

## **FIVE KINGDOM CLASSIFICATION CONCEPT MAP**



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# CONCEPT MAP

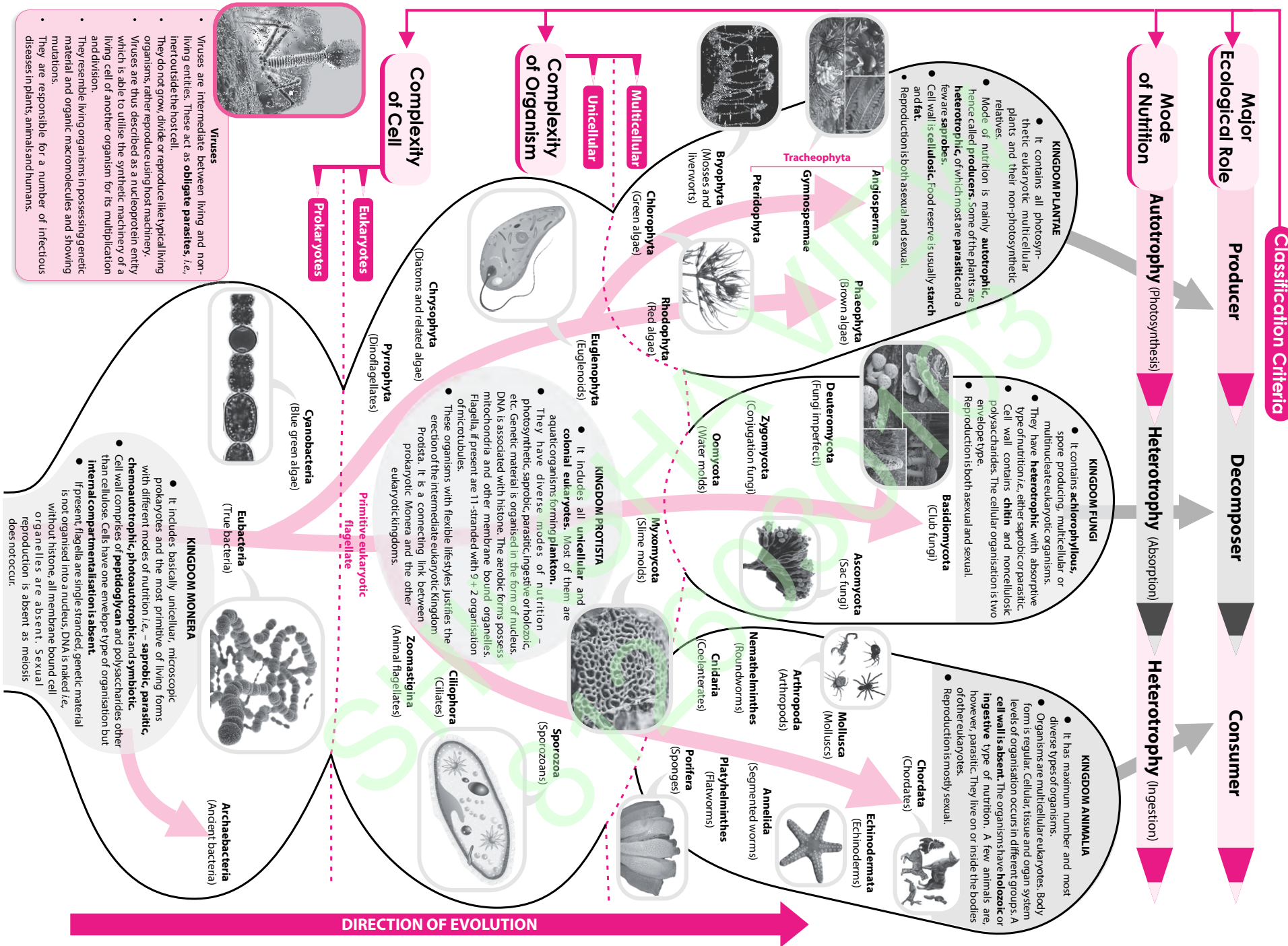
## FIVE KINGDOM CLASSIFICATION

The scientific procedure of arranging organisms into groups and subgroups on the basis of their similarities and dissimilarities and placing them in a hierarchy of categories is called **biological classification**. The earliest classification systems recognised only two kingdoms: living things: **Animalia** and **Plantae** followed by three and four kingdom classifications introducing Kingdom **Monera** and **Protista**. The most accepted and latest five-kingdom classification was proposed by **R.H. Whittaker** in 1969 to develop phylogenetic relationships. In this classification, the organisms are classified on the basis of following criteria: (i) complexity of cell, (ii) complexity of the body organisation, (iii) mode of nutrition, (iv) mode of reproduction, (v) ecological role and (vi) phylogenetic relationships.

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# CONCEPT MAP

## KINGDOM FUNGI

Fungi is a large kingdom comprising of about 5100 genera and more than 50,000 species. They are eukaryotic, heterotrophic, spore-forming, eukaryotic organisms with thalloid body made up of hyphae (together constituting mycelium). They are **cosmopolitan** in distribution. Some fungi occur in fresh or marine water, others are terrestrial and still others are air-borne. The study of fungi is known as **mycology**.

### NUTRITION

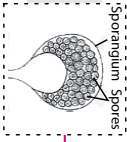
- They may be **obligate parasites** (obtain food from host plants and die with the death of host) or **facultative saprophytes** (usually parasitic but able to absorb food from decaying host plant as well), **obligate saprophytes** (obtain food from decaying organic matter) or **facultative parasites** (usually saprophytes but can live parasitically under some conditions).

### Asexual



### Zoospores

**Sporangiospores**  
Nonflagellate spores that develop inside sporangia, e.g., *Mucor*, *Rhizopus*.



### Chlamydospores

Thick-walled perennating spores which develop at places along the hyphae by accumulation of protoplasm, rounding off and secretion of thick wall.



### Oidia

Usually formed under conditions of excess water, sugar and certain salts, e.g., *Rhizopus*.



### Conidia

Nonmotile, thin-walled, exogenous spores, produced in chains upon the tip of hypha called **conidiophore**, e.g., *Aspergillus*, *Penicillium*.



### Ascospores

Nonmotile meiospores which are produced inside special sacs called **asci** and are characteristic of Class Ascomycetes.



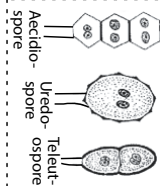
### Basidiospores

Nonmotile meiospores formed exogenously on short outgrowths of club-shaped structure called basidium and are characteristic of Class Basidiomycetes.



### Binucleate spores

Dikaryotic spores meant for multiplying the dikaryotic mycelium, e.g., ascido-spores, urospores in *Puccinia*. Another type of dikaryotic spore is teliospore or teliospore.



### REPRODUCTION

- Fungi may reproduce by vegetative, asexual and sexual means.

### Vegetative

- Budding**  
Small outgrowths from vegetative body, cut off and mature to form new individuals, e.g., yeast.
- Fission**  
Splitting of vegetative cells into two daughter cells.
- Fragmentation**  
Fragments of vegetative hyphae develop into new individual.

### Sexual

Sexual reproduction takes place by following processes:



### Gametangial contact

Here gametes are never released from gametangia. Instead the male and female gametangia come in close contact with the help of a fertilisation tube, through which one or more male nuclei migrate to the female gametangium. E.g., *Pythium*.

### Plasmogametic copulation

This involves fusion of two naked motile gametes (plasmogametes). Based upon the nature and structure of gametes, it is of three types: isogamy, anisogamy and oogamy.



### Gametangial copulation

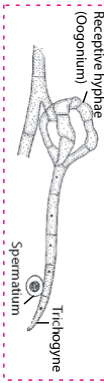
This process involves fusion of the entire contents of two compatible gametangia, resulting in karyogamy. E.g., *Mucor*.

### Somatogamy

Here sex organs are not at all formed, but two vegetative hyphae or cells take over the sexual function and fuse together. E.g., *Morchella*, *Peziza*.

### Spermatisation

In some advanced genera, the sexual process is accomplished by minute spore-like spermatia (male gametes) and specialised receptive hyphae (female gametes). The spermatia are carried by air, water or insects to the receptive hyphae. The contents of the spermatium enter the receptive hyphae through a pore.



### CLASSIFICATION

- Many botanists have classified fungi in different ways.
- Martin's** (1961) classification of fungi is most prevalent. He classified fungi into Myxomycotina (Slime molds) and Eumycotina (True fungi).
- Martin further divided Eumycotina into the following classes:

### STRUCTURE

- Fungi range from unicellular, uninucleate forms like yeast and *Saccharomyces* to thread-like structure called **mycelium** which is made up of a net-like mass of tubular filaments called **hyphae**. The hypha is usually branched, tube-like structure, having protoplasm with reserve food and bounded by a wall of **chitin**, a nitrogen-containing polysaccharide ( $C_2H_5N_2O_2$ ).
- The protoplasm of the hypha may be continuous without cross walls, called **aseptate hypha** or may have transverse partitions or septa, known as **septate hypha**. Septa are seldom complete as they are perforated and may contain plasmodesmata or central pores. When central septal pore possesses a barrel-shaped inflation, as in many basidiomycetes, it is known as **dolipore septum**. A membranous vesicle called **lomasome** is found attached to plasma membrane.

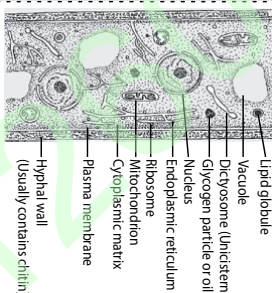


Fig: Ultrastructure of part of fungal hypha

- In some fungi, hyphae may structurally modify in response to functional needs as:

- Prosenchyma** : It is formed when the component hyphae lie more or less parallel to one another and unite to form a rather loosely interwoven structure where their individuality is not lost.
- Pseudo-parenchyma** : It is formed when the hyphae become closely intertwined, forming a tissue which consists of hollow tubes spread in all directions. These lose their individuality.
- Rhizomorph** : It is a thick strand or root-like aggregation of somatic hyphae which lose their individuality. The entire mass behaves as an organised unit and have higher infection capacity.
- Sclerotium** : It is a compact globose structure, formed by the aggregation and adhesion of hyphae.
- Appressorium** : It is a terminal, simple or lobed, swollen structure of germ tubes or infecting hyphae, found in many parasitic fungi.
- Hausorium** : These are intracellular, absorbing structures of obligate parasites meant for absorbing food material from the host. They may be variously shaped and secrete specific hydrolysing enzymes.

### Phycomycetes

- The mycelium is aseptate and coenocytic.
- The sporangia has innumerable sporangiospores (zoospores or aplanospores) formed endogenously.
- Sexual reproduction is oogamous in Oomycetes, and isogamous in Zygomycetes.
- Biflagellate motile cells (zoospores) are produced by many species.
- The zygote is uninucleate and simple. E.g., *Albugo*, *Phytophthora* (Oomycetes), *Rhizopus*, *Mucor* (Zygomycetes).

### Ascomycetes

- The mycelium consists of septate hyphae, possessing central or septal pores. Motile structures do not occur in the life cycle.
- In majority of Ascomycetes, the common mode of asexual reproduction is through the formation of conidia.
- Sexual reproduction takes place through fusion of sex cells, somatic cells, gametangial contact, between an antheridium and ascogonium and autogamy.
- Karyogamy is delayed after plasmogamy. Hence, a new transitional phase called dikaryophase appears in the life cycle. The cells of dikaryophase are called dikaryotic cells as each cell possesses two nuclei (n+n).
- Some dikaryotic cells function as ascus mother cells. **Ascus** is a sporangial sac peculiar to Ascomycetes. 4-8 haploid meiospores named ascospores are produced internally in each ascus.
- The ascus may occur freely or get aggregated with dikaryotic mycelium to form fruitifications called **ascocarps**. E.g., *Aspergillus*, *Penicillium*, *Claviceps*, morels and truffles.

### Basidiomycetes

- Basidiomycetes are the most advanced fungi and considered among the best decomposers of wood.
- Motile structures or cells are absent. Mycelia are of two types, primary and secondary.
- Karyogamy is delayed after plasmogamy. A new transitional phase called dikaryophase appears in the life cycle. It produces dikaryotic secondary mycelium. Secondary mycelium is long lived, profusely branched septate hyphae possessing dolipores.
- Hook-shaped outgrowths called **clamp connections** are found on the sides of septa which are meant for proper distribution of dikaryons at the time of cell division.
- Karyogamy and meiosis occur in club-shaped structures known as **basidia**. A basidium commonly produces four meiospores or basidiospores exogenously at the tip of fine outgrowths called **sterigmata**.
- The fungi may or may not produce fruitifications called **basidiocarps** that vary in size from microscopic to macroscopic forms. E.g., *Puccinia*, *Ustilago*, *Agaricus*, bracket fungi, etc.

### Deuteromycetes

- Deuteromycetes is an artificial class of fungi which has been created to include all those fungi in which sexual stage is either absent or not known.
- Some of the deuteromycetes are unicellular like yeast.
- The mycelium is usually septate. Coenocytic forms are not known.
- Asexual reproduction often occurs by conidia along with some other types of spores.
- It is believed that most members of deuteromycetes are actually ascomycetes in which sexual reproduction is either absent or yet to be discovered. E.g., *Colletotrichum*, *Helminthosporium*, *Tickhoderma*.

# CONCEPT MAP

## LICHENS

Lichens are composite or **dual organisms** representing an intimate symbiotic relationship between algae and fungi (De Bary, 1879). The algal component of lichen is known as **phycobiont** whereas the fungal component is known as **mycobiont**. The fungal component predominates algal component, such an association is known as **helotism** (Crombie, 1883). There are about 400 genera and 1600 species of lichens. They usually grow on bark of trees, dry logs (**corticolous**), bare rocks (**saxicolous**) or soil (**terricolous**), etc.

### Classification

#### On the basis of fungal component

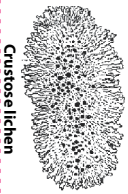
**Ascolichens**  
The fungal component of these lichens is a member of Class Ascomycetes. They are called **gymnocarpeae** if the fruiting body is a disc like apothecium (also known as discolichens, e.g., *Parmelia*). They are called **pyrenocarpeae** if the fruiting body is a flask shaped perithecium (also known as pyrenolichens, e.g., *Dermatocarpon*).

**Basidiolichens**  
The fungal component of these lichens is a member of Class Basidiomycetes. Genera like *Cortelia* and *Dictyonema* belong to this group.

**Deuterolichens**  
The fungal component of these lichens belongs to Class Deuteromycetes.

#### On the basis of external morphology

**Crustose lichen**  
These are encrusting lichens with an inconspicuous, thin and flat thallus, firm in texture. The thallus is very closely adhered to the substratum and provides a crust-like appearance.  
**Examples:** *Graphis*, *Haematomma*, *Lecanora*.



Crustose lichen

**Foliose lichen**  
These lichens are flat with leaf-like and lobed thallus attached to the substratum with the help of rhizoid-like **rhizines**.  
**Examples:** *Parmelia*, *Physcia*.



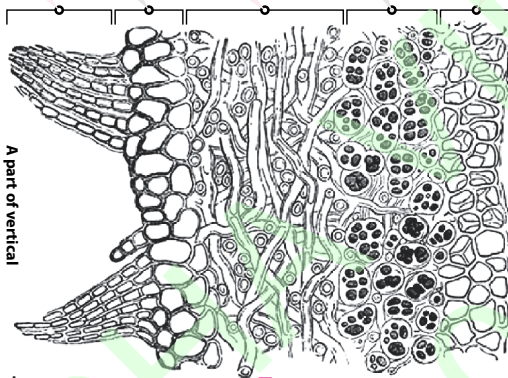
Foliose lichen

**Fruticose lichen**  
Shrub-like, cylindrical and branched thallus that grow erect or hang from the substratum with the help of a basimucilagenous disc.  
**Examples:** *Lecanora*, *Cleodonia*.



Fruticose lichen

### Internal Structure



**Upper cortex**  
Composed of compactly interwoven fungal hyphae arranged at right angles to the surface of thallus, usually lacking intercellular spaces (if present, then filled with gelatinous substance).

**Algal zone**  
This layer is composed of green or blue green algae. The algal cells remain embedded in the tangled network of fungal hyphae. Sometimes algal cells and fungal hyphae are uniformly distributed throughout the thallus (**homomorous**) whereas sometimes algal cells form a distinct layer within thallus (**heteromorous**).

**Medulla**  
Central part of thallus, comprised of loosely interwoven fungal hyphae with large spaces between them.

**Lower cortex**  
Composed of compactly arranged fungal hyphae running parallel or perpendicular to surface of thallus.

**Rhizines**  
Some hyphae of lower cortex descend down and help in attachment of thallus to substratum. These are known as rhizines.

A part of vertical section of lichen

### Reproduction

Lichens reproduce both by asexual and sexual means.

#### Asexual reproduction

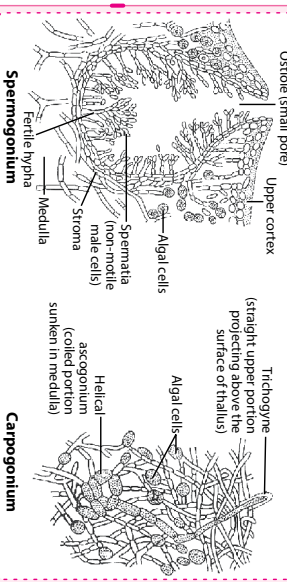
Asexual reproduction occurs by following structures:

- Cephalodium** : These appear as small, hard, dark-coloured, gall-like swellings on the free surface of some lichen thallus. They contain the same fungal hyphae as in the thallus but the algal component is always different.
- Soredium** : Small bud-like outgrowths over the upper surface of thallus, containing one or few algal cells closely enveloped by a wet of fungal hyphae. Both fungus and alga are same as in parent thallus.
- Isidium** : These are small outgrowths on the upper surface of the lichen thallus each consisting of an outer cortical layer made up of fungal cells followed by an algal layer of the same kind as in the thallus.



#### Sexual reproduction

In lichens, the process of sexual reproduction is performed only by the fungal component. The female sex organs are known as **carpogonia**. The male sex organs are known as **spermatogonia**. A carpogonium is differentiated into a basal called ascogonium and an elongated multicellular trichogyne. Each spermatogonium is a flask-shaped receptacle immersed in a small elevation on the upper surface of thallus. The spermatogonium usually develops close to carpogonium.



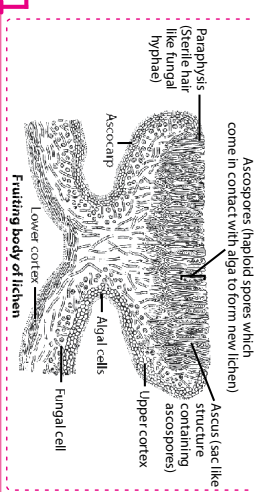
Spermatia adhere to the projected part of sticky trichogyne. On dissolution of the walls between them the nucleus of spermatium migrates into the carpogonium through trichogyne. The male nucleus fuses with the female nucleus. Several branched ascogenous hyphae develop from the base of the fertilised ascogonium. The terminal binucleate cell of ascogenous hypha develops into an ascus. The two nuclei within the ascus fuse to form a diploid nucleus which forms eight haploid daughter nuclei meiotically each metamorphosing into an ascospore. The ascospores are hyaline and green or brown in colour. They are released gradually from the ascus, and on coming in contact with a suitable alga, form a new lichen thallus.

### Economic Importance

- As food** : Species of *Lecanora*, *Parmelia*, *Umbilicaria* and *Cetraria* are used as food in many parts of the world. *Umbilicaria esculenta* is a delicacy in Japan, while the species of *Parmelia* are used as curry powder in India.
- As medicine** : *Parmelia perlatia* is specially useful in dyspepsia and in the treatment of snake and scorpion bites. *Cleodonia*, *Cetraria* and *Pertusaria* are used in intermittent fever. *Cleodonia pyxidate* is useful in whooping cough. *Usnea* sp. are used to stop bleeding. Erythrin, obtained from *Roccella montagnei*, is used in angina. *Lobaria pulmonaria* and *Cetraria islandica* are used in tuberculosis and other lung diseases.
- As dyes** : Red and purple dyes are obtained from *Ochrolechia androgyna* and *O. tartarea*. **Orchil**, a blue dye is obtained from some lichens (e.g., *Cetraria islandica*, *Parmelia omphalodes* is the source of a brown dye. **Litmus**, an important acid-base indicator dye in chemical laboratories, is obtained from *Roccella montagnei* and *Crocodia pusillata*.
- In tanning industry** : *Cetraria islandica* and *Lobaria pulmonaria* are used as tanning agents in leather industries.
- In cosmetics** : *Evernia* and *Ramalina* are the source of essential oils, used in the manufacture of cosmetic soaps. *Ramalina calicaria* is used for whitening hair in wigs. *Pseudoverna furfuracea* and *Evernia prunastri* are widely used in the manufacture of perfumes.

### Ecological Significance

Lichens are pioneer plants in ecological succession, which help in colonisation of bare rocky habitats. They secrete some organic acids which disintegrate rocks and form soil and substratum for subsequent establishment of other vegetation types. Lichens can be used as air pollution indicators especially of the concentration of sulphur dioxide in atmosphere. Several lichens are also harmful to us. They cause a considerable loss due to etching of glass surfaces and marble stones. Some lichens, such as *Letharia vulpina* (wolf moss), are poisonous.



Fruiting body of lichen



# CONCEPT MAP

## MORPHOLOGY OF ROOTS

- Root constitutes the lower part of plant axis which develops from radicle and typically grows towards gravity.
- Roots are usually non-green, underground, cylindrical or sub-cylindrical, and tapering. They do not have nodes, internodes and leaves.
- Root branches develop from interior (usually pericycle) of the parent root. Such an origin is called endogenous.

### Parts of a typical root

A typical root possesses four parts - root cap zone of cell formation, zone of cell elongation and zone of cell maturation.

- Root cap:** It is a thimble-shaped or cap-shaped parenchymatous, multicellular structure which covers the apex of root. It provides protection to the young apical cell against soil particles.
- Zone of cell formation (Region of meristematic activity):** It is subterminal. The cells of this region are thin walled, with dense cytoplasm and large nucleus. These cells are in active state of division and thus their number increases continuously.
- Zone of cell elongation:** This region is situated just above the meristematic zone. The cells of this region lose the power of division and elongate rapidly. This increases length of root.
- Zone of cell maturation:** The cells of this region are differentiated into permanent tissues depending upon the functions they have to perform. From this region some of the epidermal cells form fine, delicate, thread like structure called root hairs which absorb water and minerals from the soil.

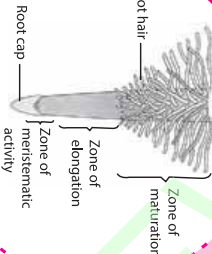
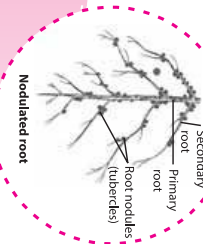


Fig.: Parts of a typical root

### Nodulated roots

The secondary, tertiary roots, sometimes primary roots also develop numerous small or large irregular swellings called nodules or tubercles. These are found in leguminous plants and harbour numerous nitrogen fixing bacteria.



Nodulated root

### Modifications of root

In addition to normal work of anchorage, absorption of water and minerals, roots perform some special functions for which they get variously modified.

### Types of root system

Root systems are of three types: tap root system, fibrous root system and adventitious root system.

- Tap root system:** In majority of dicots, direct elongation of the radicle leads to the formation of primary root which bears lateral roots of several orders that are referred to as secondary, tertiary roots, etc. The primary roots and its branches constitute the tap root system.
- Fibrous root system:** In monocotyledons, the primary root is short lived and is replaced by a large number of roots. These roots originate from base of stem and constitute the fibrous root system.
- Adventitious root system:** Adventitious roots develop from any part of the plant other than radicle. These roots constitute adventitious root system.

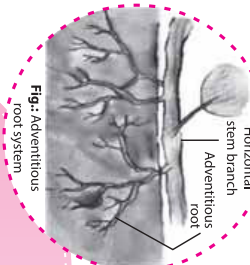


Fig.: Adventitious root system

Fig.: Fibrous root system

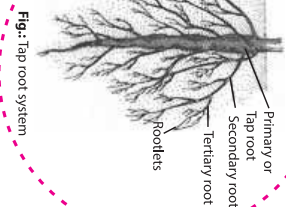
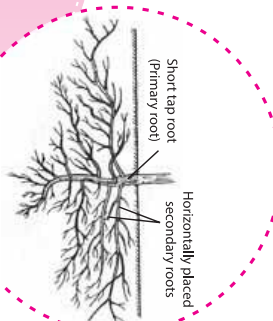


Fig.: Tap root system

### Storage of food

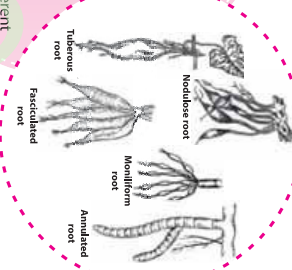
**Tuberos:** These roots arise from nodes of stem and become tuberous and fleshy for storage of food, e.g., *Ipomoea*.

**Fasciculated:** These roots arise in bunches from lower nodes of stem and become thick and fleshy, e.g., *Asparagus*.

**Moniliform:** These roots are swollen at regular intervals like beads of necklace, e.g., *Momordica*.

**Annullated:** In these roots swelling at different places takes place in such a way that closely placed ring like structures are formed, e.g., *Psychotria*.

**Nodulose:** In these roots apical portion swells up, e.g., *Curcuma amada*.



### Vital functions

**Assimilatory roots:** Roots of some plants develop chlorophyll and perform photosynthesis, e.g., *Tinospora*.

**Haustorial roots:** These roots occur in parasites for absorbing nourishment from the host. They are also called sucking roots or suckers, e.g., *Cuscuta*.

**Epiphytic roots:** These roots are found in epiphytes. They hang in air. These roots have spongy tissue called velamen for absorption of atmospheric moisture, e.g., orchids.

**Contractile roots:** These roots can shrink 60-70% of the original length which brings an underground organ to its proper depth in soil, e.g., *Crocus*.

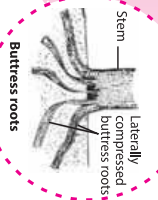
### Modifications of adventitious roots

#### Mechanical support

**Prop roots:** They are thick pillar-like adventitious roots which grow from and support heavy horizontal branches of trees, e.g., *Ficus benghalensis*.

**Stilt roots:** They are short but thick supporting roots which develop obliquely from basal nodes of stem, e.g., sugarcane.

**Climbing roots:** They are non-absorptive adventitious roots which are found in climbers. They may arise from nodes, internodes or both e.g., betel Ivy. The apices of these roots produce a viscous substance which dries in the air and so the roots get attached to substratum.



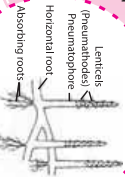
Buttress roots

### Buttress roots

They are horizontal roots that arise jointly from the bases of tap root and the trunk. They provide extra support, e.g., pipal.

### Pneumatophores

They are breathing or respiratory roots, found in plants growing in mangroves or saline swampy areas, e.g., *Rhizophora*.



Pneumatophores

### Modifications of tap roots

#### Fleshy tap roots

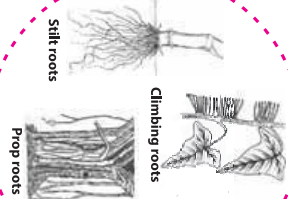
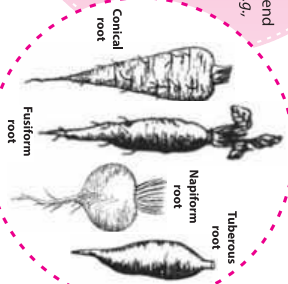
Tap roots become swollen and fleshy with stored food. These are of following types:

**Conical:** These roots get thicker on the upper end to store food and tapering at the lower end, e.g., carrot.

**Fusiform:** These roots get thicker in the middle and tapering on both ends, e.g., radish.

**Napiform:** These roots get very much swollen and spherical at the upper end for storage of food and taper downwards into a threadlike structure, e.g., turnip.

**Tuberous:** These roots get swollen in any portion, thus they do not have a regular shape, e.g., *Mirabilis*.





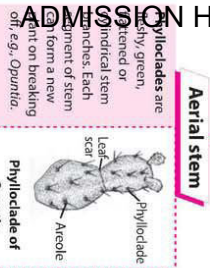
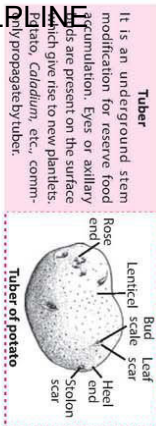
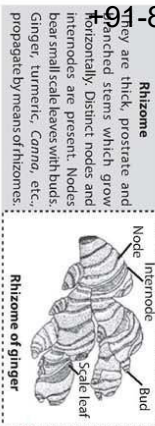
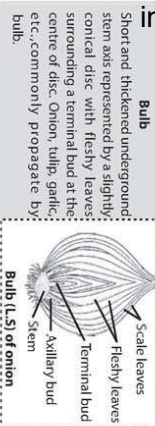
# CONCEPT MAP

## VEGETATIVE PROPAGATION IN PLANTS

Vegetative propagation is the regeneration of new plants from vegetative parts of parent plant. It includes all those processes of propagation in which a part of the plant body is separated from the parent plant and gives rise to a new individual without any obvious changes in the protoplast. All the plants developed by vegetative propagation are genetically identical to their parent plants.

### NATURAL METHODS

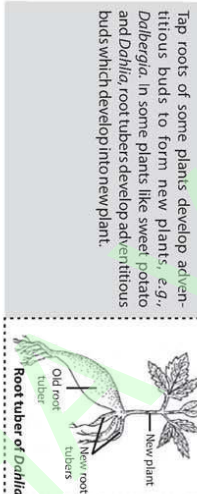
#### Propagation by Stem



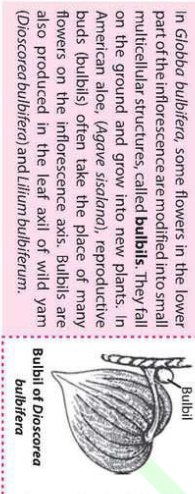
#### Propagation by Leaf



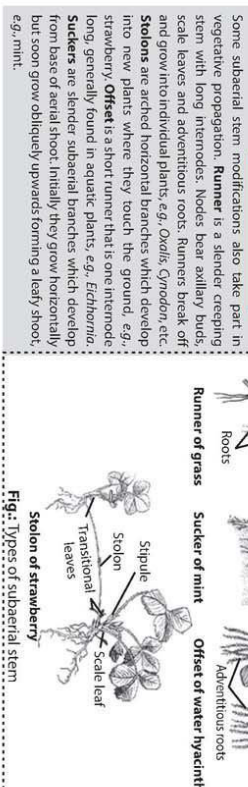
#### Propagation by Root



#### Propagation by Bulbils



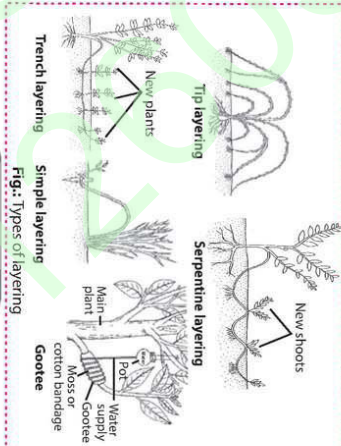
#### Subaerial stem



### ARTIFICIAL METHODS

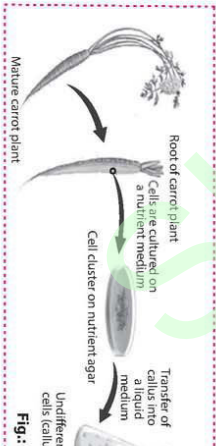
#### Layering

- It is the method of inducing root formation in stem while it is still attached to the parent plant. It is of following types:
- Tip layering:** In this method, tip portion of the shoot is bent and buried in the soil. Eg., Black raspberry.
  - Serpentine layering:** In this method, long slender shoot is bent and laid to the ground, covered with soil at short regular intervals so as to form many plants. Eg., Clematis.
  - Trench layering:** In this method, long shoot is placed in trench leaving the apical portion exposed. Roots are produced at each node on the lower side and shoot emerges on the upper side. Eg., walnut, mulberry.
  - Simple layering:** In this method, rooting is induced on a soft stem. It is delugated and a small injury is made on it. After that it is pegged in the soil to develop adventitious roots. Later on, the layer is separated and planted. Eg., Jasmine, grapevine.
  - Air layering or gootee:** In this method, rooting is induced in aerial hard branches. The stem is grided and covered with moist moss or cotton. Water is added to it along with small quantity of root promoting hormones. After 2-3 months roots appear and shoot is then cut below the cotton bandage and replanted. Eg., Ilichi, pomegranate.



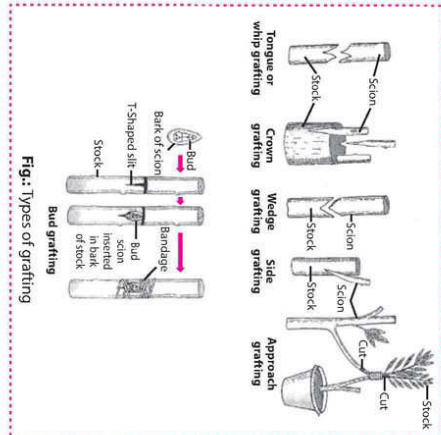
#### Cutting

- Any part of the plant (stem, root or leaf) that produces roots when put into the soil and gives rise to a new plant is called cutting. It can be done in following ways:
- Root cutting:** The pieces of roots are used to artificially propagate new plants, e.g., lemon, orange, etc.
  - Stem cutting:** 20-30 cm long stem cuttings are used to propagate both herbaceous and woody plants. Their lower ends are dipped in root promoting hormones for several minutes before planting, e.g., rose.
  - Leaf cutting:** In this technique, leaf is transversely cut into two or three parts and leaf cuttings are vertically planted in soil, e.g., Sansevieria.



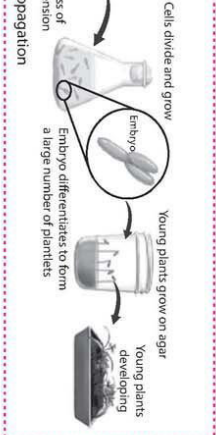
#### Grafting

- Grafting is the technique of joining together parts of two different plants in such a manner that they unite and later develop as a composite plant. Various techniques of grafting are as follows:
- Tongue grafting:** Oblique cut is given to both stock and scion (of same diameter) and they are tied together.
  - Crown grafting:** Stock has larger diameter than scion. Many slits are formed on the sides of stock and scions are inserted into them and bandaged.
  - Wedge grafting:** V-shaped notch is given to stock and wedge like cut is given to scion (both of same diameter).
  - Side grafting:** V-shaped notch is given to stock at one side and scion is inserted in it. Stock has larger diameter than scion.
  - Approach grafting:** Two independently growing plants are brought together. Their shoots are given cuts at the same level and united.
  - Bud grafting:** In bud grafting, scion consists of a single bud accompanied with a portion of living tissue. It is inserted into a T-shaped incision on the stock treated with grafting wax and bandaged. e.g., apple, peach.



#### Micropropagation

The technique of propagating plants by culturing cells, tissues and organs is known as micropropagation. It is popularly known as **tissue culture**. Methods of micropropagation are callus culture, suspension culture, embryo culture, anther culture, protoplast culture, etc. Laboratory culturing ultimately results in formation of large number of plantlets, e.g., orchids, Carnation, etc.





# CONCEPT MAP

## MORPHOLOGY OF STEM

Stem is the ascending part of the plant axis which develops from the plumule of the embryo. It grows by means of a terminal bud and shows distinction into nodes and internodes. Leaves and stem branches develop exogenously from it.

### Branching of stem

Branching of the stem is of two types: 1. Dichotomous branching and 2. Lateral branching.

**1. Dichotomous branching :** The growing point gets divided into two in the region of branching e.g., *Asclepias syriaca*, *Pandanus*.

**2. Lateral branching :** Branching occurs by exogenous growth of lateral buds. It is further divided into two main types: (i) Racemose branching and (ii) Cymose branching.

(i) **Racemose or monopodial branching :** Terminal bud continues its activity indefinitely and the lateral branches are borne in an acropetal succession, e.g., *Eucalyptus*, *Casuarina*.

(ii) **Cymose or sympodial branching :** The terminal bud, after forming a small portion of the axis, either stops its activity or gets modified into a flower, tendril, thorn etc. Lateral branches are borne in basipetal succession. Further growth of the axis is continued by one or more axillary branches. Accordingly, it is of three types: (a) **Uniparous or monochasial** – Further growth is continued by a single axillary branch. The successive branches may develop either on both the sides i.e., scorpioid (e.g., grapevine) or on one side only i.e., helixoid (e.g., *Sarcod*). (b) **Biparous or dichasial** – Further growth is continued by two axillary branches, e.g., *Vicaria*, *Mitella* etc.

(c) **Multiparous or polychasial :** Growth is continued by whorl of three or more axillary branches, e.g., *Euphorbia*, *Croton* etc.

Unbranched stem is called caudex, e.g., palm, sugarcane.

### Cladodes

These are one to two internode long stem branches which are photosynthetic and have limited growth, e.g., *Ruscus aculeatus*.



### Stem tendrils

These may be axillary (e.g., *Passiflora*), extra-axillary (e.g., *Cucurbita*), leaf opposed (e.g., grapevine), inflorescence tendrils (e.g., *Antigonon*) etc.



### Diverse forms of stem

Stems of flowering plants attain diverse forms to perform various functions. They are grouped into three broad categories: reduced stems, erect stems and weak stems.

**1. Reduced stems** – Stem is reduced to a small disc and nodes and internodes are not distinguishable, e.g., in radish, carrot, *Lemna*, etc.

**2. Erect stems** – Stems are sufficiently strong to remain erect or upright without any external support. Erect stems with swollen nodes or jointed stems (**Culms** e.g., bamboo), unbranched erect stems (**caudex or columnar** e.g., *Cocos nucifera*), branched erect stems (**Excurrent** e.g., *Eucalyptus*, **Deliquescent** e.g., *Delageia*).

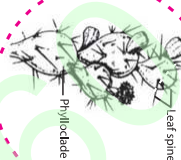
**3. Weak stems :** The stems are thin, soft and weak. These may be upright or prostrate. (i) **Upright weak stems :** These are further of two types – **Twiners** and **climbers**. **Twiners :** The stems are long, slender, flexible and sensitive. They twin or coil around an upright support on coming in its contact, e.g., *Convolvulus*, *Labiola*. **Climbers :** The stems are weak and climb up the support with the help of some clasping or clinging structures. Accordingly, these may be (a) **Root climbers** e.g., Ivy (b) **Tendrils climbers** e.g., *Passiflora*, *Gloriosa*. (c) **Scramblers** e.g., *Bougainvillea* (d) **Lianas** e.g., *Bauhinia*. (ii) **Prostrate or sub-aerial weak stems :** These spread over the ground for proper exposure of leaves. These are of two types – **Trailers** and **creepers**. **Trailers** do not root at intervals, e.g., *Euphorbia prostrata*. **Creepers** root at intervals and take part in vegetative propagation. These may be runners, stolons and offsets. (a) **Runners :** They are special narrow, green, above ground horizontal or prostrate branches which develop at the bases of erect shoots called crowns. The nodes bear scale leaves and axillary buds, which grow to form new crowns e.g., *Cynodon dactylon*, *Cenille* etc. (b) **Stolons :** These are arched runners which can cross over small obstacles, e.g., strawberry, jasmine etc. (c) **Offsets :** These are small internode long runners usually found in rosette plants at the ground or water level, e.g., *Eichornia*, *Pistia* etc.

### Modifications of stem

#### Aerial stem modifications

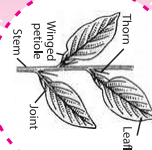
#### Thalamus

It forms the broadened tip of the pedicel or floral stalk. It bears sepals, petals, stamens and carpels.



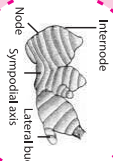
#### Stem thorns

A thorn represents an axillary branch of limited growth. Thorns are deep seated having vascular connections with stem, e.g., *Citrus*, *Duranta* etc.



#### Rhizome

It is a perennial, fleshy underground stem which grows indefinitely producing new leaves or aerial shoots during favourable season. It may be **rootstock rhizome** (e.g., *Dryopteris*) or **straggling rhizome** (e.g., *Zingiber*).



#### Tuber

It represents the swollen end of a specialised underground stem branch. Each tuber bears nodes called eyes, e.g., *Solanum tuberosum*.



#### Underground stem modifications

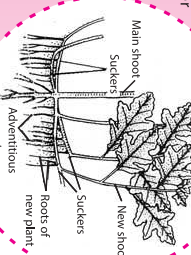
#### Corm

It is short, thick, fleshy, usually unbranched, spherical or subspherical specialised underground stem produced **annually** and growing **vertically** in soil. Circular nodes bear scale leaves and one or more axillary buds, e.g., *Amorphophallus*, *Colocasia* etc.



#### Sucker

It is an underground, non-green slender branch of the stem which arises from the axillary bud of the underground part of aerial stem, e.g., *Chrysanthemum*.

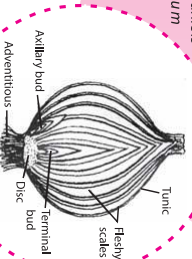


#### Bulb

It consists of a highly reduced discoid stem and several fleshy scales enclosing a terminal bud. Bulbs are of two types – **Tunicated** and **scaly**.

(i) **Tunicated bulb :** In *Allium cepa* (onion), the scale leaves occur in a concentric manner forming a series of rings and the rings are surrounded by a common tunic. Scales represent buds and are called **bulbils** or **doves**, which occur in irregular concentric rings. Each ring is surrounded by a white tunic and each bulbil has its own thick white tunic (Compound tunicated bulb).

(ii) **Scaly bulb :** Fleshy scales are narrow, small, separated, loosely arranged and overlap each other at their margins. Tunic is absent, e.g., *Lilium bulbifera*.



# CONCEPT MAP

## MORPHOLOGY OF LEAF

Leaf is an important vegetative organ of plant as it is specialised to perform photosynthesis. It is a green lateral flattened outgrowth borne on the node of a stem or stem branch and bears a bud in its axil.

### Parts of a leaf

A typical leaf consists of three parts - leaf base, petiole and lamina. **Leaf base** is the basal part of the leaf by which it is attached to the node of the stem. Different plants have different types of leaf bases viz. pinnatus, e.g., pea; sheathing, e.g., *Zea mays*; decurrent, e.g., *Crotalaria* and amplexicaul, e.g., *Polygonum*. Leaves of some plants have lateral appendages on each side of leaf base, known as **stipules** which may be caducous, deciduous or persistent. **Petiole** is the leaf stalk that joins the lamina to the stem or its branch. Sometimes the petiole is absent and then the leaf is said to be **sessile**. **Lamina** is the expanded green and conspicuous part of leaf which is specialised to perform photosynthesis. It is supported by veins and veinlets which contain vascular tissues for conduction of water, mineral salts and prepared food.

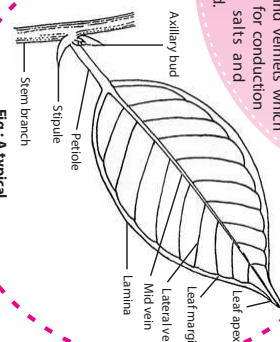
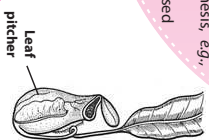
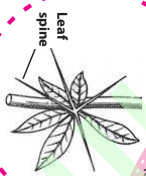


Fig.: A typical dicotyledonous leaf

### Leaf modifications

- Leaf tendrils** : Leaves are modified into slender, wiry often closely coiled structures, known as tendrils, which help in climbing. These may be whole leaf tendrils (e.g., *Lathyrus aphaca*), leaflet tendrils (e.g., *Physum sibiricum*), petiolar tendrils (e.g., *Nepenthes*), leaf tip tendrils (e.g., *Gloriosa*), Stipular tendrils (e.g., *Smilax*), etc.
- Leaf spines** : These protect the plants from grazing animals and excessive transpiration e.g., *Solanum surattense*.
- Leaflet hooks** : The terminal leaflets of compound leaves become transformed into stiff claw-like and curved hooks. These help the plant in climbing e.g., *Doxantha unguis-cati*.
- Phyllodes** : These are the flattened petioles or parts of the rachis which perform the function of photosynthesis, e.g., *Acacia* species. These help to reduce transpiration in xerophytic plants.
- Insect catching leaves** : Leaves are modified to form pitchers (e.g., *Nepenthes*) bladders (e.g., *Utricularia*) etc. to trap and digest insects.
- Succulent leaves** : These are fleshy leaves that store food material, e.g., *Aloe*, *Agave* etc.
- Scale leaves (or cataphylls)** : These are dry membranous leaves which do not take part in photosynthesis, e.g., *Casuarina*.
- Floral leaves** : These are specialised leaves i.e., sepals, petals, stamens and carpels.



Leaf pitcher

### Phyllotaxy

Phyllotaxy is the arrangement of leaves on the stem or its branches in such a way that all the leaves get proper exposure to sunlight. Phyllotaxy is of three main types -  
 (i) **Spiral or Alternate** : A single leaf is borne at each node, e.g., *Hibiscus*, mango.  
 (ii) **Opposite** : A pair of leaves are borne at each node on opposite sides, e.g., *Quisqualis* (opposite superposed) and *Calotropis* (opposite decussate).  
 (iii) **Whorled or verticillate** : More than two leaves arise at each node, e.g., *Alstonia*.



### Simple and Compound leaves

A simple leaf is the one in which lamina is undivided or incised to any depth but not upto the midrib. In a compound leaf, lamina is completely broken up into distinct segments called leaflets which are separately articulated at the base. Compound leaves are of 2 types -



Fig.: Simple leaves

- Unipinnate** : Leaflets are directly attached on the rachis, e.g., *Cassia fistula* (paripinnate), rose (imparipinnate).
- Bipinnate** : Rachis divides and gives rise to secondary axis on both sides on which leaflets are arranged, e.g., *Acacia*.
- Tripinnate** : Secondary axis too, divides and gives rise to tertiary axis on which leaflets are attached, e.g., *Moringa*.
- Decompound** : Rachis divides more than three times and gives rise to small axis on which leaflets are arranged, e.g., carrot.
- Palmitate compound leaves** : In these type of leaves, incision of leaf is directed towards the petiole due to which all leaflets seem to be articulated on the upper end of petiole. It does not have any rachis. Depending on the number of leaflets present, a palmitate compound leaf is called **unifoliate** (e.g., *Citrus*), **bifoliate** (e.g., *Belanties*), **trifoliate** (e.g., *Trifolium*), **quadrifoliate** (e.g., *Paris quadrifoliata*), **multifoliate** (e.g., *Bombax*).

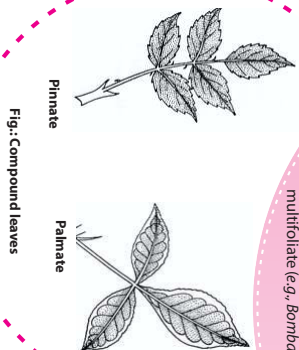


Fig.: Compound leaves

### Functions of the leaves

**Primary functions**: Photosynthesis, gaseous exchange, transpiration, protection of buds and conduction through veins.  
**Secondary functions** : Storage e.g., succulent leaves of *Aloe*, *Agave* etc.; protection e.g., spiny leaves of *Borberry*, *Opuntia* etc.; support e.g., leaflet hooks in *Doxantha*; nitrogen nutrition e.g., leaf pitchers of *Nepenthes*; reproduction e.g., leaves of *Bryophyllum* help in vegetative propagation; floral leaves help in sexual reproduction.

### Venation

Venation is the arrangement of veins and veinlets on the lamina of a leaf. Venation is of 3 main types - reticulate (veins form a network), parallel (veins run parallel) and furcate (veins branch dichotomously, e.g., *Citroseira*). **Reticulate venation** is found in most dicots. Pinnate (or unicostate) reticulate venation occurs in *Ficus religiosa*. Palmitate (or multicostate) reticulate venation occurs in *Zizyphus* (convergent) and *Luffa* (divergent). **Parallel venation** occurs in most monocots. Pinnate (or unicostate) parallel venation occurs in banana. Palmitate (or multicostate) parallel venation occurs in bamboo (convergent) and *Livistonia* (divergent).

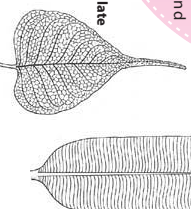


Fig.: Types of venation





# CONCEPT MAP

## MORPHOLOGY OF FRUITS AND SEEDS

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**A true fruit (or eucaarp)** is a ripened ovary. It consists of a thin or thick pericarp formed from the wall of ovary and seeds formed from the ovules. A fruit in which other floral parts (e.g., thalamus, base of sepals, petals, etc.), participate in its formation is called **false fruit (or pseudocarp)** e.g., apple and pear. The seeds within the fruits have reserve food for nourishing the young seedlings till they become nutritionally independent.

• Some fruits are formed without fertilisation i.e., seedless fruits. They are called as **parthenocarps** (e.g., banana). Fruits are classified into three main categories – **simple fruits**, **aggregate fruits** and **composite fruits**.

### Simple fruits

Simple fruits develop from monocarpellary ovary or multicarpellary syncarpous ovary. Simple fruits may be **dry** (pericarp is undifferentiated) or **succulent** (pericarp is differentiated into epicarp, mesocarp and endocarp).

### Dry fruits

Dry fruits are of three types – **Achenial** (single seeded, indehiscent), **capsular** (many seeded, dehiscent) and **schizocarpic** (many seeded, after ripening divide into single seeded segments).

### Composite fruits

A composite or multiple fruit develops from the whole inflorescence. It is of two main types: sorosis and syconus.

**Sorosis** : These fruits develop from spike, spadix or catkin inflorescence. Sorosis of pineapple develops from an intercalary spike of sterile flowers with persistent bracts. Sorosis of mulberry develops from a female catkin.

**Syconus** : It develops from hypanthodium inflorescence. Receptacle becomes fleshy and edible, many achenes develop from pistillate flowers. e.g., *Ficus carica*.

### Aggregate fruits

Aggregate fruits are the groups of fruitlets which develop from the multicarpellary, apocarpous ovaries. The individual carpel or pistil develops into a fruitlet and these fruitlets occur as a clustered unit on a single receptacle, which is referred to as an aggregate fruit or etaerio. e.g., etaerio of achenes (*Ranunculus*, *Lotus*), etaerio of follicles (*Coltropis*), etaerio of berries (custard apple), etaerio of drupes (e.g., *Rubus idaeus*), etc.

### Seed

Seed is a ripened ovule which contains an embryo, adequate reserve food and a covering for protection against mechanical injury. A seed may have 1 or 2 coverings called **seed coats**. Outer is **testa** and inner is called **tegmen**. Seeds can be endospermic and non-endospermic.

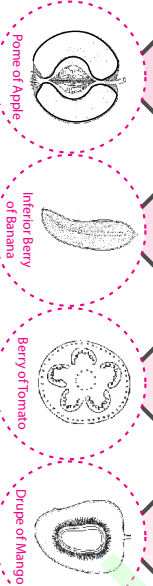
### Succulent fruits

Succulent fruits can be divided into three main types: berry, drupe and pome.

(i) **Berry**: In superior or true berry (derived from superior ovary) usually all the three layers of fleshy pericarp are edible, e.g., grape, tomato. In inferior or false berry (derived from inferior ovary) epicarp is fused with thalamus to form exocarp, e.g., banana (parthenocarpic), guava. There are some special berries also such as **balausta** (e.g., pomegranate), **pepo** (e.g., cucumber) and **hesperidium** (e.g., orange).

(ii) **Drupe (or stone fruit)**: In this fruit, epicarp forms the rind, mesocarp is fleshy and endocarp is hard and stony, e.g., almond, mango, *Zizyphus*, etc.

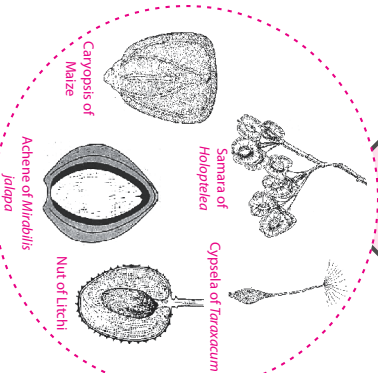
(iii) **Pome**: It is a false fruit that develops from the fleshy thalamus of multicarpellary, syncarpous, inferior ovary, e.g., apple, pear, etc.



### Achenial fruits (Indehiscent fruit)

Achenial fruits are of five types:

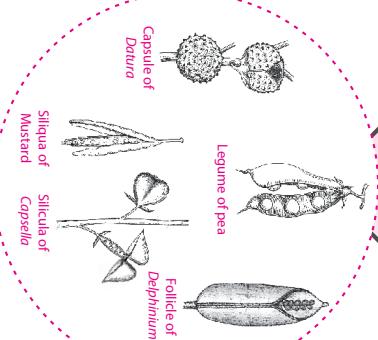
(i) **Achene** : It develops from monocarpellary, superior, unilocular and uniovuled ovary, pericarp is free from seed except at one point, e.g., *Mirabilis jalapa*. (ii) **Caryopsis (or Grain)** : It develops from monocarpellary, superior, unilocular ovary, pericarp is completely fused with the testa, e.g., members of family Poaceae. (iii) **Cypselia** : It develops from bicarpellary, syncarpous, inferior and unilocular ovary. Pappus may be present for dispersal, e.g., *Taraxacum*. (iv) **Nut**: Pericarp becomes hard, woody or leathery. Fruit may develop from monocarpellary superior ovary (e.g., cashew nut); trilocarpellary, syncarpous, trilocular ovary (e.g., litchi), etc. (v) **Samara** : Pericarp becomes flat like wings and thus help in wind dispersal e.g., *Holoptelea*.



### Capsular fruits (Dehiscent fruit)

Capsular fruits are of five types:

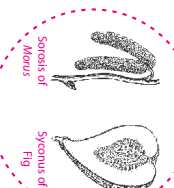
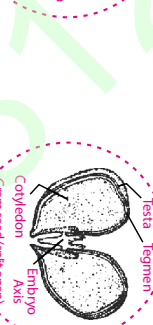
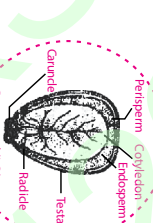
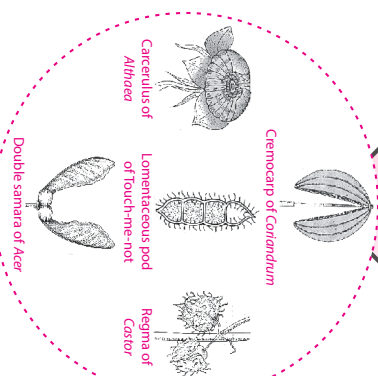
(i) **Legume (or pod)** : The fruit develops from superior, monocarpellary, unilocular ovary with marginal placentation. It dehisces by both dorsal and ventral sutures, e.g., members of family Leguminosae. (ii) **Follicle** : The fruit dehisces by only one suture, e.g., *Delphinium*. (iii) **Silique** : It develops from a bicarpellary, superior ovary with parietal placentation and a false septum called replum. It dehisces by two valves, e.g., members of family Brassicaceae. (iv) **Silicula** : It is a shortened and flattened silique, e.g., *Capsella bursa-pastoris*. (v) **Capsule**: According to the mode of dehiscence, capsule may be **porocidal capsule** (e.g., *Papaver*), **dentical capsule** (e.g., Pink), **pyxidium** (e.g., *Portulaca*), **locutical capsule** (e.g., *Gossypium*), **septicidal capsule** (e.g., *Viola*), **septicidal capsule** (e.g., *Datura*), etc.



### Schizocarpic fruits (Splitting fruits)

Schizocarpic fruits are of five types:

(i) **Cremocarp** : It develops from a bicarpellary, syncarpous, bilocular, inferior ovary. On maturity, the fruit splits into two mericarps, each with one seed, e.g., members of family Apocynaceae. (ii) **Lomentum** : The fruit is a modification of legume, which is constricted in between the seeds, e.g., *Mimosa*, *Alcedia*, etc. (iii) **Careculis** : At maturity, the fruit breaks up into single seeded indehiscent mericarps, e.g., *Althaea*. (iv) **Compound samara** : At maturity, the fruit splits up into single seeded winged mericarps, e.g., *Acer*. (v) **Regma**: It develops from multicarpellary pistil and on maturity splits into as many cood as the number of carpels, e.g., *Geranium*.



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# CONCEPT MAP

## FLORAL MORPHOLOGY

A flower is a highly condensed and modified shoot. It contains reproductive organs of the flowering plants, which develop fruits and seeds. There are four types of floral organs viz. **sepals, petals, stamens and carpel or pistil**. A flower having all the four types of floral organs is known as **complete flower** e.g., cotton, one or more of the floral organs are absent it is called **incomplete flower** e.g., cucurbits. A flower having both the essential organs i.e., stamens and carpels is called **hermaphrodite** or **bisexual flower**, e.g., China rose, whereas a flower having only one of the two essential organs is known as **unisexual flower** e.g., mulberry. Flowers having only stamens are called **staminate flower** and those having only carpels are called **pistillate** flowers. On the basis of symmetry flower can be **actinomorphic** (two equal halves in any plane), **zygomorphic** (two equal halves in one plane), or **asymmetrical**.

### GYNOECIUM

- Central, female reproductive part which develops from thalamus and consists of **carpel (megasporophyll)**.
- Each carpel consists of **stigma** (the tip which receives pollen), **style** (elongated structure connecting stigma and ovary), **ovary** (lower swollen part containing ovules).
- On the basis of number of carpel present, it can be **noncarpellary** (one carpel only) or **multicarpellary** (many carpels) which can be **apocarpous** (carpels free e.g., *Ranunculus*) or **syncarpous** (carpels fused e.g., *Retunia*).
- On the basis of number of locules (chamber) present in the ovary, it can be **unilocular** (peal), **bilocular** (mustard), **trilocular** (*Asparagus*), **tetrilocular** (*Cucurbit*), **pentilocular** (China rose) or **multilocular** (*Althaea*).

### PLACENTATION

- Arrangement of placenta (which bear ovules) on the ovary wall which can be:
  - Marginal** : One or two longitudinal alternate rows of ovules along the ventral suture in unilocular ovary e.g., pea, *Cassia* etc.
  - Parietal** : Ovules on walls of bi-multicarpellary but unilocular ovary e.g., *Algerone*.
  - Axile** : In multicarpellary, syncarpous, multilocular gynoecium, margins fuse at the centre of the ovary to form an axis which bears ovules e.g., *Solanum*.
  - Free central** : Unilocular ovary with ovules borne on central axis e.g., *Dianthus*.
  - Basal** : Ovary unilocular with a single ovule at its base e.g., sunflower.
  - Superficial** : Multicarpellary, syncarpous gynoecium bears a large number of ovules that are borne on the walls of loculi without specific order, e.g., *Nymphaea*.

### THALAMUS (Torus/Receptacle)

- Broadened or swollen part of the flower which lies at the tip of the pedicel and bears floral organs.
- In most flowers the thalamus is condensed but in some, one or more internodes elongate viz. **anthophore** (internode between calyx and corolla e.g., *Dianthus*), **androphore** or **gonophore** (internode between corolla and androecium, e.g., *Passiflora*), **gynophore** (internode between androecium and gynoecium, e.g., *Caparis*), **gynandrophore** or **androgynophore** (both androphore and gynophore present, e.g., *Gynandropsis pentaphylla*), **carpopophore** (the thalamus in between the two carpels elongates and after bifurcation protrudes out of the two carpels, e.g., *Coriandrum*).
- On the basis of relative position of floral organs on thalamus flower may be **epigynous** (ovary inferior, placed below other whorls, e.g., guava), **hypogynous** (ovary superior, e.g., China rose), or **perigynous** (ovary half superior or half inferior and thalamus may be disc e.g., pea, cup e.g., *Prunus* or flask e.g., rose shaped).

### PEDICEL OR STALK

- Lower internode of flower. A flower with pedicel is called **pedicellate** and one without it, is **sessile**. It may bear **bracteoles** along with the bracts.

### ANDROECIUM

- Third and male whorl of the flower made up of **stamens (microsporophylls)** which consist of **filament** (lower stalk-like part which may be absent in some), **anther** (upper swollen part usually having two lobes or theca i.e., **bihyecus** or in some **monothecous**, e.g., *Althaea*) and **connective** (sterile band which connects two anther lobes). In *Solanum*, connective forms a long curved structure. Its one end has a fertile anther lobe and other has a sterile anther lobe. Stamens may be shorter than other whorls (**inseerted**) or may protrude out of the flower (**exserted**).
- On the basis of attachment to the filament, anthers can be **adnate** (filament runs along the back of the anther or becomes continuous with the connective, e.g., *Ranunculus*), **basifixed** (filament fixed at anther's base, e.g., *Datura*), **dorsifixed** (filament attached to back and anther immovable, e.g., *Passiflora*), **versatile** (filament attached to back and the anther can swing freely, e.g., grasses).
- The cohesion between the stamens may be **monadelphous** (all the filaments united into a single bundle, anthers free, e.g., pea), **polyadelphous** (filaments united into more than two bundles, anthers free, e.g., castor), **syngonesis** (anthers united into a bundle, filaments free, e.g., sunflower), **synandrous** (anthers as well as filaments united throughout the length, e.g., *Colocasia*). The free stamens are called **epipetalous**.
- On the basis of adhesion of stamens to flower, it can be **epiphyllous** (attached to perianth, e.g., *Aspidelium*), **epipetalous** (attached to petals, e.g., *Datura*), **gynandrous** (attached to gynoecium, e.g., *Calotropis*).

### AESTIVATION

- Arrangement of petals (or sepals) in a flower bud with respect to members of the same whorls which can be **open** (margins of adjacent petals sufficiently apart from each other), **valvate** (margins of the adjacent petals lie close, without overlapping, e.g., mustard), **twisted or contorted** (one margin of a petal overlaps the margin of an adjacent petal (external) and the other margin is overlapped (internal) by the margin of adjacent petal, e.g., China rose), **imbricate** (one petal external, one internal, and of the remaining three petals one margin is overlapped, other overlapping, e.g., *Cassia*), **quincuncial** (special type of imbricate aestivation in which two petals external, two internal and in one petal one margin is overlapped, one is overlapping, e.g., calyx of *Cucurbita maxima*),  **vexillary** (posterior petal overlapping the two lateral petals, the latter overlapping the two anterior petals, e.g., pea).

### BRACTS

- Specialised leaves from the axil of which flower arise. They can be **foliaceous** (leaf-like, e.g., *Adhrodia*), **petaloid** (like petals, e.g., *Bougainvillea*), **scaly** (membranous, small e.g., sunflower), **spiny** (large, leaf-shaped bract enclosing an inflorescence, e.g., banana, maize), **glumes** (small, dry, scaly as in spikelets of Poaceae).
- There are one or more whorls of bracts found at the base of calyx which form **epicalyx** in most members of Malvaceae, e.g., China rose. Sometimes, bracts are in one or more whorls around and below the entire inflorescence, e.g., coriander and are called **involucre**.

### CALYX

- Outermost whorl made up of sepals which are usually green but sometimes coloured (i.e., **petaloid**). They protect the inner whorls and carry out photosynthesis when green.
- The sepals may be free (**polypetalous**) or fused (**gamopetalous**). They can be **caducous** (fall just at the time of opening of bud, e.g., poppy), **persistent** (attached till the flower withers, e.g., mustard), **decisious** (remain attached to the fruit, e.g., tomato).
- Sepals can be modified to form **pappus** (hairy structure which helps in dispersal, e.g., sunflower), **leathy perianthoid** (large leaf like coloured structure, e.g., *Muscadina*), **spinous** (prickly and modified into spines, e.g., *Tigrid*), **spurred** (drawn out into beak or spur, e.g., *Larkspur*), **hooded** (modified into a hood, covering the whole flower, e.g., *Aconitum*) or **bilabiate** (two-lipped, e.g., *Salvia*).

### COROLLA

- Second whorl inner to calyx made up of petals which protects the inner whorls and attracts insects for pollination. Corolla may be **polypetalous** (petals free) or **gamopetalous** (petals fused).
- Polypetalous corolla** may be **cruciform** (four clawed or unguiculate petals arranged cross wise, e.g., mustard), **caryophyllaceous** (five unguiculate or clawed petals with limbs placed at right angles, e.g., *Dianthus*), **rosaceous** (five or more sessile or shortly clawed petals with limbs spread regularly outwards, e.g., rose), **campanulate or bell-shaped** (e.g., *Physalis*), **papilionaceous** (five unequal or irregular petals viz. 1 standard or vexillum - posterior largest, 2 wings or alae - lateral, smaller - and 2 anterior petals fused together to form keel or carina).
- Gamopetalous corolla** may be **campanulate** (bell-shaped or inverted cup-shaped, e.g., *Campanula*), **urceolate** (urn-shaped, e.g., *Gryophyllum*), **tubular** (tube-like or cylindrical, e.g., disc flower of sunflower), **infundibuliform** (funnel-shaped, e.g., *Retunia*), **rotate** (corolla with short tube having limbs placed transversely like a saucer or the spokes of a wheel, e.g., *Solanum nigrum*), **salver shaped or hypocrateriform** (tubular corolla with spreading lobes, e.g., *Cloranthodrum*), **bilabiate** (bilipped corolla with gaping, wide open mouth, e.g., *Cucurbit*), **personate** (bilipped corolla with closed lips, e.g., *Antirrhinum*), **ligulate or strap-shaped** (short and narrow tube-like corolla with upper part flattened like a strap, e.g., ray flower of sunflower), **spurred** (one or more petals drawn out like a beak or spur, e.g., *Larkspur*).



# CONCEPT MAP

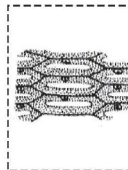
## SIMPLE PERMANENT TISSUES

Tissues can be defined as a group of cells having a common origin that interact with one another to perform a similar function. Plants are formed of two types of tissues, on the basis of tissues and on the basis of ability of cells to divide, i.e., **Meristematic** (divide indefinitely) and **Permanent**. Permanent tissues are those plant tissues that have lost the capacity to divide and attain a permanent shape, size and function due to morphological, biochemical and physiological differentiation. Based on the composition, permanent tissues can be **simple** or **complex**. **Simple permanent tissues** are made up of structurally similar cells that carry out the common function.

There are three types of simple permanent tissues

### PARENCHYMA

- Most abundant and common tissue of plants.
- Composed of thin walled, isodiametric cells that may be oval, rounded or polygonal in outline.
- Cell wall is cellulose and encloses a large central vacuole and a peripheral cytoplasm containing nucleus.
- Cells may be closely packed or have small intercellular spaces between them.
- Cells form symplasm or living continuum as they connect with the adjacent parenchyma cells by plasmodesmata.
- It is usually used for storage of food and provides turgidity to softer parts of plants.
- It may be variously modified to perform special functions.

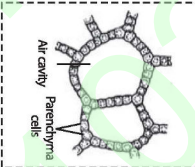


**Prosenchyma**  
Fibre like elongated parenchyma with slightly thick walls.  
**Function:** Provides rigidity and strength.

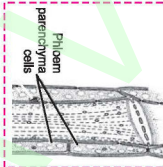
#### Idioblasts

The non-green, large sized parenchyma cells possessing inclusions or metabolic waste products like resins, tannins, crystals of calcium carbonate, calcium oxalate, etc.

#### Aerenchyma



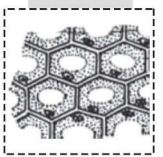
The parenchyma in hydrophytes and some land plants get specialised to form network of parenchyma cells, enclosing large intercellular spaces filled with air i.e. air cavities called as aerenchyma.  
**Function:** Stores air or gases that helps in making aquatic plants light and buoyant.



**Phloem parenchyma**  
Thin walled, elongated parenchymatous cells having abundant cytoplasm.  
**Function:** Stores food, resins, mucilage, latex etc., as well as help in lateral conduction of food.

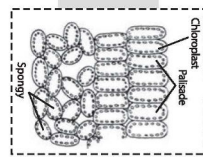
#### Xylem parenchyma

These are small and thick walled parenchymatous cells having simple pits.  
**Function:** Helps in lateral conduction of water or sap and storage of food.



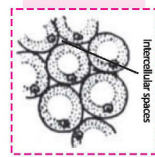
#### Chlorenchyma

Chloroplast containing parenchymatous cells. It is also called assimilatory parenchyma since it performs photosynthesis. It is differentiated into two types palisade (columnar in shape) and spongy (round in shape).



#### Storage parenchyma

Parenchyma sometimes get specialised by becoming enlarged and enclosing large vacuole. They are usually colourless.  
**Function:** Stores food, water, mucilage or ergastic substances.



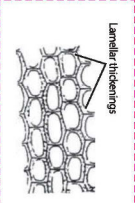
### COLLENCYMA

- Simple, living mechanical tissue, usually present in hypodermal regions of plant part or organs.
  - Cells are conspicuous, elongated and are circular, oval or angular in transverse section.
  - Each cell encloses a large central vacuole and a peripheral cytoplasm with chloroplasts often present.
  - The cell wall have uneven pectocellulosic thickenings, a characteristic feature of collenchyma.
- Functions:**
- Provides both mechanical strength and elasticity to young dicot stem, petioles and leaves.
  - Provides flexibility to organs and allow bending, e.g., in *Cucurbita* stem and prevents tearing of leaves.
  - Permits growth and elongation of organs.
  - Stores food and performs photosynthesis when chloroplasts are present.

Depending upon thickening, the collenchyma is of three types:

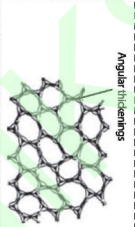
#### Lamellar collenchyma

- Cells are compactly arranged in rows.
- The cells have thickenings on tangential walls, e.g., stem of sunflower.



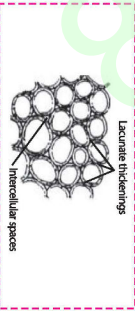
#### Angular collenchyma

- Most common type of collenchyma.
- Cells are irregularly arranged.
- Cell wall have thickening in the corners or angles and therefore intercellular spaces are absent, e.g., stem of potato, tomato.



#### Lacunar collenchyma

- Cells are irregularly arranged, hence intercellular spaces are present.
- Thickenings are present on cell wall around intercellular spaces, such thickenings are called lacunate thickenings.
- The thickened cell wall appears as a hollow cylinder, e.g., stem of *Calotropis*.

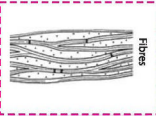


### SCLERENCHYMA

- Widely distributed, simple mechanical tissue.
- Comprises of dead and empty cells with highly thickened cell walls having little or no protoplasm.
- The lumen or cell cavity is narrow or highly reduced and sometimes obliterated (closed).
- The wall thickenings are made up of cellulose and lignin and may have few to numerous pits.

#### Sclerenchyma fibres

- Highly elongated, narrow, spindle shaped, thick walled cells with pointed or oblique end walls.
- Fibres occur in longitudinal bundles with the ends of adjacent fibres being interlocked to form a strengthening tissue.
- These are dead and empty at maturity with the exception in *Tamoxiphylla*, where fibres are living.



#### Wood fibres

Fibres associated with secondary xylem tissues and are derived from vascular cambium. Also called xylary or intraxylary fibres.

#### Basal fibres or extraaxillary fibres

Long fibres with lignified walls having simple or bordered pits. Found in cortex, pericycle and phloem.

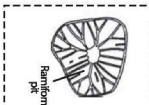
#### Surface fibres

Arise from the surface of plant organs, e.g., cotton fibres from testa of seeds, mesocarp fibres of coconut.

Types of Fibres

On the basis of length of cells, they may be of two types:

#### Brachysclereids



Isodiametric, short and unbranched cells with annular pits. Abundantly present in soft parts like cortex, phloem, flesh of fruits, e.g., guava, pear, apple, etc. Also called **stone cells**.

#### Osteosclereids



Bone shaped sclereids with rod like enlarged or lobed ends. Found in leaves and sub-epidermal covering of leguminous seeds, e.g., *Phaseolus*.

#### Macroscleireids

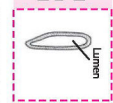
Slightly elongated and columnar rod shaped cells. Form epidermal covering of leguminous seeds such as pea and bean.

#### Filiform sclereids

Fibre like, sparingly branched sclereids. Found in leaves of *Olea*.

#### Astrosclereids

Star like, stellate sclereids having lobes. Found in leaves and petioles of aquatic plants, e.g., *Nymphaea*.





# CONCEPT MAP

## ANATOMY OF DICOTS

Anatomy is the study of internal structures of various parts of a living organism. Anatomy of dicot plants deals with the internal structures of stem, root and leaves of plants.

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- It is situated below epiblema and is made up of thin-walled parenchyma cells with intercellular spaces. Cortical cells store starch.
- Innermost layer of cortex is called **endodermis**. It is made up of single layer of barrel-shaped cells lacking intercellular spaces.
- Young endodermal cells possess **Casparian strips** (bands of thickening which run along their radial and tangential wall).
- Casparian strips prevent plasmolysis of endodermal cells and do not allow wall to wall movement of substances between cortex and pericycle.
- Endodermal cells opposite to protoxylem point lack Casparian strips and are called **passage cells**.

- It is found in the centre and is often reduced or absent in dicot root.
- If present, it consists of parenchyma cells without intercellular spaces.

- Xylem and phloem bundles are separated from each other by one or more layers of small thin-walled cells called conjunctive parenchyma.
- It becomes meristematic to form vascular cambium.

- It is the outermost layer of stem and is protective in function.
- Made up of compactly arranged, parenchymatous cells devoid of chloroplasts (except guard cells).
- The outer walls of epidermal cells are cuticularised.
- Stomata and multicellular hair are present in epidermis.

- Consists of thin-walled parenchymatous cells with intercellular spaces.
- Major function of cortex is food storage.

- It is the innermost boundary of cortex made up of compactly arranged barrel-shaped cells without Casparian strips.
- Endodermal cells of stem store starch grain and are often referred to as **starch sheath**.

- They are radial strips of parenchyma which are present between adjacent vascular bundles.
- They connect pith with pericycle and cortex.
- Ray cells are larger than cortical cells.

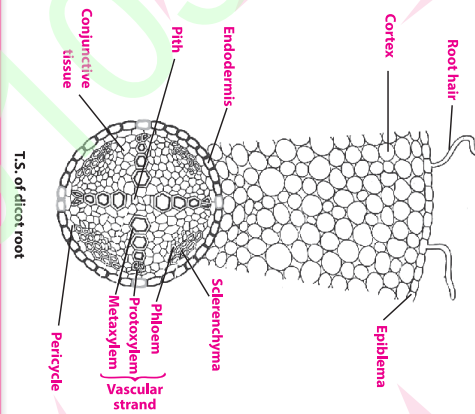
### Secondary growth in dicot stem

In a typical dicot stem the cambium is present in between the xylem and phloem. It is called **fasticulus** or **intrafascicular** cambium. Along with this cambium, some medullary ray cells also become active forming **interfascicular** cambium. Interfascicular and intrafascicular cambia together form a ring of cambium. Cambial cells give rise to secondary phloem on the outer side and secondary xylem on the inner side. **Phellogen** or cork cambium arises from permanent living cells of hypodermis or outer cortex. It divides to give rise to phellogen (cork) on the outside and phellogen (secondary cortex) on the inner side.

### Secondary growth in dicot root

In dicot roots cambium develops at the time of secondary growth. First of all parenchyma cells interior to the phloem become meristematic, and strips of cambia are formed. Later, these strips divide tangentially again and again and produce secondary tissues. The cells of pericycle lying opposite to each protoxylem divide and form a few layers of cell. Thus, a wavy continuous cambium ring is produced which cuts-off secondary xylem internally at all places and secondary phloem at all places externally. Cork cambium arises as a result of the tangential division of the outer cells of pericycle. The activity of cork cambium is similar to that found in dicot stem so it produces cork cells on the outer side and parenchyma on the inner side.

### ANATOMY OF DICOT ROOT



- It is the outermost layer of root.
- Made up of compactly arranged, thin-walled, parenchymatous cells.
- Distinct cuticle and stomata are absent.
- Some cells of epiblema give rise to thin-walled tubular outgrowths called **root hairs**. These absorb water and mineral salts from the soil.
- Due to presence of root hairs, the epiblema is also called **piliferous layer**.

- Vascular bundles are **radial**, i.e., xylem and phloem are situated on different radii and **exarch**, i.e., protoxylem arises from the centre and metaxylem towards the centre.
- Roots may be **diarch** (2 xylem bundles), **triarch** (3 xylem bundles), **tetrarch** (4 xylem bundles), **pentarch** (5 xylem bundles) or **hexarch** (6 xylem bundles).

- It is usually a single layered structure found below the endodermis and represents the outer boundary of stele.
- All lateral roots originate from pericycle.

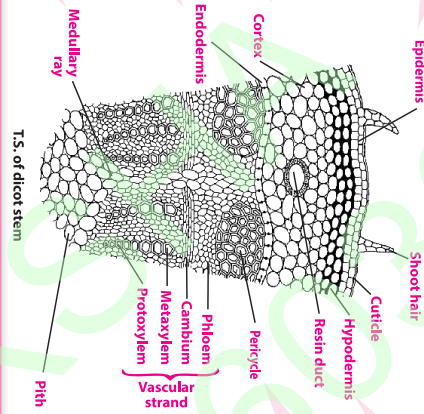
- Hypodermis lies just below epidermis and consists of 3 layers of collenchymatous cells.
- The intercellular spaces are absent and corners of cells are thickened due to deposition of extra cellulose impregnated with pectic substances.
- These cells often possess chloroplasts.

- Pericycle is **heterogenous**, i.e., made up of alternating bands of parenchymatous and sclerenchymatous cells.
- Sclerenchymatous cells are situated in between endodermis and phloem cells of vascular bundles whereas parenchymatous cells are present above the medullary rays.

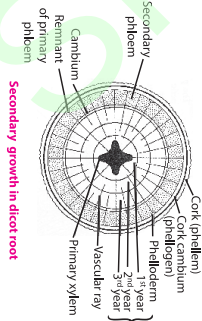
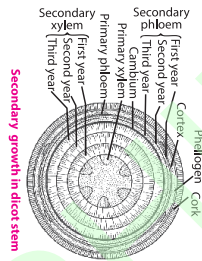
- Vascular bundles are arranged in a ring and are **conjoint** (with both phloem and xylem), **collateral** (phloem and xylem of same radius) and **open** (with a strip of cambium between phloem and xylem). Xylem is situated towards the inner side of each vascular bundle whereas phloem lies towards the pericycle on the outer side of vascular bundle.
- Xylem is **endarch** (protoxylem towards the centre).

- It is extensively developed central portion of ground tissue made up of large thin-walled polygonal parenchymatous cells with intercellular spaces.

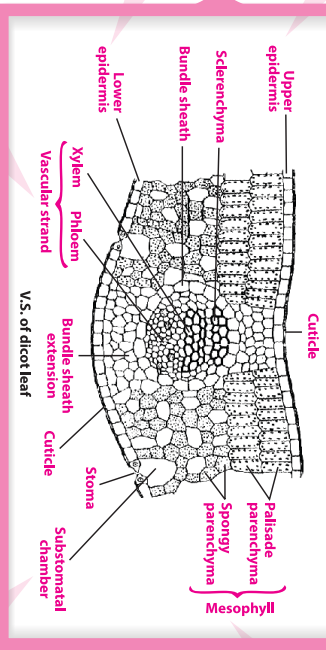
### ANATOMY OF DICOT STEM



### Secondary growth in dicots



### ANATOMY OF DICOT LEAF



- Consists of a single layer of tightly packed rectangular barrel-shaped parenchymatous cells usually devoid of stomata and chloroplasts.
- Outer walls of epidermal cells are cuticularised.

- This is like upper epidermis but with stomata and chloroplasts (in guard cells only).
- Outer walls of cells are cuticularised.

- Vascular bundles are generally found at the boundary between the palisade and spongy regions.
- Vascular bundles are **conjoint** and **collateral**.
- Around each vascular bundle a sheath of parenchymatous cells called **bundle sheath** is present.
- The midrib contains a number of vascular bundles which are embedded in parenchymatous ground tissue.

- The tissue between upper and lower epidermis is called mesophyll.
- It is differentiated into 2 regions:
  - (i) **Palisade parenchyma**: It lies below upper epidermis and consists of 1-3 layers of vertically elongated closely placed columnar or cylindrical cells. These cells have numerous chloroplasts and take part in photosynthesis.
  - (ii) **Spongy parenchyma**: It is found below palisade tissue. The cells are almost spherical and irregularly arranged with intercellular spaces. They also possess chloroplasts but fewer than present in palisade parenchyma and take part in photosynthesis.

# CONCEPT MAP

## ANATOMY OF MONOCOTS

Monocots or monocotyledonous plants are those plants whose seeds contain only one cotyledon. Anatomy of monocots deals with the internal structures of root, stem and leaves.

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- It is the outermost layer having thin walled, uncultured colourless cells and are without intercellular spaces. It is characterised by the presence of epidermal hairs.
- It is also called **rhizodermis** (piferous layer).
- Root hairs take part in absorption of water and mineral salts.

- Below the epidermis, cortex is present.
- It is very wide region of parenchymatous cells that encloses intercellular spaces for the exchange of gases.
- In older roots, the outer one (e.g., *Smilax*) or more layers (e.g., maize) of the cortex become thick walled and suberised and constitute **exodermis**. (It is protective and to some extent absorptive in function).
- The function of cortex in a monocot root is
  - (i) Conduction of water from the root hairs to the inner tissues.
  - (ii) Production of protective exodermis in older roots.
  - (iii) Storage of food.

- The centre of monocot root is occupied by pith.
- It consists of parenchymatous cells (thin or thick walled) which may be rounded or angular.
- Intercellular spaces are present amongst the pith cells.
- The function of pith cells is to store food.

- It is the outer boundary of vascular bundle below the endodermis.
- Pericycle is composed of thin-walled parenchymatous cells in the young root, but in many monocots, it becomes thick-walled in later stages.
- Pericycle may be uniseriate, (e.g., maize) or multiseriate (e.g., *Smilax* and *Salix*).
- The pericycle does not form cambium (in monocots) but produces lateral roots only.

- It is the outermost layer of the stem composed of compactly arranged, transparent, elongated and rectangular barrel-shaped parenchyma cells.
- The outer wall of epidermal cells possesses deposition of silica (provides stiffness) and cutin. The epidermal cells are cutinised which prevent the evaporation of water from the stem.
- Hairs are absent.
- Epidermis possess two dumb-bell shaped guard cells of pores called stomata (for gaseous exchange).

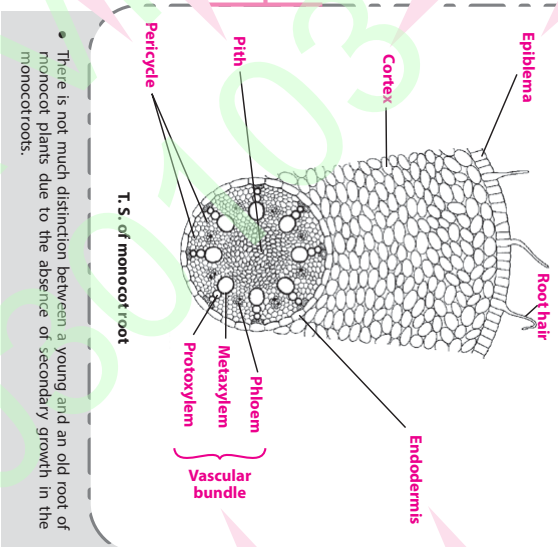
- It possesses two to three layers of sclerenchyma below the epidermis.
- Intercellular spaces are absent in this tissue.
- Provides rigidity and mechanical strength to the plant and act as heat screen

- The entire mass of parenchymatous cells next to hypodermis form ground tissue.
- There is no differentiation between cortex, endodermis, pericycle and pith.
- The cells contain reserve food materials due to the presence of chloroplasts.
- In the peripheral ground tissue, the cells are smaller, polygonal and compactly arranged while towards the centre, they become loosely arranged, rounded and are bigger. Vascular bundles are embedded in this tissue.
- Abundant intercellular spaces are present.

- There is an upper and lower layer of epidermis, covering both the surfaces respectively.
- Both the layers are composed of a single layer of cells and possess stomata hence, called **amphistomatic**.
- Some cells in the upper epidermis become large and are called **bulliform cells** or **motor cells** (helps in rolling of leaves during drought) and occur in group.
- The epidermal cells are cuticularised, therefore, protect from microbial attack and drought, besides regulating transpiration.

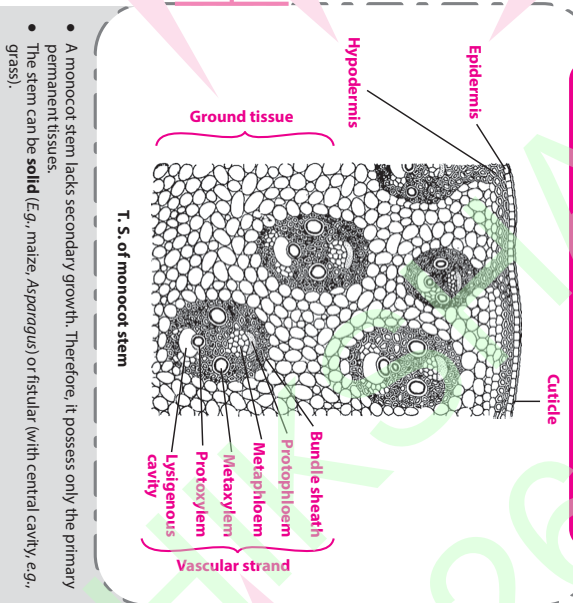
- The mesophyll is not differentiated into **palisade** and **spongy parenchyma**.
- Its cells are chlorenchymatous, large isodiametric, enclose small intercellular spaces and are irregularly arranged.

### ANATOMY OF MONOCOT ROOT



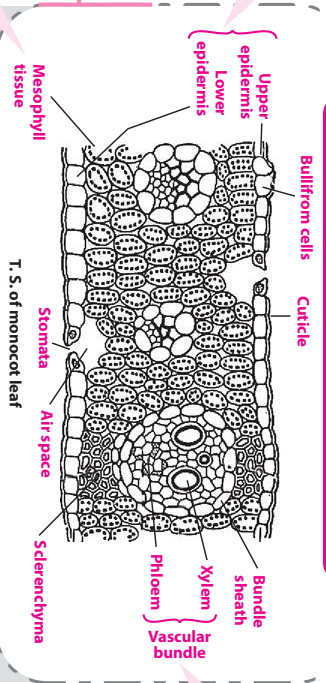
- There is not much distinction between a young and an old root of monocot plants due to the absence of secondary growth in the monocot roots.

### ANATOMY OF MONOCOT STEM



- A monocot stem lacks secondary growth. Therefore, it possesses only the primary permanent tissues.
- The stem can be **solid** (E.g., maize, *Asparagus*) or **fistular** (with central cavity, e.g., grass).

### ANATOMY OF MONOCOT LEAF



- It is also called **isobilateral leaf** and are generally vertical where both the surfaces are equally green.
- The thick cuticle, sclerenchyma patches and motor cells are the **xerophytic** features of the leaf.

- It is an inner boundary of the cortex and is usually single layered.
- It is made up of barrel-shaped cells which do not enclose intercellular spaces.
- Endodermal cells are characterised by the presence of **Casparian strips** (an internal strip of suberin and lignin) and get thickened.
- Some endodermal cells (opposite to protoxylem) remain unthickened and devoid of casparian strips and are called **passage cells** or **transfusion cells**.
- Functions of endodermis are
  - (i) Functions as a mechanical protective layer.
  - (ii) Maintenance of the root pressure.
  - (iii) It regulates the flow of fluid both inwardly as well as outwardly by functioning as biological check post.

- Vascular bundle is in the form of several alternate and radial xylem and phloem bundles.
- The vascular bundles are embedded in a cylinder of sclerenchymatous conjunctive tissue (e.g., maize).
- The vascular bundles are arranged in the form of ring around a central pith.
- The xylem bundles are *exarch* i.e., protoxylem lies towards the outside while the metaxylem faces inwards.
- Xylem of monocot root is *polyarch* i.e., presence of numerous xylem bundles.
- The xylem provides mechanical strength and helps in the conduction of water and mineral salts.
- Phloem bundles alternate with the xylem bundles. These two are separated from each other by means of narrow strip of **conjunctive tissue**.
- The cells of conjunctive tissue store food if parenchymatous and provide mechanical strength on becoming sclerified but they do not take part in formation of cambium.
- The function of phloem is conduction of organic food.

- The vascular strand is in the form of **atactostele** (where a large number of vascular bundles lie scattered throughout the ground tissue).
- Each vascular bundle is surrounded by a sclerenchymatous bundle sheath. This sheath is extensively developed at the upper and lower faces of vascular bundles.
- Vascular bundles are conjoint, collateral but closed and endarch in condition.
- The vascular bundles are almost oval in outline and are made up of xylem and phloem only.
- (a) **Phloem** : It is found above the xylem and made of sieve tubes and companion cells.
- Phloem parenchyma is absent.
- Phloem can be distinguished into an outer protophloem and inner metaphloem.
- The protophloem gets crushed in the later stages.
- (b) **Xylem** : It consists of vessels, tracheids and xylem parenchyma.
- The metaxylem and protoxylem elements are arranged in the form of letter 'Y'.
- The divergent ends of 'Y' are occupied by two big, oval metaxylem vessels with pitted thickenings.
- In between, there are small tracheids.
- The protoxylem is positioned radially towards the centre (lower arm of 'Y'), consisting of two smaller vessels with annular and spiral thickenings.
- In a completely mature vascular bundle a schizogen cavity is formed by disintegration of protoxylem and these cavities are filled with water.

- There are a number of large and small vascular bundles.
- Each bundle is surrounded by a layer of thin-walled cells called bundle sheath.
- The cells of bundle sheath contain starch.
- The large bundles have prominent sclerenchyma patches on both the upper and lower sides extending from vascular bundle to epidermis.
- The larger bundles have a distinct phloem towards the lower epidermis and xylem towards upper epidermis.
- The xylem consists of two pitted metaxylem vessels (oval in shape). In between them, tracheids are also present.
- Protoxylem is represented by a lysigenous cavity, which faces the upper epidermis (**adaxial side**).
- The smaller bundles are surrounded by individual sheaths and contain phloem and xylem.
- Phloem is present towards lower epidermis (**abaxial side**).
- The vascular bundles are conjoint, collateral and closed.



# CONCEPT MAP

## COCKROACH

Cockroaches are brown or black bodied animals included in **Class Insecta** of **Phylum Arthropoda**. They are nocturnal omnivores, that live in damp places and the most common insects usually found in the houses. They are serious pests and vectors of diseases. The common species is *Periplaneta americana*.

### MORPHOLOGY

Body is narrow, elongated bilaterally symmetrical and dorso-ventrally flattened. Body is covered by chitinous brown coloured **exoskeleton** that provides support and rigidity ventrally. They are joined to each other by **articular membrane** (arthrodial membrane) which allows movement of body and appendages.

Adults are 24-35 mm long with their body segmented into three regions – **head, thorax** and **abdomen**.

Head is triangular, formed by fusion of 6 segments and shows great mobility due to flexible **sensory receptors**. Head capsule bears a pair of **compound eyes** and a pair of **antennae** which have **maxillae and mandibles** and a **hypopharynx**. A broad rectangular **clypeus** forms lower part of face.

Thorax consists of 3 parts – **prothorax** (neck), **mesothorax** and **metathorax**. Each thoracic segment bears a pair of walking legs. Each leg consists of a series of segments or **podsomeres**.

There are two pairs of wings arising from meso and metathorax: **forewings** and **hindwings**. All **men** is 10 segmented and contains a pair of **anal cerci**, in both females and males. The differences between male and female abdomen are: Abdomen of females is broader than males and males bear anal styles in 9<sup>th</sup> sternum which are absent in females.

### ANATOMY

#### Circulatory System

- Heart of cockroach is **neurogenic**.
- It is enclosed by dorsal pericardial sinus and consists of elongated muscular tube differentiated into 13 funnel shaped chambers with **ostia** on either side. These allow flow of blood from pericardial sinus into heart only and not reverse.
- Blood vascular system is of open type and vessels open into **haemocoel**.
- Visceral organs located in haemocoel are bathed in blood (**haemolymph**) which consists of colourless plasma and haemocytes. Haemolymph is devoid of respiratory pigment and hence does not assist in respiration but in transfer of food material and metabolic wastes.

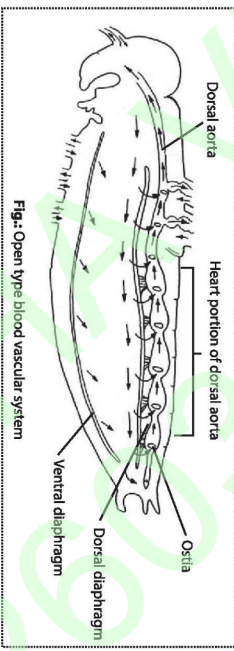


Fig.: Open type blood vascular system

#### Reproductive System

- Cockroaches are **dioecious**, i.e., sexes are separate.
- Male**: It has a pair of testes in 4<sup>th</sup>-6<sup>th</sup> abdominal segments which is 3-lobed and consists of numerous whitish transparent follicles. **Vas deferens** arise from testes and opens into **ejaculatory duct** through **seminal vesicles**.
- Ejaculatory duct opens into **male gonopore**. Sperm is stored in seminal vesicles in the form of bundles called **spermatophores** which are discharged during copulation.
- An accessory **mushroom shaped gland** is located in 6<sup>th</sup>-7<sup>th</sup> abdominal segments.
- External genitalia** are represented by male gonapophyses or phallosomes.
- Female**: Ovaries are located in 2<sup>nd</sup>-6<sup>th</sup> abdominal segments and are formed of a group of ovarian tubules (**ovarioles**) which contain a chain of developing **ova**.
- Oviducts** from each ovary unite into single median oviduct which opens into genital chamber. A pair of **spermathecae** present in 6<sup>th</sup> segment also opens into genital chambers.
- Paired **collateral glands** lie behind ovaries. Their secretion forms **egg-case** or **ootheca**.

#### Fertilisation and development

- Sperms are transferred in form of spermatophores. Fertilised eggs are encased in **ootheca**, which are reddish brown capsules and are dropped or glued to a humid surface. On average, females produce 9-10 oothecae, each containing 14-16 eggs.
- The development is **paurometabolous**, i.e., through nymphal stage.
- As nymphal development proceeds, wing pads arise, body increases in size, colouration becomes darker and ultimately after about 6-7 successive moults

#### Digestive system

- Alimentary canal is divided into 3 regions: foregut, midgut and hindgut.
- Foregut** and **hindgut** are ectodermal and lined by cuticle whereas, midgut is endodermal and lacks cuticle.
- Foregut**: Mouth opens into pharynx and leads to narrow oesophagus which in turn opens into a sac like **crop** used for storing food. This is followed by **gizzard** (proventriculus) which has 6 highly chitinous plates called teeth, used for grinding food particles.
- Midgut**: It is short and narrow. At the junction of foregut and midgut, 6-8 blind tubules called **hepatic caecae** are present which secrete digestive juice. At the junction of midgut and hindgut, thin filamentous 100-150 **Malpighian tubules** are present which remove excretory products from haemolymph.
- Hindgut**: It is differentiated into ileum, colon and rectum. Rectum has 6 **rectal glands**. It opens out through anus. Hindgut is more pervious to water than foregut.

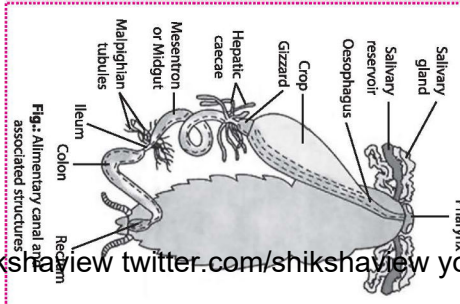


Fig.: Alimentary canal and associated structures

#### Respiratory System

- It consists of network of **tracheae** that opens through **10 pairs of spiracles** present on lateral side of body guarded by bristles or hair to keep out dirt.
- Thin branching tubes (**tracheal tubes**) carry oxygen from air to all the parts. They are subdivided into **tracheoles** where **exchange of gases** takes place by **diffusion**. Very little CO<sub>2</sub> leaves through spiracles; majority of it leaves through cuticular covering of the body.

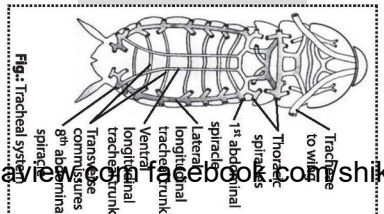


Fig.: Tracheal system

#### Nervous System

- Nervous system comprises of central peripheral and sympathetic or somatogastric system.
- It comprises of fused, segmentally arranged ganglia joined by paired connectives on the ventral side. It bears **9 ganglia**: 3 ganglia in thorax and 6 in the abdomen.
- Brain** is represented by bilobed supra-oesophageal ganglion which supplies nerves to antennae and compound eyes.
- Compound eyes**, located dorsally, consists of **2000 hexagonal ommatidia** which make up **mosaic vision** of cockroach. This type of vision is common during night (**nocturnal vision**), with more sensitivity and less resolution.
- Other sense organs include **antennae**, **maxillary palps**, **labial palps**, **anal cerci**, etc.

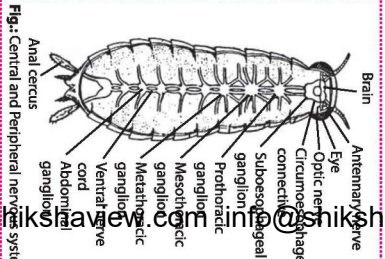
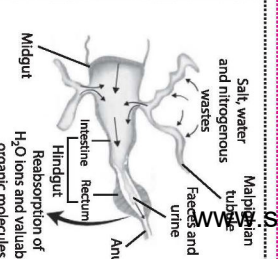


Fig.: Central and peripheral nervous system

#### Excretory System

- Excretion is performed by **Malpighian tubules** which are lined by glandular and ciliated cells. They absorb nitrogenous waste products and convert them into **uric acid** therefore insects are called **uricotelic**. They also reabsorb certain salts and water.
- Fat body**, **nephrocytes** and **uricose glands** also help in excretion.



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# CONCEPT MAP

## EARTHWORM

*Pheretima postuma* or Indian Earthworm belongs to Phylum Annelida of Kingdom Animalia. It is terrestrial, living in burrows made in moist soil. It feeds on dead and decaying organic matter present in soil. Earthworm possesses great power of regeneration.

info@shikshaview.com

### ANATOMY

#### Body wall

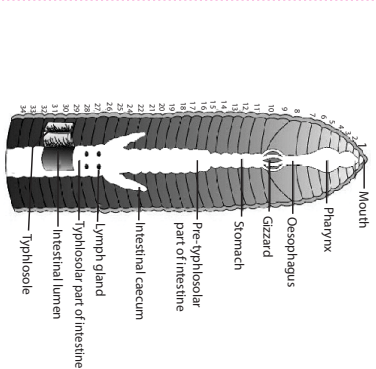
- Body wall consists of **cuticle**, **epidermis**, **muscular layer** and **parietal peritoneum**.
- Cuticle is thin, delicate, non-cellular and chitinous.
- Epidermis lies beneath cuticle and consists of **supporting cells**, **glandular cells**, **basal cells**, **receptor cells** and **setal cells**.
- Muscular layer consists of an outer layer of **circular muscles** and inner layer of **longitudinal muscles**.
- Parietal peritoneum is the innermost layer of body wall and forms outer boundary of coelom. It secretes **coelomic fluid**.

#### Coelom

- It is the space between the body wall and alimentary canal formed by splitting of embryonic mesoderm (**schizocoelom**). It is lined externally by the parietal peritoneum and internally by visceral peritoneum. It is filled with coelomic fluid.
- It is not a continuous cavity but is divided into compartments by transverse partitions called **septa**.
- Coelom consists of **phagocytes**, **circular cells**, **chloragogen cells** (excretory) and **mucocytes**.

#### Digestive system

- Alimentary canal is **complete and straight tube**.
- It is functionally regionated into various parts viz. buccal cavity, pharynx, oesophagus, gizzard, stomach, intestine and anus.
- **Mouth** leads to buccal cavity which extends from 1<sup>st</sup> to 3<sup>rd</sup> segment.
- **Oesophagus** extends from 5<sup>th</sup> to 7<sup>th</sup> segment and is dilated into **gizzard** in 8<sup>th</sup> segment.
- **Stomach** extends from 9<sup>th</sup> to 14<sup>th</sup> segment.
- **Intestine** is distinguished into **pre-typhlosolar** region (15<sup>th</sup>-26<sup>th</sup> segment), **typhlosolar** region (from 27<sup>th</sup> segment upto 25 segments in front of anus) and **post-typhlosolar** region (in last 23 to 25 segments).
- Digestive glands associated with alimentary canal include: **pharyngeal gland** (present in roof of pharynx and secretes saliva), glandular cells of gastric epithelium and intestinal epithelium.

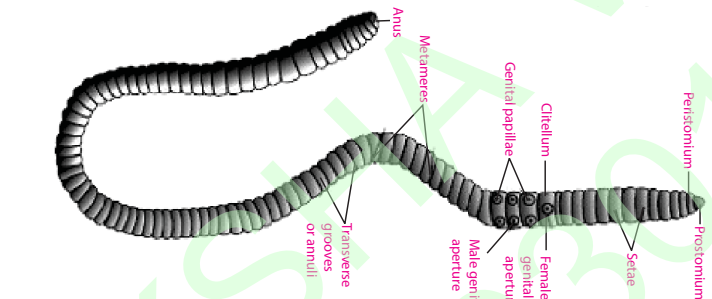


### MORPHOLOGY

- Earthworm is bilaterally symmetrical, body is pointed in front and blunt behind.
- Mature worm measures about **150 mm** in length and **3 to 5 mm** in width.
- Body glistening deep brown or clay coloured (due to presence of **porphyrin** pigment in body wall).
- Dorsal surface carries a dark median line which is actually dorsal blood vessel beneath the skin.
- Body divided into 100-120 similar segments called **metameres** or **somites**.
- External segmentation corresponds with internal segmentation (**metamerism**).
- The first segment of body is termed as **peristomium** which bears **prostomium** anteriorly.
- **Citellum** (circular band of glandular tissue) is found from 14<sup>th</sup> to 16<sup>th</sup> segments. Due to its presence, body is differentiated into **pre-clitellar**, **clitellar** and **post-clitellar** regions.
- Except the first, last and clitellar segments, each segment bears a ring of tiny curved, chitinous structures called **setae** or **chaetae**. Peristomium encloses a crescent shaped mouth and anus is situated in anal segment or **pygidium**.
- Female genital pore is situated on ventral surface of 14<sup>th</sup> segment. A pair of male genital pores lies on the ventral surface of 18<sup>th</sup> segment. Two pairs of **genital papillae** are present on the ventral surface of 17<sup>th</sup> and 19<sup>th</sup> segment (one pair in each segment). Four pairs of **spermathecal pores** are situated ventro-laterally in the intersegmental grooves of segments 5/6, 6/7, 7/8 and 8/9. **Nephridiopores** are scattered irregularly all over the body surface except first two segments.
- **Dorsal pores** located mid-dorsally one in each intersegmental groove, behind 12<sup>th</sup> segment.

#### Reproductive system

- Earthworms are **monoecious** but cannot fertilise their own eggs as they are **protandrous**.
- **Male reproductive system**: It includes **testes**, **testes sacs**, **seminal vesicles**, **vasa deferentia**, **prostate glands** and **accessory glands**.
- Testes are 2 pairs (one in 10<sup>th</sup> and other in 11<sup>th</sup> segment) lying ventro-laterally beneath the alimentary canal, on either side of nerve cord. They produce spermatozoa.
- Each testis sac of 10<sup>th</sup> segment encloses a testis and a spermiductal funnel. Each testis sac of 11<sup>th</sup> segment encloses a testis, a seminal vesicle and a spermiductal funnel.
- Seminal vesicles are two pairs and receive spermatozoa produced by testes through testis sacs. They help in maturation of spermatozoa.
- Vasa deferentia help in conduction of sperms.
- A pair of prostate glands are situated on either side of intestine and extend from 17<sup>th</sup> to 20<sup>th</sup> segment. Their secretion serves as a medium for transfer of sperms.
- Accessory glands are present in 17<sup>th</sup> and 19<sup>th</sup> segments and open to exterior by genital papillae.
- **Female reproductive system**: It consists of **ovaries**, **oviducts** and **spermathecae**.
- A pair of ovaries are attached to the posterior surface of septum present between 12<sup>th</sup> and 13<sup>th</sup> segments. They produce ova. Oviducts are two short tubes each lying immediately behind respective ovary and open to outside by female genital pore.
- Four pairs of spermathecae open to outside through spermathecal pores situated ventro-laterally. They store sperms received from other earthworm during copulation.

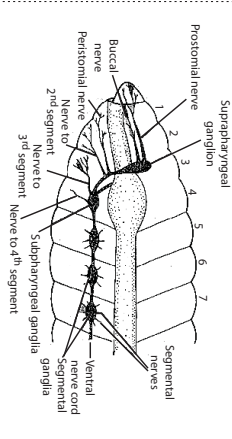
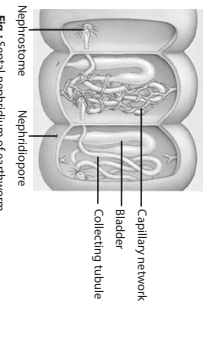
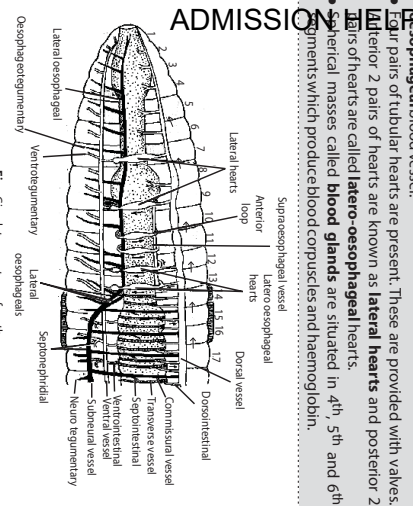


#### Excretory system

- Earthworms are both **ammonotelic** and **ureotelic**.
- Nephridia perform the function of excretion and osmoregulation.
- According to their location nephridia are: **septal**, **pharyngeal** and **integumentary**.
- **Septal nephridia** – Occur in 15<sup>th</sup> segment onward. They are attached to septa and open internally, having **nephrostome**. Vary from 80-100 per segment and are largest in size. Enteronephric and remove metabolic wastes from blood and coelomic fluid.
- **Pharyngeal nephridia** – Occur in segments 4, 5 and 6. Lie on sides of gut in 3 paired groups. Closed internally, without nephrostome. Enteronephric and remove metabolic wastes from blood only.
- **Integumentary nephridia** – Occur in all segments except first two. Attached to body wall. Closed internally without nephrostome. Smallest in size, **ectonephric** and remove wastes from blood only. In addition, **chloragogen cells** also serve the function of excretion.

#### Nervous system

- **Nervous system** is well developed and consists of central, peripheral and autonomic nervous system.
- Central nervous system comprises of **supra-pharyngeal** (cerebral) **ganglia**, a pair of **peripharyngeal connectives**, a pair of **sub-pharyngeal ganglia** and **ventral nerve cord**. Ventral nerve cord has segmental ganglia.
- Nerves arising from the central nervous system and supplying various body parts constitute peripheral nervous system.
- Autonomic nervous system consists of an extensive nerve plexus situated beneath epidermis, within the muscles of body wall and on alimentary canal.
- Various receptors include tactile receptors, buccal receptors (chemo-receptors), photoreceptors.



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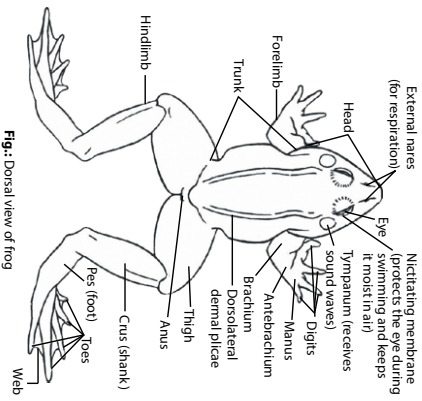
# CONCEPT MAP

## FROG

Frog belongs to the **Class Amphibia of Phylum Chordata**. Frogs are found around ditches, ponds, marshes, lakes and streams. They can live in water as well as on land hence called **amphibians**. The common Indian frog is ***Rana tigrina***.

### Morphology

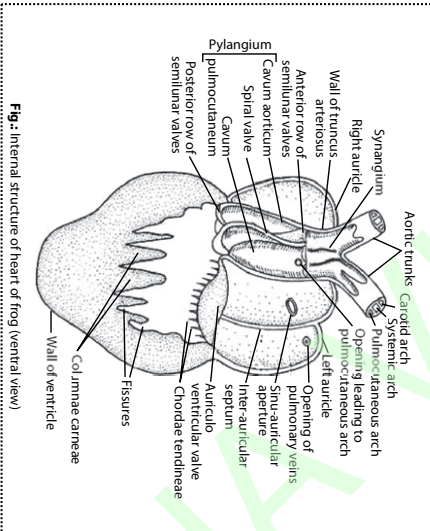
- Body of a frog is pointed anteriorly and rounded posteriorly. It is slightly flattened dorsoventrally, streamlined to swim through water and divisible into head and trunk without neck and tail.
- Skin of frog is thin, moist, smooth, slimy and green coloured with black or brown spots dorsally and lighter pale yellow ventrally. There are no scales or any other hard exoskeleton parts.
- Skin of back has dorsolateral folds or thickenings called **dermal plicae**.
- Head is roughly triangular with a short **blunt** anterior **snout** terminating in a large transverse **mouh**. It bears external nares or nostrils, eyes, brow spot and ear drums on the upper side.
- Frogs have two large and protruding eyes, having an almost immovable upper eyelid and a thin semi-transparent and freely movable lower eyelid. From lower eyelid arises **nictitating membrane** that protects eyes during swimming.
- **Vocal sacs** act as resonators to intensify sound of croaking during breeding season.
- Trunk consists of **thorax**, **abdomen** and a pair of forelimb and hindlimb.
- Frog shows **sexual dimorphism** as male frog possesses developed **vocal sacs** and **nuptial pad** during breeding season and their body is somewhat slender and darker in colour than female frog.



### Anatomy

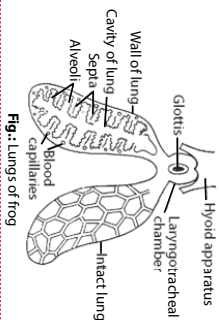
#### Circulatory System

- Circulatory system of frog is closed and includes **heart**, **arterial system**, **venous system**, **blood** and **lymphatic system**.
- Heart is **three chambered** made up of two anterior **atria** or **auricles** and a single posterior **ventricle**. Two additional chambers are **sinus venosus** and **truncus arteriosus**.
- The two auricles, right (larger) and left, are completely separated from each other by **inter-auricular septum**. Both auricles open into single ventricle by a common large **auriculo-ventricular aperture** guarded by two pairs of **auriculo-ventricular valves**.
- The inner surface of ventricle has irregular ridges called **columnae carneae** or **tabeculae**, with depressions called **fissures**.



#### Digestive System

- The digestive system mainly consists of **alimentary canal** and its associated **glands**.
- Mouth leads into a buccopharyngeal cavity which opens into oesophagus through gullet.
- **Stomach** is situated behind the oesophagus and divisible into cardiac stomach and pyloric stomach.
- The small intestine is divisible into an anterior **duodenum** and a posterior **ileum**. Digestion of food and absorption of digested food occur in the small intestine.
- Ileum leads to **rectum** or large intestine. The rectum opens into the **cloaca** through the **anus**.
- **Digestive glands** of frog include liver, pancreas, gastric glands and intestinal glands.



#### Nervous System

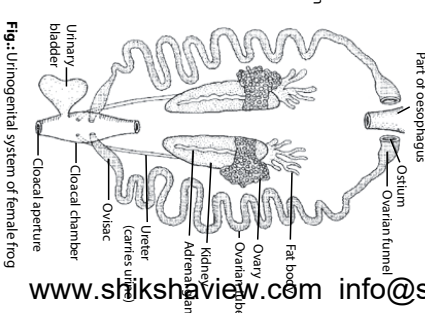
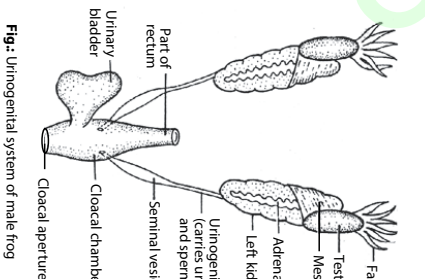
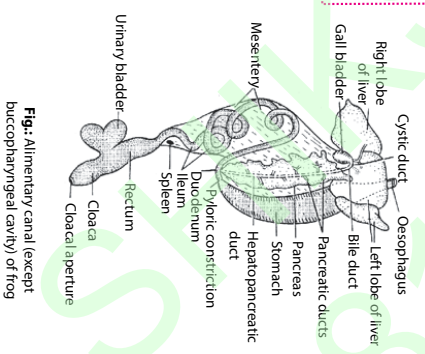
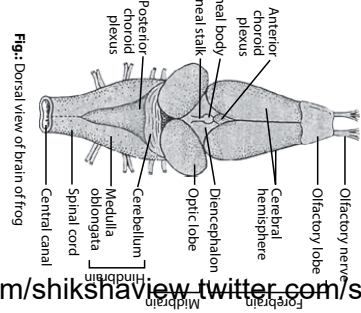
- It is highly developed and comprises of:
  - **Central nervous system (CNS)** includes brain and spinal cord. **Brain** is covered by two meninges; duramater (outer) and pia-arachnoid (inner). Brain is divisible into three parts: Forebrain, midbrain and hindbrain. **Spinal cord** is located in the vertebral column and joins the medulla oblongata via **foramen magnum** of the cranium (brain case).
  - **Peripheral nervous system (PNS)** includes 10 pairs of **cranial nerves** and 9 pairs of **spinal nerves**. Rarely 10th (paired or unpaired) spinal nerves are found.
  - **Autonomic nervous system** is made up of sympathetic and parasympathetic nerves which controls and coordinates the involuntary activities of the visceral organs.
  - Five types of sense organs are **skin** (tangerceptor), **taste buds** (gustatoreceptor), **nasal chambers** (olfatoreceptor), **eyes** (photoreceptor) and **ears** (statoreceptor).

#### Urinogenital System

- In frogs, the excretory and reproductive systems are closely associated, hence they are together called **urinogenital system**.
- **Excretory system** comprises of kidneys, ureters in females, urinogenital ducts in males, cloaca and urinary bladder. Kidneys are the chief excretory organs which are made up of large number of **uriniferous tubules** or nephrons.
- From the kidneys, arise **ureter** in females and **urinogenital duct** in males.
- Cloaca receives faecal matter, genital products and urine (from kidney). Ventrally it is attached to urinary bladder.
- In **males**, near each kidney there is a cylindrical **testis** from which several thin **vasa efferentia**, connecting the testes to kidneys on each side. The vasa efferentia run transversely through mesorchium and open into the **Bidder's canal** which in turn opens into the **ureter**. Histologically, each testis is a compact mass of seminiferous tubules, the epithelial lining of which produces **sperms**. The sperms when mature are dropped into the lumen to pass into the ureter through **vasa efferentia** and Bidder's canal.
- **Females** have two ovaries where ova are produced by ovarian follicles. On each side of an ovary is an oviduct which starts posteriorly and forms uterus, which opens into the cloaca. During breeding season ova are released into the coelom and then they reach the ovarian funnels from where they pass to the ovisacs, cloaca and then outside.
- Egg of frog is **telolecithal**.

#### Respiratory System

- Adult frog respire by three different types of respiration:
  - **Cutaneous respiration**: It occurs through the highly vascular skin of in water or land.
  - **Buccopharyngeal respiration**: It occurs on land or during partial immersion in water *via* mucous epithelial lining of buccopharyngeal cavity.
  - **Pulmonary respiration**: It is less frequent and takes place through lungs in adult frog when the frog is outside the water.





## NITROGEN NUTRITION IN PLANTS

Nitrogen is one of the most important nutrient required for proper growth of the plants as it is present in the compounds like proteins, amino acids, alkaloids, vitamins, enzymes, chlorophyll and nucleic acids. Its deficiency causes chlorosis and stops cell division and elongation thus retards growth.

### Atmospheric nitrogen

- It is available in atmosphere in high amount (78%) in the form of (dinitrogen gas,  $N_2$ ).
- It is the most critical element for plant growth.

### Nitrogen fixation

- Plants directly cannot absorb  $N_2$  from air because its acquisition from atmosphere requires breaking of an exceptionally stable triple covalent bond between two nitrogen atoms ( $N \equiv N$ ).
- Thus, it must be **'fixed'** into utilizable forms, i.e., ammonia ( $NH_3$ ) or nitrate ( $NO_3^-$ ).

### Biological nitrogen fixation

- It is the major source of nitrogen fixation and is done by prokaryotes (bacteria and cyanobacteria), either free living (asymbiotic) or symbiotic.
- Asymbiotic nitrogen fixation** is done by free living bacteria like *Azotobacter*, *Klebsiella*, etc. and cyanobacteria like *Anabaena*, *Nostoc* and *Trichodesmium*.
- Symbiotic nitrogen fixation** is done by symbiotic prokaryotes inside the body of their plant hosts. *Nostoc*, *Anabaena* and *Anthoceros* etc. are symbiotic nitrogen fixing cyanobacteria, whereas *Rhizobium* and *Frankia* etc. are symbiotic nitrogen fixing bacteria.
- Rhizobium* (in legume) and *Frankia* (in non legume plants) can fix nitrogen in anaerobic conditions by nodule formation.
- Nodules** require cooperation of **nod**, **nif** and **fix** gene clusters of bacteria for their formation.
- Roots of the legume secrete chemical attractants (**flavonoids and betaines**). Bacteria collect over the root hairs and release nod factors that cause curling of root hair around the bacteria.
- An infection thread enclosing bacteria is constructed by the root cells in response to the infection. When it reaches deep in the cortex, it bursts and the rhizobia are engulfed into membrane enclosed **symbiosomes** within the cytoplasm.
- Synthesis of **auxin** from cortical cells and cytokinin from associating bacteria stimulate nodule formation. Bacteria form irregular polyhedral structures, i.e., **bacteroids** inside nodules.
- The legume host supplies nitrogenase, the nitrogen fixing enzyme which is strongly inhibited by oxygen. **Leghaemoglobin** (Lb) an oxygen scavenger is present in nodules which protects nitrogenase.

### Mechanism of biological nitrogen fixation

- It requires:
  - $FMN$ ,  $N_2$ ,  $NADPH_2$  etc. as reducing power
  - Nitrogenase and hydrogenase enzymes
  - ATP as source of energy
  - Compound for trapping released ammonia
  - Leghaemoglobin for protection of nitrogenase from  $O_2$
  - Presence of non haeme iron protein ferredoxin as electron carrier
  - Presence of cofactors  $CoA$ ,  $TPP$ ,  $PI$ ,  $Mg^{2+}$ ,  $Co$  and  $Mo$  etc
- The overall reaction is shown as:
 
$$N_2 + 8e^- + 8H^+ + 16ATP \longrightarrow 2NH_3 + 2H^+ + 16ADP + 16P_i$$

(Ammonia)

### Assimilation of fixed nitrogen

- Plants get fixed nitrogen from the two sources- symbiotic and asymbiotic.
- In case of symbionts, the **ammonia** is taken up by host immediately and assimilated, while in case of free living nitrogen fixers the fixed nitrogen is released by their death and decay in the form of **nitrates** through **ammonification and nitrification**.

### Assimilation of ammonia

- Ammonia is **toxic** to plants and thus is readily converted to amino acids.
- The primary pathway for this conversion involves sequential actions of glutamine synthetase and glutamate synthetase, i.e., **catalytic amidation**.
 
$$\text{Glutamate} + NH_4^+ + ATP \xrightarrow{\text{glutamine synthetase}} \text{Glutamine} + ADP + P_i$$

$$\text{Glutamine} + \alpha\text{-ketoglutaric acid} + NAD(P) \xrightarrow{\text{glutamate synthetase}} 2 \text{ Glutamate} + NAD(P)$$
- In an alternative pathway, glutamate dehydrogenase catalyses a reversible reaction that synthesises glutamate, i.e., **reductive amination**.
 
$$\alpha\text{-ketoglutaric acid} + NH_4^+ + NAD(P)H \xrightarrow{\text{glutamate dehydrogenase}} \text{Glutamate} + H_2O + NAD(P)$$
- Once assimilated into glutamate, nitrogen is incorporated into other amino acids **via transamination** reactions catalyzed by **amino transferases**. E.g.,
 
$$\text{Glutamic acid} + \text{Oxaloacetic acid} \xrightarrow{\text{glutamate aspartate aminotransferase}} \alpha\text{-ketoglutaric acid} + \text{Aspartic acid}$$
- Amides** (principally asparagine or glutamine) are generally used as a medium of translocation and storage of nitrogen because of their stability and high nitrogen to carbon ratio. In some legumes e.g., soybean, **ureides** (allantoin, allantonic acid and citrulline) are used for the purpose.
- The proteins through food chain get converted into animal proteins. By death and decay of both plant and animal organic matter (ammonification and nitrification) the nitrogen cycle continues in the environment.

### Abiological nitrogen fixation

- Abiological fixation occurs naturally or by industrial processes.
- Natural fixation** occurs by electric discharge, ozonisation and combustion.
- Different types of oxides of nitrogen are formed, which ultimately come to the soil by the means of mixing with rain water.
 
$$N_2 + O_2 \xrightarrow{\text{Electric discharge}} 2NO_2 \text{ (Nitrogen oxide)}$$

$$2NO + 2IOI \xrightarrow{\text{Ozonisation}} 2NO_2$$

$$2NO + 3IOI \xrightarrow{\text{Ozonisation}} N_2O_5$$

$$H_2O + 2NO \rightarrow HNO + HNO_2$$

$$H_2O + 2NO_2 \rightarrow HNO_2 + HNO_3$$

$$H_2O + N_2O_5 \rightarrow 2HNO_3$$
- Industrial fixation** involves production of ammonia by directly mixing nitrogen with hydrogen (from water) under high pressure and temperature.
- Various fertilisers are produced industrially to provide nitrogen to the plants.

### Assimilation of nitrate

- Nitrate is the most important source of nitrogen to the non legume plants. It is not used by plants as such but is stepwise reduced to the level of ammonia before being incorporated into organic compounds.
- Firstly **nitrate reductase**, an inducible enzyme (having molybdoflavoprotein) favours the formation of reduced nitrite in the presence of reduced coenzyme.
 
$$NO_3^- + MAD(P)H + H^+ + 2e^- \xrightarrow{\text{Nitrate reductase}} NO_2^- + H_2O + MAD(P)$$
- Then an enzyme **nitrite reductase** (metalloflavoprotein containing copper and iron) favours the formation of nitrite under reduced condition.
 
$$2NO_2^- + 7MAD(P)H + 7H^+ \xrightarrow{\text{Nitrite reductase}} 2NH_3 + 4H_2O + 7MAD(P)^+$$
- Formed ammonia is not liberated. It combines with acid to form amino acids and is utilised in making various types of nitrogenous compounds (*As discussed under Assimilation of ammonia*).

### Nitrification

- Ammonia thus produced gets readily converted to nitrates by various microorganisms.
- It takes place in two steps. First ammonia is oxidised to nitrites and then nitrites are oxidised to nitrates by different microorganisms.
 
$$2NH_3 + 3O_2 \xrightarrow{\text{Nitrosococcus, Nitrosomonas}} 2NO_2^- + 2H^+ + 2H_2O + \text{Energy}$$

$$2NO_2^- + O_2 \xrightarrow{\text{Nitrobacter, Nitrospira}} 2NO_3^- + \text{Energy}$$
- Bacteria performing nitrification are **chemoautotrophs** which utilise the energy released during the reaction for the synthesis of organic substances.

### Ammonification

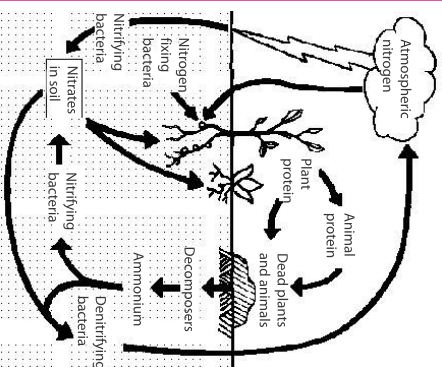
- Decay causing organisms e.g., *Bacillus ramosus*, *B. vulgaris*, and actinomycetes convert dead bodies of microorganisms as well as other soil organic matter (excreta and dead body of other animals) into organic acid and ammonia.
 
$$\text{Protein} \xrightarrow{H_2O} R-NH_2 \xrightarrow{H_2O} ROH + NH_3$$

(Amino acid) (Organic acid) (Ammonia)

### Denitrification

- In anaerobic condition, some microbes reduce nitrates to gaseous compounds of nitrogen which release from the soil.
 
$$2NO_3^- \rightarrow 2NO_2^- \rightarrow 2NO \rightarrow N_2O \rightarrow N_2$$
- Denitrification is mainly carried out by *Pseudomonas denitrificans*, *Thiobacillus denitrificans* and *Micrococcus denitrificans*.
- It depletes the soil of an important nutrient and causes acidification and leads to the solubilisation of harmful metals. Denitrification has a role in nitrogen cycle as it supplies nitrogen to its reservoir pool, the atmosphere.

### NITROGEN CYCLE





# CONCEPT MAP

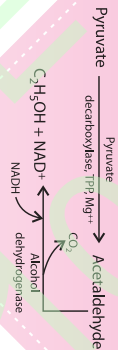
## CELLULAR RESPIRATION

- Cellular respiration is the oxidative breakdown of food materials within the cell which releases energy and biochemical intermediates.
- The energy is used in the synthesis of ATP and the biochemical intermediates are used for synthesis of organic compound that take part in growth, repair and metabolism.

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### ANAEROBIC RESPIRATION

- It is a type of respiration in which oxygen is not used as an oxidant and the organic food is broken down incompletely to liberate energy by breaking of bonds between various types of atom.
- The common products of anaerobic respiration are  $\text{CO}_2$ , **ethyl alcohol** and **lactic acid**.
- Under anaerobic conditions, in lactic acid bacteria, fungi, some muscles, pyruvate is directly reduced by NADH to lactic acid, in the presence of the enzyme lactate dehydrogenase.
- Pyruvic acid + NADH  $\xrightarrow{\text{Lactate dehydrogenase}}$  Lactic acid + ATP
- In yeast, pyruvate is broken down to ethyl alcohol and  $\text{CO}_2$  by sets of reactions in the presence of enzymes pyruvate decarboxylase and alcohol dehydrogenase.



### AEROBIC RESPIRATION

- The oxidative breakdown of respiratory substrates with the help of atmospheric oxygen is known as **aerobic respiration**.
- It involves complete breakdown of substrates into  $\text{CO}_2$  and water and release of energy.
- $\text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2 \xrightarrow{\text{Enzymes}} 6\text{CO}_2 + 6\text{H}_2\text{O} + 686 \text{ Kcal}$
- The common pathway of aerobic respiration consists of three steps: glycolysis, Krebs cycle and terminal oxidation.

### Terminal Oxidation

- It occurs towards the end of catabolic process.
- Involves passage of both electrons and protons of reduced co-enzymes to oxygen and produces water.
- Consists of two processes – **electron transport chain** and **oxidative phosphorylation**.
- An electron transport chain or system is a series of coenzymes and cytochromes that take part in passage of electrons from a chemical to its ultimate acceptor.
- In electron transport chain, the reducing equivalents from various metabolic intermediates are transferred to coenzymes  $\text{NAD}^+$  and FAD to produce NADH and  $\text{FADH}_2$ , respectively.
- Oxidative phosphorylation is the synthesis of energy rich ATP molecules with the help of energy liberated during oxidation of reduced co-enzymes (NADH,  $\text{FADH}_2$ ) produced in respiration. The enzyme required for this synthesis is called **ATP synthase**.

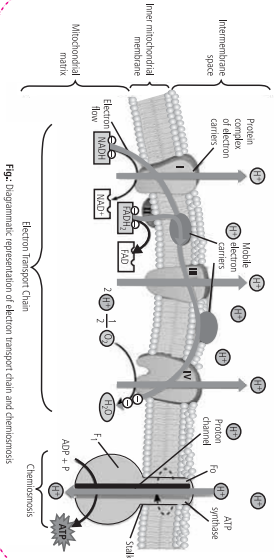


Fig. Diagrammatic representation of electron transport chain and chemiosmosis.

ATP BALANCE SHEET			
Stage	ATP by substrate phosphorylation	Formation of NADH/ $\text{FADH}_2$	ATP through ETS in mitochondria
Glycolysis in cytoplasm	2	2 NADH on oxidation through ETS form 3 or 2 ATP depending upon shuttle system.	$2 \times 3 = 6$
Formation of acetyl CoA in matrix of mitochondria	-	2 NADH	$2 \times 3 = 6$
Krebs cycle	2	2 $\text{FADH}_2$ 6 NADH	$2 \times 2 = 4$ $6 \times 3 = 18$
Total net gain of ATP = 36 or 38 depending upon type of aerobic respiration.			34 (or 32)

### Glycolysis

- It is the process of partial oxidation of glucose or similar hexose sugar into two molecules of pyruvic acid through a series of ten enzyme mediated reactions, releasing energy as ATP and reducing power as NADH $_2$ .
- It occurs in cytosol or cytoplasm.
- It is common to both aerobic and anaerobic respiration.
- It is regulated by three enzymes, catalysing non-equilibrium reactions: **hexokinase, phosphofructokinase and pyruvate kinase**.

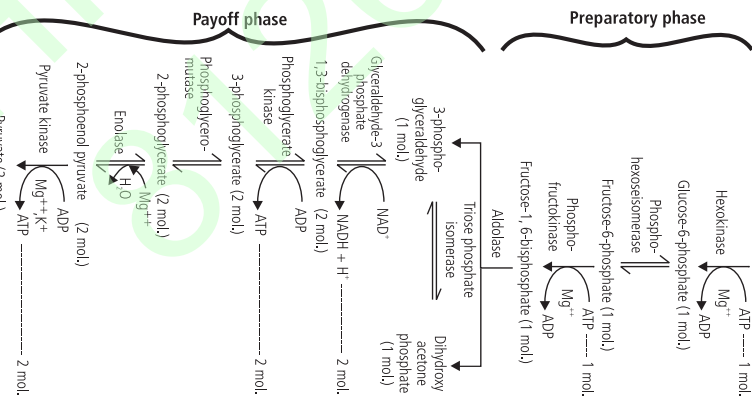
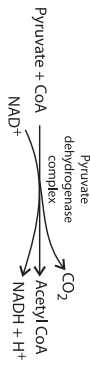


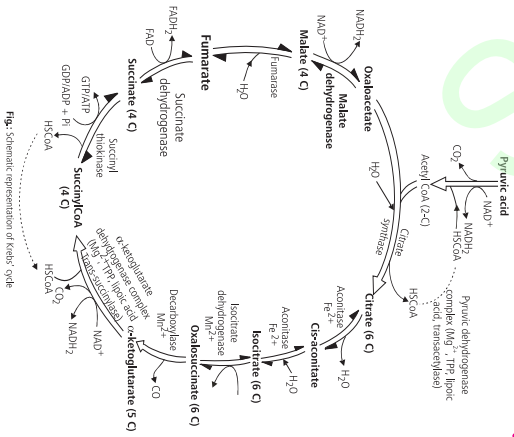
Fig.: Glycolysis or EMP pathway

### Krebs Cycle

- Pyruvate formed in glycolysis undergoes oxidation to get converted to **acetyl CoA**.
- It is catalysed by multi-enzyme **pyruvate dehydrogenase complex (PDH)**.
- In this reaction (highly exergonic and irreversible in vivo) carboxyl group of pyruvate is lost as  $\text{CO}_2$  while the remaining two carbons form acetyl CoA.



- Pyruvate oxidation is the gateway step or **link reaction** as acetyl CoA acts as a connecting link between glycolysis and Krebs cycle.
- Krebs cycle is also known as Citric acid cycle.
- It is a nearly universal central catabolic pathway in which compounds derived from the breakdown of carbohydrates, fats and proteins are oxidised to  $\text{CO}_2$ .
- It occurs in mitochondrial matrix.
- The Citric acid cycle is **amphibolic** since in addition to oxidation it is important in provision of carbon skeletons, for gluconeogenesis, fatty acid synthesis and interconversion of amino acids.



# CONCEPT MAP

## PHYTOHORMONES

Phytohormones refer to a chemical substances other than nutrient molecules produced naturally in plants. They may be translocated to another region and are capable of regulating one or more physiological reactions, when present in low concentrations.

Plant growth regulators or hormones are broadly classified into two categories.

### PHYTOHORMONES

#### Auxin

**Nature:** Weakly acidic growth hormone having an unsaturated ring structure. Auxins refer to natural (IAA, PAA, IAN) and synthetic (Indole-3-butyric acid, NAA, 2, 4-D, 2, 4, 5-T) compounds having similar structure and properties.

**Discovery:** Darwin (1880) was first to find sensation of unilateral illumination in the coleoptile tip of canary grass. Later Kogl and Smith (1931) isolated three chemicals from human urine which they named as auxin a, auxin b and hetero auxin. IAA is the universal natural auxin.

**Location:** It is found in shoot apices, leaf primordia and developing seeds and is synthesised from amino acid **tryptophan**, a precursor of IAA or auxins.

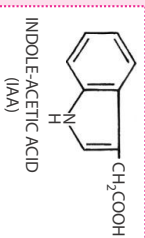
**Bioassay:** Avena curvature test and root growth inhibition test are done for examining auxin effect.

#### Physiological functions:

- Promotes cell enlargement and division and initiates root formation on stem cuttings.
- Cambial activity and xylem differentiation is also regulated by auxins.
- Shows apical dominance i.e., inhibits the growth of lateral buds.
- Prevents or delays abscission as well as induces synthesis of ethylene.
- Produces tropic plant responses like phototropism and geotropism.
- Shows feminising effect on some plants.

#### Commercial uses:

- In tissue and organ culture to form callus and initiate rooting.
- To produce parthenocarpic fruits.
- Auxins like 2, 4-D and 2, 4, 5-T acts as weedicides by being selectively harmful to broad leaved dicot weeds.
- Induces flowering in jilchi and pineapple.
- NAA increases the number of dwarf shoots and fruits on them.
- Prevents pre-harvest fruit drop of orange and apple (by low concentration of 2, 4-D) and tomato (by NAA)



#### Gibberellin

**Nature:** Weakly acid growth hormone having gibberane ring structure.

**Discovery:** Horii and Kurosawa discovered the active substance from filtrate of fungus, *Gibberella fujikuroi* (causing bakana disease in rice plants) and named it gibberellin. GA<sub>3</sub> was first gibberellin to be isolated in its pure form and remains the most extensively studied.

**Location:** The major sites of gibberellin production in plants are embryos, roots and young leaves near the shoot tip. **Mevalonic acid** (derived from acetyl Co-A) acts as precursor for synthesis of gibberellins. It is transported through simple diffusion as well as via conducting channels.

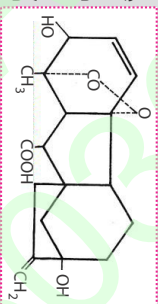
**Bioassay:** Bailey endosperm test and germination of dwarf pea seeds are used as bioassays.

#### Physiological functions:

- Stimulates stem elongation and leaf expansion.
- Overcome natural dormancy of buds, tubers, seeds etc.
- Induces elongation of reduced stem or bolting in rosette plants e.g., henbane, cabbage.
- Promotes seed germination by inducing production of hydrolytic enzymes for solubilising reserve food.
- Promotes flowering in long day plants during non-inductive period.
- Controls fruit growth and development as well as induces parthenocarp.
- Promotes formation of male flowers on female plants e.g., *Cannabis*. They can also replace female flowers with male ones on monoecious plants of cucurbits.

#### Commercial uses:

- Exogenous application of GA<sub>4</sub> and GA<sub>7</sub> mixture to increase the number and size of fruits e.g., apple, grapes, tomato.
- Production of seedless pomaceous fruits by parthenocarp.
- GA<sub>7</sub> delays senescence of fruits and delays its ripening thus, extending its shelf life and storage period.
- Induces off-season flowering in many long day plants as well as those requiring vernalisation.
- Application of gibberellins increases length of stem and yield of sugarcane.
- Promotes early maturity resulting in seed production in juvenile conifers.



#### Cytokinin

**Nature:** These are basic hormones, being derivatives of either **aminopurine** or **phenyl urea** that promote cytokinesis. **Discovery:** The first cytokinin was discovered from autoclaved herring sperm DNA which stimulated cell division in tobacco pith cells. It is called **Kinetin** and does not occur naturally in plants.

The first natural cytokinin was obtained from unripe maize grains, called **zeatin** (6-hydroxy 3-methyl trans-2-butenyl amino purine).

It is found in coconut milk.

**Location:** It is mainly found in roots, however it is also synthesised in endosperm regions of seeds, growing embryos, young fruits and developing shoot buds.

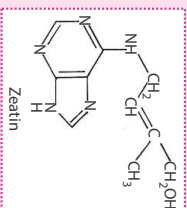
**Bioassay:** Tobacco pith culture, retardation of leaf senescence and excised radish cotyledon expansion are used as bioassays for cytokinins.

#### Physiological functions:

- Promotes cell division.
- Essential for morphogenesis and differentiation of tissues and organs.
- Delays senescence by mobilisation of nutrients.
- Overcome apical dominance caused by auxins and promote lateral bud development.
- Induces accumulation of salts inside cells and help in phloem transport.
- Promotes femaleness in flowers.

#### Commercial uses:

- Forms essential component of tissue culture as required for morphogenesis.
- Application of cytokinin increases the shelf life of flowers and vegetables, keeping them fresh for longer periods.
- Helps in developing resistance to pathogens and extremes of temperature, in plants.
- Delays senescence of intact plant parts.



#### Ethylene

**Nature:** It is the only gaseous phytohormone which stimulates transverse or isodiametric growth but retards the longitudinal one.

**Discovery:** R. Gene (1934) found that substance causing ripening was ethylene. But it was recognised as a plant hormone by Crocker *et al.* (1935).

**Location:** It is found in almost all parts of plants in minimal amount but maximum production occurs during ripening of fruits and in tissues undergoing senescence. It is synthesised from amino acid **methionine** in plants.

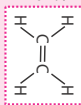
**Bioassay:** The triple response of etiolated pea plant and gas chromatographic assay are used as bioassays.

#### Physiological functions:

- Promotes apical dominance and prolongs dormancy of lateral buds but breaks the dormancy of buds, seeds and storage organs.
- Induces abscission and senescence of various parts i.e., leaves, flowers and fruits etc.
- Induces epinasty, a phenomenon which decreases the sensitivity to gravity.
- Helps in root initiation, growth of lateral roots and root hairs.
- Stimulates flowering in pineapple and other related plants and helps in synchronising fruit set.
- Induces ripening of fleshy climacteric fruits and dehiscence of dry fruits.

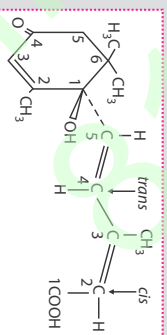
#### Commercial uses:

- Ethylene lamps are used for ripening of fleshy fruits e.g., banana, mango, apple, tomato.
- Ethylene is used to induce feminising effect e.g., number of female flowers and thus fruits in cucumber.
- Ethylene also permits thinning of excess flowers and young fruits so as to allow better growth of remaining fruits.



#### Absciscic Acid

**Nature:** It is a mildly acidic growth hormone which acts as a general growth inhibitor. It is also called as **stress hormone** since its production is stimulated under conditions of drought, water logging and adverse environmental conditions.



**Discovery:** The hormone was first isolated by Addicott *et al.* (1963) from cotton bolls.

**Location:** It is found in many parts of the plant but is more abundant in chloroplast of green cells. It is synthesised from **mevalonic acid** or **xanthophyll**.

**Bioassay:** Rice seedling growth inhibition test and inhibition of  $\alpha$ -amylase synthesis in barley endosperm are used as bioassays.

#### Physiological functions:

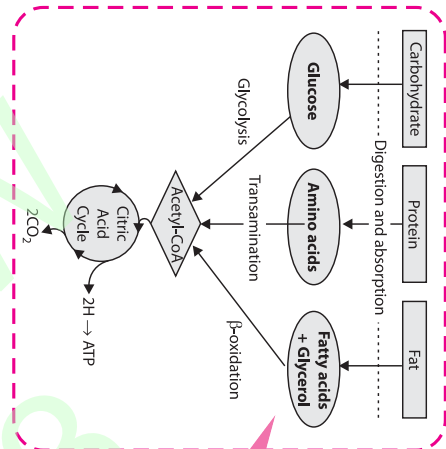
- Induces dormancy of buds, seeds and underground stems, hence also called as **dormin**.
- Promotes abscission of flowers and fruits.
- Induces senescence of leaves by promoting degradation of chlorophyll and proteins.
- Stops cambium activity (in vascular cambium) towards the approach of winter.
- Inhibits seed germination by inhibiting gibberellin mediated amylase formation.
- It is antagonist to gibberellin and counteracts the effect of growth promoting hormones-auxins and cytokinins.

#### Commercial uses:

- Used as antitranspirant (as application of even minute quantities of ABA on leaves causes partial closure of stomata), thus, preventing transpiration as well as reducing photosynthesis.
- Induces flowering in some short day plants, even under unfavourable photoperiods.
- External application on stem cuttings initiate rooting.
- Induces parthenocarpic development in rose.
- Used in prolonging dormancy of buds, storage organs and seeds.

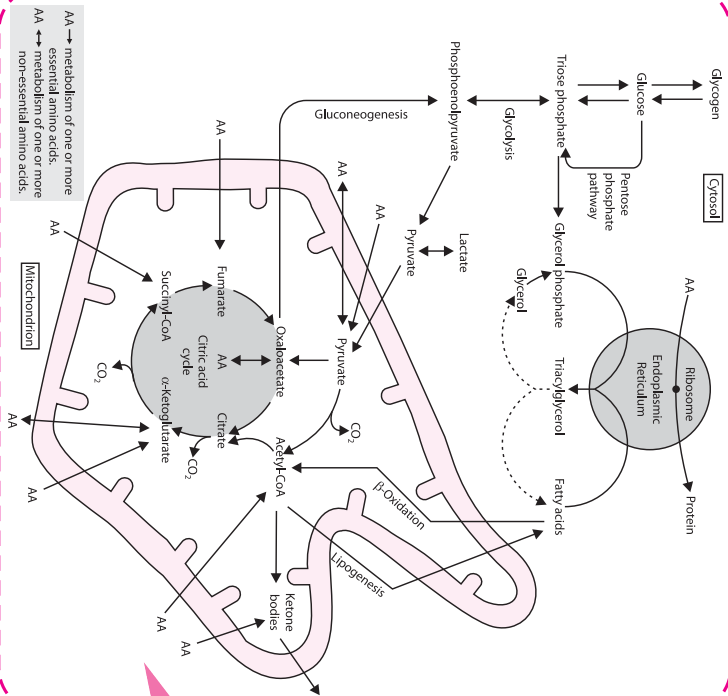






### Integration of metabolic pathways at tissue and organ level

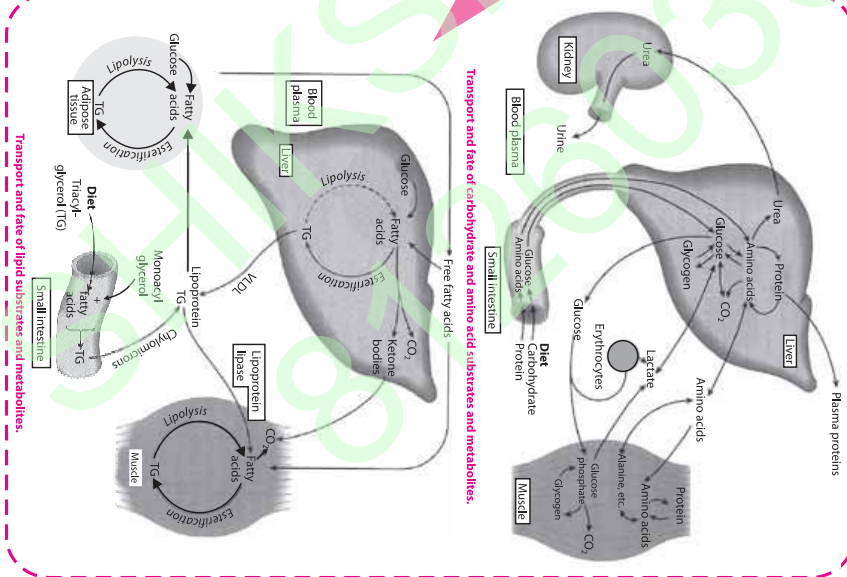
- At tissue and organ level, the nature of substrates entering and metabolites leaving tissues and organs is defined.
- Amino acids and glucose resulting from digestion of proteins and carbohydrates, respectively are absorbed via hepatic portal vein.
- Excess glucose is converted to glycogen (**glycogenesis**) or to fatty acids (**lipogenesis**) in liver.
- In between the meals, glycogen is broken down to glucose (**glycogenolysis**) and non-carbohydrate metabolites (lactate, glycerol, etc.) are converted to glucose (**gluconeogenesis**) in liver.
- Liver synthesises major plasma proteins and deaminates amino acids that are in excess, forming urea which is transported to kidney and excreted.
- Skeletal muscles utilise glucose both aerobically forming  $\text{CO}_2$  and anaerobically forming lactate.
- Lipids in the diet are hydrolysed to **monoglycerols** and fatty acids in the gut, packaged with protein and secreted into the lymphatic system and thence into the bloodstream as **chylomicrons**. It is first metabolised by tissues that have **lipoprotein lipase**, which hydrolyses the triacylglycerol, releasing fatty acids.
- The other major source of long-chain fatty acids is synthesis from carbohydrate (**lipogenesis**) in adipose tissue and the liver.
- Adipose tissue triacylglycerol is hydrolysed (**lipolysis**) and the fatty acids are transported, bound to serum albumin, they are taken up by most tissues (but not brain or erythrocytes) and either esterified to triacylglycerols for storage or oxidised as a fuel.
- In the liver, triacylglycerol arising from lipogenesis, free fatty acids and chylomicron remnants are secreted into the circulation in **very low density lipoprotein (VLDL)**. This triacylglycerol undergoes a fate similar to that of chylomicrons.
- Partial oxidation of fatty acids in the liver leads to ketone body production (**ketogenesis**).



- Metabolism is a highly coordinated cellular activity** in which many multi-enzyme systems (**metabolic pathways**) cooperate to:
  - Obtain chemical energy by capturing solar energy or degrading energy-rich nutrients from the environment;
  - Convert nutrient molecules into the cells own characteristic molecules, including precursors of macromolecules;
  - Polymerise monomeric precursors into macromolecules: proteins, nucleic acids, and polysaccharides; and
  - Synthesise and degrade biomolecules required for specialised cellular functions, such as membrane lipids, intracellular messengers and pigments.
- Metabolic pathways fall into three categories:
  - Anabolic pathways**, which are those involved in the synthesis of larger and more complex compounds from smaller precursors;
  - Catabolic pathways**, which are involved in the breakdown of larger molecules, commonly invoking oxidative reactions; and are exothermic; and
  - Amphibolic pathways**, which occur at the "crossroads" of metabolism, acting as links between the anabolic and catabolic pathways, e.g., the Citric acid cycle.

### Metabolism of Carbohydrates, Proteins and Lipids

- The products of digestion of dietary carbohydrates, lipids and proteins are glucose, fatty acid + glycerol and amino acids, respectively.
- All the products of digestion are metabolised to a common product, **acetyl-CoA**, which is then oxidised by the Citric acid cycle.
- Glucose is metabolised to pyruvate by the pathway of **glycolysis**. Aerobic tissues metabolise pyruvate to acetyl-CoA, which can enter the Citric acid cycle for complete oxidation to  $\text{CO}_2$  and  $\text{H}_2\text{O}$ , linked to the formation of ATP in the process of oxidative phosphorylation. Glycolysis can also occur anaerobically when the end product is **lactate**.
- Fatty acids may be oxidised to acetyl-CoA by  $\beta$ -oxidation or esterified with glycerol, forming **triacylglycerol** (fat) as the body's main fuel reserve. Acetyl-CoA formed by  $\beta$ -oxidation may undergo three fates:
  - It is oxidised to  $\text{CO}_2$  +  $\text{H}_2\text{O}$  via the Citric acid cycle (ii) It is the precursor for synthesis of cholesterol and other steroids (iii) In the liver, it is used to form **ketone bodies** (acetoacetate and 3-hydroxybutyrate) that are important fuels in prolonged fasting.
- The non-essential amino acids, which are supplied in the diet can also be formed from metabolic intermediates by **transamination** using the amino nitrogen from other amino acids. After deamination, amino nitrogen is excreted as urea, and the carbon skeletons that remain after transamination may:
  - be oxidised to  $\text{CO}_2$  via the Citric acid cycle (ii) be used to synthesise glucose (**gluconeogenesis**), or (iii) form ketone bodies, which may be oxidised or be used for synthesis of fatty acids.



### Integration of metabolic pathways at sub-cellular level

- Each cell organelle, (e.g., mitochondrion) or compartment (e.g., cytosol) has specific roles that form part of the sub-cellular pattern of metabolic pathways.
- Compartmentation of pathways in separate sub-cellular compartments or organelles permits integration and regulation of metabolism. There is central role of the **mitochondrion**, since it acts as the focus of carbohydrate, lipid, and amino acid metabolism. It contains the **respiratory chain** and **ATP synthase** as well as the **enzymes of the Citric acid cycle**,  **$\beta$ -oxidation of fatty acids** and **ketogenesis**.
- Glycolysis**, the pentose phosphate pathway, and fatty acid synthesis all occur in the cytosol. In gluconeogenesis, substrates such as lactate and pyruvate, which are formed in the cytosol, enter the mitochondrion to yield **oxaloacetate** as a precursor for the synthesis of glucose in the cytosol.
- The membranes of the endoplasmic reticulum contain the enzyme system for triacylglycerol synthesis, and the ribosomes, are responsible for protein synthesis.



# CONCEPT MAP

## HUMAN HEART: STRUCTURE AND FUNCTION

Human heart is a hollow, four chambered, fibro-muscular organ of somewhat conical or pyramidal shape having upper broad base and lower narrow apex. Apex is slightly directed towards the left.

### Structure of Heart

- Entire heart is enclosed by a double layered sac called **pericardium**. In between the two layers, **pericardial cavity** is present. It normally contains 5-30 mL of **pericardial fluid** which lubricates the heart, permits it to contract with minimal friction and protects the heart from external injury.
- Internally, heart contains four chambers i.e., two thin walled **atria** separated from each other by interatrial septum and two thick walled **ventricles** separated from each other by interventricular septum. Of the two ventricles, left ventricle is thicker.

**Superior vena cava** : Carries blood from body's upper region to right atrium.

**SA node** : Pacemaker of the heart, which spreads waves of contraction across walls of atria.

**Right atrium** : It receives deoxygenated blood from systemic circulation via superior and inferior vena cavae and coronary sinus.

**Pulmonary valve** : Allows unidirectional flow of deoxygenated blood from right ventricle to pulmonary artery.

**Tricuspid valve** : Guards the right atrio-ventricular opening.

**Inferior vena cava** : Carries blood from body's lower region to the heart.

**Bundle of His** : Mass of specialised fibres, originating from AV node.

**Right ventricle** : It supplies deoxygenated blood to the lungs via pulmonary artery for oxygenation.

**Purkinje fibres** : Network of fine fibres, formed by division of Bundle of His. Purkinje fibres convey impulse of contraction from AV node to the myocardium of the ventricles.

**Left ventricle** : It supplies oxygenated blood to different body tissues.

**Aortic valve** : It is situated at the aortic orifice which leads from left ventricle to the aorta.

**Bicuspid valve** : Also known as mitral valve. It guards the left atrio-ventricular opening.

**Left atrium** : It receives oxygenated blood from lungs via pulmonary veins.

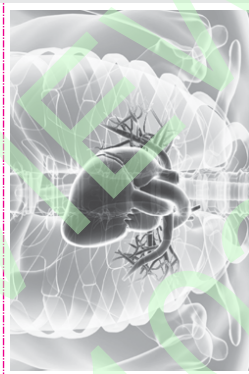
**Pulmonary veins** : Carry oxygenated blood from lungs to left atrium.

**Pulmonary artery** : Carries deoxygenated blood from right ventricle to lungs.

**Aorta** : The main artery from which all other arteries arise and run through different body regions.

### Location and Size

- Heart is located between the lungs in the thoracic cavity. An average adult heart is about 12 cm.
- It weighs around 280-340 gms (in an average male) and 230-280 gms (in an average female).



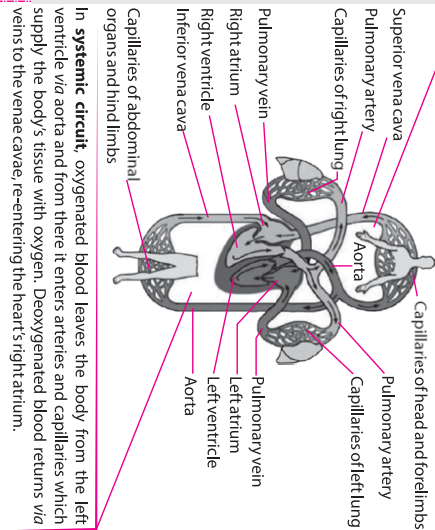
### Cardiac Cycle

Cardiac cycle consist of one cycle of contraction and relaxation of cardiac muscles.

### Function of Heart

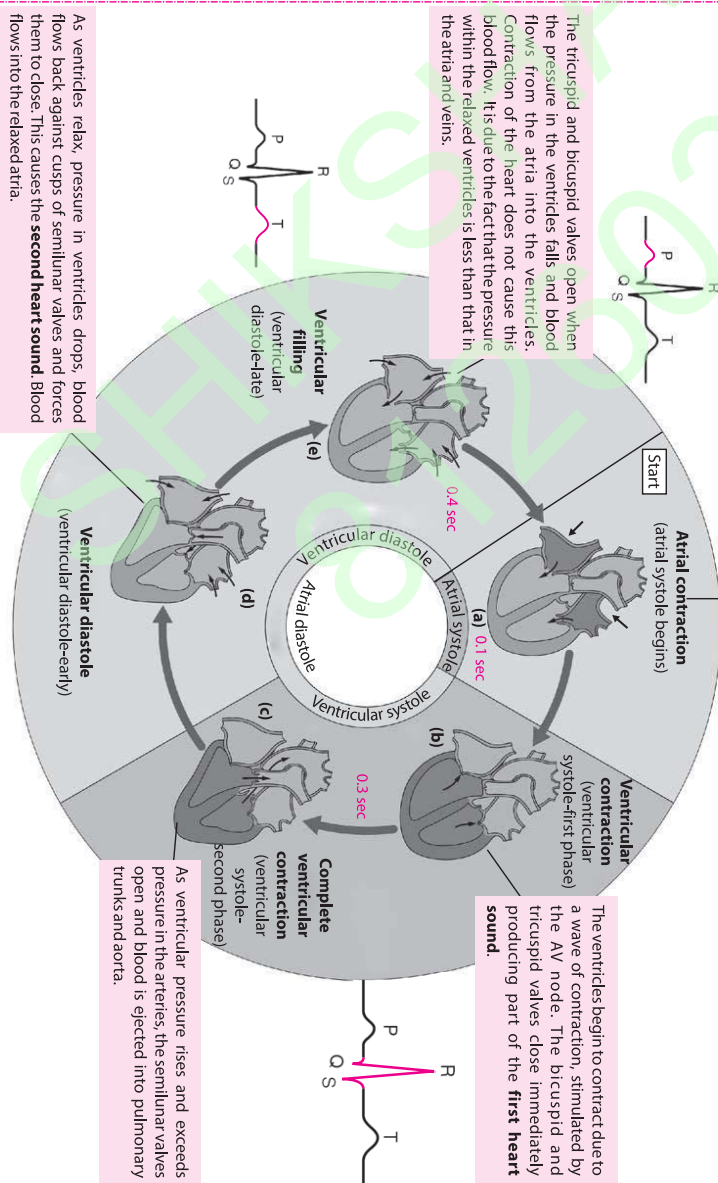
Function of heart is to pump blood throughout the body via the circulatory system supplying oxygen and nutrients to the tissues and removing carbon dioxide and other wastes from the same. The heart circulates the blood through two pathways (**double circulation**) i.e., pulmonary and systemic circuits. It checks mixing of blood.

In **pulmonary circuit**, deoxygenated blood flows from right ventricle to the lungs and oxygenated blood returns from lungs to the left atrium.



In **systemic circuit**, oxygenated blood leaves the body from the left ventricle via aorta and from there it enters arteries and capillaries which supply the body's tissue with oxygen. Deoxygenated blood returns via veins to the venae cavae, re-entering the heart's right atrium.

Contraction of atria stimulated by SA node, forces blood into the relaxed ventricles.



# CONCEPT MAP

## HUMAN SKELETON

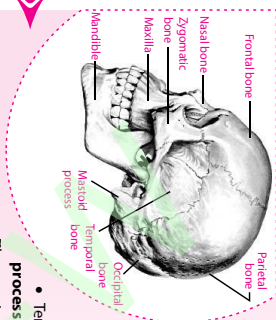
Human skeleton constitutes the rigid framework of connected bones that gives shape to the body, protects and supports its soft organs and tissues and provides attachments for muscles. Human skeleton is made up of 206 bones (300 bones in newborns) which are distributed into axial and appendicular skeleton.

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### AXIAL SKELETON

- It lies along the longitudinal axis of the body, supports and protects the organs of the head, neck and trunk.
- It includes **skull, vertebral column, sternum** and **ribs**.

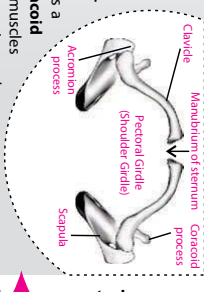
#### SKULL



- Skull is the bony framework of the head.
- It consists of **29 bones**, separated by sutures. These bones are **cranial bones** (8 flattened bones forming the brain box or **cranium**), **facial bones** (14 bones forming the front part of the skull), **hyoid bone** (single bone forming floor of the buccal cavity) and **bones of middle ear** (3 small bones in each ear, namely **malleus, incus** and **stapes**).
- The bones of cranium are: **1 frontal bone, 2 parietal bones, 2 temporal bones, 1 occipital bone, 1 sphenoid bone** and **1 ethmoid bone**.
- Temporal bone has a projection called **mastoid process**.
- The cranium has two small protuberances at the posterior end called **occipital condyles**, that articulate with the **first vertebra** (alias vertebra), thus, human skull is **dicondylic**.
- 14 bones form the skeleton of face viz. **2 zygomatic, 2 maxilla, 2 nasal, 2 lacrimal, 1 vomer, 2 palatine, 2 inferior nasal conchae** and **1 mandible**.
- **Hyoid** is a U-shaped bone which attaches tongue with the floor of buccal cavity. It does not articulate with any other bone.
- A large hole called **foramen magnum** at the base of skull allows the brain to continue into the spinal cord located in the backbone.
- Skull protects our brain; it bears jaws which help in mastication of food, etc.

#### PECTORAL GIRDLE

- Each pectoral girdle consists of two bones : **1 clavicle** and **1 scapula**. The scapula (shoulder blade) consists of a sharp ridge, the **spine** and a triangular **body**. The end of the spine projects as a flattened and expanded process called **acromion**. This process articulates with the clavicle.
- At the lateral end of the superior of the scapula is a projection of the anterior surface called the **coracoid process**, to which the tendons of the muscles attach. At the point where the superior and lateral borders of the scapula meet there is the lateral angle which presents a shallow articular surface termed as **glenoid cavity** into which the head of the humerus is articulated.
- The primary function of the pectoral girdle is to provide an attachment point for the numerous muscles that allow the shoulder and elbow joints to move.

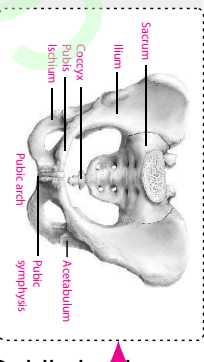


#### FORELIMBS

- Each arm has **30 bones**, which constitute **1 humerus** (upper arm), **1 radius** and **1 ulna** (lower arm), **8 carpal**s (wrist), **5 metacarpal**s (palm) and **14 phalanges** (digits).
- The **humerus** is the **longest bone** in the upper extremity.
- At the bottom of the humerus, are two depressions where it connects to the ulna and radius of the forearm.
- Together, the humerus and the ulna make up the elbow, ulna is longer than the radius. Radius, however, contributes more to the movement of the wrist and hand than the ulna.
- Each wrist is composed of **eight carpal**s which are arranged in two rows: **scaphoid, lunate, triquetrum** and **pisiform** in proximal row and **trapezium, trapezoid, capitate** and **hamate** in distal row.
- The forelimbs give support to the shoulders by articulating the head of the humerus with the glenoid cavity of the pectoral girdle.

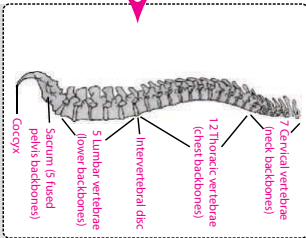
#### PELVIC GIRDLE

- The **pelvic girdle**, also called the **hip girdle**, is composed of two coxal (hip) bones.
- The **coxal bones** are also called the **os coxae** or **innominate bones**.
- Each coxal bone consists of three separate parts : the **ilium** (short and straight bone), the **ischium** (lower, elongated bone, running parallel to vertebral column) and the **pubis** (inner, smaller bone).
- On its outer surface it has a deep depression called the **acetabulum** which, with almost spherical head of the femur, forms the hip joint.
- It supports the weight of the body from the vertebral column. It also protects and supports the lower organs, including the urinary bladder, the reproductive organs, and the developing foetus in case of a pregnant woman.

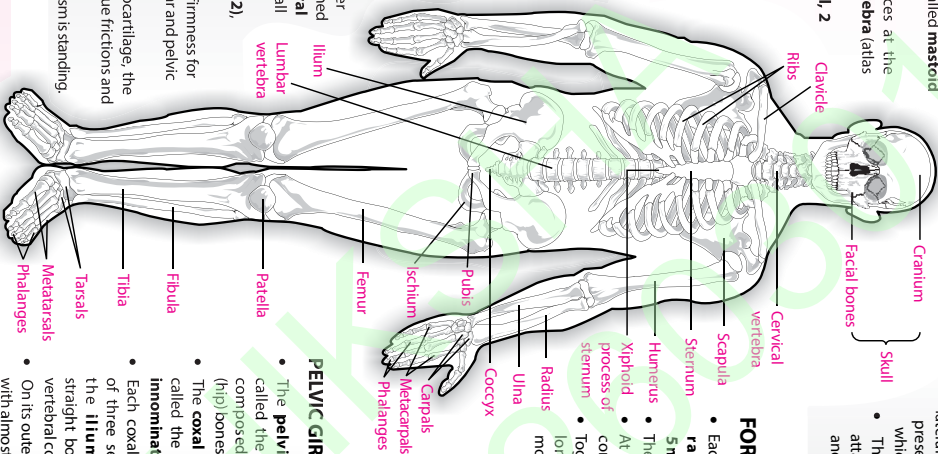


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#### VERTEBRAL COLUMN

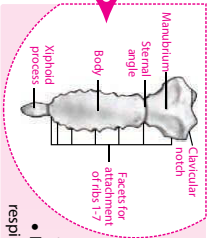


- It is also called **backbone** or **spine**. It is curved, vertical rod, about **70 cm long**, in the mid-dorsal line of the neck and trunk. It consists of **33 vertebrae**. However it consists of 26 bones, because five sacral vertebrae are fused to form one sacrum and four coccygeal vertebrae are fused to form one coccyx.
- A typical vertebra has a large, disc-like anterior, flattened portion, the **centrum** or **body** and a posterior portion, the **neural arch**. The latter encloses the spinal cord. The hole formed by the neural arch is the **vertebral foramen**. The vertebral foramina of all twenty-four vertebrae form the **vertebral canal** or **neural canal**.
- Vertebrae are categorised into five groups: **cervical** (7), **thoracic** (12), **lumbar** (5), **sacral** (5) and **coccygeal** (4).
- Vertebral column displays four curves to enhance balancing powers and firmness for upright posture of the body. These curvatures are cervical, thoracic, lumbar and pelvic (=sacral).
- Between the centre of adjacent vertebrae there are elastic pads of fibrocartilage, the **intervertebral discs** which provide mobility to the vertebrae, check undue frictions and take up shocks.
- Vertebral column carries the weight of the body in motion and when the organism is standing.



### ADMISSION HELPLINE

#### STERNUM



- This is a flat bone which is present just under the skin in the middle of the front of the chest. It is about 15 cm long.
- Its shape is like a dagger and consists of three parts—the **manubrium** is the uppermost part, the **body** is the middle portion and the **xiphoid process** is the tip of the bone.
- The true ribs (7 pairs) are attached to the sternum.
- It protects the internal organs in the thoracic region and helps in the respiratory mechanism.

#### RIBS

- The ribs are thin, flat, curved bones that form a protective cage around the organs in the upper body.
- Ribs comprise of **24 bones arranged in 12 pairs**. Each rib remains attached to the respective thoracic vertebra.
- The **first seven pairs of ribs** are attached directly with the sternum and are called **true ribs**. The **8<sup>th</sup>, 9<sup>th</sup> and 10<sup>th</sup>** pairs of ribs do not articulate directly with sternum, but join the seventh rib by hyaline cartilage. These are called **vertebrochondral ribs** or **false ribs**. The last two, **11<sup>th</sup> and 12<sup>th</sup>** pairs of ribs remain free anteriorly and are not attached either to sternum or cartilage of another rib, and are called **floating ribs**.
- A typical rib consists of 2 parts: **vertebral** and **sternal**. The vertebral part is long and bony, it articulates with the thoracic vertebrae.
- The sternal part is short and cartilaginous. It articulates with the sternum or sternal part of its upper rib.

#### HIND LIMBS

- Each leg has **30 bones** which constitute **1 femur, 1 tibia, 1 fibula, 7 tarsals, 5 metatarsals** and **14 phalanges**.
- **Femur, tibia and fibula** bones together support the shank of the leg. The **tarsals** form the ankle, **metatarsals** form the sole and **phalanges** form the digits of the foot.
- The **femur** is the **longest, largest, and strongest bone** in the body whose head fits into the acetabulum of hip girdle.
- The **tibia** connects to the femur to form the knee joint and with the talus, a foot bone, to allow the ankle to flex and extend.
- The **tibia is larger than the fibula** because it bears most of the weight, while the fibula serves as an area for muscle attachment.
- **Fibula** is shorter, thinner and slender.
- Each ankle is composed of seven **tarsals** which are **calcaneum, talus, cuboid, navicular** and **first, second, third cuneiforms**.
- The leg bones carry the weight of the body and are involved in propulsion and support.



# CONCEPT MAP

## SYNAPSE

Synapse is an anatomically specialised junction between two neurons, where the axon (or some other portion) of one cell (neuron) terminates on the dendrites or some other portion of another cell. The term 'synapse' was first introduced by Charles Sherrington (1924). Transmission of nerve impulse takes place across a synapse between neurons or neurons and an effector. The neuron which sends messages is called presynaptic cell whereas the neuron which receives messages is postsynaptic neuron.

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### STRUCTURE OF SYNAPSE

Most of the synapses comprise the following structures:

- Synaptic knob** - Terminal bulbous ending of presynaptic axon which is devoid of neurofilaments but its cytoplasm contains:
  - Synaptic vesicles** - Small vesicles present in presynaptic cytoplasm that contain neurotransmitters (for excitation or inhibition), like acetylcholine, GABA, etc.
  - Mitochondria, ER and microtubules.**
  - Presynaptic membrane** - Nerve membrane which is in close approximation with membrane of postsynaptic cell.
- Sub-synaptic and postsynaptic membrane** - The surface of the cell membrane involved in the synapse is called the sub-synaptic membrane and the remaining of the motor neuron cell membrane is called the postsynaptic membrane. Receptor sites for neurotransmitters are usually located on the sub-synaptic membrane.

### TYPES OF SYNAPSE

On the basis of position and location within nervous system

On the basis of physiology

#### Axo-axonal Synapse

Synapse between axons of two neurons. It is present in spinal cord.

#### Axo-dendritic Synapse

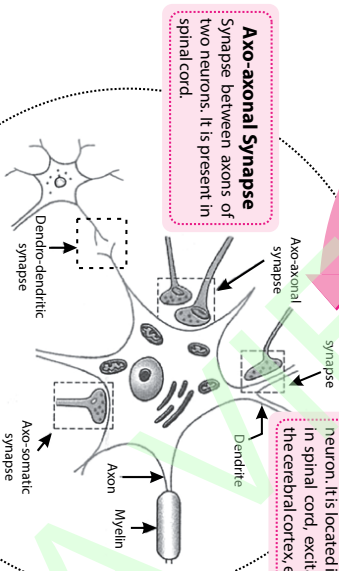
Synapse between fine terminal branches of axon of one neuron and dendrites or cell body of another neuron. It is located in motor neurons in spinal cord, excitatory synapse in the cerebral cortex, etc.

#### Dendro-dendritic Synapse

Synapse between dendrites of two neurons, but is rare. It is present between mitral and granule cells in the bulb.

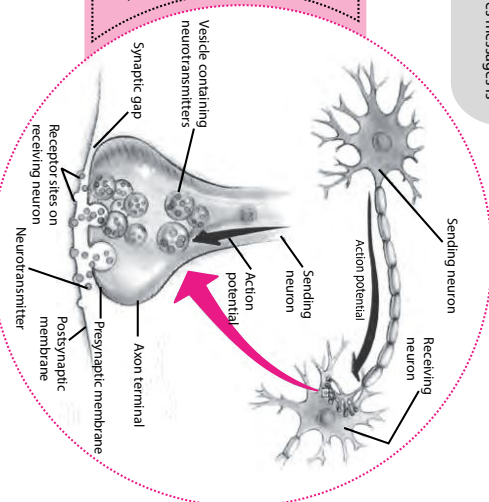
#### Axo-somatic Synapse

Synapse between axon of one neuron and soma of another neuron. It is present in motor neurons in spinal cord and autonomic ganglia.



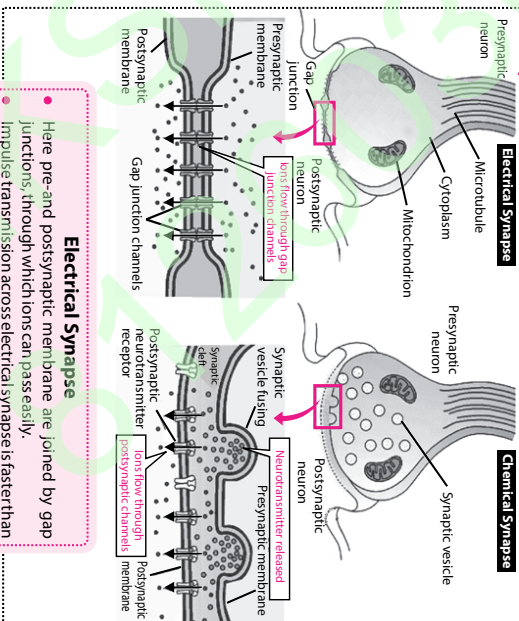
### Chemical Synapse

- Signals are transmitted across synaptic cleft in form of chemical messenger - a neurotransmitter, released from presynaptic axon terminal.
- Chemical synapse operates only in one direction, as neurotransmitter is stored on the presynaptic side of synaptic cleft, whereas receptors for neurotransmitters are on postsynaptic side.



### Electrical Synapse

- Here pre- and postsynaptic membrane are joined by gap junctions, through which ions can pass easily.
- Impulse transmission across electrical synapse is faster than chemical synapse because of the direct flow of electrical current from one neuron to another through gap junction.



### MECHANISM OF IMPULSE CONDUCTION

### PROPERTIES OF SYNAPSE

- Convergence and Divergence** : Many presynaptic neurons **converge** on any single postsynaptic neuron, eg, in spinal motor neurons, some inputs come from dorsal root, some from long descending spinal tracts and many from interconnecting neurons. The axons of most presynaptic neurons divide into many branches that **diverge** to end on many postsynaptic neurons.
- Fatigue** : Repeated stimulation of presynaptic neuron leads to gradual decrease and finally disappearance of the postsynaptic response. This is due to exhaustion of chemical transmitter, as its synthesis is not as rapid as the release.
- Synaptic Delay** : When an impulse reaches the presynaptic terminal, there is a gap of about 0.5 msec, before a response is obtained in postsynaptic neuron. This is due to the time taken by synaptic mediator to be released and to act on postsynaptic membrane.
- Synaptic Plasticity** : Plasticity implies the capability of being easily moulded or changed. Synaptic conduction thus can be increased or decreased on the basis of past experience. These changes can be presynaptic or postsynaptic in location and play an important role in learning and memory.

### At Chemical Synapse

- Mechanism of chemical transmission across a synapse is as follows:
- Action potential arrives at axon terminal
  - Voltage gated  $Ca^{2+}$  ion channels open and electrochemical gradient favours influx of  $Ca^{2+}$  and  $Ca^{2+}$  flows into axon terminal
  - $Ca^{2+}$  ions cause synaptic vesicles to move to the surface of the knob and fuse with synaptic membrane terminal
  - Vesicles release neurotransmitters by exocytosis
  - Neurotransmitters diffuse across synaptic cleft and bind to receptors on postsynaptic membrane
  - This causes depolarisation and generation of action potential in the postsynaptic membrane.

### At Electrical Synapse

- Gap junctions in electrical synapse allow the local currents resulting from arriving action potentials to flow directly across the junction from one neuron to the other.
- This depolarises the membrane of the second neuron to threshold, continuing the propagation of the action potential.

ADMISSION HELPLINE

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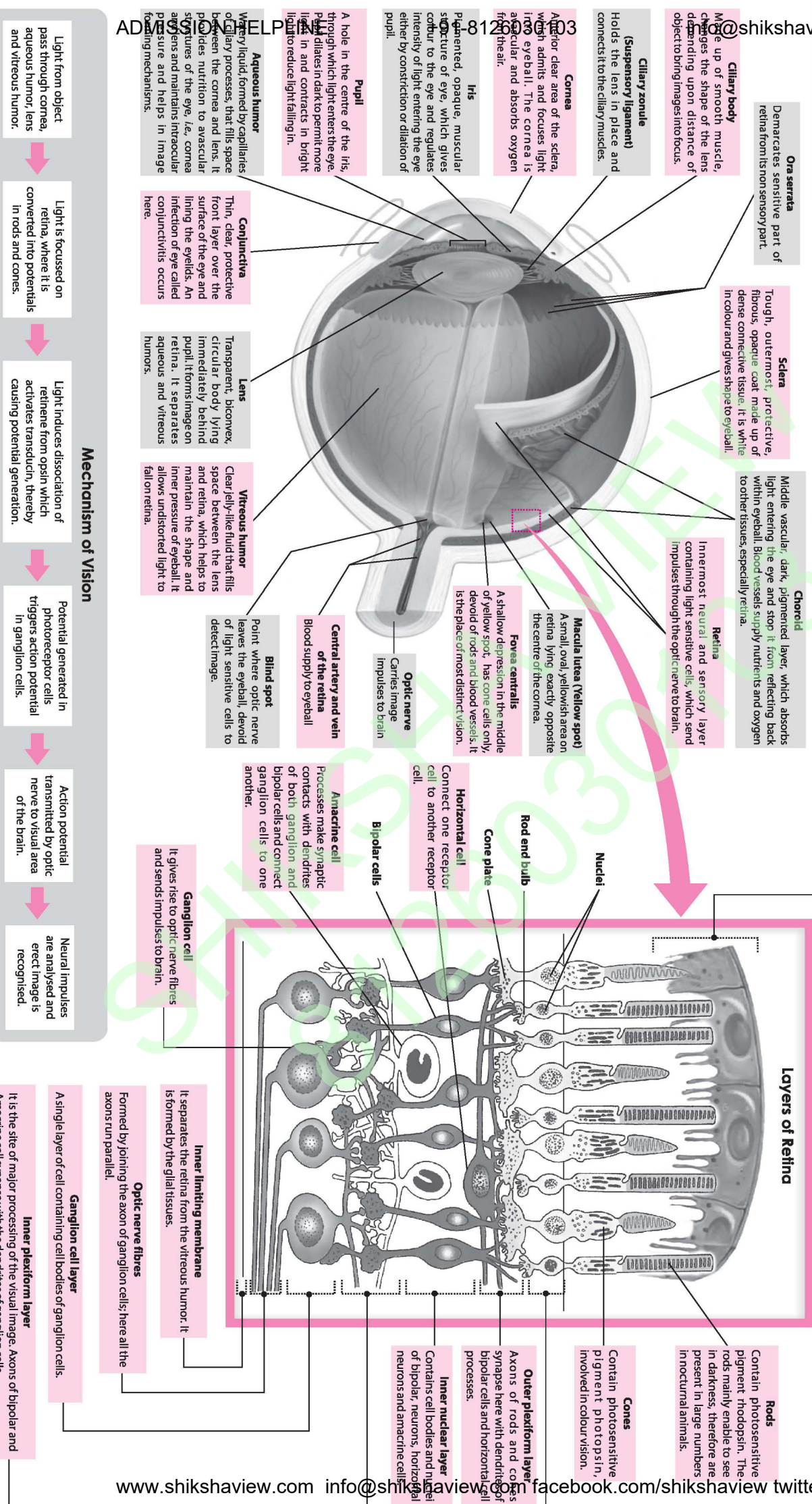


# CONCEPT MAP

## THE EYE

The eye is a special organ of the sense of sight, an extension of human brain which permits humans to connect with the outside world. The adult human eyeball is hollow, spherical structure, situated in the orbital cavity. Only 1/6<sup>th</sup> of the eyeball is visible outside.

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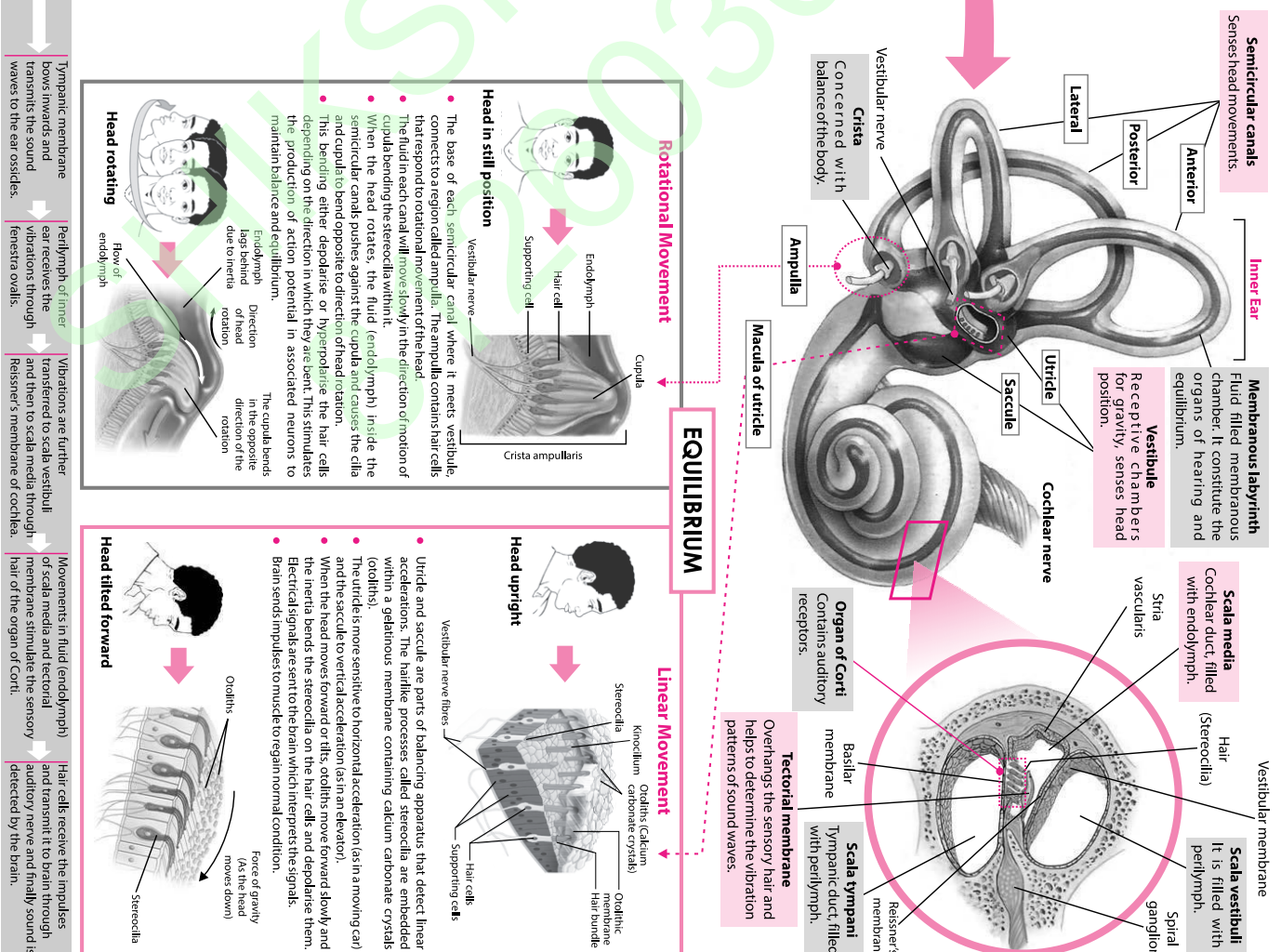
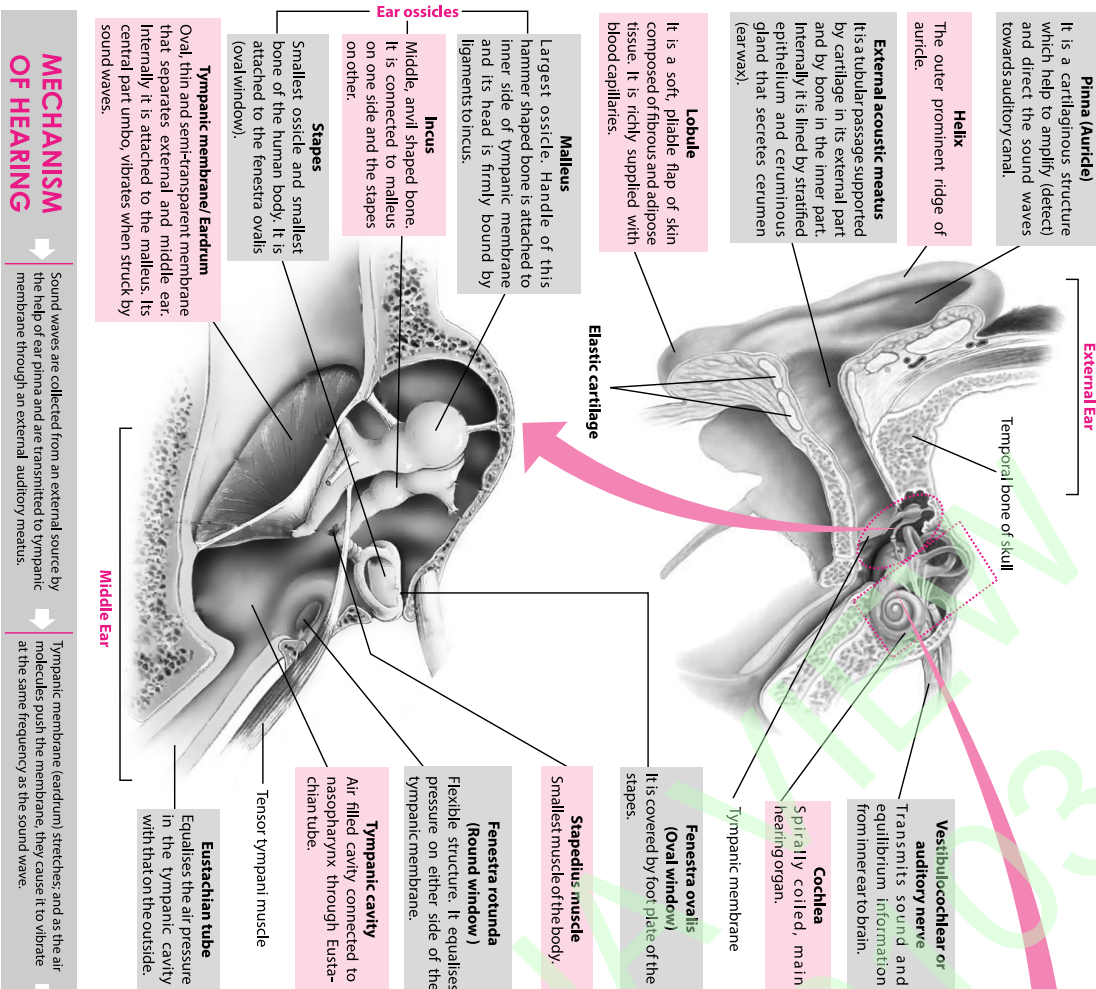




# CONCEPT MAP

## THE EAR

Ears are a pair of sense organs that are situated on the either sides of the head to produce a sensation of hearing and to maintain body's equilibrium and balance. Anatomically, human ear is divided into three regions - external ear, middle ear and inner ear.



**MECHANISM OF HEARING**

Sound waves are collected from an external source by the help of ear pinna and are transmitted to tympanic membrane through an external auditory meatus.

Tympanic membrane (eardrum) stretches and as the air molecules push the membrane, they cause it to vibrate at the same frequency as the sound wave.

Tympanic membrane bows inward and transmits the sound waves to the ear ossicles.

Perilymph of inner ear receives the vibrations through fenestra ovalis.

Vibrations are further transferred to scala vestibuli and then to scala media through Reissner's membrane of cochlea.

Movements in fluid (endolymph) of scala media and tectorial membrane stimulate the sensory hair of the organ of Corti.

Hair cells receive the impulses and transmit it to brain through auditory nerve and finally sound is detected by the brain.

# CONCEPT MAP

## ASEXUAL REPRODUCTION

Life cannot be created *de novo* rather it arises from pre-existing life. Reproduction is the only method by which continuity of life is maintained. It is of two types: asexual and sexual. Asexual reproduction is the formation of new individual without involving fusion of gametes. It is uniparental as offspring are produced by a single parent.

### Fission

- It is a type of asexual reproduction in which the parent organism divides into two or more daughter cells.
- In this type of reproduction, whole parent body acts as the reproductive unit.
- It is of three types:

(a) **Binary fission**: In this, parent organism divides into two halves, each half forming an independent daughter organism. It can be simple (occurs through any plane, e.g., Amoeba), longitudinal (plane of division is longitudinal axis of body, e.g., Euglena), transverse (plane of division runs along transverse axis of body, e.g., Paramecium) and oblique (plane of division is oblique, e.g., Ceratium).

(b) **Multiple fission**: In this process, parent body divides into many similar daughter organisms. It occurs during unfavourable conditions. Nucleus of the parent divides by repeated mitosis into many nuclei which eventually form several daughter cells. E.g., Amoeba, Plasmodium (malaria parasite).

(c) **Plasmotomy**: Division of multinucleate parent into many multinucleate daughter individuals without division of nuclei. Nuclear division occurs later to maintain number of nuclei. E.g., *Opalina*, *Plasmodium*.

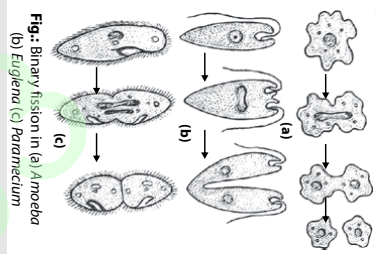


Fig.: Binary fission in (a) Amoeba (b) Euglena (c) Paramecium

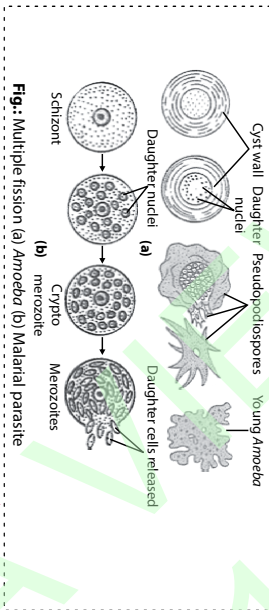


Fig.: Multiple fission (a) Amoeba (b) Malarial parasite

### CHARACTERISTICS OF ASEAXUAL REPRODUCTION

- It is more primitive than sexual reproduction as it involves only mitotic divisions.
- New organisms are produced from the somatic part of parental organism, so it is also called as somatogenetic reproduction.
- New individuals produced are genetically similar to the parent as well as to each other and are called clones. Hence, it plays a role in evolution.
- Unit of reproduction may be either whole parent body, or a bud, or a body fragment, or a single somatic cell.
- It is usually found in lower organisms like protistan protozoans (Amoeba, Paramecium), sponges (Scypha), coelenterates (Hydra, Tubularia, etc.), certain flatworms (Planaria), some worms and tunicates (Salpa, Ascidia, etc.). It is absent in higher invertebrates and all vertebrates.

### Regeneration

- It refers to the growth of new tissues or organs to replace lost or damaged part.
- Regeneration is of two types: **morphallaxis** (formation of whole body from a fragment) and **epimorphosis** (replacement of lost part). It can be reparative (regeneration of damaged tissue only) or restorative (development of severed body part). In epimorphosis, a mass of undifferentiated cell referred to as blastema is formed after wound healing and then the blastema cells actively proliferate to restore the lost part of the amputated organ.
- Regeneration is found in Hydra, starfish, Planaria, etc.

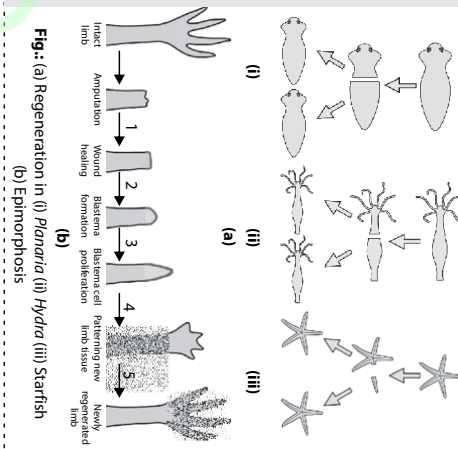


Fig.: (a) Regeneration in (i) Planaria (ii) Hydra (iii) Starfish (b) Epimorphosis

### Budding

- Budding refers to the process of formation of daughter individuals from a small projection or bud arising on the parent body.
- Each bud enlarges, develops parental characters and separates to lead an independent life.
- Budding can be either **exogenous** (formed on the outer surface) e.g., Hydra, Yeast or **endogenous** (formed inside parent body) e.g., Spongilla. In Spongilla bud is called a **gemmule**.

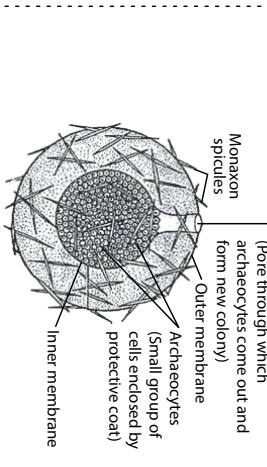
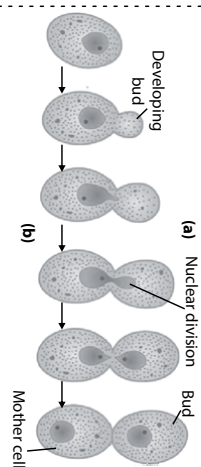
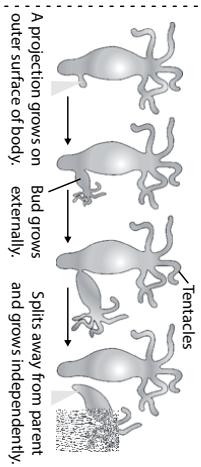


Fig.: (a) Exogenous budding in Hydra (b) Exogenous budding in yeast (c) Endogenous budding (gemmule) in Spongilla

### Sporulation

- Spores are minute, single celled, thin or thick walled propagules which are dispersive structures released from the parent body and form new individuals. Spore formation is common in members of monera, protista, algae and fungi. Some of the commonly produced spores are:
- (a) **Zoospores**: Motile and flagellated spores produced inside zoosporangia. Flagella help in proper dispersal in aquatic habitat. E.g., algae and lower fungi like Phycomycetes.
- (b) **Conidia**: Non-motile spores produced singly or in chains by constriction at the tip or lateral side of special hyphal branches called conidiophores. These are dispersed by wind and germinate to form new individuals. E.g., Penicillium.
- (c) **Chlamydospores**: Thick walled spores produced directly from hyphal cells. May be terminal or intercalary in position and capable of withstanding unfavourable conditions. E.g., Rhizopus.
- (d) **Oidia**: Small fragments of hyphae that are thin walled and do not store reserve food material. Oidia give rise to new hyphae. These are formed under conditions of excess water, sugar and certain salts. E.g., Agaricus.
- (e) **Sporangiospores**: Non-motile spores produced inside sporangia. Usually get dispersed by wind and germinate to form new mycelium. E.g., Rhizopus, Mucor.

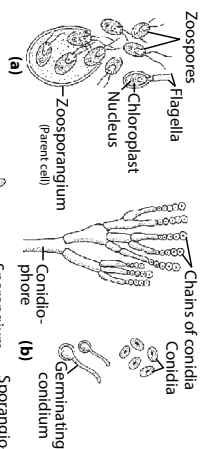


Fig.: Various types of spores (a) Zoospores (b) Conidia (c) Chlamydospores (d) Oidia (e) Sporangiospores

### Fragmentation

- In this type of reproduction, parent body breaks into two or more pieces called fragments.
- Each fragment develops into a new organism.
- In fragmentation, rate of reproduction is high.
- It occurs in flatworms, sea anemones, coelenterates, echinoderms, algae like Spirogyra, etc.

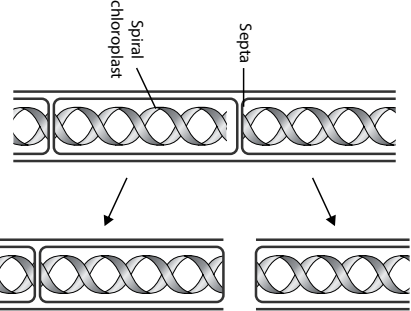


Fig.: Fragmentation in Spirogyra



# CONCEPT MAP

## ASEXUAL REPRODUCTION

Asexual reproduction is the production of offspring from a single parent with or without the involvement of gamete formation. The offspring produced are morphologically and genetically similar to one another and are exact copies of their parents, hence called clones.

### Binary fission

The parent organism divides mitotically into two halves, each half forming an independent daughter organism. It is of following types: (i) **Simple binary fission** - division occurs through any plane, e.g., Amoeba, (ii) **Longitudinal binary fission** - division takes place along the longitudinal axis of an organism, e.g., Euglena, (iii) **Transverse binary fission** - division occurs along the transverse axis of the individual, e.g., Planaria, (iv) **Oblique binary fission** - division is oblique, e.g., Ceratium.

### Plasmotomy

There is division of a multinucleate parent into many multinucleate daughter individuals without division of nuclei, e.g., Opalina.

### FISSION

It is the division of parent body into 2 or more daughter individuals identical to the parent. It is of three types: binary fission, multiple fission and plasmotomy.

#### Multiple fission

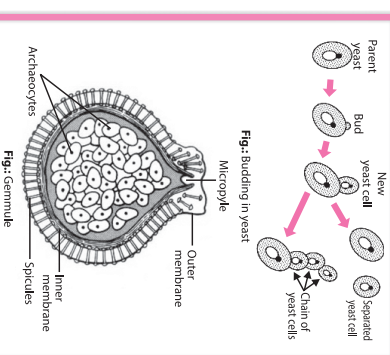
There is repeated division of the parent body into many daughter organisms, e.g., Plasmodium.



### BUDDING

Daughter individual is formed from a small part or bud, arising from parent body. In animals it is of three types:

- Exogenous budding**: The bud grows externally on the surface of the body. It may split away from the parent e.g., Hydra or remain attached to it, e.g., Sycon. In yeast, bud is formed on one side of the parent cell and soon it separates and grows into a new individual.
- Endogenous budding**: The buds are formed within the parent's body. They are called gemmules which consist of small group of cells in a protective covering, e.g., Sporangia.
- Strobilation**: The repeated formation of similar segments by a process of budding is called strobilation. The segmented body is called a **strobila** larva and each segment is called an **ephyra** larva e.g., Aurelia.

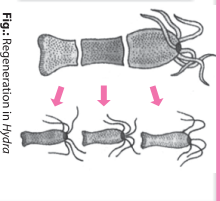


### FRAGMENTATION

The parent body breaks into two or more pieces called fragments. Each fragment develops into an individual, e.g., Spirogyra, Rhizopus etc.

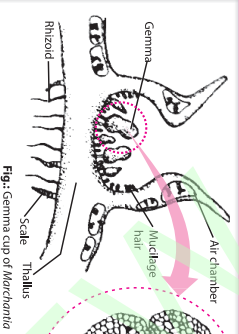
### REGENERATION

Regeneration is the regrowth in the injured region. It is of two types: (i) **Morphallaxis**: The whole body is formed from a small fragment, e.g., Hydra, (ii) **Epinormophosis**: It is the replacement of lost body part. It can be **reparative** (only certain damaged tissues regenerate) or **restorative** (several body parts can regenerate, e.g., broken tail of wall lizard).



### SPORE FORMATION

Spores are microscopic, single-celled, thin or thick walled propagules which develop asexually on the parent body. Spores can be of various types viz. **zoospores** (motile and flagellated, e.g., Chlamydomonas), **oidia** (non-motile and produced exogenously e.g., Penicillium), **chlamydozoospores** (thick-walled and non-motile e.g., Rhizopus), **oidia** (small, thin-walled fragments, e.g., Agaricus) and **sporangiospores** (non-motile e.g., Mucor).



### GEMMAE

These are unicellular or multicellular propagules which develop in small receptacles called gemma cups. They detach from the parent and grow into new individuals, e.g., Marchantia.

### VEGETATIVE PROPAGATION

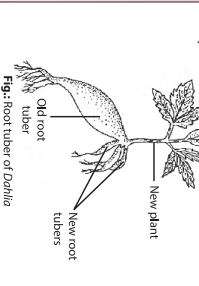
Natural methods of the plant detach naturally from it and develop into new plants under suitable conditions. It takes place by roots, stems, leaves, bulbils and turions.

### Artificial methods

Vegetative propagules are developed by horticulturists to quickly multiply, desired varieties of plants from parts of their somatic body. It can be done by cutting, layering, grafting, bud grafting and microporopagation.

#### Roots

Tap roots of some plants develop adventitious buds to form new plants, e.g., Dahlbergia. In some plants like sweet potato and Dahlia root tubers develop adventitious buds which develop into a new plants.



#### Leaves

Leaves of many plants have adventitious buds. Such leaves when fall on the ground, their buds develop root, and mature into individual plants, e.g., Bryophyllum, Begonia etc.



#### Turions

A turion is a swollen bud which contains stored food. It detaches from the parent plant and germinates under favourable conditions e.g., Utricularia.

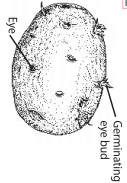
#### Bulbils

These are multicellular fleshy buds that take part in vegetative propagation, e.g., Oxalis, Agave etc.



#### Stems

Certain stem modifications take part in vegetative propagation such as **tubers** (have buds over their nodes or eyes which produce new plantlets when placed in the soil, e.g., potato), **bulbs** (underground condensed shoots with buds which form new plants, e.g., onion), **corms** (unbranched swollen underground stems with circular nodes having buds which germinate into new plants, e.g., Colocasia), **rhizomes** (main underground stems with buds which give rise to new aerial shoots during favourable conditions, e.g., ginger), **suckers** (slender underground branches which develop from base of aerial shoot, breaking forms new plants e.g., mint), **runners** (narrow horizontal branches which develop at the base of crown and root at intervals, breaking helps in vegetative propagation, e.g., Cynodon), **stolons** (arched horizontal branches which develop at the base of crown, breaking results in formation of new plant e.g., strawberry), **offsets** (one internode long runners breaking helps in propagation, e.g., Eichhornia) and **phyllodes** (each segment of stem can form a new plant, e.g., sugarcane).

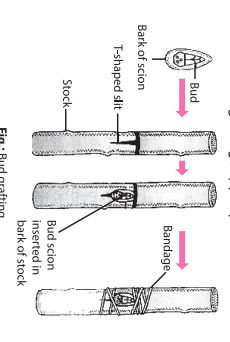


#### Cuttings

These are cut pieces of plant parts which are planted in the nurseries. These can be: (i) **Root cuttings** - The pieces of roots are used to artificially propagate new plants e.g., lemon, orange etc. (ii) **Stem cuttings** - 20-30 cm long pieces of one year old stems are cut and planted. Before planting they are treated with root promoting chemicals like IBA, e.g., rose, sugarcane etc. (iii) **Leaf cuttings** - Leaves are cut transversely into 2-3 parts and planted in vertical position in the soil, e.g., Sansevieria and Scintipaulia.

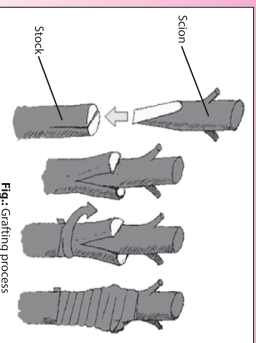
#### Bud grafting

Scion is a bud with small piece of bark and cambium. Stock is given a T-shaped cut and bud is inserted in it. The joint is treated with grafting wax and bandaged, e.g., apple, peach etc.



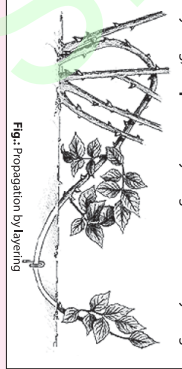
#### Grafting

Grafting is a technique of connecting two parts, usually a root system and a shoot system of two different plants in such a way that they unite and later develop as a composite plant. A small shoot of plant with superior characters is employed as graft or scion. The root system of the other plant which is disease resistant and has good root system is used as stock (not successful in monocots). It is done in mango, apple etc. The various techniques of grafting are **tongue grafting**, **crown grafting**, **wedge grafting**, **side grafting** and **approach grafting**.



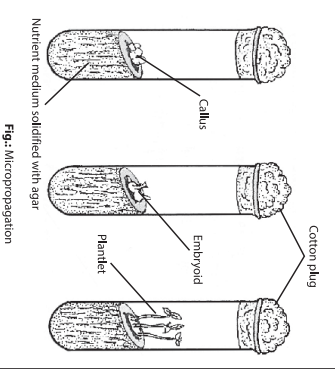
#### Layering

In this method, adventitious roots are induced to develop on a soft stem by delimiting the soft basal branch and a small injury or cut is given. The injured delimitated part is pegged in the soil to develop adventitious roots. The pegged down branch of the plant is called layer. Once the roots develop, the layer is separated and planted. It can be of following types: **Mound layering**, **Gootee** or **air layering**, **Simple layering**, **Serpentine layering** and **Trench layering**.



#### Microporopagation

This method includes propagation of plants by culturing the cells, tissues and organs. This is known as tissue culture. The culturing results in formation of callus, an undifferentiated mass of cells which later differentiates to form a large number of plantlets. It is useful in obtaining virus free plants, disease free plants, homozygous diploids and quick commercial production of orchids, Carnation, Gladiolus etc.



# CONCEPT MAP

## SEXUAL REPRODUCTION

The process of development of new individuals through the formation and fusion of male and female gametes is known as sexual reproduction or amphimixis or syngamy.

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### TYPES

#### Syngamy

It is the complete and permanent fusion of male and female gametes to form the zygote.

**Endogamy**  
It is the fusion of male and female gametes of the same parent, hence, uniparental e.g., *Toenia*.

**Exogamy**  
It is the fusion of two gametes produced by different parents, hence, biparental e.g., Rabbit.

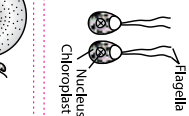
On the basis of source of fusing gametes

#### Conjugation

A process of sexual reproduction in which organisms of the same species temporarily couple and exchange or in some cases transfer their genetic material. It takes place in *Paramoecium*, *Spirogyra*, bacteria etc.

#### Isogamy

It involves the fusion of gametes which do not differ morphologically but may be different physiologically. It takes place in *Chlamydomonas*, red algae etc.



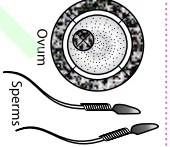
Flagella  
Nucleus  
Chloroplast

Male gamete  
Female gamete

Ovum  
Sperms

Oogamy

**Antisogamy**  
It involves the fusion of gametes which differ in size or form. It takes place in *Chlamydomonas*, red algae etc.



Ovum  
Sperms

Hologamy

**Hologamy**  
It involves the fusion of two organisms. It occurs in yeasts.

On the basis of structure of fusing gametes

### PHASES OF LIFE

#### Juvenile/Vegetative phase

It is pre-reproductive phase. The period of growth between the birth upto the reproductive maturity of an organism is called the juvenile phase. In plants, it is known as vegetative phase.

#### Reproductive phase

The period when organisms start producing offspring is called reproductive phase. On the basis of it, plant can be **monocarpic** (flower only once in their life cycle, e.g., bamboo) or **polycarpic** (flower every year in a particular season, e.g., apple).

On the basis of time of breeding, animals are of two types:

- Seasonal breeders:** These animals reproduce at a particular period of the year such as frog, lizard etc.
- Continuous breeders:** These animals continue to breed throughout their sexual maturity e.g., mice, cattle, etc.

#### Senescent phase

It is the post-reproductive phase that begins from the end of the reproductive phase. The terminal irreversible stage of ageing is called senescence. It is the last phase of life span and ultimately leads to death.

### EVENTS IN SEXUAL REPRODUCTION

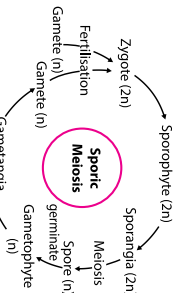
#### Pre-fertilisation events

These events of sexual reproduction take place before the fusion of gametes. These include:

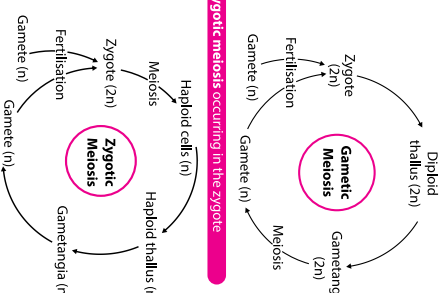
##### Gametogenesis

It is the formation of gametes. Gametes can be **isogametes** (morphologically similar) or **heterogametes** (morphologically dissimilar). Gametes are formed as a result of meiosis which can be of three types:

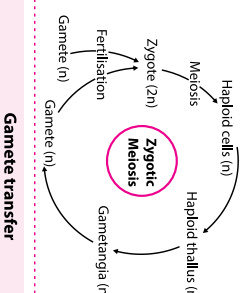
##### Spotic meiosis occurring inside the sporangia



##### Gametic meiosis occurring in the germinal cell



##### Zygotic meiosis occurring in the zygote



##### Gamete transfer

It is the transfer of gametes to bring them together for fertilisation. In algae, bryophytes and pteridophytes water serves as the medium. In flowering plants it is done by pollination. Animals have copulatory organs to transfer male gametes.

#### Fertilisation

It is the complete and permanent fusion of two gametes from different or same parent to form a diploid zygote (syngamy). It can be of two types.

##### External fertilisation

When fertilisation occurs outside the body of the organism, it is called external fertilisation or external syngamy. It requires an external medium such as water, e.g., bony fish and amphibians.

##### Internal fertilisation

When egg is retained inside female body where it fuses with the male gamete, the process is called internal fertilisation or internal syngamy, e.g., reptiles, birds, mammals etc.

#### Parthenogenesis

Development of egg (ovum) into a complete individual without fertilisation is known as parthenogenesis. It occurs in rotifers, arthropods, insects etc. It is of two types:

##### Natural

It occurs regularly in the life cycle of certain animals. It can be complete (occurs in animals which breed exclusively by parthenogenesis), incomplete (occurs in animals in which both sexual reproduction and parthenogenesis occur) and paedogenetic (occurs in larva).

##### Artificial

In this type, the ovum is induced to develop into a complete individual by artificial stimuli. The stimuli can be physical or chemical.

#### Neoteny

When the larva retains adult characters such as gonads and starts producing young ones by sexual reproduction, it is called neoteny. It occurs in axolotl larva.

#### Embryogenesis

During embryogenesis zygote undergoes mitotic cell division and cell differentiation. On the basis of development of zygote, animals can be **oviparous** (egg-laying; zygote develops outside the female body) e.g., all birds, most reptiles etc., **viviparous** (zygote develops inside the female body) e.g., mammals (except egg-laying mammals) or **ovoviviparous** (retains egg inside; zygote development is internal) e.g., sharks. In flowering plants, zygote is formed inside the ovule. After fertilisation the ripened ovary forms the fruit. The ovule matures and get converted into seeds. The ovary wall produces pericarp which protects the seeds.

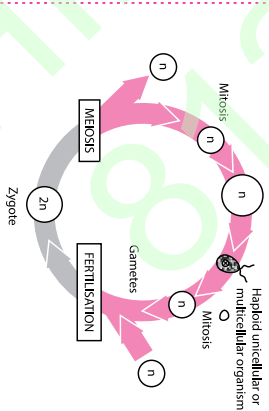
#### Post-fertilisation events

It includes development of zygote and embryogenesis.

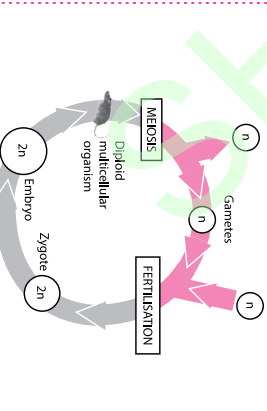
##### Development of zygote

The zygote formed by fusion of two gametes is always diploid. It is a link between one generation and next generation. The development of zygote depends upon the type of life cycle of the organisms and environmental conditions. There are three types of life cycles:

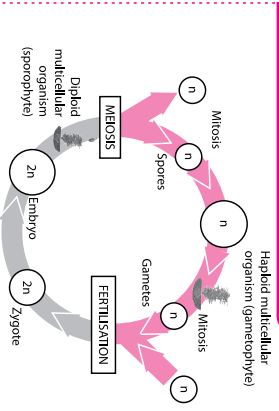
##### Haplontic life cycle occurs in many algae and fungi



##### Diplontic life cycle occurs in higher animals and seed bearing plants



##### Diplohaplontic life cycle occurs in bryophytes, pteridophytes and some algae.



ADMISSION HELPLINE

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### SPECIAL MODES OF REPRODUCTION



# CONCEPT MAP

## HUMAN MALE REPRODUCTIVE SYSTEM

- The male reproductive system is located in the pelvic region. It is a system of sex organs and accessory glands.
- It has main functions are:-
- Production of sperms by spermatogenesis.
  - Secretion of male sex hormone testosterone.
  - Ensures internal fertilisation.

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### ADMISSION HELPLINE

- **Sterility**
  - Inability of sperms to fertilise the ovum, due to low sperm count or low sperm motility.
- **Prostate cancer**
  - Common malignancy, accounting for 2-3% of male deaths.
  - Dysuria, difficulty in voiding, increased frequency of urination.
  - Treatment involves surgical removal of testes.

- **Sertoli / Sustentacular cells**
  - Large, pyramidal cells, projecting into lumen of seminiferous tubules, provide attaching sites to spermatocytes and spermatids.
  - Secrete **androgen binding protein (ABP)** that concentrates testosterone in the seminiferous tubules.
  - Function in response to FSH, secrete **inhibin** which suppresses FSH synthesis by negative feedback.
- **Impotence**
  - Inability of adult male to achieve or hold penile erection.
  - Occurs due to psychological, physiological or neuromuscular defects.

- **Germinal epithelium**
  - PGC undergo spermatogenesis to form spermatozoa.
- **Sertoli or sustentacular cells**
  - Wall of each seminiferous tubule is formed of single layered **primordial germinal epithelium**, PGC, of cuboidal cells, and tall **sertoli or sustentacular cells**.

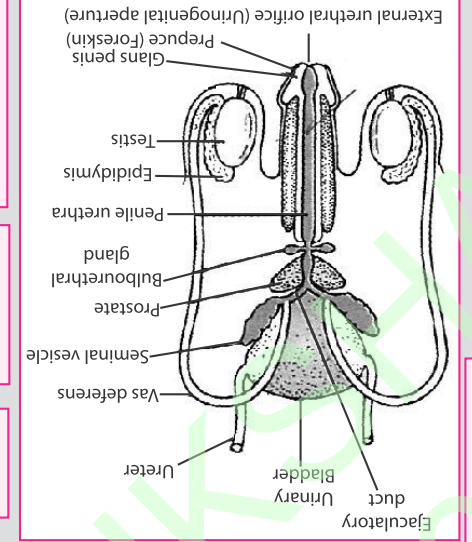
- **BPH or Benign prostatic hypertrophy**
  - Enlargement of prostate gland, common in old age.
  - Nocturia, dysuria and may lead to kidney damage.
- **Disorders of the male reproductive system**

- **Seminiferous tubules**
  - 250 compartments called testicular lobules are present in each testis, with 1-3 **seminiferous tubules** in each lobule, along with connective tissue.
  - Connective tissue contains endocrine cells called **Leydig's cells**.
- **Leydig's or interstitial cells**
  - Endocrine part of testis.
  - Secrete androgens, e.g., **testosterone**, which maintain male sexual characteristics and also stimulate spermatogenesis in germinal epithelium.
- **Tunica vasculosa**
  - Consists of rich network of capillaries, supported by delicate loose connective tissue which lines tunica albuginea.

- **Testicular lobules**
  - 3 Protective covering or tunicae surround each testis.
- **Protective coverings**
  - **Tunica vaginalis**
    - Flatsac, having a narrow coelomic cavity. Helps the testis in frictionless sliding.
  - **Tunica albuginea**
    - Fibrous covering of each testis, lying below tunica vaginalis.
    - Divides each testis into about 250 testicular lobules by forming vertical septa.
  - **Tunica vasculosa**
    - Consists of rich network of capillaries, supported by delicate loose connective tissue which lines tunica albuginea.

- **Seminal vesicles**
  - A pair of sac like structures near the base of bladder.
  - Produce an alkaline secretion, **seminal fluid** (pH 7.4), which forms 60% of volume of semen.
  - Seminal fluid is rich in **fructose** for nourishing sperms; **prostaglandins**, which stimulate uterine contractions for upward movement of sperms and **clotting proteins** for coagulation of semen after ejaculation.
- **Prostate gland**
  - Single gland, produces a milky secretion (pH 6.5), which forms 25% of volume of semen.
  - Prostate secretion contains citric acid, enzymes (acid phosphatase, amylase, pepsinogen), and **prostaglandins**.
  - Secretions nourish and activate the spermatozoa to swim.
- **Cowper's/bulbourethral glands**
  - A pair of glands present on either side of membranous urethra.
  - Secrete alkaline fluid lubricates the end of penis and lining of urethra.

- **Testes in scrotum**
  - Abdominal in early foetal life; extra-abdominal later.
  - Descend into pouch like scrotum in 7<sup>th</sup> month of embryonic development through inguinal canal.
  - A pair of testes is suspended in scrotum by **spermatic cords**.
  - Temperature is 2-2.5°C lower than internal body temperature.
  - Under hormonal control of **FSH** and **LH** from anterior lobe of pituitary.
- **Accessory glands**
  - Secrete seminal plasma or calcium, prostaglandins, semen rich in fructose, clotting proteins and certain enzymes.



- **Penis**
  - Erectile male copulatory organ.
  - Conducts both urine and semen, opens to the outside by urino-genital aperture on glans penis, covered by prepuce.
  - Contains three cylindrical masses of erectile tissue - two dorsal **corpora cavernosa** and one ventral **corpus spongiosum**, which help in stiffening during copulation.
  - Helps to transfer semen to female reproductive tract resulting in internal fertilisation.
- **Urethra**
  - Much longer, as compared to females, about 20 cm, common internal and external sphincters.
  - Differentiated into anterior **prostatic urethra**, surrounded by prostate gland carrying urine only; middle **membranous urethra**, which receives ducts from Cowper's gland; and distal **penile urethra**, which opens to the outside through penile meatus.

- **Ejaculatory ducts**
  - 2 short tubes each formed by union of duct from a seminal vesicle and a vas deferens.
  - They pass through prostate gland and join prostatic urethra to produce single **urinogenital duct**.
  - Muscular walls of ejaculatory ducts quickly conduct ejaculate through urinogenital duct.
- **Vasa deferentia**
  - Conduct sperms.
  - Leave the scrotal sac and enter abdominal cavity through inguinal canal.
  - Joined by duct from seminal vesicle to form ejaculatory duct.

- **Vasa efferentia**
  - 10-20 fine tubules connecting rete testis with epididymis, lined by many ciliated cells, which help in conducting sperms, and endocytic cells that remove debris accompanying sperms.
- **Rete testis**
  - Network of 20-30 fine seminiferous tubules open.

- **Epididymis**
  - Differentiated into anterior **caput epididymis**, middle **corpus epididymis** and posterior **cauda epididymis**.
  - Store sperms and also secrete nutrients required for maturation of spermatozoa.
- **Intratesticular genital duct system**
  - Store and transport sperms from the testes to the outside through urethra.
  - Include intratesticular genital duct system and vasa deferentia.

- **Accessory ducts**
  - Store and transport sperms from the testes to the outside through urethra.
  - Include intratesticular genital duct system and vasa deferentia.
- **Accessory glands**
  - Secrete seminal plasma or calcium, prostaglandins, semen rich in fructose, clotting proteins and certain enzymes.

- **Primary sex organs**
  - Produce male gametes or sperms.
  - Secrete male sex hormone or testosterone.
- **Secondary sex organs**
  - Secrete seminal plasma or calcium, prostaglandins, semen rich in fructose, clotting proteins and certain enzymes.

# CONCEPT MAP

## HUMAN FEMALE REPRODUCTIVE SYSTEM

The human female reproductive system is located in the pelvic region and consists of a pair of ovaries, along with a pair of oviducts, uterus, cervix, vagina, external genitalia and glands. Breasts or mammary glands are considered part of the female reproductive system, because of their role in nourishing the offspring. Main functions of female reproductive system are:

- Production of ova by oogenesis.
- Secretion of female sex hormones e.g., estrogen, progesterone, etc.
- Fertilization, pregnancy, giving birth and child care.

### Primary sex organs

- Paired structures located in upper pelvic cavity.
- 2 to 4 cm in length, shaped like an unshelled almond.
- Covered by a layer of cubical epithelium called the germinal epithelium and further by visceral peritoneum. Beneath the underlying tunica albuginea - a layer of connective tissue.
- Underlying tunica albuginea is the ovarian stroma, differentiated into dense outer layer called cortex, and a less dense inner portion called medulla.
- Interspersed throughout the cortex are many ovarian follicles in different stages of development and are called primary, secondary, tertiary and Graafian (mature) follicles.
- A mature Graafian follicle consists of an oocyte surrounded by a homogeneous membrane **zona pellucida** and radially elongated follicle cells called **corona radiata**, further surrounded by follicular cells forming **membrana granulosa**.
- Granulosa cells are differentiated into outer fibrous **theca externa** and inner cellular **theca interna** which secrete a fluid called **liquor folliculi** creating a large cavity called **antrum** or follicular cavity.
- Oocyte adheres to the granulosa layer by a stalk called **cumulus ovaricus** or **cumulus oophorus**.
- Total number of follicles in two ovaries of a normal young adult woman is about four lakhs, but only 450 mature during the entire reproductive span. Many ovarian follicles undergo degeneration, called **follicular atresia**.
- Graafian follicle releases an oocyte during ovulation and converts into a yellow body called **corpus luteum**, which secretes mainly progesterone and some relaxin hormone.
- In absence of fertilization, corpus luteum degenerates about 12 days after ovulation becoming the corpus albicans which is replaced by connective tissue and over months is absorbed.
- Ovaries perform two functions: production of ova and secretion of female sex hormones.

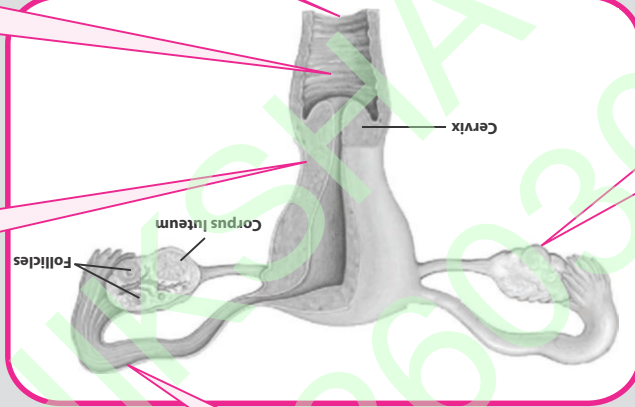
### Ovary

### Glands

- **Vestibular glands:** They are of two types-
  - **Greater vestibular glands/Bartholin's glands** are paired glands, situated one on each side of vaginal orifice; homologous to bulbourethral/Cowper's glands of male and secrete viscous fluid that supplements lubrication during sexual intercourse.
  - In females, breasts are undeveloped, until puberty.
  - Externally, each breast has a projection, i.e., **nipple** surrounded by a circular pigmented area of skin called **areola**.
  - Mammary glands consist of glandular, fibroid and adipose tissues.
  - Lobules, which contain grape like clusters of milk secreting glands called **alveoli**.
  - When milk is produced, it passes from **alveoli** into the **mammary tubules** and then into **mammary ducts**. Near the nipple, mammary ducts expand to form **mammary ampullae**, where some milk may be stored, before going to **lactiferous ducts** from which, it is secreted out.
  - **Fibrous tissue** supports the alveoli and ducts.
  - **Fatty or adipose tissue** is found between the lobes and covers the surface of the gland. The amount of adipose tissue determines the size of the breasts.
  - Main function of mammary glands is secretion and ejection (release) of milk.
  - Milk production is stimulated by hormone prolactin, and ejection of milk by the hormone oxytocin.

### Fallopian tube/oviduct

- There are two Fallopian tubes and each is about 10-12 cm long consisting of
  - **Infundibulum**, ampulla and isthmus.
  - The **infundibulum** is a dilated trumpet-like portion of the Fallopian tube, with fingerlike projections called **fimbriae**, and an **ostium** which helps in collection of the ovum after ovulation.
  - **Ampulla** is the widest and longest part of the Fallopian tube. **Isthmus** is the short, narrow thick-walled portion that follows the ampulla. Fertilization of ovum occurs at the **ampullary-isthmic junction**.
  - **Uterine part** passes through the uterine wall and communicates with the uterine cavity.
  - Function of the Fallopian tube is to convey the ovum from ovary to the uterus by peristalsis.



### Disorders of female reproductive system

- **Breast cancer**
  - It is rarely seen before age of thirty; incidence increases after menopause.
  - Standard treatment is mastectomy.
- **Ectopic pregnancy**
  - It is implantation of embryo at a site other than uterus, generally in the oviduct.
- **Menstrual disorders**
  - Amenorrhea - Absence of menstruation.
  - Menorrhagia - Excessive menstruation.
  - Dysmenorrhea - Painful menstruation.
- **Infertility**
  - In women, infertility is inability to become pregnant.
  - It may be due to failure to ovulate or any anatomical factor which prevents the union of egg and sperm or subsequent implantation.

### Uterus

- Also known as metra/hystera/womb.
- It is a hollow muscular, inverted pear shaped structure lying in the pelvic cavity between the urinary bladder and the rectum.
- It is differentiated into the following parts:
  - (i) **Fundus** is the upper dome-shaped part of the uterus, above the openings of the uterine parts of the Fallopian tubes.
  - (ii) **Cornua (sing. cornu)** are upper corners where the oviducts enter the uterus.
  - (iii) **Body** is the main part, which is narrowest inferiorly, where it continues with the cervix.
  - (iv) **Cervix** joins the anterior wall of vagina and opens into it. The cervix communicates above with the body of uterus by an aperture called **internal os**, and with the vagina by an opening, **external os**.
  - Walls of the uterus are composed of three layers of tissues, **perimetrium** - outer thin covering of peritoneum, (ii) **myometrium** - middle thick layer of smooth muscle fibres that shows strong contraction during delivery of the baby and (iii) **endometrium** - inner glandular layer that lines the uterine cavity and undergoes cyclical changes during menstrual cycle.
  - After puberty, the uterus goes through the menstrual cycle in absence of fertilization.
  - After fertilization, embryo gets attached to the uterine wall, where it is nourished and protected and menstruation is temporarily suspended.

### Vagina

- A tube that extends from cervix to the outside of the body.
- A passageway for menstrual flow, receptacle for sperms during intercourse, and part of the birth canal, during labour.
- The opening of vagina, called vaginal orifice is partially covered by a membrane called **hymen**.
- Two Fallopian tubes (oviducts), uterus and vagina constitute the female accessory ducts.

### External genitalia

- Collectively called vulva or pudendum. It is differentiated into the following parts:
  - (i) **Mons pubis** : Anterior most portion of the external genitalia, consists of fatty tissue covered by skin and pubic hair.
  - (iii) **Clitoris** : Posterior to mons pubis; homologous to glans penis of male.
  - (iiii) **Labia majora** : Two large fleshy folds of skin, which form the boundary of vulva; partly covered by pubic hair and contain large number of sebaceous (oil) glands; homologous to scrotum of the male.
  - (iv) **Labia minora** : Two smaller folds of skin lie under the labia majora; are homologous to penile urethra of male. The area between the labia minora is called **vestibule**. Posteriorly the labia minora are fused to form **fourchette**.
  - (v) **Perineum** : The area which extends from the fourchette to anus.



# GAMETOGENESIS

Gametogenesis is the process by which male and female sex cells or gametes i.e., sperms and ova are formed respectively in the male and female gonads (testes and ovaries). It is the major reproductive event in sexual reproduction.

## Spermatogenesis

- Process of sperm formation in testes after puberty.
- Occurs in seminiferous tubules of testes, which are lined by germinal epithelium, consisting of interstitial (Leydig) cells and Sertoli (nurse) cells.
- Includes formation of PGCs and formation of spermatogonia.
- PGCs are largely cuboidal in outline, which divide first by mitosis and later by meiosis.
- Spermatozoa are produced from one spermatogonial cell.
- Spermatozoa consists of multiplication, growth, maturation and differentiation phases.

### Multiplication phase

- At sexual maturity, the PGCs divide several times by mitosis to produce a large number of **spermatogonia (2n)**.
- Spermatogonia are of two types: **Type A spermatogonia**, which serve as stem cells, and **Type B spermatogonia**, which are the precursors of sperms.

### Growth phase

- Each Type B spermatogonium actively grows to a larger **primary spermatocyte (2n)** by obtaining nourishment from the Sertoli cells.

### Maturation phase

- Each primary spermatocyte undergoes two successive divisions of meiosis.
- As a result of 1<sup>st</sup> meiotic division, which is reductional division, two haploid **secondary spermatocytes (n)** are produced.
- Secondary spermatocytes undergo the 2<sup>nd</sup> meiotic division, which is an equational or mitotic division, producing four haploid **spermatids (n)**.

## Differentiation phase or Spermiogenesis

- It is the transformation of the spermatids into **spermatozoa**, or **sperms** in about 64 days, and involves the following changes:
  - Formation of acrosome by Golgi apparatus; elongation and condensation of nucleus; formation of axial filament from distal centriole; separation of centrioles; development of mitochondrial spiral; formation of flagellum.
- **Sperm/Spermatozoan**: Sperms are microscopic, motile and remain viable for 24 to 48 hrs. after their release in the female genital tract.
- A typical spermatozoan consists of head, neck, middle piece and tail.
- **Head**: Contains anterior acrosome and posterior nucleus; acrosome contains sperm lysins for egg penetration during fertilisation.
- **Neck**: Very short; connects head to middle piece; contains proximal centriole towards the nucleus, which has a role in the first cleavage of the zygote and distal centriole, that gives rise to the axial filament of the sperm.
- **Middle piece**: Bears the mitochondrial spiral, therefore called 'power house of sperm'; ring centriole or annulus, with unknown function at the end of middle piece.
- **Tail**: It is several times longer than the head; the sperm swims about by its tail in a fluid medium.

## Spermiogenesis

It is the process of release of sperms from the Sertoli cells. Sperms, after release are stored in epididymis and upper portion of vasa deferentia for upto one month, where they obtain nourishment from epithelium of epididymis and gain motility.

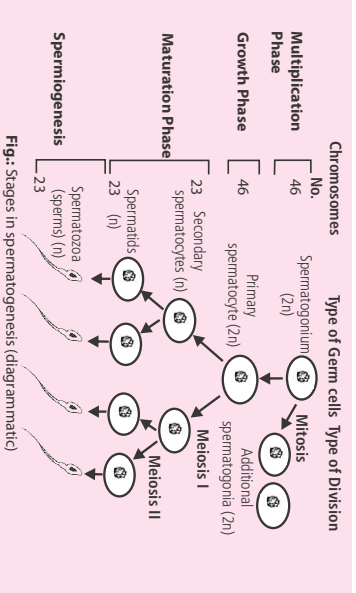
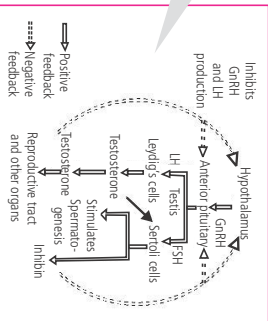


Fig.: Stages in spermatogenesis (diagrammatic)

## Hormonal control

- Spermatogenesis is initiated due to increase in GnRH by hypothalamus.
- GnRH acts on anterior lobe of pituitary to secrete LH and FSH.
- LH acts on Leydig's cells to secrete testosterone.
- FSH acts on Sertoli cells to secrete ABP and Inhibin.
- FSH also stimulates spermatogenesis, thus promoting sperm production.
- ABP concentrates testosterone in the seminiferous tubules.
- Inhibin suppresses FSH synthesis.



## Oogenesis

- Process of ovum formation, which starts in the foetal ovary (25 weeks old) and is completed after puberty.
- Occurs in the germinal epithelium of the foetal ovary.
- Results in the formation of one ovum and three polar bodies, every month after puberty.
- Cells of germinal epithelium, larger than the others, function as **germ cells**.
- Germ cells divide first by **mitosis** and then by **meiosis**.
- Consists of multiplication, growth and maturation phases.

### Multiplication phase

- Germ cells in the foetal ovary divide by mitosis to form millions of egg mother cells or **oogonia**.
- Oogonia form **egg tubes** into the stroma of ovary, which form a multicellular mass called **egg nest**.
- All the oogonia are formed in the foetal ovary, and no more are formed after birth.

### Growth phase

- One oogonium of the egg nest grows in size forming **primary oocyte**, surrounded by layer of granulosa cells, forming **primary follicle**.
- Total number of **primary follicles** in foetal ovary is about 60 lakhs.
- Large number of primary follicles undergo **follicular atresia**, so that a young adult woman has only about 4 lakhs primary follicles in both ovaries.

### Maturation phase

- Primary oocyte begins meiosis I, but division is arrested at diakinesis of prophase I.
- Ovarian follicle containing primary oocyte occurs in the foetal ovary and remains so, till puberty.
- At puberty, primary oocyte grows and completes meiosis I, producing large **secondary oocyte (n)** and small **polar body** or **polocyte (n)**.
- Secondary oocyte proceeds with meiosis II, but the division gets arrested in metaphase II, followed by ovulation.
- Meiosis II is completed only after entry of sperm, resulting in the formation of ovum and another polar body.

## Ovulation

- It is the release of secondary oocyte, after puberty, once every month from Graafian follicle, by any one ovary. Only 450 secondary oocytes are produced during the entire reproductive span. Ruptured Graafian follicle forms corpus luteum.
- **Ovum**: Spherical, alethal, with cytoplasm containing germinal vesicle or nucleus, nucleolus and cortical granules; cytoplasm protected by plasma membrane. Shows polarity, differentiated into an animal pole and a vegetal pole; centrioles absent, protected by two coverings.
- **Corona radiata**: Outer, multilayered covering of radially elongated follicular cells, held together by hyaluronic acid.
- **Zona pellucida**: Inner, noncellular, glycoprotein rich covering with receptor proteins; bears in growth of follicular cells for transfer of nutrients to the egg.
- **Perivitelline space**: Narrow space present between plasma membrane and zona pellucida.

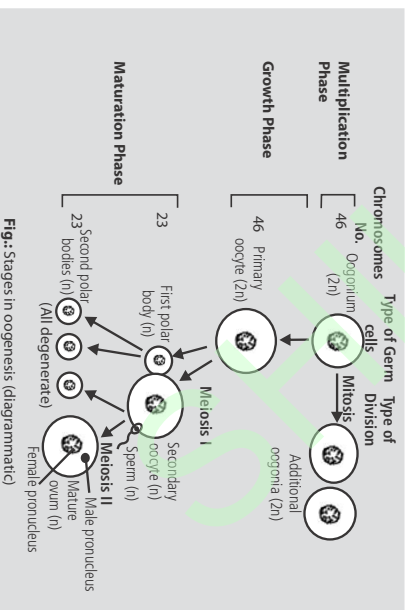
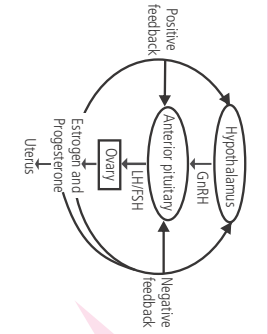


Fig.: Stages in oogenesis (diagrammatic)

## Hormonal control

- Oogenesis is initiated due to increase in GnRH by hypothalamus.
- GnRH acts on anterior lobe of pituitary to secrete FSH and LH.
- FSH stimulates follicular growth and maturation of oocyte; FSH stimulates the follicular granulosa cells to secrete estrogen.
- LH stimulates corpus luteum to secrete progesterone.





# CONCEPT MAP

## DNA REPLICATION

Replication is the process of formation of carbon copies of DNA. The primary function of DNA replication is to provide same genetic material as possessed by the parent to the progeny. Thus, the replication of DNA must be complete and carried out in such a way as to maintain genetic stability within the organism and the species. For replication, DNA itself functions as template, therefore, DNA replication is an autocatalytic function of DNA. It occurs during S-phase of the cell cycle and is a multistep complex process which requires over a dozen of enzymes and protein factors.

### Semi-conservative Replication

DNA replication is **semi-conservative** i.e., a type of replication in which one strand of the daughter duplex is derived from the parent while the other strand is formed anew. The parent strands are separated and act as template for synthesis of new daughter strand. The new strand has complementary base pairs to template strand. (A opposite T and G opposite C).

### Origin of Replication

Replication begins at a particular region called **origin of replication** or *Ori* on the chromosome. Most of the bacterial DNA has single *Ori* hence functions as a **replicon** while eukaryotes have multiple *Ori* (multirepliconic). The interaction of specific proteins with *Ori* defines the start site of replication and provides a short region of ssDNA to initiate synthesis of the nascent DNA at each point along the chromosome where replication is occurring.

### Helicases

These are the proteins/enzymes which act over the *Ori* site in order to unwind the two strands of DNA by breaking hydrogen bonds. One particular protein **Dnaa** initiates first step in unwinding of DNA helix. This facilitates the subsequent binding of **DnaB** and **DnaC** proteins that further open and destabilise the helix. The energy required by the proteins to break hydrogen bonds or denaturing the double helix is supplied by the hydrolysis of ATP. The separation of strands create a **replication fork**. Such a fork will initially appear at the point of origin of synthesis and then move along the DNA duplex as replication proceeds. Replication is **bidirectional** and **two forks** migrate in opposite directions away from the origin.

### DNA Polymerase

The main enzyme of replication is **DNA dependent DNA polymerase** that catalyses the polymerisation of deoxynucleotides to synthesise a new strand. **Prokaryotes** have **three major types** of DNA synthesising enzymes called **DNA polymerase III, II and I**, whereas **five types** of DNA polymerase are found in **eukaryotes** ( $\alpha, \beta, \gamma, \delta, \epsilon$ ) to accommodate increased number of replicons. In eukaryotes, polymerase  $\alpha$  initiates replication but is soon replaced by the polymerase  $\delta$  which is the primary enzyme for DNA synthesis. **Polymerase III** is considered to be the enzyme responsible for the **polymerisation** in prokaryotes.

### Topoisomerases

As unwinding proceeds, a coiling tension is generated ahead of the replication fork, often producing supercoiling. Such supercoiling can be relaxed by **DNA gyrase**, a member of a larger group of enzymes referred to as DNA topoisomerases. The gyrase makes either single or double stranded "cuts" and catalyses localised movements that have the effect of "undoing" the twists and knots created during supercoiling. The strands are then resealed. These various reactions are driven by the energy released during ATP hydrolysis.

### Single Strand Binding Proteins

The separated strands are stabilised and maintained by **single strand binding proteins (SSBs)** which prevent premature reannealing of ssDNA to dsDNA. This allows enzymes including helicase, primase and DNA polymerase, to bind and initiate DNA synthesis.

### Proofreading and Error Correction

Although the action of DNA polymerase is very accurate, synthesis is not perfect and a noncomplementary nucleotide is occasionally inserted erroneously. To compensate for such inaccuracies, all DNA polymerases possess **3' → 5' exonuclease activity**. This property enables them to detect and excise a mismatched nucleotide (in the 3' → 5' direction). Once the mismatched nucleotide is removed, 5' → 3' synthesis can again proceed. This process **increases the fidelity** of synthesis.

### DNA Polymerase in Prokaryotes and Eukaryotes

**DNA polymerase I** demonstrates 5' → 3' exonuclease activity apart from 3' → 5' exonuclease activity. Polymerase I is believed to be responsible for removing the primer, as well as for filling the gaps which naturally occur as primers are removed. Its exonuclease activity also allows for proofreading during this process, a form of DNA repair. **Polymerase II** is also involved in DNA repair. The **3' → 5' exonuclease** activity of polymerase III provides its **proofreading function**. **Polymerase  $\epsilon$**  in eukaryotes may help in synthesis of lagging strand along with other roles and **polymerase  $\beta$**  helps in DNA repair.

### Leading Strand

**DNA polymerase can polymerise nucleotides only in 5' → 3' direction** because it adds them at the 3' end. Since the two strands of DNA run in **antiparallel direction**, the two templates provide different ends for replication. Replication over the two templates thus, proceeds in **opposite direction**. The strand with polarity 3' → 5' forms its **complementary strand** continuously because 3' is always open for elongation. It is called **leading strand** with polarity 5' → 3'.

### Primase

DNA polymerase III requires a primer with a free 3' end in order to elongate a polynucleotide chain. A short segment of RNA called **RNA primer** (about 5 to 15 nucleotides long), which is complementary to DNA, is first synthesised on the DNA template directed by a form of RNA polymerase called primase. It does not require a **free 3' end** to initiate synthesis. It is to this short segment of RNA that **DNA polymerase III** begins to add 5'-deoxyribonucleotides, initiating DNA synthesis. Later the **RNA primer** clip out and is replaced with DNA. RNA priming is a universal phenomenon recognised in viruses, bacteria and several eukaryotic organisms, during the initiation of DNA synthesis.

### Sliding clamp or DNA clamp

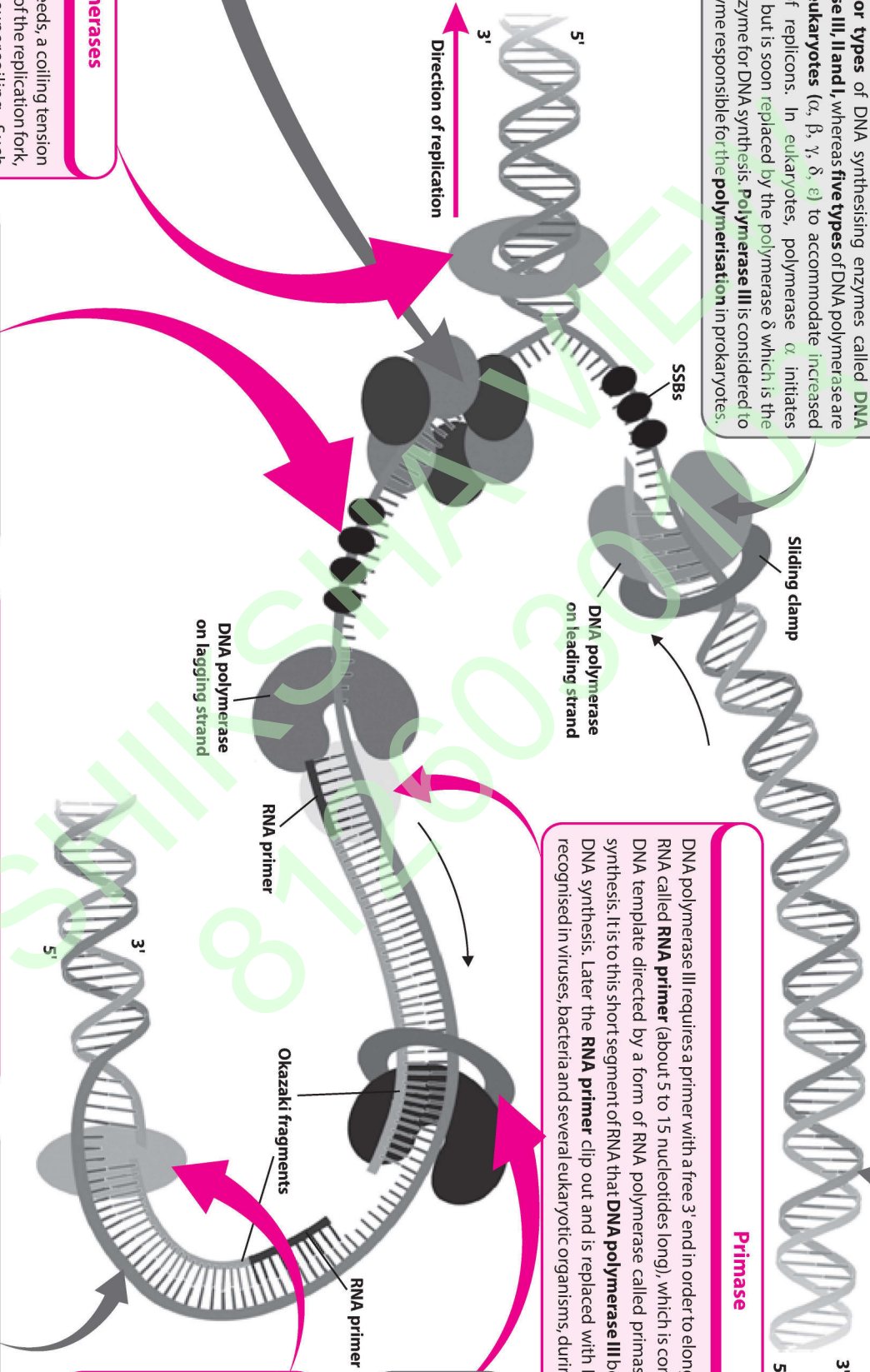
It is an important protein of DNA polymerase III holoenzyme that prevents the dissociation of polymerase from template strand of DNA.

### DNA Ligase

Discontinuous synthesis of DNA requires enzyme DNA ligase that both removes the RNA primer and unites the Okazaki fragments into the lagging strand. DNA ligase, catalyses the formation of the **phosphodiester bond** that seals the nick between the 3'-hydroxyl of the growing strand and 5'-phosphate of an Okazaki fragment.

### Lagging Strand

Lagging strand is the strand synthesised in direction opposite to the growing replication fork, i.e., (3' → 5'). Here, the DNA is synthesised discontinuously in short (1-5 kb) fragments, known as **Okazaki fragments**. Several Okazaki fragments (upto a thousand) must be sequentially synthesised for each replication fork. To ensure that this happens, the helicase associates with the primase. This allows the RNA primer to be made and, in turn, the polymerase begin replication of DNA. An RNA primer is required every time to form a new Okazaki fragment.





CONCEPT  
MAP

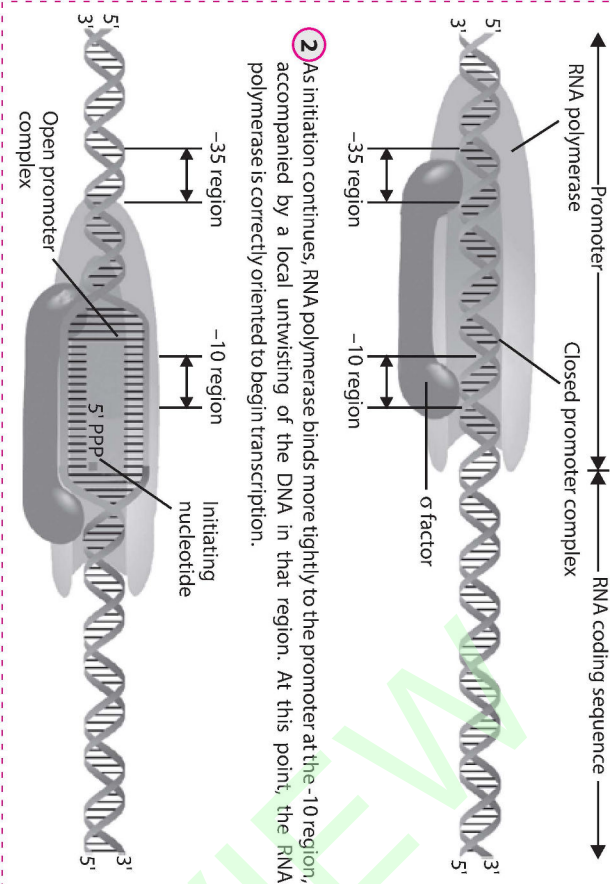
TRANSCRIPTION

Transcription is the process of copying of genetic information from template strand of DNA to an RNA molecule. Template strand refers to DNA strand that directs synthesis of RNA and have 3' → 5' polarity. The other strand having 5' - 3' polarity is called antisense strand. RNA synthesis occurs in 5' → 3' direction and requires an enzyme complex called RNA polymerase and other initiation and termination proteins.

IN PROKARYOTES

The sigma (σ) factor binds to promoter site of DNA and initiates transcription.

- 1 In initiation, the RNA polymerase holoenzyme first recognises the promoter at the -35 region and binds to the full promoter.



- 2 As initiation continues, RNA polymerase binds more tightly to the promoter at the -10 region, accompanied by a local untwisting of the DNA in that region. At this point, the RNA polymerase is correctly oriented to begin transcription.

MECHANISM OF TRANSCRIPTION

Involves three steps:

Initiation

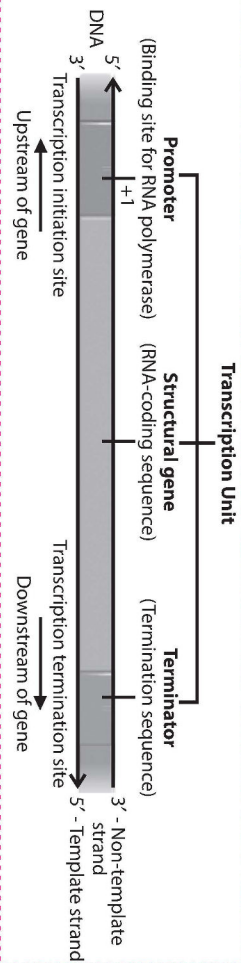
Just before initiation, RNA polymerase and accessory proteins bind to a DNA molecule upstream of the initiation point. The DNA is unwound to separate and expose the strand to be transcribed. Then, the RNA polymerase complex binds to promoter sequence, which initiates transcription. Polymerase begins to synthesise a strand of RNA complementary to one side of the DNA strand, moving into the coding sequence portion of the gene being transcribed. The enzyme and the factors involved are different in both eukaryotes and prokaryotes.

Elongation

During elongation, a lengthening RNA molecule is synthesised by DNA polymerase as it reads the DNA triplet code on the template strand. The DNA polymerase will continue reading the template until it reaches a sequence that provides a signal indicating that transcribed region is at an end. Another RNA polymerase can attach to the promoter to begin synthesising another RNA before the first one is finished.

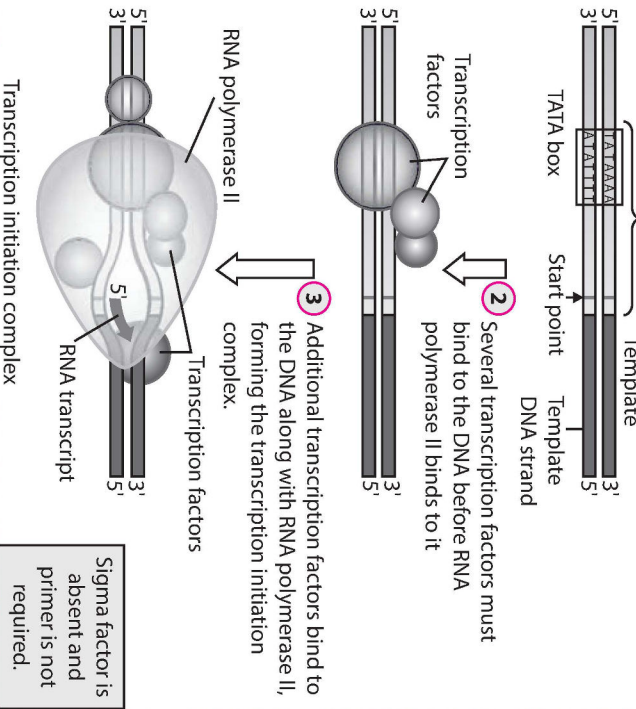
TRANSCRIPTION UNIT

Refers to the sequence of nucleotides in DNA that codes for an RNA molecule along with other sequences necessary for transcription.



IN EUKARYOTES

- 1 An eukaryotic promoter includes a TATA box and CAAT box



- 2 Several transcription factors must bind to the DNA before RNA polymerase II binds to it
- 3 Additional transcription factors bind to the DNA along with RNA polymerase II, forming the transcription initiation complex.

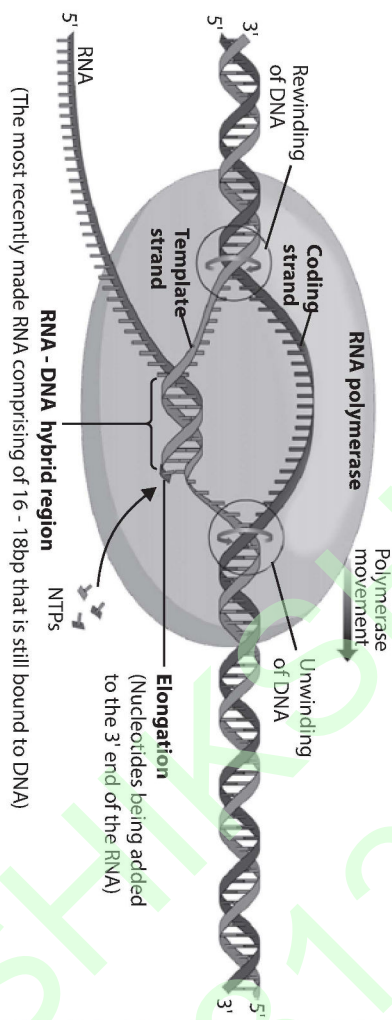
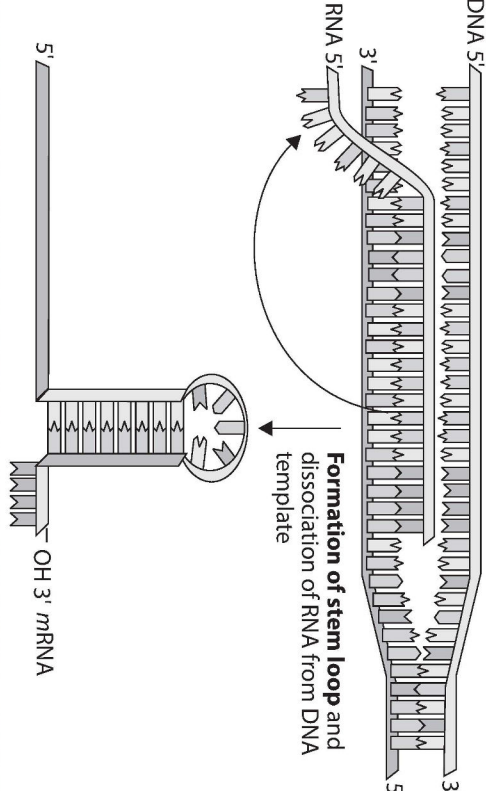
Sigma factor is absent and primer is not required.

- Transcription takes place in nucleus.
- Structural genes are monocistronic i.e., encodes for single polypeptide.
- Promoters include- (i) "-25 sequence" is TATAAAA, called "Hogness box" or "TATA box" (ii) "-75 sequence" is GGCCAATCT, called "CAAT box".
- Besides promoters, eukaryotes also require enhancers.
- Three types of RNA polymerases are involved: RNA Pol I (transcribes rRNAs), RNA Pol II (transcribes mRNA, hnRNA), RNA Pol III (transcribes tRNA, 5S rRNA, etc.)

- Termination may or may not require rho (ρ) factor.

- mRNA do not undergo any processing and may undergo translation before the completion of transcription i.e., coupled as both the processes takes place in cytosol and in 5' → 3' direction.

Most prokaryotic mRNAs terminate with the sequence 5'-UUUUUA-3', which allows nascent transcript to form hairpin loop that disrupts the RNA-DNA hybrid as well as the interaction between DNA and polymerase resulting in dissociation and termination of transcription of RNA molecule.



Termination

Termination of transcription is triggered when the RNA polymerase encounters a particular DNA sequence, causing the polymerase to lose affinity for the DNA template. At this point, RNA polymerase disengages from the DNA and the RNA molecule is released for translation or post-transcriptional processing.



Post Transcriptional Modifications of hnRNA

Capping

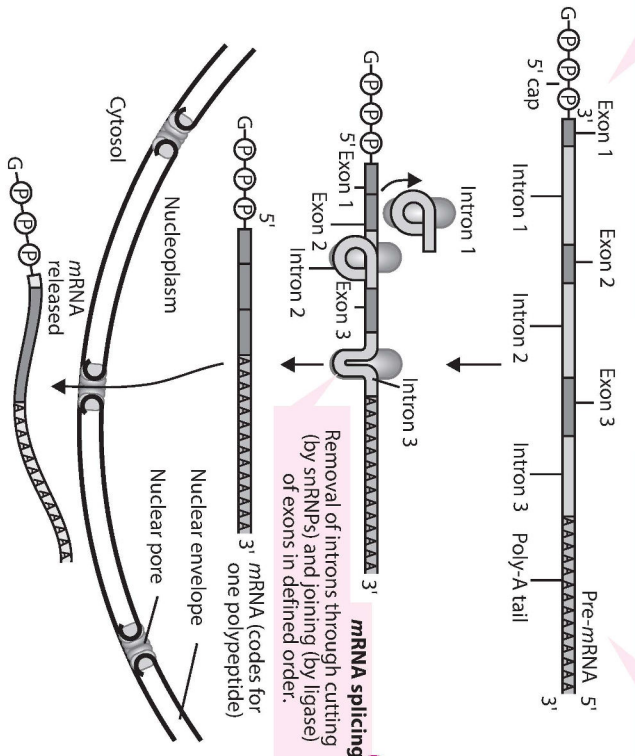
- 1 Addition of methyl guanosine triphosphate (mGPP) that protects mRNA from nucleases and provides ribosome binding site.

Tailing

- 2 Addition of 200-300 polyadenylate residues with the help of poly A polymerase. It protects 3' end from degradation by exonucleases.

mRNA splicing

- 3 Removal of introns through cutting (by snRNPs) and joining (by ligase) of exons in defined order.



- Termination - Coupled transcription-translation is not possible in eukaryotes, as transcription products i.e., RNA pass from nucleus to cytoplasm for translation. The nascent RNA i.e., hnRNA or primary transcript undergoes modifications to form functional mRNA.



# TRANSLATION

Translation is the process by which a protein or polypeptide is synthesised inside the living cell using mRNA as a template. This biochemical process is called translation because the information present in the form of four letter alphabet of nucleic acid is translated into twenty letter alphabets of proteins.

- The steps of translation are common in both prokaryotes and eukaryotes. Three main steps involved in translation are initiation, elongation and termination. Before initiation amino acids are activated and attached to tRNAs in two steps called activation of amino acids and charging or aminoacylation of tRNA respectively.
- In eukaryotes, the initiating amino acids methionine, not N-formylmethionine (fMet) as in prokaryotes.
- The main difference between initiation of translation in prokaryotes and eukaryotes is that in bacteria, a Shine-Dalgarno sequence (4 to 9 purine residues, 8 to 13 base pairs to the 5' side of initiation codon) guides correct initiation codon (5' AUG) and is the binding site for the 30S ribosomal subunit.
- In contrast, most eukaryotic mRNAs do not contain Shine-Dalgarno sequences. Instead, a 40S ribosomal subunit attaches at the 5' end of the mRNA and moves downstream (i.e., in 5' to 3' direction) until it finds the AUG initiation codon. This process is called **scanning**.

- Amino acids are activated by activating enzymes, aminoacyl tRNA synthetases in presence of ATP to produce aminoacyl-adenylate-enzyme complex.

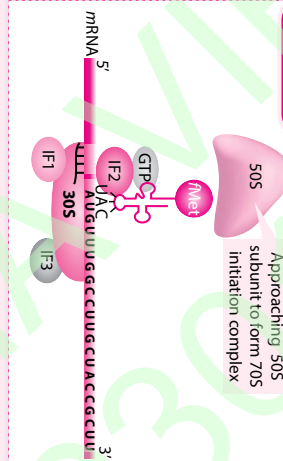


- This complex reacts with tRNA specific for the amino acid. Amino acid links to 3' - OH end of tRNA through its - COOH group to form aminoacyl-tRNA complex.



## Prokaryotes

Approaching 50S subunit to form 70S initiation complex

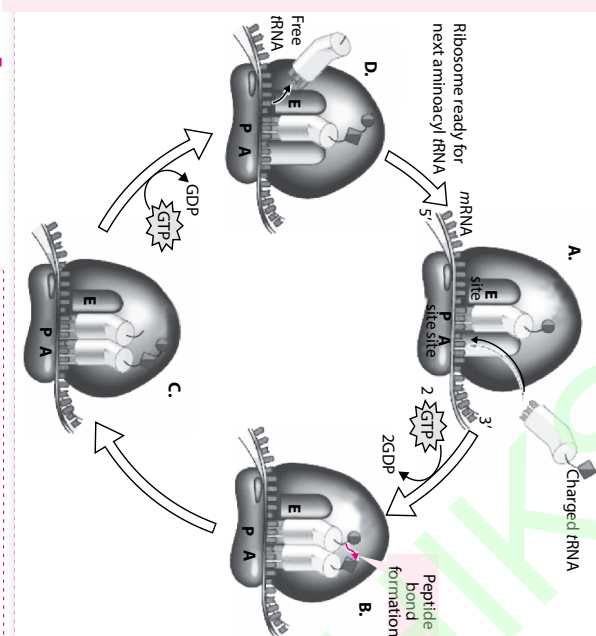


## 2 Initiation

- Initiation factors are required, i.e., **IF1**, **IF2** and **IF3**.
  - Initiation begins with the binding of **IF1** and **IF3** to the small (30S) ribosomal subunit.
  - The small subunit then binds to the mRNA *via* complementary pyrimidine rich sequences close to 3' end of 16S rRNA guided by Shine-Dalgarno sequence and moves 3' along the mRNA until it locates the AUG initiation codon.
  - The initiator tRNA charged with N-formylmethionine and a complex of IF2 and GTP (Met-tRNA<sup>Met</sup>/IF2/GTP) now binds to mRNA and 30S subunit.
  - The complex of mRNA, Met-tRNA<sup>Met</sup>, IF1, IF2 and the 30S ribosomal subunit is called the **30S initiation complex**.
  - Structural changes then lead to the ejection of IF1 and IF3 and IF2 now stimulates the association of 50S subunit of ribosomes. Simultaneously, the GTP bound to IF2 is hydrolysed to GDP and Pi and leading to release of IF2. This forms **70S initiation complex**.
- When this complex is formed, the ribosome is ready for the elongation phase.
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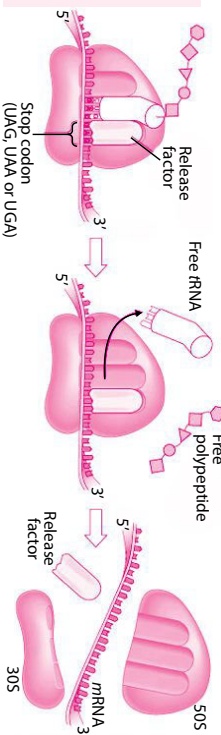
### Elongation

- Elongation requires three factors, i.e.,
  - **EF-Tu**, **EF-Ts** and **EF-G** and enzyme **peptidyl transferase**.
- The **Met-tRNA<sup>Met</sup>** occupies the P site and carries an aminoacyl-tRNA complex (aminoacyl-tRNA-EF-Tu-GTP) react at A site depending upon the anticodon present on mRNA. EF-Ts and GTP are required for the regeneration of **EF-Tu-GTP complex**.
- First peptide linkage is now established between -COOH group of amino acids at P site and -NH<sub>2</sub> group of amino acid at A site catalysed by the enzyme **peptidyl transferase**.
- This produces a dipeptidyl-tRNA in the A site and now uncharged tRNA<sup>Met</sup> remains bound to the P site. With the help of EF-G (translocase) dipeptidyl-tRNA moves from A site to P site. The ribosome moves one codon toward the 3' end of mRNA (called translocation). Free tRNA slips to E site and from there to outside in the cytoplasm.
- New codon exposed at A site attract new aminoacyl-tRNA complex and thus peptide chain elongates.



#### 4 Termination

- Termination occurs when a **non sense** or **stop codon** (UAA, UAG, UGA) reaches a site.
- Stop codons are recognised by 2 release factors **RF1** and **RF2**. A third factor **RF3** mediates interaction between RF1 or RF2 with the ribosome.
- RF-1 is specific to UAGand UGA.
- RF-2 is specific to UAA and UGA.
- RFs hydrolyse the terminal peptide-rRNA bond, release polypeptide and last rRNA.
- From the P site and dissociates two subunits of ribosomes to start new cycle of translation.



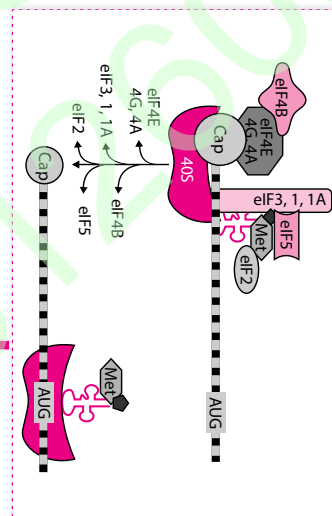
## Translational Machinery

- Basic translational machinery is same in eukaryotes and prokaryotes, however few differences occur. It is composed of five components, i.e., mRNA, rRNA, amino acid, enzymes (aminoacyl tRNA synthetase, peptidyl transferase) and ribosome.
- In eukaryotes, each rRNA is **monocistronic** (encodes for only one polypeptide) whereas in prokaryotes, many rRNAs are **polycistronic** (encodes for two or more different polypeptides).
- **Ribosome** is the **site of protein synthesis**. **70S** (30S + 50S) ribosomes are involved in prokaryotic translation while **80S** (40S + 60S) ribosomes are involved in eukaryotic translation. The two subunits of ribosomes, associate at the time of protein synthesis and then separate after the completion of process. Ribosomes have three sites; **the peptidyl (P) site**, **aminoacyl (A) site** and **exit (E) site**. Eukaryotic ribosomes do not have E-site.
- **tRNAs pick up particular amino acids** (at CCA or 3' end) and take the same to mRNA over particular codons corresponding to their anticodons. Each rRNA contact with ribosome at T<sup>Ψ</sup>C loop and the enzyme aminoacyl tRNA synthetase at DHU loop. Eukaryotic rRNAs have 5'-cap and poly A tail at 3' end.

## Eukaryotes

## Initiation

- Eukaryotic cells have at least nine initiation factors, *i.e.*, **eIF2**, **eIF2B**, **eIF3**, **eIF4A**, **eIF4B**, **eIF4E**, **eIF5** and **eIF6**.
- The first step is the formation of a **pre-initiation complex** consisting of the 40S small ribosomal subunit, Met-rRNA<sub>Met</sub>, eIF2 and GTP.
- The pre-initiation complex now binds to the 5' end of the eukaryotic mRNA, a step that requires **eIF4F** complex (eIF4A, eIF4E, also called **cap binding complex**) and **eIF3**. Thus, this complex interact both the 5' and 3' ends of the mRNA.
- The eIF4A is a RNA helicase that unwinds any secondary structure of mRNA, preparing it for translation.
- The complex now moves along the mRNA in a 5' to 3' direction until it locates the AUG initiation codon (*i.e.*, scanning of mRNA).
- Once the complex is positioned over the initiation codon, the 60S large ribosomal subunit binds to form an **80S initiation complex**, a step that requires the hydrolysis of GTP and leads to the release of several initiation factors.



## Elongation

- The elongation stage of translation in eukaryotes is quite similar to the prokaryotes. It requires three elongation factors, **eEF1 $\alpha$** , **eEF1 $\beta$**  and **eEF2** as counterparts of prokaryotic EF-Tu, EF-Ts and EF-G, respectively.
- The GTP form of EF1 $\alpha$  delivers aminoacyl-tRNA to the A site of the ribosome and EF1 $\beta$  catalyses the exchange of GTP for bound GDP. eEF2 mediates GTP driven translocation similar to prokaryotic EF-G.
- As eukaryotic ribosome do not have E site, uncharged tRNAs are expelled directly from the P site.
- The elongated peptide chain or polypeptide lies in the groove of the larger subunit of ribosome.

## Termination

- Termination in eukaryotes is similar to that in prokaryotes.
- In eukaryotes, a single factor **eRF1** recognises **all three termination codons** and with the help of **eRF3**, ribosomal subunits are released.
- **eRF3** prevents the reassociation of ribosomal subunits in the absence of an initiation complex.



# CONCEPT MAP HUMAN EVOLUTION

The process of evolution involves a series of natural changes that cause species to arise, adapt to the environment and become extinct. Humans too have originated through the process of biological evolution. The study of human evolution is called Paleanthropology. Most of the scientists currently recognise 15-20 different species of early humans, of which major landmark species are discussed below.



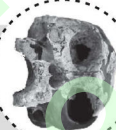
**Homo sapiens sapiens**  
(Homo sapiens)  
**Period :** 25,000 years ago (Holocene)  
**Location :** First appeared around Caspian and Mediterranean sea, from where it migrated and changed into present day Caucasian, Mongloid and Negroid races.  
**Brain size :** ~1450 cc  
**Adaptations :** Reduction in cranial capacity and cultural evolution rather than that of anatomy.  
**Characteristics :** Slightly raised skull cap, thinning of skull bones, forehead rising sharply, four curves in vertebral column. Prominent chin, thin skeleton and non-existent brow ridges. Reduction in tooth and facial bone size.



First ape man

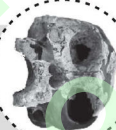
## Australopithecus africanus

**Period :** 5 million years ago (Pliocene)  
**Location :** Pliocene rocks near Tlunq in Africa  
**Brain size :** 500 cc  
**Adaptations :** Bipedal locomotion, omnivorous but mostly vegetarian feeding on fruits, vegetables, nuts, seeds and eggs. Erect posture but climbed trees too.  
**Characteristics :** Fully human shaped jaw and human like pelvis. Brow ridges projecting over eyes. Absence of chin. Lumbar curve in vertebral column.



## Homo habilis

**Period :** 1.5-2 million years ago (Pleistocene)  
**Location :** Pleistocene rocks to olduvai Gorge in East Africa.  
**Brain size :** 700 cc, with an expansion of frontal lobe.  
**Adaptations :** Bipedal locomotion, omnivorous  
**Characteristics :** 1.2- 1.5 metres tall, had a nose and elevated forehead. Thumbs broader, teeth like modern man. Tool maker (as found with heaps of tools made from chipped stones). Community life, lived in caves. Nurtured young ones. Successful due to change in climate.



Able or skillful man



## Homo sapiens fossils

(Cro-Magnon man)  
**Period :** 50,000-10,000 years ago (Holocene)  
**Location :** Cro-Magnon rocks in France.  
**Brain size :** 1650 cc  
**Adaptations :** Walk and run faster, omnivorous, direct ancestor of living modern man.  
**Characteristics :** Well built body and about 1.8m tall. Face orthognathous with an elevated nose, broad and arched forehead and moderate brow ridges. Strong jaws with teeth close together and a well developed chin. Lived in families in caves. Made excellent tools as spears, bows and arrows as well as ornaments from stones, bones and elephant tusks. Had art and culture, obvious from carvings and paintings in caves. Became extinct about 10,000-11,000 yrs ago.

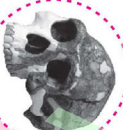


Living modern man

+91-8126030103

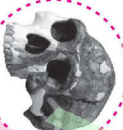
## Australopithecus afarensis

**Period :** 3-2.9 million years ago (Pliocene)  
**Location :** Ethiopia, Tanzania  
**Brain size :** 375-500cc (male and female size different)  
**Adaptations :** Bipedal locomotion, walked upright and survived during dramatic climate fluctuations.  
**Characteristics :** Looked and acted like ape. From waist down resemble humans (having pelvis and tibia/femur). Lived both on ground and on trees. Presence of lunate sulcus makes their occipital lobe smaller, suggesting greater reasoning skills and more control of motor functions.



## Homo erectus

(Erect man)  
**Period :** 1.8-1.7 million years ago (Middle Pleistocene)  
**Location :** Africa, Europe, Asia  
**Brain size :** 800-1300 cc  
**Adaptations :** Erect posture, omnivorous and first to eat animal meat and lake care of old.  
**Characteristics :** 1.5-1.8 metres tall. Skull flatter and cranium dome shaped to accommodate large brain. Protruding jaws, projecting brow ridges. Small canines and large molar teeth. Increase in intellect, memory and speech usage. Ability to run on two legs and less body hair which allowed sweating. Males were larger than females. Made elaborate tools of stones and bones, hunted for meat. Use of fire probably for cooking and protection. Group living forming hunts-gatherer society.



Able or skillful man



## Homo sapiens neanderthalensis

(Neanderthal man)  
**Period :** 400,000-300,000 years ago. (Late Pleistocene)  
**Location :** Neander valley in Germany.  
**Brain size :** 1,300-1,600 cc  
**Adaptations :** Walked upright with bipedal movement, cannibals.  
**Characteristics :** Slightly prognathous face, low brows, receding jaws and high domed heads. Diet include significant amount of meat supplemented with vegetation. Skilled hunters with simple tools as heavy spears or knives to kill prey. First to use skin hides as clothing so as to protect from harsh environment. Legendary cave dwellers, illuminated and heated them with fire. First nomads to bury dead and may had religion.



GAP

## Ramapithecus

**Period :** 14-15 million years ago (from late Miocene to Pliocene)  
**Location :** Pliocene rocks of Shivalik Hills of India.  
**Brain size :** Unknown  
**Adaptations :** Walk erect on its hind feet on ground and lived on tree tops.  
**Characteristics :** Small canines and large molars like humans. Ate hard nuts and seeds.



## Dryopithecus

**Period :** 20-25 million years ago (Miocene)  
**Location :** Miocene rocks of Africa and Europe  
**Brain size :** Large (size not known)  
**Adaptations :** Arboreal and ate soft fruits and leaves, semi-erect posture.  
**Characteristics :** Arms and legs of same length, feet with heels, without throw ridges, knuckle walker.



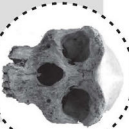
## Pithecanthropus erectus

(Java ape man)  
**Period :** Pleistocene  
**Location :** Pleistocene rocks in central Java, an island of Indonesia.  
**Brain size :** 800-1000 cc  
**Adaptations :** First prehistoric man with long legs and erect body, but slightly bent when moving, omnivorous and cannibal.  
**Characteristics :** 1.65-1.75m tall and weighing about 70 kg. Skull cap thick and heavy but flattened in front. Forehead low and receding but brow ridges high (as in apes). Inconspicuous chin and broader nose, lower jaw large and heavy. Canines of lower jaw larger and lips thick and protruding. Use of fire for hunting, defence and cooking.



## Homo erectus pekinensis

(Peking man)  
**Period :** 1.8 million-300,000 years ago (Pleistocene)  
**Location :** Rocks of limestone caves of Choukoutien, near Peking (China).  
**Brain size :** 850-1100 cc (large cranial capacity)  
**Adaptations :** Omnivorous and cannibal  
**Characteristics :** Similar in structure to Java man, except that Peking man was slightly shorter (1.55-1.60m tall), lighter and weaker. Used to live in caves in small tribes. Tools used were more sophisticated.



## Homo erectus heidelbergensis

(Heidelberg man)  
**Period :** 500,000 years ago (Middle Pleistocene)  
**Location :** Near Heidelberg, Germany.  
**Brain size :** 1100-1400 cc  
**Adaptations :** Intermediate between erectus and Neanderthal man, first to venture into cold climate.  
**Characteristics :** Human like teeth and ape like massive jaw. Receding forehead and lack of chin. Use of tools and fire. First species to build substantial shelters and showed planning symbolic behaviour. Gave rise to both Neanderthals and modern humans.



ADMISSION HELPLINE

info@shikshaview.com





# CONCEPT MAP

## MALARIA : CAUSE, SYMPTOMS AND TREATMENT

Malaria is an acute febrile illness that results in intermittent fevers, and is caused by a parasite of Genus *Plasmodium* belonging to a protozoan phylum, Apicomplexa. The parasite shows an alternation of generation accompanied by an alternation of host (**digenetic**). Asexual cycle (schizogonic cycle) occurs inside the red blood cells of the vertebrate host (human), and sexual cycle (sporogonic cycle) occurs in an invertebrate host (*Anopheles* mosquito). Malarial parasite is transmitted to human through the bite of infected female *Anopheles* mosquito during its blood-meal. Distinct species of *Plasmodium* are *Plasmodium malarie* (causes quartan malaria), *Plasmodium vivax* (causes benign tertian malaria), *Plasmodium falciparum* (causes malignant tertian malaria) and *Plasmodium ovale* (causes mild tertian malaria). **Laveran** (1880) discovered the malarial parasite, *Plasmodium*. **Sir Ronald Ross** (1897) observed that malarial parasite is transmitted by the bite of a female, *Anopheles* mosquito.

### LIFE CYCLE OF PLASMODIUM

The life cycle of *Plasmodium* requires two hosts, mosquito and human.

#### MOSQUITO (Definitive or primary host)

Infected female *Anopheles* mosquito bites human for a blood-meal. During biting mosquito's proboscis pierces the skin and injects sporozoites via saliva into the blood stream.

These sporozoites are liberated into the haemocoel of the mosquito and finally to the salivary glands. The mosquito becomes infective.

Oocyst ruptures to release sporozoites.

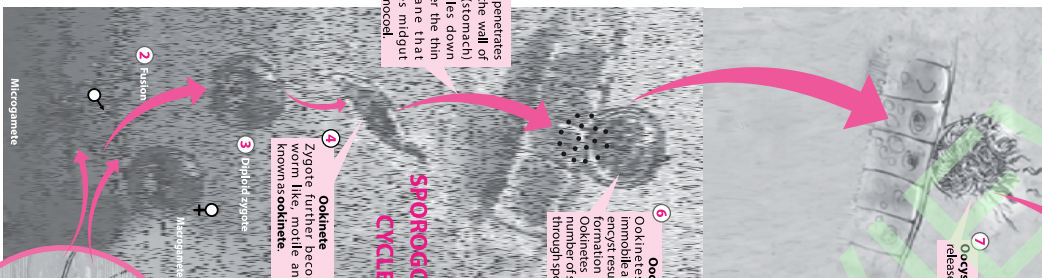
Ookinetes become immobile and begin to encyst resulting in the formation of oocyst. Oocyst contains a large number of sporozoites through sporogony.

Ookinete penetrates through the wall of midgut (stomach) and settles down just under the thin membrane that separates midgut from haemocoel.

Ookinete further becomes known as **ookinete**.

Diplo-zygote

Fusion



#### HUMAN (Intermediate or secondary host)

Sporozoites travel in the bloodstream and reach liver cells (hepatocytes). After penetrating a hepatic cell each sporozoite becomes a **cryptozoite**.

Cryptozoite grows for a number of days and becomes spherical and non-pigmented **schizont** which divides by schizogony to form a large number of uninucleate cells, **cryptomerizonts**.

They enter fresh liver cells to become **metacryptomerizonts** which again undergo schizogony to form metacryptomerizonts and this is referred to as **exoerythrocytic cycle**.

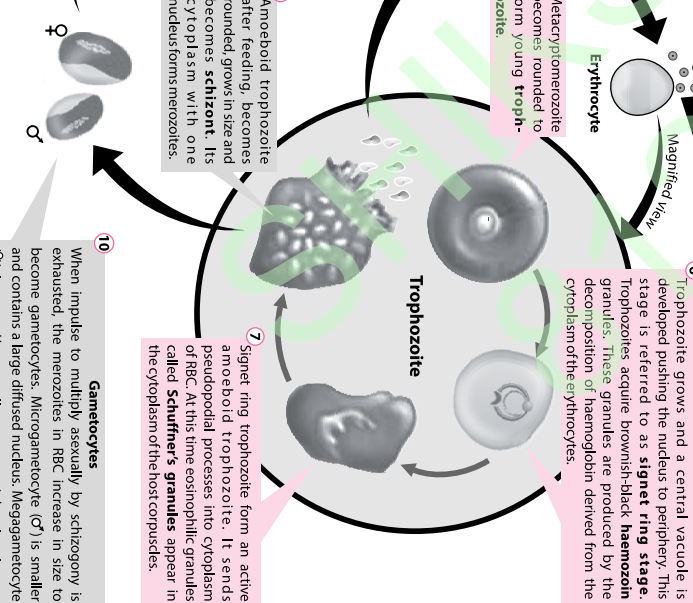
**Metacryptomerizonts in bloodstream:** Further the liver cells rupture and release thousands of metacryptomerizont-stage parasites into bloodstream that infect red blood cells.

**Amplification of Infection**  
Schizont ruptures to release merozoites which invade fresh corpuscles to repeat erythrocytic cycle and amplify the infection.

### SCHIZOGONIC CYCLE

Another mosquito bites infected human and ingests gametocytes. The male and female gametocytes remain undigested in the mosquito's gut. The gametocytes come out of the RBCs into the lumen of the stomach of mosquito. The male gametocytes divide and form long motile, whip-like microgametes. The female gametocytes do not divide and mature to become macrogametes.

Mosquito ingests gametocytes with blood-meal



Metacryptomerizont becomes rounded to form young **trophozoite**.

Erythrocyte

Trophozoite grows and a central vacuole is developed pushing the nucleus to periphery. This stage is referred to as **signet ring stage**. Trophozoites acquire brownish-black **haemozoin** granules. These granules are produced by the decomposition of haemoglobin derived from the cytoplasm of the erythrocytes.

Amoeboid trophozoite after feeding, becomes rounded, grows in size and becomes **schizont**. Its cytoplasm with one nucleus forms merozoites.

Signet ring trophozoite form an active amoeboid trophozoite. It sends pseudopodial processes into cytoplasm of RBC. At this time eosinophilic granules called **Schuffner's granules** appear in the cytoplasm of the host corpuscles.

When impulse to multiply asexually by schizogony is exhausted, the merozoites in RBC increase in size to become gametocytes. Microgametocyte (♂) is smaller and contains a large diffused nucleus. Megagametocyte (♀) is larger and has a small, compact peripheral nucleus.

### PROPHYLAXIS

Protection against mosquito bite can be achieved by using mosquito repellents and insecticide treated mosquito nets. Destruction of mosquitoes by spraying DDT or gammaexane. Adopting antimalarial measures by eliminating breeding places and using larvicides (Oil fention, thermiphos, etc.)

### RECURRENT MALARIA

**Relapse** is a re-attack of malaria because of infection by the malarial parasites that were surviving in the liver cells (hypozoites). Among the malarial parasite species that infect humans, *P. vivax*, *P. falciparum* and *P. malarie* can develop dormant liver stages that can reactivate after symptomless intervals of upto 2 to 4 years.

**Recrudescence** is a re-attack of malaria because of the surviving malarial parasites in red blood cells. It occurs in all four species of *Plasmodium*. It is the reappearance of infection from persistent blood stages of malarial parasites (drug resistance).

### SYMPTOMS

Common symptoms include chills, fever, malaise, muscular pain, severe headache, sweating, nausea. In severe cases haemoglobin in the urine, cerebral malaria (coma) and retinal damage, etc. occur.

### DIAGNOSIS

Diagnosis of malaria is usually done by examination of thin and thick blood smears.

### TREATMENT

Various antimalarial drugs are used to cure malaria such as **chloroquine**, **amodiaquine**, **sulphadoxine**, etc. Antimalarial vaccine known as **RTS,S** is the world's first malaria vaccine to obtain a positive scientific opinion.