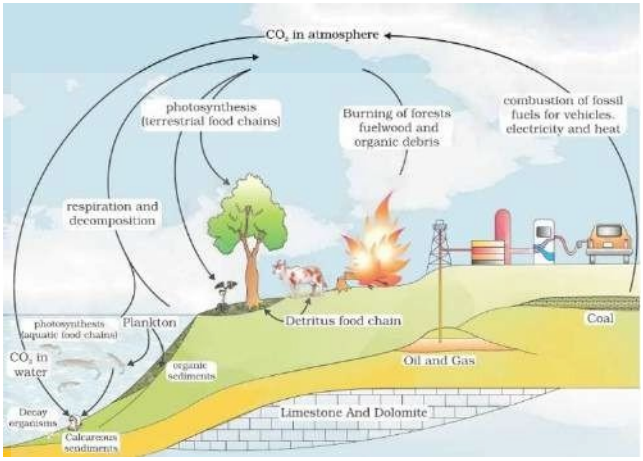
4. NUTRIENT CYCLING

- Amount of nutrients (C, N, P, Ca etc.) present in the soil in a given time is called the **standing state**. It varies in different kinds of ecosystems and also on a seasonalbasis.
- Nutrients are never lost from the ecosystems. They are recycled again and again.
- The movement of nutrient elements through various components of an ecosystem is called **nutrient cycling (biogeochemical cycles).**
- Nutrient cycles are 2 types:
  a. **Gaseous cycle:** For this, the reservoir exists in the atmosphere. E.g. Nitrogen & Carbon cycles.

b. Sedimentary cycle: For this, the reservoir is located in Earth's crust. E.g. Sulphur & Phosphorus cycles.

- Environmental factors (soil, moisture, pH, temperature, etc.) regulate the rate of release of nutrients into the atmosphere. The reservoir meets with the deficit of nutrients due to imbalance in the rate of influx and efflux.

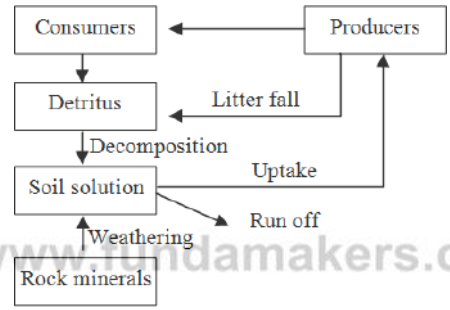
Carbon Cycle



- **Reservoir of carbon:** Atmosphere (about 1%), organisms (49% of dry weight), oceans (71% dissolved carbon. It regulates the amount of atmospheric CO_2), fossil fuel etc.
- Carbon cycling occurs through atmosphere, ocean and through living and dead organisms.
- 4×10^{13} kg of carbon is fixed in the biosphere through photosynthesis annually.
- A major amount of carbon returns to the atmosphere as CO_2 through respiration.
- Processing of wastes & dead organic matter by decomposers also release CO_2.
- Some amount of the fixed carbon is lost to sediments and removed from circulation.
- Burning of wood, forest fire and combustion of organic matter, fossil fuel and volcanic activity are other sources for releasing CO_2 in the atmosphere.
- **Role of human activities in carbon cycle:** Deforestation, burning of fossil fuel etc. has increased the rate of release of CO_2 into the atmosphere.

Phosphorus Cycle

- Phosphorus is a constituent of biological membranes, nucleic acids & cellular energy transfer systems. Many animals use phosphorus to make shells, bones and teeth.
- The natural reservoir of phosphorus is rock (in the form of phosphates).
- When rocks are weathered, minute amounts of phosphates dissolve in soil solution and are absorbed by the plants. Herbivores and other animals obtain this from plants. The waste products and the dead organisms are decomposed by phosphate-solubilising bacteria releasing phosphorus.



Differences between carbon & phosphorous cycles

Carbon cycle	Phosphorous cycle
Atmospheric input is higher	Much smaller
There is gaseous exchange b/w organism & environment	Gaseous exchange is negligible

ECOSYSTEM SERVICES

- The products of ecosystem processes are called **ecosystem services.**
- E.g. forest ecosystems purify air and water, mitigate droughts and floods, cycle nutrients, generate fertile soils, provide wildlife habitat, maintain biodiversity, pollinate crops, provide storage site for carbon and provide aesthetic, cultural & spiritual values.
- **Robert Costanza** and his colleagues have tried to put price tags on nature's life-support services.
- Researchers have put an average price tag of US $ 33 trillion a year on fundamental ecosystems services. This is nearly twice the value of the global gross national product GNP (US $ 18 trillion).
- Out of this total cost, soil formation accounts for about 50%.
- Contributions of other services like recreation & nutrient cycling are less than 10% each.
- The cost of climate regulation and habitat for wildlife are about 6 % each.

BIODIVERSITY AND CONSERVATION

Biodiversity is the diversity of biological organisation ranging from cellular macromolecules to biomes.

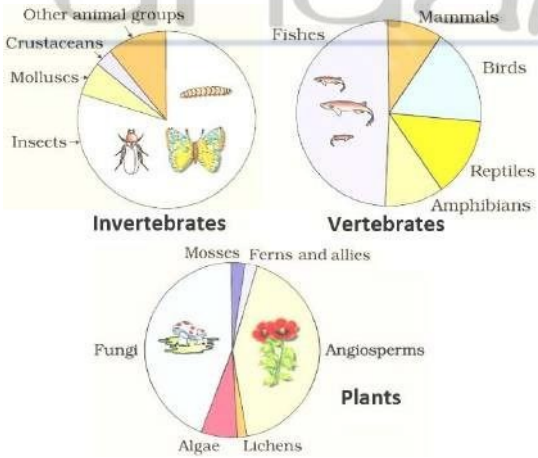
Edward Wilson popularized the term 'biodiversity'.

LEVELS OF BIODIVERSITY

1. **Genetic diversity:** Diversity shown by a single species at **genetic level.** E.g. ***Rauwolfia vomitoria*** **(Himalaya)** shows genetic variation in the **potency** & **concentration** of the chemical **reserpine.** India has more than **50,000** different strains of **rice** and **1000 varieties** of **mango.**
2. **Species diversity:** Diversity at **species level.** E.g. **Western Ghats** have greater **amphibian species** than **Eastern Ghats.**
3. **Ecological diversity:** Diversity at **ecosystem level.** E.g. In India, **deserts, rain forests, mangroves, coral reefs, wet lands, estuaries** & **alpine meadows** are seen.

NUMBER OF SPECIES ON EARTH (GLOBAL SPECIES DIVERSITY)

- According to **IUCN (2004),** more than **1.5 million species** described so far.
- According to **Robert May's Global estimate,** about **7 million** species would have on earth. (He considered the species to be discovered in the tropics. i.e. only **22%** of the total species have been recorded so far).
- **Animals** are more diverse (**above 70%**) than **plants** including Plantae and Fungi (**22%**).
- Among animals, **insects** are most species rich group **(70%,** i.e. out of every 10 animals, 7 are insects).
- Number of fungi species is more than the combined total of the species of fishes, amphibians, reptiles & mammals.



- India has only **2.4%** of world's land area, but has **8.1%** of the species diversity. India is one of the **12 mega diversity** countries of the world. Nearly **45,000 plant species** and **twice** as many of **animals** have been recorded from India.
- Applying **May's global estimates,** India would have more than 1 lakh plant species and 3 lakh animal species.
- Biologists are not sure about total number of prokaryotic species because
  - Conventional taxonomic methods are not suitable for identifying microbial species.
  - In laboratory, many species cannot be cultured.

PATTERNS OF BIODIVERSITY

i. Latitudinal gradients

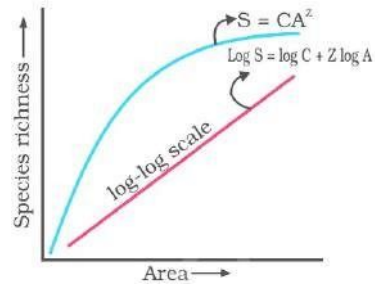
- Species diversity decreases from the equator to the poles.
- **Tropics** (latitudinal range of 23.5° N to 23.5° S) have more species than temperate or polar areas.

  E.g. Number of **bird species** in different latitudes:
  - **Colombia** (near equator): about **1400 species.**
  - **India** (in tropics): > **1200 species.**
  - **New York (41° N): 105 species.**
  - **Greenland (71° N): 56 species.**
- Tropical forest region like **Equador** has up to **10 times** of vascular plant species as compared to a temperate forest region like the **Midwest of USA.**
- **Tropical Amazonian rain forest** (South America) is the greatest biodiversity on earth. It contains
  - > 40000 species of plants
  - 3000 species of fishes
  - 1300 species of birds
  - 427 species of mammals
  - 427 species of amphibians
  - 378 species of reptiles
  - > 1,25,000 species of invertebrates
- Biodiversity (species richness) is highest in tropics because
  - Tropics had more evolutionary time.
  - Relatively constant environment (less seasonal).
  - They receive more solar energy which contributes to greater productivity.

ii. Species- Area relationship

According to the study of **Alexander von Humboldt** in South American jungles, within a region, species richness increases with increasing explored area, but only up to a limit.

Relation between species richness and area gives a **rectangular hyperbola.**



S= CA^Z

Where,
S= Species richness
A= Area
C= Y-intercept
Z= slope of the line (regression co-efficient)

- On a logarithmic scale, the relationship is a straight line described the equation **Log S = log C + Z log A**
- Generally, for small areas, the Z value is **0.1 to 0.2.**
- But for large areas (e.g. entire continents), slope of the line is steeper **(Z value: 0.6 to 1.2).**
- E.g. for frugivorous birds and mammals in the tropical forests of different continents, the Z value is **1.15.**

IMPORTANCE OF SPECIES DIVERSITY

- According to **David Tilman,** plots with more species shows less year-to-year variation in total biomass.
- Increased diversity contributes to higher productivity. It is essential for ecosystem health and survival of human race.

- **'Rivet popper hypothesis':** It is an analogy used to understand the importance of biodiversity.

  It is proposed by Stanford ecologist **Paul Ehrlich.**

  In an airplane **(ecosystem),** all parts are joined with many rivets **(species).** If passengers pop a rivet (extinction of a species), it may not affect flight safety **(functioning of the ecosystem).** But as more and more rivets are removed, the plane becomes dangerously weak. Loss of rivets on the wings (**key species** that drive major ecosystem functions) is more dangerous than loss of a few rivets on the seats or windows.

LOSS OF BIODIVERSITY

- **IUCN Red List (2004)** says that 784 species (338 vertebrates, 359 invertebrates & 87 plants) were extinct in the last 500 years. E.g. **Dodo (Mauritius), Quagga (Africa), Thylacine (Australia), Stellar's sea cow (Russia)** and **3 subspecies (Bali, Javan, Caspian) of tiger.**
- **27 species** have been disappeared in the last 20 years.
- More than **15,500 species** are facing threat of extinction.
- **12% birds, 23% mammals, 32% amphibians, 31% gymnosperm species** face the threat of extinction.
- The current extinction rate is 100 - 1000 times faster than in the pre-human times. If this trend continues, nearly 50% species might be extinct within next 100 years.

Impacts of Loss of biodiversity

- Decline in plant production.
- Environmental perturbations such as drought.
- Increased variability in ecosystem processes such as plant productivity, water use and pest & disease cycles.

Causes of Biodiversity losses ('The Evil Quartet')

1. **Habitat loss and fragmentation:** Most important cause.
   - E.g. Tropical rain forests (loss from 14% to 6%).
   - Thousands of hectares of rain forests are being lost within hours.
   - **The Amazon rain forest** is being cut for cultivating soya beans or for conversion of grass lands for cattle.
   - Fragmentation badly affects animals requiring large territories and migratory animals.
2. **Over-exploitation: Stellar's sea cow, Passenger pigeon** etc. extinct due to over exploitation.
3. **Alien species invasions:** Alien species cause decline or extinction of **indigenous species.** E.g.
   - **Nile Perch** introduced in **Lake Victoria (East Africa)** caused extinction of more than 200 species of **cichlid fish**.
   - Invasive weed species like ***Parthenium*** **(carrot grass), Lantana** and ***Eicchornia*** **(water hyacinth)** caused damage to our native species.
   - Illegal introduction of the **African Catfish (*Clarias gariepinus*)** for aquaculture is a threat to the indigenous catfishes in our rivers.
3. **Co-extinction:** When a species becomes extinct, the species associated with it also extinct. E.g.
   - Extinction of the **parasites** when the **host** is extinct.
   - In co-evolved **plant-pollinator mutualism,** extinction of one causes the extinction of the other.

BIODIVERSITY CONSERVATION

There are 3 categories of reasons for conservation.

a. Narrowly utilitarian arguments

- Human derive economic benefits from nature such as food, firewood, fibre, construction material, industrial products (tannins, lubricants, dyes, resins, perfumes) and medicines.
- More than 25% of the drugs are derived from plants.
- 25,000 species of plants have medicinal value.

b. Broadly utilitarian arguments

Biodiversity has many ecosystem services. E.g.

- Amazon forest *('lung of the planet')* produces 20% of total O_2 in the earth'satmosphere.
- Pollination through bees, bumblebees, birds and bats.
- Aesthetic pleasures.

c. Ethical arguments

- Every species has an **intrinsic value**. We have a moral duty to care for their well-being.

Biodiversity conservation is 2 types: ***In situ*** **(on site)** conservation and ***Ex situ*** **(off site)** conservation.

a. In situ conservation (on site)

It is the conservation of genetic resources within natural or human-made ecosystems in which they occur. E.g. Protected areas such as **National Parks, Sanctuaries, Biosphere reserves, cultural landscapes, natural monuments etc.**

- **National Park:** Strictly reserved for the welfare of the wildlife where private ownership, cultivation, grazing etc. are prohibited. E.g. **Eravikulam National Park in Kerala.**
- **Sanctuary:** Here, protection is given only to the animals. Collection of timbers, minor forest products and private ownership are allowed so long as they do not harm the animals. E.g. **Periyar wildlife sanctuary in Kerala.**
- **Biosphere Reserves:** Areas of land or coastal ecosystems for conservation and sustainable use.
- **Sacred forests (Sacred groves):** Forest fragments which are communally protected based on religious beliefs. E.g.
  - Sacred groves in **Khasi** & **Jaintia Hills** in Meghalaya.
  - **Aravalli Hills** of **Rajasthan.**
  - **Western Ghat** regions of Karnataka & Maharashtra.
  - **Sarguja, Chanda** & **Bastar** areas (Madhya Pradesh).

India has **14 Biosphere Reserves, 90 National Parks** and **448 wildlife sanctuaries.**

b. *Ex situ* conservation (off site)

It is the conservation of organisms outside their habitats. E.g. genetic resource centres, zoological parks, wildlife safari parks, botanical gardens, gene banks, cryopreservation etc.

Hotspots

- These are the regions with very high species richness, high degree of **endemism** (species confined only to a specific region) but most threatened.
- There are **34 hotspots** in the world.
- **3 hotspots** cover India's biodiversity regions- **Western Ghats & Sri Lanka, Indo-Burma and Himalaya.**

- All hotspots together cover only < 2% of the earth's land area. But the species richness is extremely high. Protection of hotspots reduced the ongoing extinctions by 30%.

International Efforts for conserving biodiversity

- **The Earth Summit** or **Convention on Biological Diversity (Rio de Jeneiro**, **1992)** - 3 objectives:
  a. Conservation of biodiversity.
  b. Sustainable use of biodiversity.
  c. Sharing of benefits arising from genetic resources.
- **The World Summit on Sustainable Development (Johannesburg, South Africa, 2002):** 190 countries pledged to reduce the current rate of biodiversity loss.

36. MOLECULAR BASIS OF INHERITANCE

- Nucleic acids (DNA & RNA) are the building blocks of genetic material.
- DNA is the genetic material in most of the organisms.
- RNA is the genetic material in some viruses. RNA mostly functions as **messengers.**

THE DNA

STRUCTURE OF POLYNUCLEOTIDE CHAIN

Polynucleotides are the polymer of **nucleotides.** DNA & RNA are polynucleotides. A nucleotide has 3 components:

1. **A nitrogenous base.**
2. **A pentose sugar (ribose** in **RNA & deoxyribose** in **DNA).**
3. **A phosphate group.**

Nitrogen bases are 2 types:

☐ **Purines:** It includes **Adenine (A)** and **Guanine (G).**

☐ **Pyrimidines:** It includes **Cytosine (C), Thymine (T)** & **Uracil (U).** Thymine (5-methyl Uracil) present only in DNA and Uracil only in RNA.

A nitrogenous base is linked to the OH of 1' C pentose sugar through an **N-glycosidic linkage** to form **nucleoside.**

Nucleosides in RNA	Nucleosides in DNA
Adenosine	Deoxyadenosine
Guanosine	Deoxyguanosine
Cytidine	Deoxycytidine
Uridine	Deoxythymidine

A phosphate group is linked to OH of 5' C of a nucleoside through **phosphoester linkage** to form **nucleotide** (or deoxynucleotide).

In RNA, each nucleotide has an additional –OH group at 2′ C of the ribose (2'- OH).

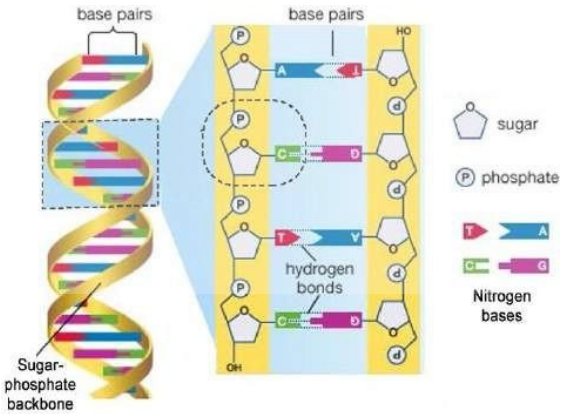
2 nucleotides are linked through **3'-5' phosphodiester bond** to form **dinucleotide.**

When more nucleotides are linked, it forms **polynucleotide.**

STRUCTURE OF THE DNA

☐ **Friedrich Meischer (1869):** Identified DNA and named it as **'Nuclein'.**

☐ **James Watson** & **Francis Crick (1953)** proposed **double helix model of DNA.** It was based on X-ray diffraction data produced by **Maurice Wilkins** & **Rosalind Franklin.**



Pitch of helix= 3.4 nm (34 Å)
Number of base pairs in each turn= 10
Distance between adjacent base pairs= 0.34 nm (3.4 Å)

☐ DNA is made of 2 polynucleotide chains coiled in a right-handed fashion. Its backbone is formed of sugar & phosphates. The bases project inside.

☐ The 2 chains have **anti-parallel polarity**, i.e. one chain has the polarity **5'→3'** and the other has **3'→5'.**

☐ The bases in 2 strands are paired through **H-bonds** forming **base pairs (bp).**

A=T (2 hydrogen bonds) **C≡G (3 hydrogen bonds)**

☐ Purine comes opposite to a pyrimidine. This generates uniform distance between the 2 strands.

☐ **Erwin Chargaff's rule:** In DNA, the proportion of A is equal to T and the proportion of G is equal to C.

$\therefore$ **[A] + [G] = [T] + [C]**

or [A] + [G] / [T] + [C] =1

- **Φ 174 (a bacteriophage)** has 5386 nucleotides.
- **Bacteriophage lambda** has **48502 base pairs (bp).**
- ***E. coli*** has **4.6×10^6 bp.**
- Haploid content of human DNA is **3.3×10^9 bp.**

Length of DNA = number of base pairs X distance between two adjacent base pairs.

Number of base pairs in human = 6.6×10^9

Hence, the length of DNA = $6.6 \times 10^9 \times 0.34 \times 10^{-9}$

= 2.2 m

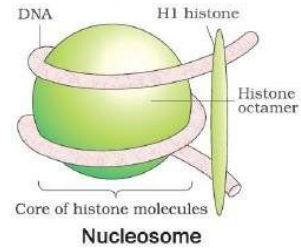
In *E. coli*, length of DNA = 1.36 mm (1.36×10^{-3} m)

$\therefore$ The number of base pairs $= \frac{1.36 \times 10^{-3}}{0.34 \times 10^{-9}}$

$= 4 \times 10^6$ bp

PACKAGING OF DNA HELIX

- In prokaryotes (E.g. *E. coli*), the DNA is not scattered throughout the cell. DNA is negatively charged. So it is held with some positively charged proteins to form **nucleoid.**
- In eukaryotes, there is a set of positively charged, basic proteins called **histones.**
- Histones are rich in positively charged basic amino acid residues ***lysines*** and ***arginines.***
- **8 histones** form **histone octamer.**
- Negatively charged DNA is wrapped around histone octamer to give **nucleosome.**



Nucleosome

- A typical nucleosome contains **200 bp.**

  Therefore, total number of nucleosomes in human = $\frac{6.6 \times 10^9 \text{bp}}{200} = 3.3 \times 10^7$

- Nucleosomes constitute the repeating unit to form **chromatin.** Chromatin is the thread-like stained bodies.

- Nucleosomes in chromatin = ***'beads-on-string'.***
- Chromatin is packaged → chromatin fibres → coiled and condensed at metaphase stage → chromosomes.
- Higher level packaging of chromatin requires **non-histone chromosomal (NHC) proteins.**
- Chromatin has 2 forms:
  - **Euchromatin:** Loosely packed and transcriptionally active region of chromatin. It stains light.
  - **Heterochromatin:** Densely packed and inactive region of chromatin. It stains dark.

THE SEARCH FOR GENETIC MATERIAL

Griffith's Transforming Principle experiment (1928)

Frederick Griffith used **mice** & ***Streptococcus pneumoniae*.**

Streptococcus pneumoniae has 2 strains**:**

- **Smooth (S) strain (Virulent):** Has polysaccharide mucus coat. Cause pneumonia.
- **Rough (R) strain (Non-virulent):** No mucus coat. Do not cause Pneumonia.

Experiment:

- S-strain → Inject into mice → Mice die
- R-strain → Inject into mice → Mice live
- S-strain (Heat killed) → Inject into mice → Mice live
- S-strain (Hk) + R-strain (live) → Inject into mice → Mice die

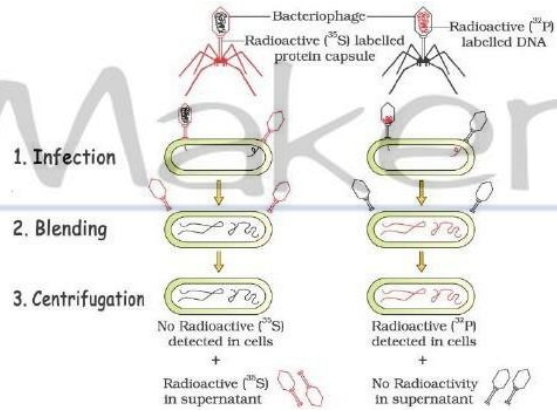
He concluded that some **'transforming principle'** transferred from heat-killed S-strain to R-strain. It enabled R-strain to synthesize smooth polysaccharide coat and become virulent. This must be due to the transfer of genetic material.

2. Biochemical characterization of transforming principle (1933-44)

- **Oswald Avery, Colin MacLeod** & **Maclyn McCarty** worked to determine the biochemical nature of **'transforming principle'** in Griffith's experiment.
- They purified biochemicals (proteins, DNA, RNA etc.) from heat killed S cells using suitable enzymes.
- They discovered that
  - Digestion of protein and RNA (using *Proteases* and *RNases*) did not affect transformation. It means that the transforming substance was not a protein or RNA.
  - Digestion of DNA with *DNase* inhibited transformation. It means that DNA caused transformation of R cells to S cells. It proves that DNA was the transforming principle.

3. Hershey-Chase Experiment (Blender Experiment)-1952

- **Hershey** & **Chase** grew some bacteriophage viruses on a medium containing radioactive phosphorus (**P^{32}**) and some others on medium containing radioactive sulphur (**S^{35}**).
- Viruses grown in P^{32} got **radioactive DNA** because only DNA contains phosphorus. Viruses grown in S^{35} got **radioactive protein** because protein contains sulphur.
- These preparations were used separately to infect ***E. coli.***
- After infection, the *E. coli* cells were gently agitated in a blender to remove the virus particles from the bacteria.
- Then the culture was centrifuged to separate lighter virus particles from heavier bacterial cells.
- Bacteria infected with viruses having radioactive DNA were radioactive. i.e., DNA had passed from the virus to bacteria. Bacteria infected with viruses having radioactive proteins were not radioactive. i.e., proteins did not enter the bacteria from the viruses. This proves that DNA is the genetic material.



PROPERTIES OF GENETIC MATERIAL (DNA v/s RNA)

A genetic material must have the following properties:

- Ability to generate its replica (Replication).
- Chemical and structural stability.
- Provide the mutations that are required for evolution.
- Ability to express as Mendelian Characters.

Reasons for stability (less reactivity) of DNA	Reasons for mutability (high reactivity) of RNA
Double stranded	Single stranded
Presence of thymine	Presence of Uracil
Absence of 2'-OH in sugar	Presence of 2'-OH in sugar

- RNA is unstable. So, RNA viruses (E.g. *Q.B bacteriophage, Tobacco Mosaic Virus* etc.) mutate and evolve faster.
- DNA strands are complementary. On heating, they separate. In appropriate conditions, they come together. In Griffith's experiment, some properties of DNA of the heat killed bacteria did not destroy. It indicates the stability of DNA.
- For the storage of genetic information, DNA is better due to its stability. But for the transmission of genetic information, RNA is better.
- RNA can directly code for the protein synthesis, hence can easily express the characters. DNA is dependent on RNA for protein synthesis.

RNA WORLD

☐ RNA was the first genetic material.
☐ It acts as genetic material and catalyst.
☐ Essential life processes (metabolism, translation, splicing etc.) evolved around RNA.
☐ DNA evolved from RNA for stability.

CENTRAL DOGMA OF MOLECULAR BIOLOGY

- It is proposed by **Francis Crick.** It states that ***the genetic information flows from DNA → RNA → Protein.***

Central dogma

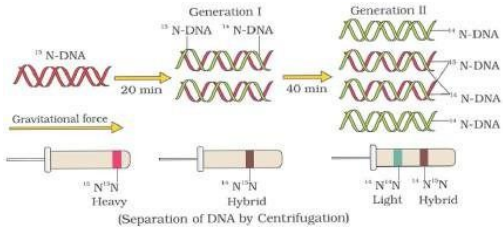
- In some viruses, flow of information is in reverse direction (from RNA to DNA). It is called **reverse transcription.**

DNA REPLICATION

- Replication is the copying of DNA from parental DNA.
- **Watson** & **Crick** proposed **Semi-conservative model** of replication. It suggests that the parental DNA strands act as **template** for the synthesis of new complementary strands. After replication, each DNA molecule would have one parental and one new strand.
- **Matthew Messelson & Franklin Stahl** (1958) experimentally proved Semi-conservative model.

Messelson & Stahl's Experiment

- They grew ***E. coli*** in **$^{15}NH_4Cl$ medium** (^{15}N = heavy isotope of nitrogen) as the only nitrogen source. As a result, ^{15}N was incorporated into newly synthesised DNA **(heavy DNA or ^{15}N DNA).**
- Heavy DNA can be distinguished from normal DNA (light DNA or ^{14}N DNA) by centrifugation in a **cesium chloride (CsCl) density gradient.**
- *E. coli* cells from ^{15}N medium were transferred to $^{14}NH_4Cl$ medium. After one generation (i.e. after 20 minutes), they isolated and centrifuged the DNA. Its **density** was **intermediate (hybrid)** between ^{15}N DNA and ^{14}N DNA. This shows that in newly formed DNA, one strand is old **(^{15}N type)** and one strand is new **(^{14}N type).** This confirms semi-conservative replication.
- After II generation (i.e. after 40 minutes), there was equal amounts of hybrid DNA and light DNA.

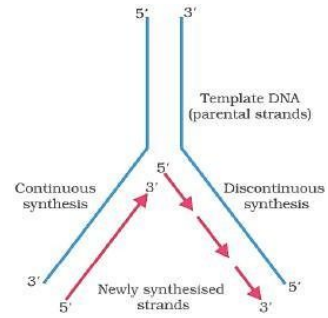


(Separation of DNA by Centrifugation)

Taylor & colleagues (1958) performed similar experiments on ***Vicia faba*** (faba beans) using **radioactive thymidine** to detect distribution of newly synthesized DNA in the chromosomes. It proved that the DNA in chromosomes also replicate semi-conservatively.

The Machinery and Enzymes for Replication

- DNA replication starts at a point called ***origin* (*ori*).**
- A unit of replication with one origin is called a ***replicon.***
- During replication, the 2 strands unwind and separate by breaking H-bonds in presence of an enzyme, ***Helicase.***
- Unwinding of the DNA molecule at a point forms a 'Y'-shaped structure called **replication fork.**
- The separated strands act as **templates** for the synthesis of new strands.
- DNA replicates in the **5'→3' direction.**



- ***Deoxyribonucleoside triphosphates*** (dATP, dGTP, dCTP & dTTP) act as substrate and provide energy for polymerization.
- Firstly, a small **RNA primer** is synthesized in presence of an enzyme, ***primase***.
- In presence of an enzyme, DNA dependent ***DNA polymerase,*** many nucleotides join with one another to primer strand and form a polynucleotide chain (new strand).
- During replication, one strand is formed as a continuous stretch in 5'→ 3' direction **(Continuous synthesis).** This strand is called **leading strand.**
- The other strand is formed in small stretches **(Okazaki fragments)** in 5'→ 3' direction **(Discontinuous synthesis).**
- The Okazaki fragments are then joined together to form a new strand by an enzyme, ***DNA ligase***. This new strand is called **lagging strand.**
- If a wrong base is introduced in the new strand, DNA polymerase can do **proof reading.**
- *E. coli* completes replication within 18 minutes. i.e. 2000 bp per second.
- In eukaryotes, the replication of DNA takes place at **S-phase** of the cell cycle. Failure in cell division after DNA replication results in **polyploidy.**

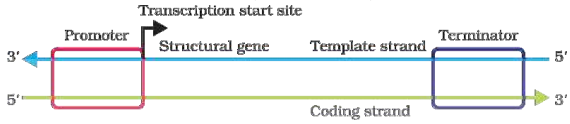
TRANSCRIPTION

- It is the process of copying genetic information from one strand of the **DNA into RNA.**
- Here, adenine pairs with uracil instead of thymine.
- The **DNA- dependent *RNA polymerase*** catalyzes the polymerization only in 5'→3'direction.
- 3'→5' acts as **template strand**. RNA is built from this.
- 5'→3' acts as **coding strand.** This is copied to RNA.
  3'-ATGCATGCATGCATGCATGCATGC-5' template strand.
  5'-TACGTACGTACGTACGTACGTACG-3' coding strand.
- During transcription, both strands are not copied because
  - The **code for proteins is different in both strands.** This complicates the translation.
  - If **2 RNA molecules** are produced simultaneously, this would be **complimentary** to each other. It forms a **double stranded RNA** and prevents translation.

Transcription Unit

- It is the segment of DNA between the sites of initiation and termination of transcription. It consists of 3 regions:

- **A promoter:** Binding site for *RNA polymerase*. Located towards 5'-end (upstream).
- **Structural gene:** The region between promoter and terminator where transcription takes place.
- **A terminator:** The site where transcription stops. Located towards 3'-end (downstream).



Transcription unit and gene

Gene is a functional unit of inheritance. It is the DNA sequence coding for an RNA (mRNA, rRNA or tRNA).

Cistron is a segment of DNA coding for a **polypeptide** during protein synthesis. It is the largest element of a gene.

Structural gene in a transcription unit is 2 types:

☐ **Monocistronic structural genes (split genes)**: It is seen in eukaryotes. Here, coding sequences ***(exons or expressed sequences)*** are interrupted by ***introns*** (intervening sequences). Exons appear in processed mRNA. Introns do not appear in processed mRNA.

☐ **Polycistronic structural genes**: It is seen in prokaryotes. Here, there are no split genes.

Transcription in prokaryotes

In bacteria (Prokaryotes), synthesis of all types of RNA are catalysed by a single *RNA polymerase*. It has 3 steps:

☐ **Initiation:** Here, the enzyme ***RNA polymerase*** binds at the promoter site of DNA. This causes the local unwinding of the DNA double helix. An ***initiation factor (σ factor)*** present in *RNA polymerase* initiates the RNA synthesis.

☐ **Elongation:** RNA chain is synthesized in 5'-3' direction. In this process, activated **ribonucleoside triphosphates** (ATP, GTP, UTP & CTP) are added. This is complementary to the base sequence in the DNA template.

☐ **Termination:** A ***termination factor (ρ factor)*** binds to the *RNA polymerase* and terminates the transcription.

In bacteria, transcription and translation can be coupled (translation begins before mRNA is fully transcribed) because

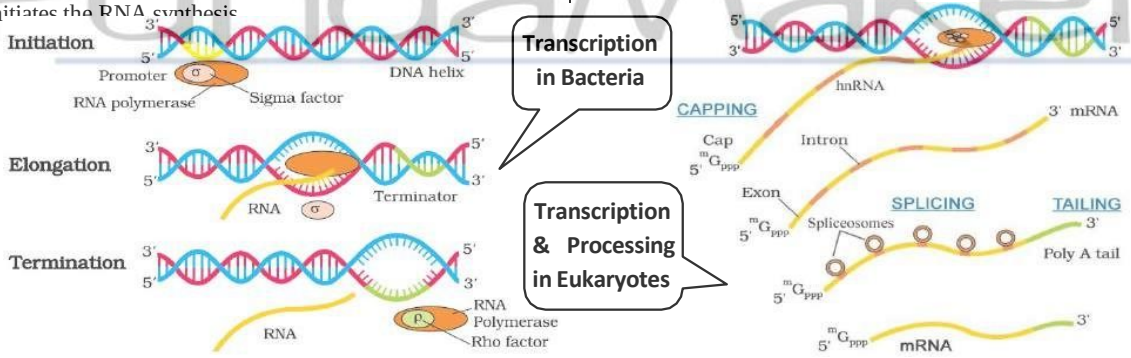
- mRNA requires no processing to become active.
- Transcription and translation take place in the same compartment (no separation of cytosol and nucleus).

Transcription in eukaryotes

In eukaryotes, there are 2 additional complexities:

1. **There are 3 *RNA polymerases:***
   - ***RNA polymerase I:*** Transcribes rRNAs (28S, 18S & 5.8S).
   - ***RNA polymerase II:*** Transcribes the heterogeneous nuclear RNA (hnRNA). It is the precursor of mRNA.
   - ***RNA polymerase III:*** Transcribes tRNA, 5S rRNA and snRNAs (small nuclear RNAs).
2. **The primary transcripts (hnRNA)** contain exons and introns and are non-functional. Hence introns must be removed. For this, it undergoes the following processes:
   - **Splicing:** From hnRNA, introns are removed (by the spliceosome) and exons are spliced (joined) together.
   - **Capping:** Here, a nucleotide **methyl guanosine triphosphate (cap)** is added to the 5' end of hnRNA.
   - **Tailing (Polyadenylation):** Here, **adenylate residues** (200-300) are added at 3'-end.

   Now, it is the fully processed hnRNA, called **mRNA.**



GENETIC CODE

- It is the sequence of nucleotides (nitrogen bases) in mRNA that contains information for protein synthesis (translation).
- The sequence of 3 bases determining a single amino acid is called **codon.**
- **George Gamow** suggested that for coding 20 amino acids, the code should be made up of 3 nucleotides. Thus, there are 64 codons (4^3= 4 x 4 x 4).
- **Har Gobind Khorana** developed the chemical method in synthesizing RNA molecules with defined combinations of bases (homopolymers & copolymers).
- **Marshall Nirenberg** developed cell-free system for protein synthesis.
- **Severo Ochoa (*polynucleotide phosphorylase*) enzyme** is used to polymerize RNA with defined sequences in a template independent manner.

20 types of amino acids involved in translation

1. Alanine (Ala)
2. Arginine (Arg)
3. Asparagine (Asn)
4. Aspartic acid (Asp)
5. Cystein (Cys)
6. Glutamine (Gln)
7. Glutamic acid (Glu)
8. Glycine (Gly)
9. Histidine (His)
10. Isoleucine (Ile)
11. Leucine (Leu)
12. Lysine (Lys)
13. Methionine (Met)
14. Phenyl alanine (Phe)
15. Proline (Pro)
16. Serine (Ser)
17. Threonine (Thr)
18. Tryptophan (Trp)
19. Tyrosine (Tyr)
20. Valine (Val)

The codons for various amino acids

	U		C		A		G		
U	UUU	Phe	UCU	Ser	UAU	Tyr	UGU	Cys	U
	UUC	Phe	UCC	Ser	UAC	Tyr	UGC	Cys	C
	UUA	Leu	UCA	Ser	UAA	Stop	UGA	Stop	A
	UUG	Leu	UCG	Ser	UAG	Stop	UGG	Trp	G
C	CUU	Leu	CCU	Pro	CAU	His	CGU	Arg	U
	CUC	Leu	CCC	Pro	CAC	His	CGC	Arg	C
	CUA	Leu	CCA	Pro	CAA	Gln	CGA	Arg	A
	CUG	Leu	CCG	Pro	CAG	Gln	CGG	Arg	G
A	AUU	Ile	ACU	Thr	AAU	Asn	AGU	Ser	U
	AUC	Ile	ACC	Thr	AAC	Asn	AGC	Ser	C
	AUA	Ile	ACA	Thr	AAA	Lys	AGA	Arg	A
	AUG	Met	ACG	Thr	AAG	Lys	AGG	Arg	G
G	GUU	Val	GCU	Ala	GAU	Asp	GGU	Gly	U
	GUC	Val	GCC	Ala	GAC	Asp	GGC	Gly	C
	GUA	Val	GCA	Ala	GAA	Glu	GGA	Gly	A
	GUG	Val	GCG	Ala	GAG	Glu	GGG	Gly	G

Salient features of genetic code

- **Codon is triplet** (three-letter code).
- 61 codons code for amino acids. 3 codons (**UAA, UAG** & **UGA)** do not code for any amino acids. They act as **stop codons (Termination codons or non-sense codons).**
- Genetic code is **universal.** E.g. From bacteria to human UUU codes for Phenylalanine. Some exceptions are found in mitochondrial codons, and in some protozoans.
- **No punctuations** b/w adjacent codons (comma less code). The codon is read in mRNA in a contiguous fashion.
- Genetic code is **non-overlapping.**
- An amino acid is coded by more than one codon (except AUG for methionine & UGG for tryptophan). Such codons are called **degenerate codons.**
- Genetic code is **unambiguous** and **specific.** i.e. one codon specifies only one amino acid.
- AUG has dual functions. It codes for Methionine and acts as **initiator codon.** In eukaryotes, ***methionine*** is the first amino acid and ***formyl methionine*** in prokaryotes.

Mutations and Genetic Code

- Relationship between genes & DNA are best understood by mutation studies. Deletions & rearrangements in a DNA may cause loss or gain of a gene and so a function.
- **Insertion or deletion** of **one or two bases** changes the reading frame from the point of insertion or deletion. It is called **frame-shift insertion or deletion mutations.**
- Insertion/ deletion of **three or its multiple bases** insert or delete one or multiple codon. The reading frame remains unaltered from that point onwards. Hence one or multiple amino acids are inserted /deleted.
- It proves that codon is a triplet and is read contiguously.

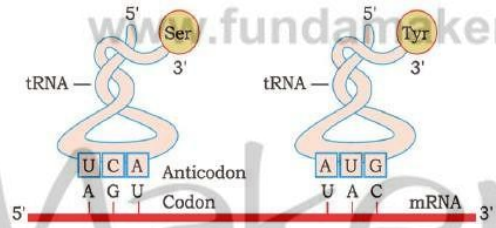
TYPES OF RNA

- **mRNA (messenger RNA):** Provide template for translation (protein synthesis).
- **rRNA (ribosomal RNA):** Structural & catalytic role during translation. E.g. 23S rRNA in bacteria acts as ribozyme.
- **tRNA (transfer RNA or sRNA or soluble RNA):** Brings amino acids for protein synthesis and reads the genetic code.

Francis Crick postulated presence of an adapter molecule that can read the code and to link with amino acids.

tRNA is called **adapter molecule** because it has

- **An Anticodon (NODOC) loop** that has bases complementary to the codon.
- **An amino acid acceptor end** to which amino acid binds.
- **Ribosome binding loop.**
- **Enzyme binding loop.**



- For initiation, there is another tRNA called **initiator tRNA.**
- There are no tRNAs for stop codons.
- **Secondary (2-D)** structure of tRNA looks like a **clover-leaf. 3-D structure** looks like **inverted 'L'.**

TRANSLATION (PROTEIN SYNTHESIS)

- It is the process of **polymerisation of amino acids** to form a polypeptide based on the sequence of codons in mRNA.
- It takes place in **ribosomes.** Ribosome consists of structural RNAs and about 80 types of proteins.
- Ribosome also acts as a **catalyst** (23S rRNA in bacteria is the enzyme- ribozyme) for the formation of peptide bond (***peptidyl transferase*** enzyme in large subunit of ribosome).
- Translation includes 4 steps:

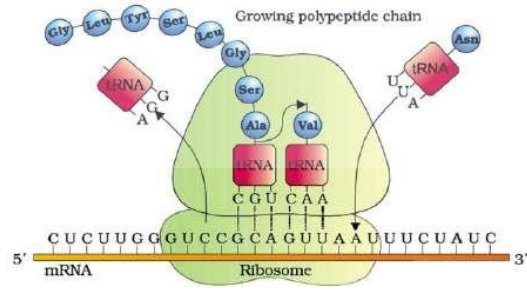
1. **Charging of tRNA**
2. **Initiation**
3. **Elongation**
4. **Termination**

1. Charging (aminoacylation) of tRNA

- Formation of peptide bond needs energy obtained from ATP.
- For this, amino acids are activated (amino acid + ATP) and linked to their cognate tRNA in presence of ***aminoacyl tRNA synthetase.*** Thus, the tRNA becomes charged.

2. Initiation

- In this, small subunit of ribosome binds to mRNA at the **start codon (AUG).**
- Now large subunit binds to small subunit to form **initiation complex.**
- Large subunit consists of **aminoacyl tRNA binding site (A site)** and **peptidyl site (P site).**
- The **initiator tRNA** (which carries methionine) binds on P site. Its **anticodon (UAC)** recognises start codon **AUG.**



3. Elongation

- Second aminoacyl tRNA binds to the A site of ribosome. Its anticodon binds to the second codon on the mRNA and

a **peptide bond** is formed between first and second amino acids in presence of ***peptidyl transferase.***
- First amino acid and its tRNA are broken. This tRNA is removed from P site and second tRNA from A site is pulled to P site along with mRNA. This is called **translocation.**
- These processes are repeated for other codons in mRNA.
- During translation, ribosome moves from codon to codon.

4. Termination

- When a **release factor** binds to stop codon, the translation terminates.
- The polypeptide and tRNA are released from the ribosomes.
- The ribosome dissociates into large and small subunits.

A group of ribosomes associated with a single mRNA for translation is called a **polyribosome (polysomes).**

An mRNA has additional sequences that are not translated **(untranslated regions or UTR).** UTRs are present at both 5'-end (before start codon) and 3'-end (after stop codon). They are required for efficient translation process.

REGULATION OF GENE EXPRESSION

In eukaryotes, gene expression occurs by following levels:

1. **Transcriptional** level (formation of primary transcript).
2. **Processing** level (splicing, capping etc.).
3. **Transport** of mRNA from nucleus to the cytoplasm.
4. **Translational** level (formation of a polypeptide).

The metabolic, physiological and environmental conditions regulate gene expression. E.g.

- In *E. coli*, the ***beta-galactosidase*** enzyme hydrolyses lactose into galactose & glucose. In the absence of lactose, the synthesis of *beta-galactosidase* stops.
- The development and differentiation of embryo into adult are a result of the expression of several set of genes.

If a substrate is added to growth medium of bacteria, a set of genes is switched on to metabolize it. It is called **induction.**

When a metabolite (product) is added, the genes to produce it are turned off. This is called **repression.**

OPERON CONCEPT

- ***"Each metabolic reaction is controlled by a set of genes"***
- All the genes regulating a metabolic reaction constitute an ***Operon.*** E.g. **lac operon, trp operon, ara operon, his operon, val operon etc.**

Lac Operon in *E. coli*

- The operon controlling lactose metabolism.
- It is proposed by **Francois Jacob & Jacque Monod.**

It consists of

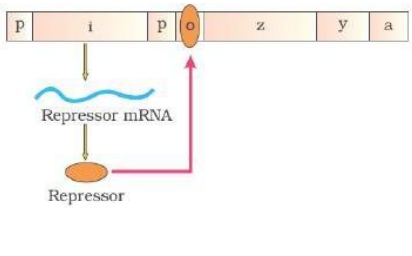
a) A regulatory or inhibitor (i) gene: Codes for repressor protein.

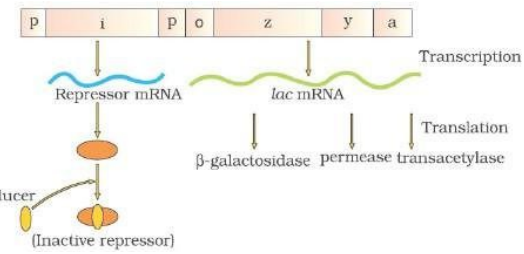
b) 3 structural genes:

i. **z gene:** Codes for β ***galactosidase.*** It hydrolyses lactose to galactose and glucose.
ii. **y gene:** Codes for ***permease.*** It increases permeability of the cell to β-galactosides (lactose).
iii. **a gene:** Codes for a ***transacetylase.***

- Genes in the operon function together in the same or related metabolic pathway.
- If there is no **lactose (inducer),** lac operon remains switched off. The regulator gene synthesizes mRNA to produce **repressor protein.** This protein binds to the **operator** region and blocks *RNA polymerase* movement. So the structural genes are not expressed.
- If lactose or allolactose is provided in the growth medium, it is transported into ***E. coli*** cells by the action of ***permease.*** Lactose (inducer) binds with repressor protein. So repressor protein cannot bind to operator region. The operator region becomes free and induces the *RNA polymerase* to bind with **promoter.** Then transcription starts.
- Regulation of lac operon by repressor is called **negative regulation.**

In the absence of inducer





In the presence of inducer

HUMAN GENOME PROJECT (HGP)

- The entire DNA in the haploid set of chromosomes of an organism is called a **Genome**.
- In Human genome, DNA is packed in 23 chromosomes.
- Human genome contains about **$3x10^9$ bp.**
- **Human Genome Project** (1990-2003) was the first mega project for the sequencing of nucleotides and mapping of all the genes in human genome.
- HGP was coordinated by **U.S. Department of Energy and the National Institute of Health.**

Goals of HGP

a. Identify all the estimated genes in human DNA.
b. Sequencing of 3 billion chemical base pairs of human DNA.
c. Store this information in **databases.**
d. Improve tools for data analysis.
e. Transfer related technologies to other sectors.
f. Address the **ethical, legal and social issues (ELSI)** that may arise from the project.

Methodologies of HGP: 2 major approaches.

- **Expressed Sequence Tags (ESTs):** Focused on identifying all the genes that are expressed as RNA.
- **Sequence annotation:** Sequencing whole set of genome containing all the coding & non-coding sequence and later assigning different regions in the sequence with functions.

Procedure of sequencing:

Isolate DNA from a cell → Convert into random fragments → Clone in a host (bacteria & yeast) using vectors (e.g. BAC & YAC) for amplification → Sequencing of fragments using Automated DNA sequencers (Frederick Sanger method) → Arrange the sequences based on overlapping regions→ Alignment of sequences using computer programs.

BAC= Bacterial Artificial Chromosomes
YAC= Yeast Artificial Chromosomes

- **Sanger** has also developed method for **sequencing of amino acids** in proteins.
- DNA is converted to fragments as there are technical limitations in sequencing very long pieces of DNA.
- HGP was closely associated with **Bioinformatics. Bioinformatics:** Application of computer science and information technology to the field of biology & medicine.
- Of the 24 chromosomes (22 autosomes and X & Y), the last sequenced one is **chromosome 1** (May 2006).
- DNA sequencing also have been done in bacteria, yeast, *Caenorhabditis elegans* (a free living non-pathogenic nematode), *Drosophila*, plants (rice & *Arabidopsis*), etc.

Salient features of Human Genome

a. Human genome contains **3164.7 million** nucleotide bases.
b. Total number of genes= about **30,000.**
c. Average gene consists of **3000 bases,** but sizes vary. Largest known human gene (**dystrophin** on X-chromosome) contains 2.4 million bases.
d. 99.9% nucleotide bases are same in all people. Only **0.1%** ($3x10^6$ bp) difference makes every individual unique.
e. Functions of over 50% of discovered genes are unknown.
f. Chromosome I has most genes **(2968)** and Y has the fewest **(231).**
g. Less than 2% of the genome codes for proteins.
h. Very large portion of human genome is made of **Repeated (repetitive) sequences.** These are stretches of DNA sequences that are repeated many times. They have no direct coding functions. They shed light on chromosome structure, dynamics and evolution.
i. About **1.4 million** locations have single-base DNA differences. They are called **SNPs (Single nucleotide polymorphism or 'snips').** This helps to find chromosomal locations for disease-associated sequences and tracing human history.

DNA FINGERPRINTING (DNA PROFILING)

- It is the technique to identify the similarities and differences of the DNA fragments of 2 individuals.
- It is developed by **Alec Jeffreys (1985).**

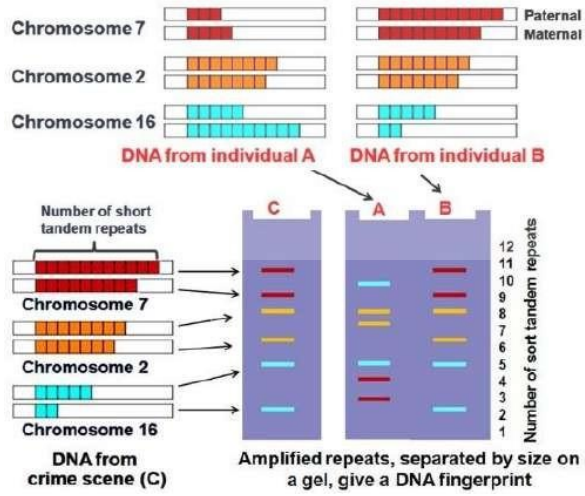
Basis of DNA fingerprinting

- DNA carries some non-coding **repetitive sequences.**
- Repetitive DNA can be separated from bulk genomic DNA as different peaks during density gradient centrifugation.
- The **bulk DNA** forms a **major peak** and the small peaks are called **satellite DNA.**
- **Satellite DNA** is classified as **micro-satellites, mini-satellites** etc. based on base composition (A:T rich or G:C rich), length of segment and number of repetitive units.
- A DNA sequence which is tandemly repeated in many copy numbers is called **variable number tandem repeats (VNTR).** It belongs to mini-satellite DNA.
- In a person, copy number varies in each chromosome.
- The two alleles (paternal and maternal) of a chromosome also contain different copy numbers of VNTR.
- VNTR is specific from person to person.
- The size of VNTR varies from **0.1 to 20 kb.**
- Any difference in the nucleotide sequence (inheritable mutation) observed in a population is called **DNA polymorphism** (variation at genetic level).
- Polymorphism is higher in non-coding DNA sequence because mutations in these sequences may not affect an individual's reproductive ability. These mutations accumulate generation to generation causing polymorphism.
- Polymorphisms have great role in evolution & speciation.

Steps of DNA fingerprinting (Southern Blotting Technique)

a. Isolation of DNA (from any cells or blood stains, semen stains, saliva, hair roots, bone, skin etc.).
b. Digestion of DNA by **restriction endonucleases.**
c. Separation of DNA fragments by **gel electrophoresis.**
d. Transferring (blotting) DNA fragments to synthetic membranes such as **nitrocellulose** or **nylon**.
e. Hybridization using radioactive labelled **VNTR probe.**
f. Detection of hybridized DNA by **autoradiography.**

The autoradiogram gives an image in the form of dark & light bands. It is called **DNA fingerprint.**



DNA fingerprint differs in everyone except in **monozygotic (identical) twins.**

The sensitivity of the technique can be increased by use of **polymerase chain reaction (PCR).** Therefore, DNA from a single cell is enough for DNA fingerprinting.

Application of DNA fingerprinting

- **Forensic tool** to solve paternity, rape, murder etc.
- For the diagnosis of **genetic diseases.**
- To determine **phylogenetic status** of animals.
- To determine **population and genetic diversities.**