MSCBOT-502

M. Sc. I Semester

ALGAE AND BRYOPHYTES

DEPARTMENT OF BOTANY
SCHOOL OF SCIENCES
UTTARAKHAND OPEN UNIVERSITY

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BLOCK-1 BASICS OF ALGAE

UNIT-1 HABITAT, THALLUS ORGANIZATION, CELL ULTRASTRUCTURE AND REPRODUCTION

1.1 OBJECTIVES

After reading this unit student will be able-

- To know the history of phycology.
- To understand about the algal habitats, their cell organization and how they reproduce in nature to maintain their life on earth.
- To understand the algal thallus organization from single cell to complex thalli.
- To understand different life cycles of algae.

1.2 INTRODUCTION

The term "algae" was coined by Linnaeus in 1754 but he had used this term for the plants we know as bryophytes now a days. It was A. L. de Jusssieu (1789) who delimited the term for the algae only known to us at present. Algae, commonly known as pond scum, can be seen easily growing on water surface of ponds, ditches, tanks, pools, etc. These have been placed under thallophyta. Plant body of algae is always a thallus that never forms true root, stem and leaves. We may define algae as a green group of autotrophic, non-vascular thalloid plants having unicellular or muticellular, non jacketed sex organs with no embryo formation. The study of algae is called Phycology (a Greek word *Phycos* means 'sea weeds' and *logos* means 'study') and references of algae are available in ancient literature of Greek, Roman and Chinese.

Distinctive Characters of Algae

- Algae are chlorophyll bearing thalloid plants with no differentiation into tissue or tissue system; however some algae have advanced complex thalli with slight differentiation of true tissues (*Ulva, Sargassum*, etc.).
- All the algae except few are aquatic.
- Sex organs are unicellular generally, when multicellular, each cell is capable to reproduce.
- Sex organs are never surrounded by sterile jacket layer.
- No embryo is formed after gametic fusion.
- Sporophytic and gametophytic generations are independent when represented in life cycle.
- Reproduction in algae takes place by vegetative, asexual and sexual modes.

History of Phycology

The history of algae is quite old and is available in early literature of Chinese, Roman and Greek. Romans called algae as *Fucus*. Chinese named it *Tsao* while Hawanians called them as *Limu.* In ancient literature it was reported that algae were used as manure on the north coast of France. As we can see that the algae were used for different purposes in various countries from ancient time but the detailed knowledge of algae was available after the invention of microscope in the middle of 17th century.

Many European biologists took interest in phycology after the invention of microscope. Roth (1797-1805) described *Hydrodictyon, Batrachospermum* and *Rivularia*. *Tetraspora, Oedogonium* and *Spirogyra* were described by H. E. Link (1820-33) of Germany. Lamouroux (1805, 1816) described *Laminaria*. C. A. Agardh established six orders of algae, viz., Diotomaceae, Nostochineae, Confervoideae, Ulvaceae, Florideae and Fucoideae. Thurret (1854-55) published first monograph on *Fucus*. Areschoug (1866-84) studied zoospore in *Urospora* and *Cladophora*, also he made a morphological account of *Laminaria* and *Macrocystis*.

O. Borge (1894-1936) worked out on the fresh water algae of Sweden. Classical work on fresh water algae of Britain was carried out by West and West. G. S. West wrote a book 'Algae' on structure and reproduction of algae. F. E. Fritsch and Rich (1907-37) studied fresh water algae of South Africa. Pia (1910) and Wolcott (1914) gave significant contribution on some fossil algae. Harvey produced a series of flora of marine algae, viz., *Phycologia Australica, Phycologia Brittanica* etc.

In India, literature provided the evidence of phycology since 18^{th} century where major interests were on macroscopic forms of algae. F. E. Fritsch (1907) published a marvelous work on sub-aerial and fresh water algae from Ceylon. He published the classification of algae in his book 'Structure and Reproduction of the algae'.

Ghose (1919-32) was the pioneer of phycology in India. He conducted research on blue green algae of Burma and Punjab. Prof. M. O. P. Iyengar is regarded as 'Father of modern phycology of India'. He together with his students Balakrishna, Desikachary, Kanthamma, Ramanathan and Subramanium studied a number of Indian algae during 1920. Iyengar discovered *Fritschiella tuberosa* from India. Biswas (1922-26) wrote on algal flora of East India, Assam and Bengal. Prof. Y. Bhardwaj established a school of algology at Banaras Hindu University. He contributed significant knowledge on Cyanophyceae of Uttar Pradesh. It is important to mention the monumental work of R. N. Singh (1938-68) on cyanobacteria. He worked on saline usar land in India for making the land fertile by cultivating blue green algae and published a monograph on the 'Role of blue green algae in nitrogen economy of Indian agriculture'.

M. S. Randhawa (1932-59) worked on Zygnemaceae, Vaucheriaceae and Oedogoniales. He made discovery of new species of *Mougeotia, Spirogyra, Zygogonium* and *Debarya* from Uttar Pradesh and Punjab. He published a monumental monograph on Zygnemaceae. Desikacharya's monograph on 'Cyanophyta' (1950) is to be mention here as it is regarded as the recent work on taxonomy of blue green algae. S. R. Narayana Rao (1941-49) worked on fossil algae of India. Pandey and Mitra (1959) studied heterocystous blue green algae in context of nitrogen fixation.

G. S. Venkataraman wrote monographs on Vaucheriaceae (1964) and Charophyta (1962). R. S. Rattan (1960) made a significant contribution to the Zygnemaceae of Punjab. H. D. Kumar (1970) made contributory work on physiology of algae and also on genetics of blue green algae. A monograph on 'Phaeophyceae in India' was written by J. N. Mishra (1966). B. N. Prasad

(1970-83) worked on diatoms and Zygnemaceae of Andaman and Nicobar Island. G. L. Tewari (1990) has made significant contribution on blue green algae and its use as biofertilizers.

1.3 HABITAT

As you have studied in previous section that algae are generally aquatic but there are many algae which are found inhabiting in a variety of habitats, like terrestrial, cryophytic, parasitic, endophytic, thermophytic, halophytic etc. So, according to the habitat, we may classify algae as aquatic algae, terrestrial algae and algae of specialized habitats.

A. **Aquatic algae-** Majority of algae are aquatic and found either completely submerged or free floating on the surface of water. These algae occur on pools, ponds, ditches, river, streams, tanks, salt water, etc. Aquatic algae can be further divided into fresh water forms and marine forms.

(i) Fresh water forms- Numerous types of algae are found in fresh water habitats like pool, ponds, lake, ditches or slow running river. *Chlamydomonas, Volvox* and *Hydrodictyon* are found in stagnant water, whereas *Cladophora, Oedogonium, Ulothrix* and few species of *Vaucheria* occur in slow running water bodies. The members of Xanthophyceae, Euglenophyceae, Cyanophyceae, Chrysophyceae, Conjugales and Diatoms are common in fresh water.

(ii) Marine forms- Marine algae are found in salty water of sea and oceans. Generally, the members of phaeophyceae, Rhodophyceae and some Chlorophyceae (*Enteromorpha, Caulerpa. Ulva, Codium*, etc.) are found in marine water. Marine algae have macroscopic thalli and are generally considered as 'sea weeds'.

The free floating and free swimming microscopic algal forms together with other similar organisms constitute the planktons of water bodies, plankton forming algae may either be free floating from the beginning and never attached are called Euplantons (e.g., *Microcystis, Chlamydomonas, Scenedesmu, Cosmarium* etc.) or attached in the beginning but later becomes free floating are called as Tychoplanktons such as *Cladophora, Cylindrospermum, Rivularia* etc.

Some unicellular and filamentous forms of algae grow luxuriantly on the surface of water and make the place leathery called water blooms that give fishy smell and water is not considered for drinking purpose. Water blooms are generally formed by solitary alga, rarely by few algae. The colour of the algae determines the colour of the bloom. Water blooms are generally formed by the rapid growth and multiplication of algae. They generally belong to class Cyanophyceae. However, some members of Chlorophyceae, Chrysophyceae, Pyrrophyceae and Euglenophyceae are also known to cause water blooms. In the salt lake of Sambhar, *Anabaenopsis* forms bloom.

B. **Terrestrial algae-** Those algae which are found in soil are termed as terrestrial algae. These algae are either found on the surface of the soil (saprophytes) or beneath the soil surface (cryptophytes). *Vaucheria, Botrydium, Fritschiella* and *Oedocladium* are some examples of saprophytes while *Nostoc, Ananbaena* are cryptophytes.

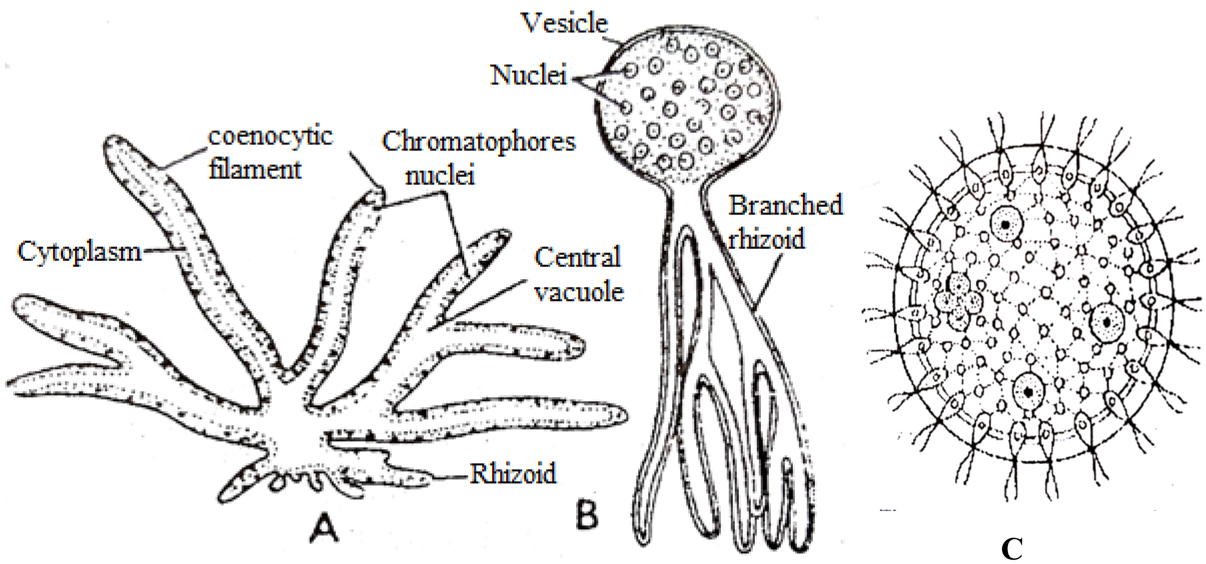


Fig- 1.1 Terrestrial Algae- (A) *Vaucheria*, (B) *Botrydium* (C) *Volvox* (Fresh water algae)

C. **Specialized algae-** Such algae are found in habitats other than water or soil. There are several types of specialized habitats:

(i) Thermophytic algae- The algae occurring in hot water springs at a very high temperature (70 degree or above) are thermophytic algae. *Oscillatoria brevis, Synechococcus elongates, Mastigocladus, Haplosiphon lignosum*, etc. are some of the examples of thermophytes.

(ii) Cryophytic algae- These algae are found on snow clad mountains and impart attractive colours to the snow. *Haematococcus nivalis* imparts red colour to the snow, whereas *Chlamydomonas yellowstonensis* is responsible for the green colour of the snow particularly in Arctic region. Certain species of *Protoderma* and *Scotiella* cause yellow or yellow green colour, whereas *Ancyclonema nordenskioldii* imparts brown or purple tinge to the snow.

(iii) Halophytic algae- These algae are found in saline water containing high percentage of salts e.g., *Dunaliella, Stephanoptera* and *Chlamydomonas ehrenbergii.*

(iv) Lithophytic algae- Some algae grow on moist rocks, wet walls and other rocky surfaces. e.g., *Rivularia* and *Gloeocapsa*.

(v) Epiphytic algae- These algae grow on other aquatic plants e.g., *Oedogonium, Aphanochaete, Bulbochaete*, etc.

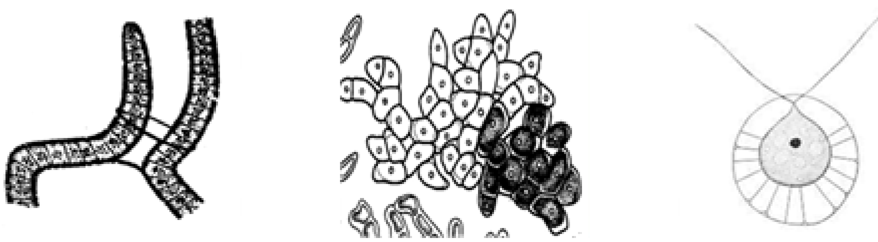
(vi) Endophytic algae- These algae are found inside the higher plants. *Nostoc* is found in the thallus of *Anthoceros,* and *Anabaena* grows inside the coralloid roots of *Cycas*.

(vii) Epizoic algae- Many algae grow on the shells of mollusks, turtles and fins of fishes and are known as epizoic algae. *Cladophora* is found on snails and shells of bivalves, *Protoderma* and *Basicladia* are found growing on back of turtles.

(viii) Endozoic algae- Endozoic algal cells are found inside the body of aquatic animals. E.g. *Zoochlorella* is found inside the *Hydra*.

(ix) Parasitic algae- The best example of parasitic algae is *Cephaleuros virescens* causing red rust of tea (*Camelia sinensis*). *Polysiphonia festigata* is reported as semiparasite on *Ascophyllum nodosum.*

(x) Symbiotic algae- Several members of Cyanophyceae (Cyanobacteria) grow in association with other plants. Lichen serves as the best example of symbiosis in which fungi from Ascomycetes and Basidiomycetes grow together with members of Cyanophyceae.



A B C

Fig. 1.2 (A- *Scytonema*) Thermophytic algae, (B-*Protoderma*, C- *Haematococcus*) Cryophytic algae

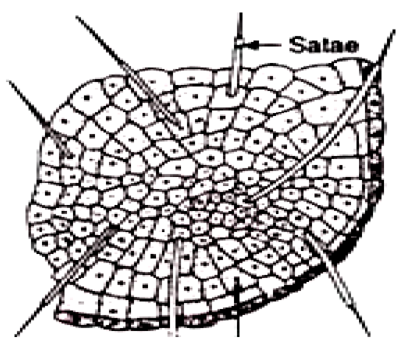


Fig. 1.3 Epiphytic algae (*Coleochaete*)

1.4 THALLUS ORGANIZATION

As we all know that algae are thalloid plants that lack differentiation into roots, stem and leaves. The thallus of algae ranges from simple unicellular to the highly organized one having differentiation of tissues yet lack vascular tissues. There exists motile unicellular solitary or colonial, unicellular non motile may be solitary or colonial, coenobial filamentous forms either unbranched or branched, heterotrichous filament etc.

In this section of the unit we will able to know the varied forms of thallus in algae which are as follows:-

1. **Unicellular motile form-** Unicellular motile algae can move with the help of flagella attached at the anterior end of the body e.g., *Chlamydomonas* (Fig 1.4, A). The number of the flagella may vary in different algal forms.
2. **Unicellular non-motile forms-** These unicellular forms have no locomotory organ (flagella are absent) e.g., *Chlorella, Gloeocapsa* (Fig. 1.4, B, C) *Cosmarium, Closterium*, etc.
3. **Multicellular colonial forms-** Many cells come together and forms colony and each cell of colony is capable of doing life processes. The colonial forms are of following types-

a) **Motile coenobial colony-** Definite numbers of motile cells are embedded in gelatinous matrix with flagella protruded out and all cells are connected with cytoplasmic connections in a motile colony. The cells are compactly or loosely arranged. A colony formed of definite number of cells arranged in a specific manner is known as **coenobium**. e.g., *Volvox* (Fig. 1.4 E)*, Pandorina, Eudorina* etc.

b) **Non-motile coenobial colony or coccoid form-** In this type of colony definite number of cells are closely attached together in specific manner and does not have flagella as locomotory organ. E.g., *Hydrodictyon, Pediastrum* (Fig. 1.4 D) etc.

c) **Palmelloid form-** In this type of colony, cells are aggregated together in a gelatinous matrix of indefinite shape but the number of cells are not fixed as in the case of coenobium. In palmelloid form cells are embedded in mucilaginous substance. It can be a temporary stage as in the case of asexual reproduction of *Chlamydomonas* or may be permanent as in *Tetraspora*.

d) **Dendroid form-** This is also a non motile colony of unfixed number of cells but differs from palmelloid form in having attachment of cells to the substratum. e.g., *Prasinocladus, Mischococcus* etc.

4. **Filamentous form-** Filamentous thallus may be of indefinite length. The cells are attached end to end in a linear fashion and form a filament. The filamentous form may be branched, unbranched or falsely branched.

a) **Unbranched filament-** Simple unbranched filaments are found in many algal forms. They are either free living e.g., *Spirogyra* or attached e.g., *Oedogonium*, *Ulothrix* or may be found in colonial forms e.g., *Nostoc*.

b) **Branched filament-** In this type of algal forms, filaments are branched e.g., *Cladophora*.

c) **False branching-** In falsely branched filamentous forms, filament appear to be branched but it is not actually branched. Two filaments generally come so close to each other that they appear to be branched e.g., *Scytonema.*

5. **Siphonaceous form-** The thallus is coenocytic non-septate, multinucleate siphon like structure. It may be simply branched or elaborately developed with clear division of labour being differentiated into aerial and subterranean and in some cases into subaerial branches. E. g., *Vaucheria* (Fig.1.4 F)*, Botrydium, Caulerpa, Codium, Halimeda* etc.
6. **Heterotrichous form-** This is a highly advanced type of thallus which is characterized by the differentiation of plant body into prostrate and erect system. This type of thallus shows a good amount of labour division. This algal form is characteristic feature of Chaetophorales order of class Chlorophyceae, in many Phaeophyceae, Rhodophyceae, in some Chrysophyceae and Dinophyceae. The prostrate system is attached to the substratum with the help of some rhizoidal filaments. The erect system is developed from the prostrate part. e.g., *Fritschiella, Ectocarpus* (Fig.1.6) *Dinoclonium, Stigeoclonium, Trentepholia, Coleochaete, Drapanaldiopsis* etc.
7. **Pseudoparenchymatous form-** As the name implies it is a type of thallus which looks like parenchymatous but not a true parenchymatous form. Parenchyma is a type of tissue in which a single parent cell divides and redevides to form a tissue whereas in pseudoparenchymatous algal forms the thallus is constructed by the close association of cells or of filaments rather than a parent cell. The filament may form uniaxial axis as in *Batrachospermum* or multiaxial as in the case of *Polysiphonia*. Other examples include *Chara* and *Nitella.*
8. **Parenchymatous Form-** Parenchymatous thallus organization is a modification of the filamentous habit; in which cell division occur in various directions to form parenchymatous structure. Such thallus may appear flat, leaf like or cylindrical or well branched. Common examples of flat and leaf like parenchymatous thalli are *Ulva, Punctaria* and *Porphyra.* Tubular parenchymatous thallus is found in *Enteromorpha*. *Sargassum* shows specialized differentiation of cells. The other examples are *Laminaria, Fucus, Dictyota* etc.

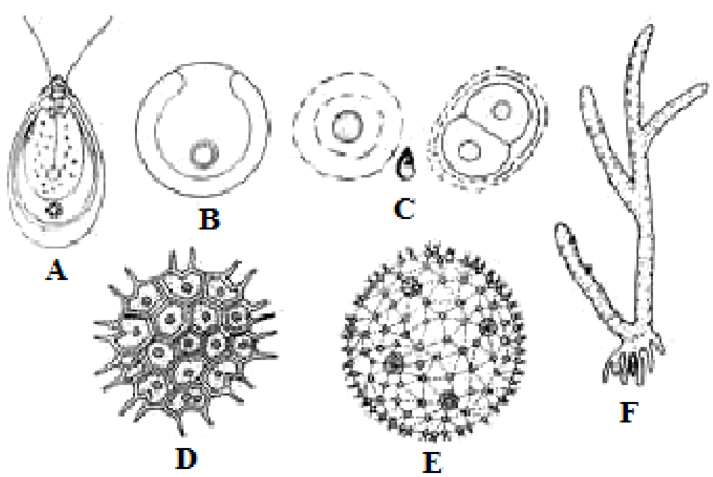


Fig. 1.4 Range of thallus organization in algae. (A) *Chlamydomonas,* (B) *Chlorella,* (C) *Gloeocapsa,* (D) *Pediastrum,* (E) *Volvox,* (F) *Vaucheria*

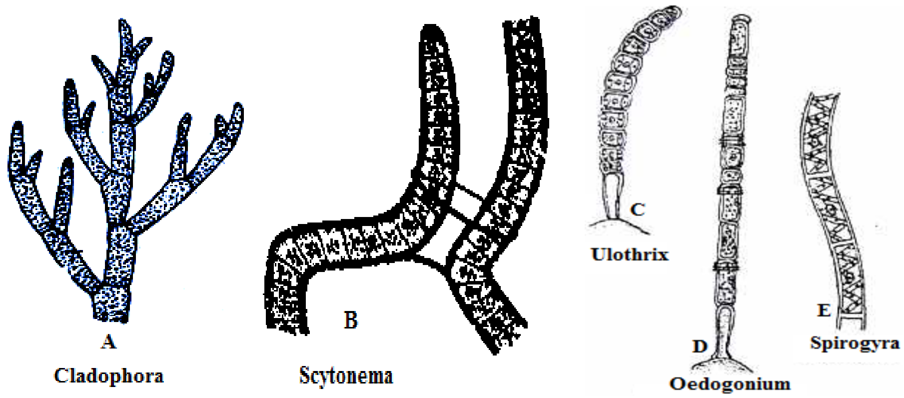


Fig. 1.5 Filamentous thallus (A) Branched filament, (B) False branching, (C, D, E) Unbranched filaments

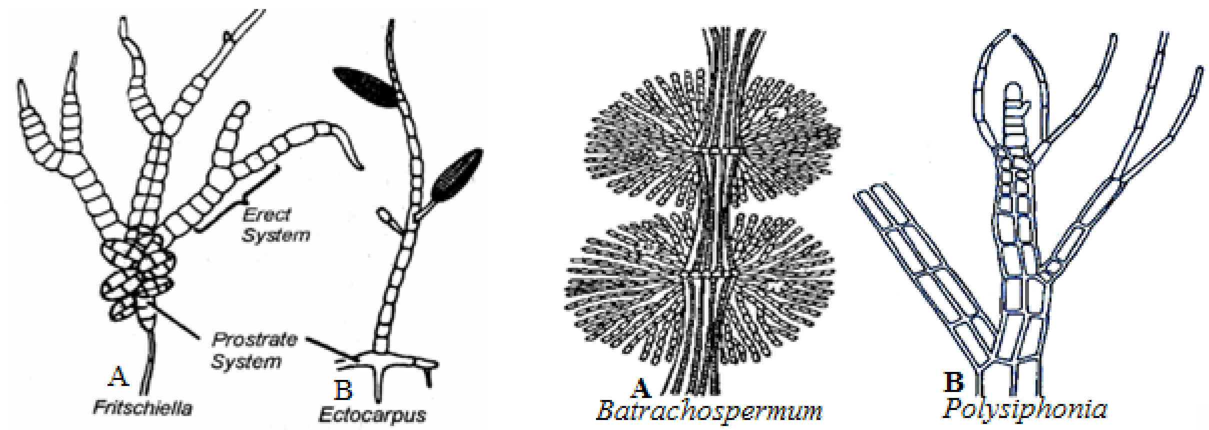


Fig. 1.6 (A-B) Heterotrichous thallus **Fig. 1.7 (A-B) Pseudoparaenchymatous thalli**

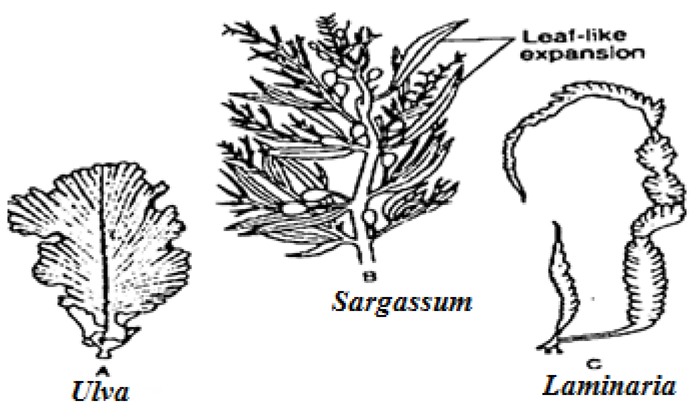


Fig. 1.8 (A-C) Parenchymatous thallus

1.5 CELL ULTRASTRUCTURE

Algal cells are of two kinds- **Prokaryotic** and **Eukaryotic.** Prokaryotic algal cell is found in cyanobacteria (blue green algae) while in other members of algae eukaryotic cell is found.

In this section we will discuss about the ultrastructure of prokaryotic and eukaryotic algal cell wall.

1.5.1 Ultrastructure of Prokaryotic Algal Cell

The prokaryotic algal cell can be divided into two parts- Outer cellular covering and cytoplasm.

(A) Outer cellular covering: It can be discussed under following headings:-

a) **Slime layer or mucilaginous sheath-** Outer the cell wall there is present a mucilaginous sheath that is a characteristic feature of all cyanobacteria (blue-green algae). In the sheath, fibrils of peptic acid and mucopolysachharides are arranged reticulately so that the sheath appears to be homogenous. Its main function is to retain absorbed water to protect the cell from desiccation.
b) **Cell wall-** The cell wall is rigid and made up of mucopeptide. It consists of four layers which are named as L1, L2, L3 and L4. L1 is somewhat transparent and occurs between L2 and plasma membrane. L2 and L3 are mucopolymer, made up of alanine, glucosamine, peptidoglycan, muramic acid, glutamic acid and α-diaminopimelic acid. L4 layer is wavy and made up of lipopolysachharides and proteins.
c) **Plasma membrane-** Plasma membrane is present beneath the cell wall and is made up of lipid bilayer. Plasma membrane and its invaginations are the sites of biochemical functions.

(B) Cytoplasm: It is differentiated into chromoplasm and centroplasm.

a) **Chromoplasm-** It is the outer and peripheral pigmented region. It consists of parallel photosynthetic lamellae or thylakoids. These lamellae contain chlorophyll a, carotenoids and phycobilins. Three types of phycobilins are found in cyanobacterial cell- C-phycocyanin, C-phycoerythrin and allophycocyanin. The phycobilins are found in phycobilisomes which are present in between the photosynthetic lamellae as small granules. The membrane bound organelles such as mitochondria, chloroplasts, golgi bodies, endoplasmic reticulum, vacuoles etc are not found in chromoplasm. However, cytoplasmic inclusions like 70s ribosomes, α-granules, β-granules, structural granules, polyhedral bodies, gas vacuoles etc are found in chromoplasm. Gas vacuoles are made up of vesicles. These vacuoles provide buoyancy to the cell.
b) **Centroplasm-** It is the central colourless region which consists of chromatin material or DNA material that is not bounded with histone proteins. Hence no organized nucleus is found. Like bacteria, small circular DNA fragments occur which are called plasmids or transposons. 70s ribosomes are also present in this region.

1.5.2 Ultrastructure of Eukaryotic algal cell

The cells of all other algae except the blue green algae constitute the eukaryotic cell. Different parts of eukaryotic algal cell can be discussed as follows-

a) **Cell wall-** The cell is bounded by a cell wall made up of cellulose. In many algal forms pectose layer is also found outside the cellulosic cell wall. In some brown algae, alginic acid is present in their cell wall. Certain algae, particularly the diatoms possess silicified cell wall. Xylan, agar and carrageenin are present in cell wall of red algae.

b) **Plasma membrane-** It is present just beneath the cell wall and is made up of protein lipid bilayer.

c) **Cytoplasm-** Inside the plasma membrane dense cytoplasm is present. In cytoplasm, membrane bound cell organelles such as mitochondria, chloroplasts, Golgi-bodies, endoplasmic reticulum and other eukaryotic cell organelles are present. Ribosomes are of 80s type. Cells of most algae contain one chloroplast per cell with the exception of few species whose cells have more than one chloroplast. Besides this, almost all chloroplasts bear one or more pyrenoids. The chloroplasts may be- cup-shaped, parietal, discoid, lobed, star shaped, spiral, and barrel or girdle shaped.

d) **Nucleus-** In eukaryotic algal cell, single nucleus is present in most of the algae, but multinucleate eukaryotic algal cell are also found in considerable number. True nucleus having nuclear membrane with nuclear pores is present in eukaryotic algal cell which is not different from the nucleus of higher plants. DNA is bounded with the histone proteins.

e) **Flagella-** In motile algal cell, thallus bears flagella which originates from the basal granules or blepharoplast and comes out through a fine canal in cell wall. It shows a typical 9+2 arrangement. Two central singlet fibrils are surrounded by nine doublet peripheral fibrils. They are extremely fine and hyaline emergence of the cytoplasm. Flagella are connected with the inner cytoplasm through small pores in the cell wall. They may be single or present in pairs or indefinite in number. The core of flagellum is axoneme which is surrounded by a cytoplasmic sheath. The naked, terminal portion of axoneme is called end piece. In cross section, flagellum consists of two inner central simple fibrils which are surrounded by nine united, peripheral contractile, thicker doible fibrils. Each peripheral fibril is composed of two thin fibrils. The two central fibrils are single. The nine peripheral fibrils join the basal granule while two central fibrils stop short of the granule.

Other structures like contractile vacuoles, flagella, stigma and eye spots are also found in some algae which are associated with motility of the algal cells.

In Cyanophyceae and Rhodophyceae, flagella are never formed in any stage of life cycle.

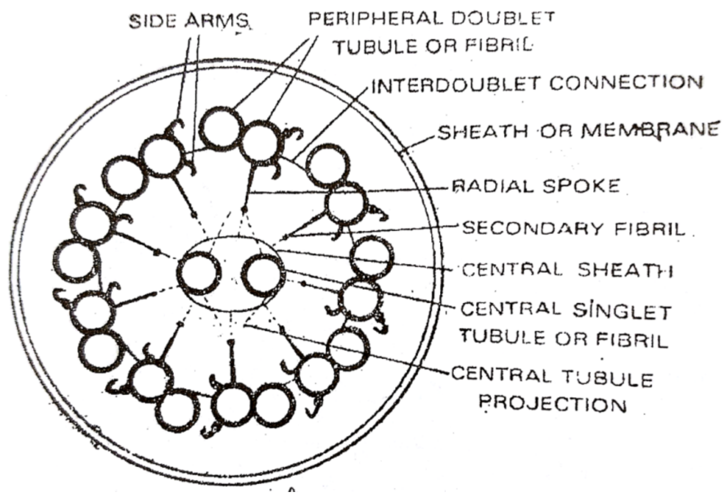


Fig. 1.9 Ultrastructure of a flagellum

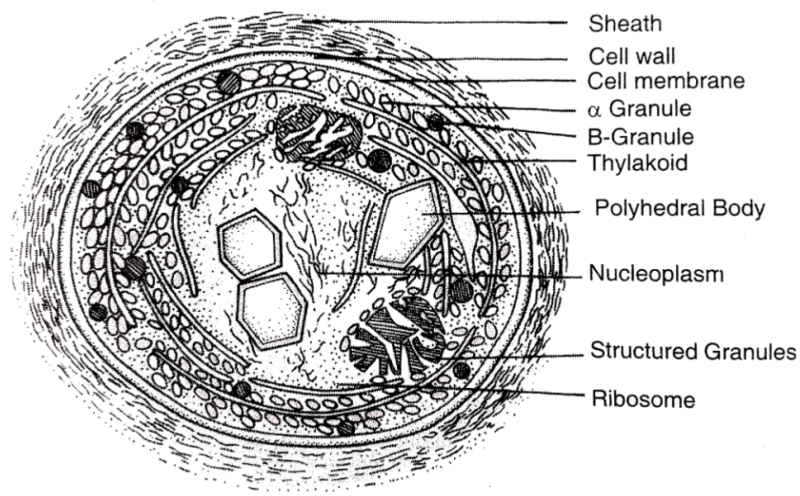


Fig. 1.10 Ultrastructure of prokaryotic cell

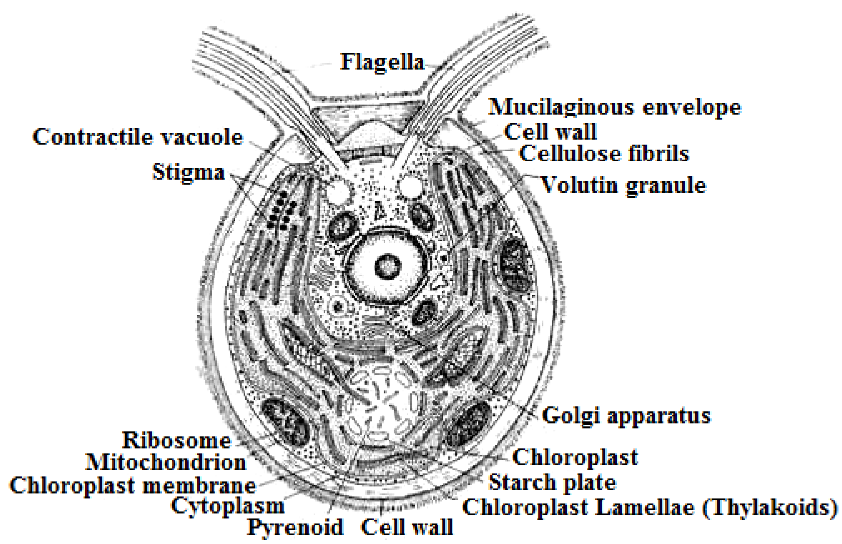


Fig. 1.11 Ultrastructure of eukaryotic cell

1.6 REPRODUCTION IN ALGAE

Reproduction in algae takes place by vegetative, asexual and sexual methods. Vegetative mode of reproduction is known in primitive algae whereas; in higher forms both asexual and sexual reproductions are common.

A. **Vegetative Reproduction-** The vegetative reproduction in algae takes place by following methods:

a) **Fragmentation-** Fragmentation is common in filamentous forms. In this process, filament breaks into fragments and each fragment give rise to a new filamentous thallus. The common examples are *Ulothrix, Spirogyra, Oedogonium, Zygnema, Oscillatoria, Nostoc* etc.

b) **Fission-** This process is common in desmids, diatoms, and other unicellular algae. The cell divides into two by mitotic division and then separation occurs through septum formation.

c) **Adventitious branches-** Protonema develops in certain algae like *Chara* and give rise to new thalli when detached from parent thallus. These adventitious branches develop mainly on the rhizoids. Other examples include *Dictyota* and *Fucus.*

d) **Tubers-** Tubers are spherical or globular bodies which are found on lower nodes or rhizoids of *Chara*. These tubers when detach from parent plant can give rise to new thalli.

e) **Amylum stars-** In *Chara*, star shaped bodies filled with amylum starch are formed that give rise to new individual after detaching from the parent plant.

f) **Budding-** In some algae like *Protosiphon*, budding takes place which results in new individuals.

g) **Hormogonia-** In some cyanobacteria like *Nostoc, Cylindrospermum* hormogonia develop that may give rise to new thalli. These hormogonia are of varying lenths and may develop at the place of heterocysts in the thallus. These hormogones are produced by breakage of filament into two or more cells.

h) **Hormospores or hormocysts-** Hormospores are thick walled hormogones which are produced in drier conditions.

B. **Asexual Reproduction-** In a large number of algae asexual reproductions takes place with the help of different kind of spores and other structures. Basically, spores are meant for asexual reproduction and each spore can grow into a new thallus. Spores are one celled structure and are produced internally in the case of algae. They are produced within the vegetative cell (*Chlamydomonas*) or in a specialized structure called sporangia. They may be motile or non-motile. Motile spores are called zoospores and non-motile as aplanospores.

Different types of asexual spores and structures are as follows-

a. **Akinetes-** In filamentous forms, certain vegetative cells become thick walled elongated structures called as akinetes. Akinetes are perennating bodies that can survive under unfavourable conditions and can give rise to new individual on occurrence of favourable conditions. e.g., *Anabaena*

b. **Hypnospores-** Hypnospores are thick walled, non flagellated spores with plenty of food reserves. They are produced under unfavourable conditions by some green algae. They germinate into new plants with return of favourable environmental conditions. e.g., *Chlamydomonas, Protosiphon.* In *Chlamydomonas nivalis* the walls of hypnospores become red due to the presence of pigment *Haematochrome* due to which snow becomes red.

c. **Zoospores-** These are flagellated asexual spores which are formed in zoosporangium or directly from the vegetative cells. The zoospores may be bi, quadric or multiflagellate. The multiflagellate zoospores are of again two types- flagella arranged on entire length of body or arranged in a ring surrounding a beak like projection. e.g., *Chlamydomonas* (biflagellate), *Ulothrix, Cladophora* (quadriflagellate), *Vaucheria, Oedogonium* (multiflagellate). In *Pediastrum*, the zoospores do not germinate or divide but orientate themselves in a single plane and become opposed to form a colony just like the parent cell. This feature is not met in any other algae.

d. **Aplanospores-** These are non flagellated thin walled asexual spores that are formed in majority of aquatic algae by the failure of flagella formation due to some unfavourable conditions.

e. **Tetraspores-** Tetraspores are non motile asexual spores that are formed in some members of Rhodophyceae and Phaeophyceae. Tetraspores are formed in tetrads in the tetrasporangia. e.g., *Polysiphonia*

f. **Monospores-** Single spore formed in the sporangia is called monospore. Monospores are found as asexual mode of reproduction in some members of Rhodophyceae.

g. **Autospores-** These are actually aplanospores which appear identical to the parent cell. Hence referred as autospores.

h. **Heterocysts-** According to some phycologists, heterocysts are sometimes able to reproduce asexually. However, their exact function is still in question. These structures are found in blue green algae and depending upon the position in thallus they may be terminal or interstitial.

i. **Auxospores-** auxospores are produced in the member of Bacillariophyceae.

j. **Carpospores-** Carpospores are produced in carposporophyte of red algae.

k. **Paraspores-** In some members of Rhodophyceae, paraspores are formed that give rise to new individual.

l. **Statospores-** Statospores are produced in the members of Bacillariophyceae and Xanthophyceae. These are asexual perennating bodies that may give rise to new individual upon occurrence of favourable condition. Statospores formed by diatoms are thick walled.

m. **Neutral spores-** In some alga, the protoplast of vegetative cells directly functions as spores and these are called neutral spores. e.g., *Asterocystis, Ectocarpus*.

n. **Nannocytes-** In the members of chroococcales, the cell content divide repeatedly to produce numerous very small spores. The name nannocytes to these very small spores was given by Geitler. E.g., *Macrocystis, Gloeocapsa.*

o. **Gongrosira stage of *Vaucheria*-** In *Vaucheria*, the protoplast divides into several cysts like structures or hypnospores. This stage looks like an algal form '*Gongrosira'*. Each hypnospore or cyst may give rise to new thallus.

C. **Sexual Reproduction-** Sexual reproduction is found in advanced algae as compared to less advanced forms where vegetative and asexual methods are main modes of reproduction. Sexual reproduction takes place by fusion of gametes of different sexuality. There is a wide range of variation in the nature of gametes and the mode of sexual reproduction. Any vegetative cell of thallus may produce gametes and thus behave as gametangium or a specialized gametangium may be developed. The gametangia may be morphologically similar (isogametangia) or dissimilar (heterogametangia). The gametes are produced in the gametangia by simple mitotic division or by reduction division. The haploid gametes fuse to make diploid zygote that give rise to the thallus. Depending upon the morphological and physiological characteristics of gametes, sexual reproduction can be of the following types-

a) **Isogamous-** When fusing gametes are morphologically similar and physiologically different (+ and -) then the sexual reproduction is called as isogamous. E.g., *Chlamydomonas, Ulothrix, Zygnema, Spirogyra.*

b) **Anisogamous-** In anisogamous sexual reproduction fusing gametes are morphologically as well as physiologically different. The gametes are produced in different gametangia. The microgametes are male gametes while macrogametes are female gametes. e.g., *Chlamydomonas*.

c) **Oogamous-** Oogamy is the most advanced type of sexual reproduction in which microgamete or male gamete fuses with a large female gamete or egg. Male gametes are produced in antheridium while female gamete or egg is produced within a structure called as oogonium. During fertilization male gamete reaches the oogonium to fertilize the egg and a diploid zygote is formed. e.g., *Chlamydomonas*.

d) **Hologamy-** In certain unicellular algae whole thallus behaves like gamete and in this process fusion takes place between opposite strained gametes or thalli that after fusion make diploid zygote. e.g., *Chlamydomonas*.

e) **Autogamy-** In autogamy fusion between two gametes of opposite strains from same mother cell takes place. Since both the fusion gametes comes from same mother cell there is no genetic recombination e.g., Diatoms.

1.7 LIFE CYCLES IN ALGAE

The sequence of events through which one generation passes into the next generation is called life cycle. Sexual reproduction involves alternation between haploid and diploid generation which we call alternation of generation. In algae, there are five main types of life cycles or alternation of generation. These are as follows-

1. **Haplontic Life Cycle-** In this type of life cycle the main plant body is gametophytic (haploid) that produces mitospore during growing season that develops into gametophytic plant. Towards the end of the growing season gametophyte produces gametes (haploid). Zygote/zygospore (diploid) is formed after gametic fusion, which is the only diploid phase in the life cycle. Soon after their formation zygospores/zygote divides by meiosis to form meiospores that germinates into gametophytic thallus. Such a life cycle is called haplontic life cycle and the most primitive one in which zygotic meiosis takes place and there is no formation of sporophytic thallus (diploid). This type of life cycle is shown by majority of green algae, Charophytes and *Bangia* of red algae.

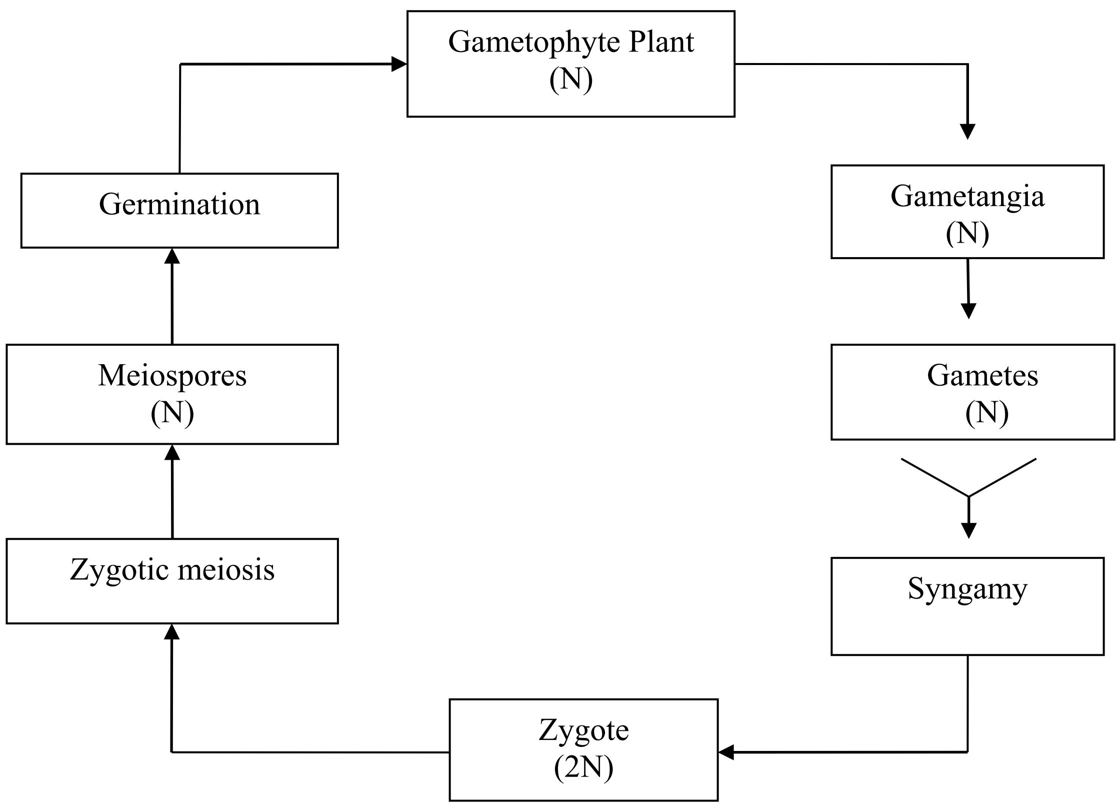


Fig. 1.12- Haplontic Life Cycle

2. **Diplontic Life Cycle-** The dominant plant thallus is diploid. The thallus reproduces sexually by gametes that are formed by meiosis in sex organs. These gametes represent the haploid phase in the life cycle. These gametes fuse to form zygote/zygospore that ultimately forms the diploid plant body. No true alternation of generation as in the first case (haplontic) occurs. This type of life cycle is called diplontic life cycle. This life cycle is shown by diatoms (Bacillariophyceae), some members of Siphonales, Siphonocladiales and Dasycladiales of green algae and Fucales of Brown algae.

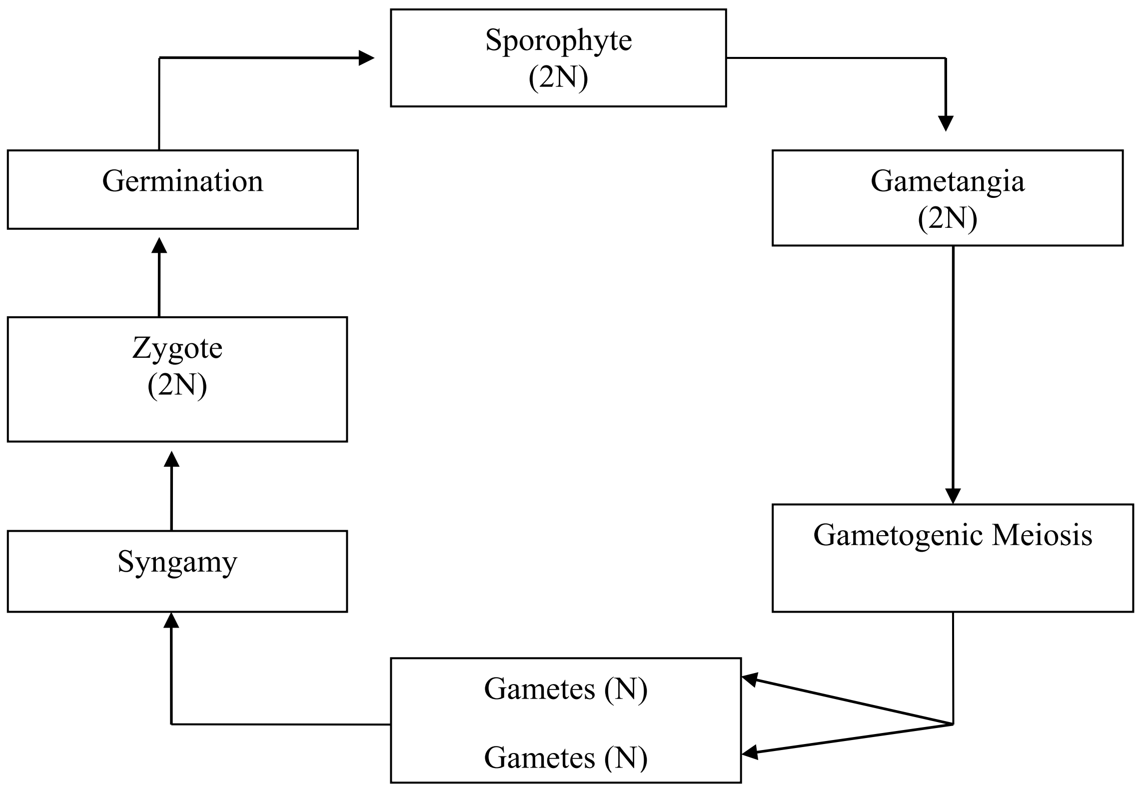


Fig.1.13- Diplontic life cycle

3. **Diplohaplontic Life Cycle-** This type of life cycle is exhibited by Ulvales and Cladophorales of Chlorophyceae and some brown algae (*Ectocarpus, Dictyota*). In this type of life cycle two different generations alternate each other. True alternation of generation occurs. This type of life cycle that consists of two different vegetative individuals alternating with each other is called diplohaplontic. There are two types of diplohaplontic life cycles- isomorphic and heteromorphic.

a. **Isomorphic-** In isomorphic diplohaplontic life cycle, alternating sporophyte and gametophyte are morphologically similar. Zygote produces sporophytic thallus that produces meiospores in sporangium by reduction division. Meiospores germinate to form a gametophytic thallus that forms gametes in sex organs. Syngamy between gametes yields zygote that produces diploid thallus. E.g., Ulvales, Cladophorales, Ectocarpales, Dictyotales and red algae.

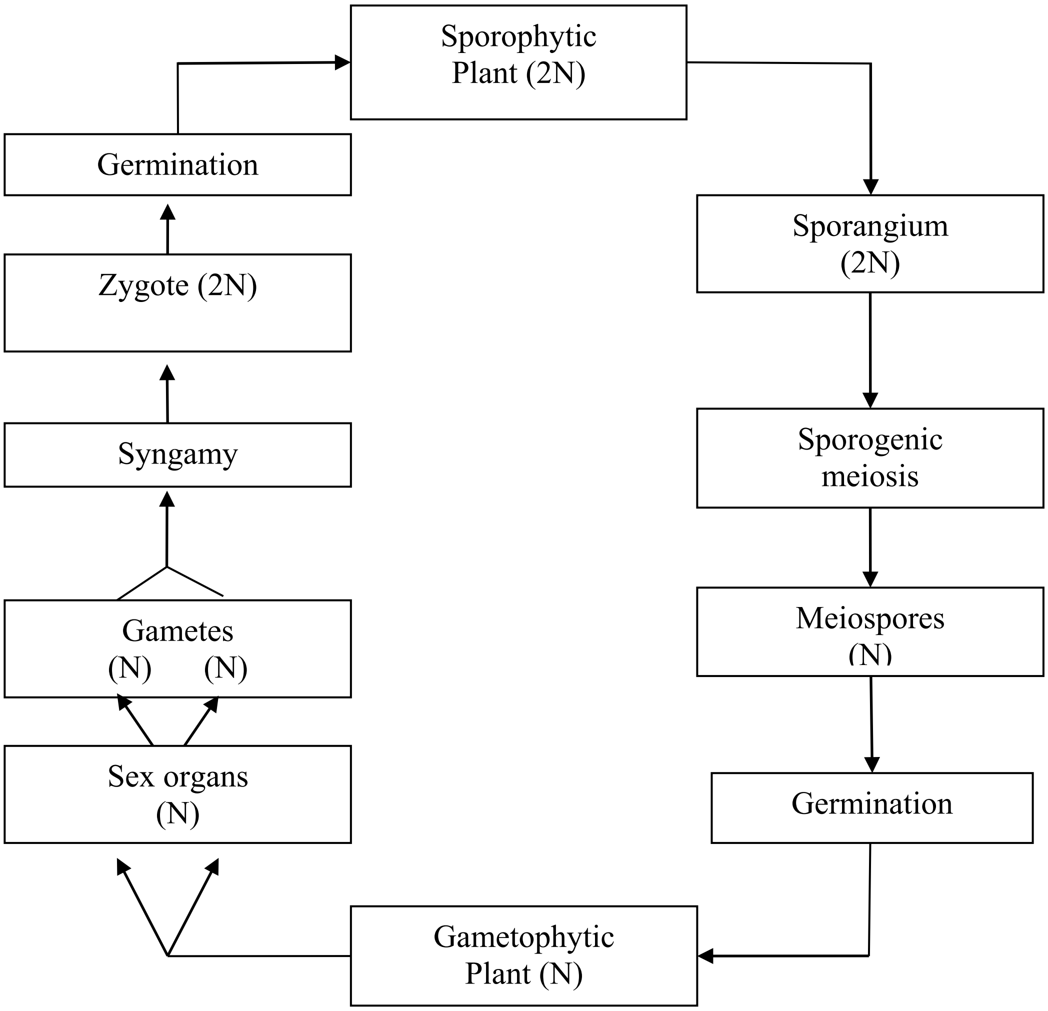


Fig.1.14- Diplohaplontic Life Cycle

b. Heteromorphic- In heteromorphic diplohaplontic life cycle, alternating generations are morphologically dissimilar. Sporophyte has elaborate development as compared to the gametophyte. E.g., Laminarials, Desmarestiales etc.

4. Haplobiontic Life Cycle- This is either diphasic or triphasic life cycle. In *Nemalion* a red alga exhibits two haploid phases and a diploid zygote. Hence, this type of haplobiontic is diphasic as it consists of two haploid thallus. It is also called as haplo-haplontic. In *Nemalion* dominant phase is a gametophyte that produces gametes. Zygote is formed after gametic union that develops into carposporophyte after meiosis. Carposporophyte produces carpospores that ultimately germinate into main gametophytic plant body.

Batrachospermum (red alga) do exhibit haplobiontic life cycle but it is triphasic as it consists of three prominent haploid phases (main gametophyte, carposporophyte and chatransia phase). Therefore, this life cycle may be called as haplo-haplo-haplontic life cycle. Zygote is the only diploid phase. The main plant body which is gametophyte produces gametes. These gametes fuse to form zygote that undergoes meiosis and develops into carposporophyte. Carpospores of carposporophyte germinates to form chatransia stage. Chatransia stage then develops into normal gametophyte.

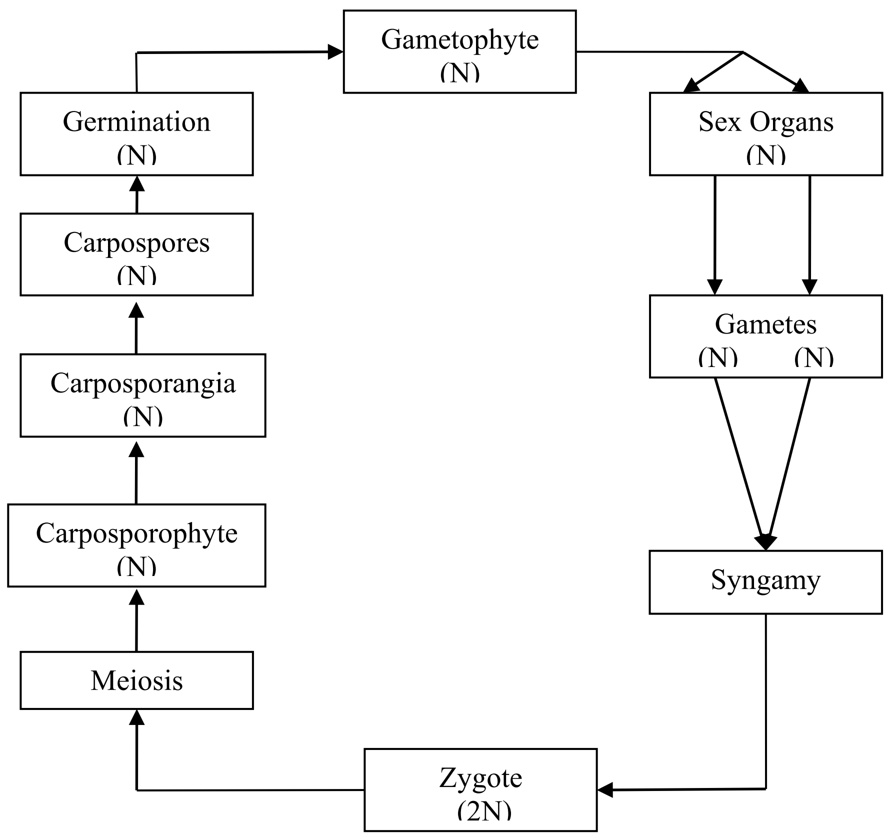


Fig.1.15- Haplo-haplobiontic life cycle

5. **Diplobiontic Life Cycle-** It is also a triphasic life cycle also called as diplodiplohaplontic life cycle. This life cycle consists three phases of which two phases are diploid and one is haploid. The main plant body is gametophyte that produces gametes. Zygote is formed by syngamy. In this life cycle, zygote differentiates into diploid carposporophyte. Diploid carposporangia develops in carposporophyte and diploid carpospores are produced within carposporangia. On liberation, carpospores develops into diploid tetrasporophyte. Tetraspores are produced after meiosis inside tetrasporangia. Tetraspores eventually develop

into main gametophytic plant thallus. This type of life cycle is exhibited by some members of red algae such as *Polysiphonia*.

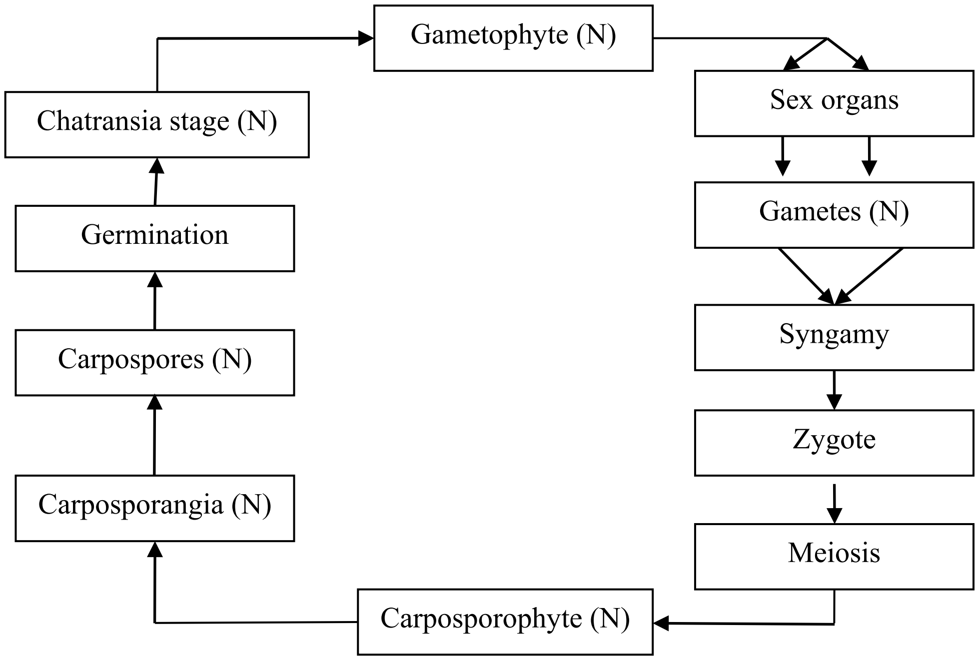


Fig. 1.16- Haplohaplohaplontic life cycle

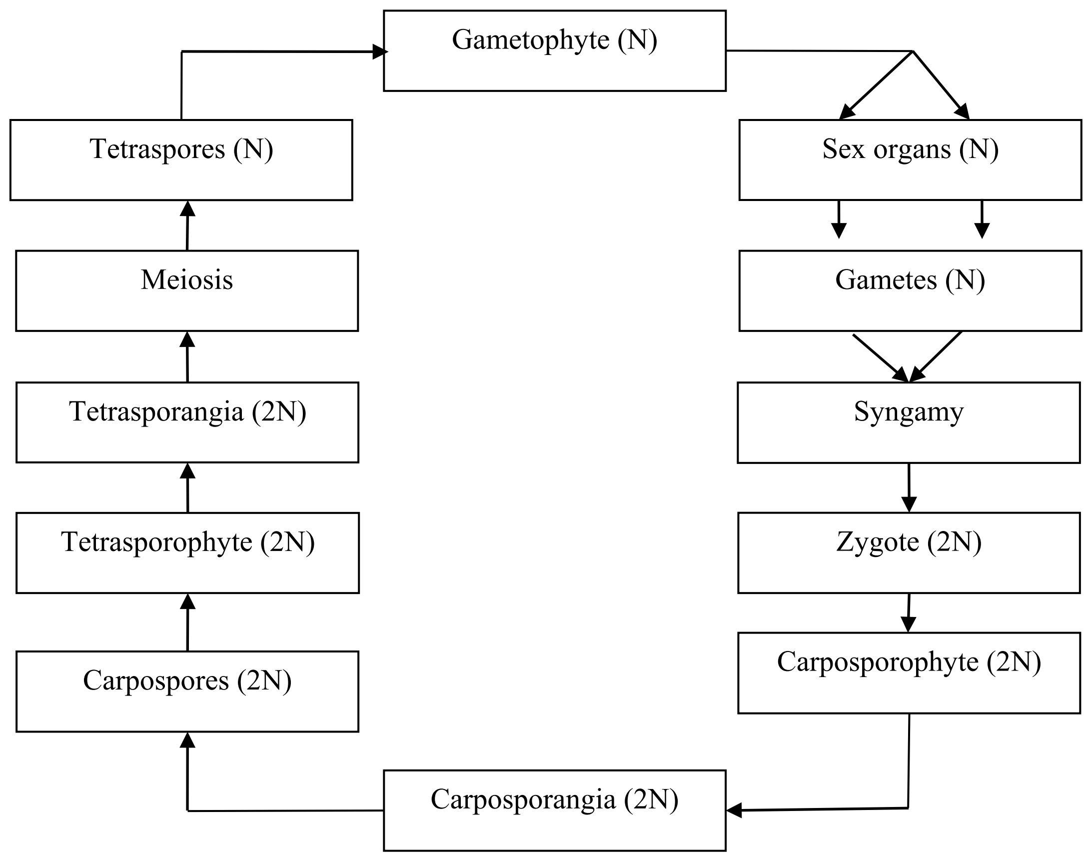


Fig. 1.17- Diplodiplohaplontic (Diplobiontic) Life Cycle

1.8 SUMMARY

- The term "algae" was coined by Linnaeus in 1754.
- A. L. de Jusssieu (1789) delimited the term 'algae' from bryophytes.
- Algae are thalloid, autotrophic, non-vascular plants having unicellular or multicellular (where all the cells are capable to reproduce), non-jacketed sex organs with no embryo formation.
- The study of algae is called Phycology.
- F. E. Fritsch published the classification of algae in his book 'Structure and Reproduction of the algae'.
- Ghose (1919-32) was the pioneer of phycology in India.
- A monograph on Zygnemaceae was written by M. S. Randhawa.
- Prof. Y. Bhardwaj established a school of algology at Banaras Hindu University.
- M. O. P. Iyenger is regarded as the 'Father of Indian Modern phycology'.
- Desikachary wrote a monograph on 'Cyanophyta'.
- R. N. Singh worked on blue green algae for reclamation of usar land.
- *Fritischiella tuberosa* was discovered in India.

- The free floating and free swimming microscopic algal forms together with other similar organisms constitute the Planktons of water bodies.
- Euplanktons (eg., *Microcystis, Chlamydomonas, Scenedesmu, Cosmarium* etc.) are free floating algae from the beginning of their life.
- Tychoplanktons are the algae which are attached to the substratum in the beginning but later become free floating such as *Cladophora, Cylindrospermum, Rivularia* etc.
- Thick algal growth over the surface of water is known as water blooms.
- *Anabaenopsis* is responsible for causing water bloom in Sambhar lake.
- *Oscillatoria brevis, Synechococcus elongates, Mastigocladus, Haplosiphon lignosum* etc. are some of the examples of thermophytes.
- *Haematococcus nivalis* imparts red colour to the snow whereas *Chlamydomonas yellowstonensis* is responsible for the green colour of the snow.
- Red rust of tea (*Camelia sinensis*) is caused by parasitic algae *Cephaleuros virescens*.
- In algae, thallus ranges from simple unicellular to complex thalli in which tissue differentiation occur to some extent.
- Coenobium is a colony of algal cells in which a fixed number of cells are arranged in a specific manner.
- *Volvox* is the example of motile coenobium.
- Palmella stage is a temporary stage in *Chlamydomonas.*
- In *Tetraspora,* palmelloid form is permanent.
- Lichen is the example of symbiosis between algae and fungi.
- *Vaucheria* is the best example of siphonaceous thallus.
- In *Batrachospermum* uniaxial pseudoparenchymatous thallus is found whereas in *Polysiphonia* multiaxial pseudoparenchymatous thallus is found.
- Flat and leaf like parenchymatous thalli are *Ulva, Punctaria* and *Porphyra.*
- Tubular parenchymatous thallus is found in *Enteromorpha*.
- *Sargassum* shows specialized differentiation of cells.
- Prokaryotic algal cell is found in cyanobacteria (blue green algae) while in other members of algae eukaryotic cell is found.
- Cell wall of cyanobacteria is made up of mucopeptide.
- Alginic acid is present in the cell wall of brown algae.
- In diatoms cell wall is silicified.
- Xylan, agar and carrageenin are present in cell wall of red algae.
- The chloroplasts in algae may be- cup-shaped, parietal, discoid, lobed, star shaped, spiral, and barrel or girdle shaped.
- Mucilages prevent algae from desiccation.
- In blue green algae or cyanobacteria, three types of phycobilins namely C-phycocyanin, C-phycoerythrin and allophycocyanin are present. Due to the presence of these phycobilins the colour of cyanobacteria appears to be blue green.

- Flagella are the locomotory organs found in motile algae or motile cells of algae.
- In cyanophyceae and rhodophyceae, flagella are never formed.
- Flagella in algae shows 9+2 pattern.
- Reproduction in algae takes place by vegetative, asexual and sexual methods.
- Vegetative reproduction takes place by different methods like fragmentation, fission, budding, protonema, tubers etc.
- In *Chara*, protonema and tubers are common methods for vegetative reproduction.
- Hormogones are found in some blue green algae.
- Asexual reproduction takes place by different asexual spores and similar structures like akinete, hypnospores, zoospores, hormogones, tetraspores etc.
- Akinetes are thick walled non flagellated asexual structures.
- Hypnospores are found in *Chlamydomonas* and *Protosiphon.*
- Tetraspores are asexual haploid spores produced form a diploid thallus tetrasporophyte.
- Heterocysts are found in blue green algae.
- Sexual reproduction takes place by fusion of gametes.
- In hologamy, whole thallus behaves as gamete.
- Autogamy is the fusion between the gametes of same thallus.
- Five types of life cycles are found in algae.

1.9 GLOSSARY

Akinete- A resting cell in certain green algae, which will later reproduce.
Algin- A mucilaginous substance alginic acid obtained from certain algae.
Algology- The study of algae.
Anisogamous- Differentiated gametes.
Aplanospore- A non-motile thin walled spore.
Aseptate- Without any septum.
Asexual- Having no sexual organs.
Asexual spore- Asexually developed spore.
Auxospore- Spore that are produced after sexual reproduction in diatoms.
Blepharoplast- A basal granule in relation with a motor cell organ.
Carpospore- A spore formed from carpogonium in Rhodophyceae.
Carposporophyte- The diploid generation of red algae.
Cellulose- A carbohydrate forming main part of plant cell ($C_6H_{10}O_5$).
Cell wall- Investing portion of cell.
Chlorophyll- The green coloured pigment found in plants.
Chloroplast- A minute granule or plastid containing chlorophylls.
Coenobium- A colony of unicells with definite number and shape.
Cyanin- A blue pigment.

Cytoplasm- Substance of cell body exclusive of nucleus.
Dendroid- Highly branched.
Diatom- A unicellular form of alga with walls impregnated with silica.
Epiphyte- Plant which live on surface of other plants.
Epizoic- Living on the body of an animal.
Fertilization- The union of male and female gamete.
Fission- Cleavage of cells.
Flagella- Plural of flagellum.
Heterocysts- Clear large cells found in blue green algae.
Hormocyst- A modified thick walled hormogones.
Hormogone- Cells between two heterocysts.
Hyaline- Colourless
Isogamous- Having alike gametes.
Multiaxial- Having several axes.
Oogamy- The union of a motile male gamete with non motile female gamete or egg.
Palmella- A sedentary stage of certain algae, the cells dividing within a jelly-like mass and producing motile gamete.
Perrenating bodies- bodies that store enough nutrients to sustain under unfavourable conditions.
Phycocyanin- A blue coloured pigment of algae.
Phycoerythrin- The red coloured pigment of red algae.
Plankton- Free floating small plants.
Tetrasporangium- Sporangium producing tetraspores.
Tetraspore- Non motile spore that are produced by tetrasporophyte of red algae.
Thallus- Plant body type that is not divided into root, stem and leaves.
Thermophyte- A heat tolerant plant.
Uniaxial- With one Axis; Monoaxial.
Vegetative- Stage of growth in plants.
Zygote- Cell formed by union of two gametes.

1.10 SELF ASSESSMENT QUESTION

1.10.1Multiple choice questions:

1. Phycology is the study of-
(a) Algae (b) Fungi
(c) Bryophyte (d) Bacteria

2. In algae, sex organs are-
(a) Multilayered (b) Without jacket layer
(c) With two layered jacket (d) None of the above

3. Father of modern Indian phycology is-
(a) M. S. Randhava (b) F. E. Fritsch
(c) M. O. P. Iyengar (d) R. N. Singh

4. The photosynthetic, genetic and respiratory apparatus are not bound by membranes in-
(a) Chrysophyceae (b) Cholorophyceae
(c) Cyanophyceae (d) Rhodophyceae

5. Heterotrichous means-
(a) Rhizoids and aerial branches (b) Long and short branches
(c) Prostrate and erect branches (d) None of the above

6. Plastids are absent in
(a) Chorophyceae (b) Myxophyceae
(c) Xanthophyceae (d) Rhodophyceae

7. Which of the following is a marine alga?
(a) *Ectocarpus* (b) *Oedogonium*
(c) *Chlamydomonas* (d) *Batrachospermum*

8. Statospores are formed in
(a) Diatoms (b) *Chlamydomonas*
(c) *Pilularia* (d) *Gloeocapsa*

9. Uniaxial pseudoparenchymatous thallus is found in-
(a) *Polysiphonia* (b) *Batrachospermum*
(c) *Fritsciella* (d) *Coloeochaete*

10. Which of the following shows heterotrichous habit-
(a) *Volovox* (b) *Pediastrum*
(c) *Coleochaete* (d) *Oedogonium*

11. An alga growing on snail is called-
(a) Epiphytic (b) Hydrophytic
(c) Endozoic (d) Epizoic

12. Red snow is caused by-
(a) *Chlamydomonas yellowstonensis* (b) *Chlamydomonas ehrenbergii*
(c) *Chlamydomonas nevalis* (d) Both a and b

13. Red rust of tea is caused by-
(a) *Volvox* (b) *Chlamydomonas*
(c) *Fritscheilla* (d) *Cephaleuros*

14. Cyanophyta is written by-
(a) Desikacharya (b) R. N. Singh
(c) M. S. Randhava (d) J. N. Mishra

15. Cryophytes are found in-
(a) On ice and snow (b) On soil
(c) On rocks (d) On plants

16. Zygnemaceae is written by
(a) M.O.P. Iyenegar (b) R. N. Singh
(c) M.S. Randhawa (d) J. N. Mishra

17. Amylum stars are found in-
(a) *Ectocarpus* (b) *Zygnema*
(c) *Chara* (d) *Polysiphonia*

18. Hetrocysts are found in-
(a) Chlorophyceae (b) Phaeophyceae
(c) Cyanophyceae (d) Xanthophyceae

19. Auxospores are formed in-
(a) Bacillariophyceae (b) Chlorophyceae
(c) Rhodophyceae (d) Phaeophyceae

20. Fusion between gametes of unequal sizes is called-
(a) Anisogamy (b) Oogamy
(c) Isogamy (d) Dichogamy

21. *Polysiphonia* exhibits
(a) Haplontic life cycle (b) Diplobiontic life cycle
(c) Haplobiontic life cycle (d) Heteromorphic life cycle

22. Triphasic life cycle is found in
(a) *Chara* (b) *Batrachospermum*
(c) *Ulva* (d) *Nemalion*

1.10.2 Fill in the blanks:

a) The plant in which root, stem and leaf is not differentiated is called…………..
b) ……………is parasitic on tea plants.
c) *Botrydium* has a ………………….thallus.
d) Fusion between gametes of same size is called………
e) Planktons are……………
f) Red rust of tea is caused by……….
g) ……………worked on reclamation of usar land.
h) *Polysiphonia* has…………………… thallus.
i) Green snow is caused by………………
j) ……………coined the term algae.
k) Flagellum in algae shows……………
l) Palmella stage as a temporary stage is found in…………
m) A motile colony with fixed number of cells in a fixed pattern is called…………
n) …………..shows false branching.
o) Luxuriant growth of some algae in water often imparting colour to water is called…….

1.10.1 Answer key- 1.(a), 2.(b), 3.(c), 4.(c), 5.(c), 6.(b), 7.(d),8.(a),10.(c), 11.(d), 12.(c), 13.(d), 14.(a), 15.(a), 16.(c), 17.(c), 18.(c), 19.(a), 20.(a), 21.(b), 22.(b)

1.10.2 Answer key- a-thallus, b-*Cephaleuros*, c-siphonaceous, d-isogamy, e-free floating algae, f-*Cephaleuros*, g-R. N. Singh, h-multiaxial pseudoparenchymatous, i-*Chlamydomonas yellowstonensis*, j-Linnaeus, k-9+2 pattern, l-*Chlamydomonas,* m-coenobium, n-*Scytonema*, o-water bloom.

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1.13 TERMINAL QUESTIONS

1.13.1 Short answer questions:

1. Describe vegetative reproduction in algae.
2. Write short note on asexual spores of algae.
3. Write short note on aquatic algae.
4. Describe sexual reproduction in algae
5. Give an account of ultrastructure of cyanobacteria.
6. Write short note on ultrastructure of flagellum.
7. Write short account on filamentous algae.
8. With suitable diagram, describe ultrastructure of eukaryotic algae.
9. Write short note on heterotrichous habit.
10. Describe the distinctive characteristics of algae.
11. Give an account of algae with unusual habitats.
12. What are planktons? Write a short note on water bloom.
13. How algae differ from fungi?
14. Give an account on the contribution of Indian phycologists.
15. Write a note on thermophytic, cryophytic and halophytic algae.

1.13.2 Long answer questions:

1. With the help of suitable diagrams, describe the cell structure of algae.
2. How algae reproduce? Describe in detail and give necessary diagrams wherever needed.
3. Describe the occurrences of algae.
4. Give a detailed account of thallus organization in algae.
5. Write a note on contribution of Indian phycologists.
6. Describe various types of life cycles found in algae.

UNIT-2 CLASSIFICATION

2.1 OBJECTIVES

After reading this unit students will be able to understand

- The criteria for the classification of algae
- The history of classification
- The classification proposed by various phycologists
- Distinguishing characteristics of different classes of algae

2.2 INTRODUCTION

As you have studied in the previous unit that algae are thalloid, chlorophyllous plants with no differentiation into root, stem and leaves, in which sex organs are without jacket layers and embryo formation does not take place. Algae contain various pigments that imparts colour to their body and hence be named according to their colour as green algae, brown algae, red algae etc.

In this unit, we will go through the criteria for the classification of the algae and various classifications as proposed by various scientists time to time.

For the classification of algae, certain suffixes have been recommended by the committee of International Code for Nomenclature. These are phyta for division, phyceae for class, phycideae for sub-class, ales for order, inales for sub-order, aceae for family, oideae for sub-family.

With the advancement of the techniques in the area of biochemistry, physiology, biotechnology, electron microscopy etc. different criteria to classify the algae came into knowledge like types of pigments, flagellation, reserve food material, pattern of life cycle etc.

2.3 MODERN CONCEPT TO CLASSIFY ALGAE

The criteria and modern concept to classify algae are-

1. Nuclear organization
2. Cell wall components
3. Pigments
4. Flagellation
5. Chemical nature of reserve food material
6. Type of life cycle and reproduction

1. **Nuclear organization:** On the basis of nuclear organization, algae can be prokaryotic or eukaryotic. Cyanophyceae or cyanobacteria (blue green) are prokaryotic in nature while all other algae are eukaryotic. In cyanophyceae, nuclear membrane is absent and genetic material (chromatin threads) is not bounded with histone proteins. Moreover, membrane bound organelles like mitochondria, plastids, golgi bodies, endoplasmic reticulum, vacuoles

etc are not found. Eukaryotic algae have well organized nucleus, mitochondria, golgi bodies, chloroplasts, endoplasmic reticulum etc. in their cell structure.

2. **Chemical composition of Cell wall:** The cell wall of algae is made up of cellulose (polysaccharide). In general, the inner wall is insoluble cellulosic layer and outer wall is made up of pectic substances which are soluble in water. In addition to this certain classes of algae possess certain chemical components in their cell wall which make them distinct from other classes. For example, members of Phaeophyceae possess alginic acid and fucinic acid in their cell wall while silica is impregnated in the cell wall of bacillariophyceae. Xylan and galactan is found in cell wall of Rhodophyceae. Cell wall of cyanophyceaea is made up of mucopeptide.

3. **Pigments:** It is one of the most important criteria of classification of algae. In the beginning, algae were classified as red algae, brown algae, green algae and blue green algae on the basis of their colour. Pigments are present in plastids of eukaryotic algae while in thylakoids of prokaryotic algae.

Plastids contain three types of pigments in algae. These are chlorophyll, carotenoids and phycobilins.

a) **Chlorophyll-** Five types of chlorophyll namely-chlorophyll a, b, c, d and e are found in algae.

Chlorophyll a is present in all classes of algae.
Chlorophyll b is present in Chlorophyceae and Euglenineae.
Chlorophyll c is present in Phaeophyceae and Cryptophyceae.
Chlorophyll d is found in Rhodophyceae only.
Chlorophyll e is present in Xanthophyceae only.

b) **Carotenoids-** Carotenoids are yellow or orange coloured pigments. They are capable of absorbing destructive oxygen molecules from light and provide a protective sheath. The various colours in algae is due to these pigments.

Carotenoids are of fat soluble and divided into carotene, xanthophylls and carotenoid acids.

Carotene- There are six types of carotenes- α, β, γ, ε, flavicine and lycopene etc. Carotene is a linear chain of unsaturated hydrocarbons and fat soluble. β-carotene is found in all classes of algae. α-carotene is found in Rhodophyceae and Cryptophyceae. γ-carotene and lycopene is found in Charophyceae. ε-carotene is present in Cryptophyceae and Bacillariophyceae. In Cyanophyceae, flavicin is found.

Xanthophyll- Xanthophylls are oxygen derivatives of carotenes. There are about 20 types of xanthophylls are found in algae. e.g., Zeathanthin, Flavoxanthin, Diatoxanthin, Myxoxanthin, Myxoxanthophylls, Fucaxanthin, Zeaxanthin, Ocillaxanthin, Terraxanthin etc.

Myxoxanthin and Myxoxanthophyll are present only in Cyanophyceae, Terraxanthin only in Rhodophyceae, Antheroxanthin only in Euglenineae.

Carotenoid acids- Carotenoid acid resembles with carotene and xanthophylls and are hydrocarbons, consisting a chain of carbon atoms.

c) **Phycobilins or biliprotiens-** Phycobilins are soluble in water. They are attached to a protein moiety. There are three types of phycobilins- phycocyanin, phycoerythrin and allophycocyanin. r-phycocyanin and r-phycoerythrin are confined to Rhodophyceae while c-phycocyanin and c-phycoerythrin are found in cyanophyceae. Allophycocyanin is found in Rhodophyceae.

4. **Nature of reserve food material:** The main reserve food material in algae is starch which is a product of photosynthesis. Due to accumulation of food over long period the nature of reserve food material may be different. In Chlorophyceae starch remains the reserve food material. In Cyanophyceae it is myxophycean starch. Floridean starch is found in Rhodophyceae. In Pheaophyceae, mannitol and laminarin are main reserve food material while in Xanthophyceae, leucosine and oil are reserve food.

5. **Flagellation:** Flagella are the important basis of criteria to classify the algae. The type, number and position of flagella is different for different classes of algae (Fig.2.1). Flagella are entirely absent in Cyanophyceae and Rhodophyceae.

There are two main types of flagella- **whiplash** or **acronematic** and **tinsel** or **pleuronematic**.

A. **Whiplash** or **acronematic-** It has smooth surface.

B. **Tinsel** or **pleuronematic** tinsel flagellum bears longitudinal rows of fine, minute flimmers or mastigonemes. Tinsel flagella may be *pantonematic, pantoacronematic* or *stichonematic.*

a. **Pantonematic**- Mastigonemes are arranged in two opposite rows in the flagellum.

b. **Pantoacronematic**- It is a pantonematic flagellum with terminal fibril.

c. **Stichonematic-** Mastigonemes are present only on one side of flagellum.

In Chlorophyceae flagella are of 2, 4 or indefinite in number, apical or sub-apical in position and acronematic type (isokontic- all flagella are of same type). In Xanthophyceae flagella are two, unequal, apical in position (heterokontic-one whiplash and one tinsel). In phaeophyceae flagella are two, lateral and unequal (one whiplash and one tinsel).

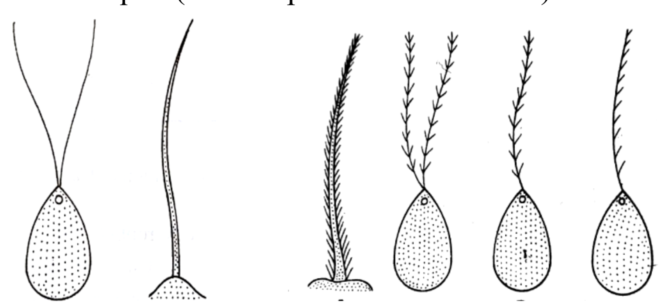

Fig.2.1- Flagellation in algae (A- F). (A, B) Acronematic flagella; (C) Pleuronematic flagellum with mastigonemes (D) Cell with two equal pantonematic flagella, (E) Pantoacronematic flagellum, (F) Stichonematic flagellum

6. **Type of life cycle and reproduction-** The presence or absence of sexual reproduction, complexity of reproductive organs, and method of reproduction is also considered as criteria to classify the algae. Haplontic, diplontic and triphasic life cycle are characteristics of different groups. Sexual reproduction is completely absent in Cyanophyceae. In Rhodophyceae and Phaeophyceae, reproduction is oogamous and life cycles are usually complex. In chlorophyceae reproduction may be isogamous, anisogamous and oogamous, the life cycle may be simple or complex.

2.4 CLASSIFICATION

In 1753, Linnaeus placed algae in the class cryptogamia together with mosses, vascular cryptogams and fungi in his *Species Planatarum*. He did not classified algae further. Since then classification of algae has been continually modified.

Vaucher (1803) was perhaps the first to propose a system of classification of algae. He recognized three groups, *Conferves, Ulves* and *Tremelles.* Link (1820) and Robert Brown classified algae on the basis of colours of algae. On the basis of habitat and the pigment classification was proposed by Harvey (1836). Agardh (1849-98) divided algae into six orders-Diatomaceae, Nostochineae, Confervoideae, Ulvaceae, Florideae and Fucoideae.

Algae along with fungi were grouped under Thallophyta, a division created by Eichler (1836). Engler and Prantl (1912) proposed a system of classification which is summarized as follows-

1. Schizophyta
2. Phytosarcodina
3. Flagellata
4. Dinoflagellata
5. Bacillariophyta
6. Conjugatae
7. Chlorophyceae
8. Charophyta
9. Phaeophyceae
10. Rhodophyceae
11. Eumycetes

Pascher (1914-1931) proposed a classification on the basis of phylogeny and interrelationships of various groups. He divided algae into 8 divisions and divisions into classes. The classification as proposed by him is as follows-

Division 1. **Chrysophyta**

a. Chrysophyceae
b. Diatomaceae
c. Heterokontae

Division 2. **Phaeophyta**

a. Phaeophyceae

Division 3. **Pyrrophyta**

a. Cryptophyceae
b. Desmokontae
c. Dinophyceae

Division 4. **Euglenophyta**

a. Euglenophyceae

Division 5. **Chlorophyta**
- a. Chlorophyceae
- b. conjugatae

Division 6. **Charophyta**
- a. Characeae

Division 7. **Rhodophyta**
- a. Bangineae
- b. Floridineae

Division 8. **Cyanophyta**
- a. Myxophyceae

On the basis of reserve food material, flagellation and pigments Tilden (1933) classified algae into following classes-

1. **Chlorophyceae**
2. **Myxophyceae**
3. **Rhodophyceae**
4. **Phaeophyceae**
5. **Chrysophyceae**

F. E. Fritsch (1935, 1945) proposed classification of algae on the basis of reserve food material, flagellation and pigments. He ranked algae as division and classified it into 11 classes. It was supposed to be most authentic and comprehensive classification then. The scheme of classification as proposed by him is as follows-

Class
1. **Chlorophyceae**
2. **Xanthophyceae**
3. **Chrysophyceae**
4. **Bacillariophyceae**
5. **Cryptophyceae**
6. **Dinophyceae**
7. **Chloromonadineae**
8. **Euglenophyceae**
9. **Phaeophyceae**
10. **Rhodophyceae**
11. **Myxophyceae**

G. M. Smith (1955) modified classification of Pascher (1914-1931). He divided algae into 7 divisions and divisions into classes as follows-

Division 1. **Chlorophyta-** The division includes approximately 5700 forms out of which 90% are fresh water and remaining are marine. Dominant pigments are chlorophyll a and b. reserve food material is starch. The division is divided into two classes-

a. Chlorophyceae (green algae) e.g., *Chlamydomonas, Volvox*
b. Charophyceae (Stoneworts) e.g., *Chara*

Division 2. **Euglenophyta-** It includes about 450 species from fresh water and terrestrial habitats. Dominant pigments are Chlorophyll a and b and β-carotene. Reserve food is paramylum and fats. It has been divided into single class.-

a. Euglenophyceae e.g., *Euglena*

Division 3. **Pyrrophyta-** It includes about 1000 species. Members are generally unicellular forms rarely colonial. Principle pigments are chlorophyll a and c, β-carotene and xanthophylls. It has been further divided into two classes-

a. Desmophyceae (Dinophycids) e.g., *Desmarestia*
b. Dinophyceae (Dinoflagellates) e.g., *Dinophysis*

Division 4. **Chrysophyta-** It includes approximately 6000 species of freshwater forms (75%) and marine forms (25%). Dominant pigments are carotene and Xanthophylls. Reserve food material is leucosine and oil. It is divided into three classes-

a. Chrysophyceae (golden brown algae) e.g., *Chromulina*
b. Xanthophyceae (yellow green algae) e.g., *Botrydium*
c. Bacillariophyceae (Diatoms) e.g., *Pinnularia*

Division 5. **Phaeophyta (Brown algae)-** These are mostly marine forms and are generally known as sea weeds. Dominant pigments are phycophyein and fucoxanthin. Reserve food materials are laminarin and mannitol. It is divided into three classes-

a. Isogeneratae e.g, *Ectocarpus*
b. Heterogeneratae e.g., *Myrionema*
c. Cyclosporae e.g., *Sargassum*

Division 6. **Cyanophyta (Blue-green algae)**- These are mostly fresh water forms and include about 1500 species. Principle pigments are Chlorophyll a, c-phycocyanin and c-phycoerythrin. Reserve food material is cyanophycean starch. Motile cells are completely absent. It include a single class-

a. Myxophyceae e.g., *Nostoc, Anabaena*

Division 7. **Rhodophyta (Red algae)-** These are mostly marine and include about 2500 species. Dominant pigments are chlorophyll a and d, r-phycoerythrin and r-phycocyanin. Reserve food material is floridean starch. Motile cells are absent. It is divided into single class-

a. Rhodophyceae e.g., *Batrachospermum* (fresh water), *Polysiphonia, Gracillaria.*

G. E. Papenfuss (1955) classified algae on the basis of phylogeny. He recognized 8 phyla and classified them into 12 classes as follows-

Phylum 1. **Chlorophycophyta**
a. Chlorophyceae

Phylum 2. **Charophycophyta**
a. Charophyceae

Phylum 3. **Euglenophycophyta**
a. Euglenophyceae

Phylum 4. **Chrysophycophyta**
a. Xanthophyceae
b. Chrysophyceae
c. Bacillariophyceae

Phylum 5. **Pyrrophycophyta**
a. Dinophyceae
b. Cryptophyceae
c. Chloromonadophyceae

Phylum 6. **Phaeophycophyta**
a. Phaeophyceae

Phylum 7. **Schizophycophyta**
a. Schizophyceae

Phylum 8. **Rhodophycophyta**
a. Rhodophyceae

Chapman (1962) divided algae into 4 phyla on the basis of pigments, morphological characteristics and biochemical differences. His classification is as follows-

Phylum 1. **Euphycophyta**
a. Charophyceae
b. Chlorophyceae
c. Phaeophyceae
d. Rhodophyceae

Phylum 2. **Myxophycophyta**
a. Myxophyceae

Phylum 3. **Chrysophycophyta**
a. Chrysophyceae
b. Xanthophyceae
c. Bacillariophyceae

Phylum 4. **Pyrrophycophyta**
a. Cryptophyceae
b. Dinophyceae

Christensen (1964) proposed a new scheme of primary classification of algae on the basis of their cell structure. Prescott (1969) classified algae on the basis of cell structure along with pigments, cell wall, reserve food material etc. into 9 phyla and fourteen classes. The scheme as proposed by him is as follows-

Phylum 1. **Chlorophyta**
- a. Chlorophyceae
- b. Charophyceae

Phylum 2. **Euglenophyta**

Phylum 3. **Chrysophyta**
- a. Chrysophyceae
- b. Bacillariophyceae
- c. Heterokontae (Xanthophyceae)

Phylum 4. **Pyrrophyta**
- a. Desmokontae (Desmophyceae)
- b. Dinokontae (Dinophyceae)

Phylum 5. **Phaeophyta**
- a. Isogenerateae
- b. Heterogeneratae
- c. Cyclosporae

Phylum 6. **Rhodophyta**
- a. Bangioideae
- b. Florideae

Phylum 7. **Cyanophyta**
- a. Coccogoneae
- b. Hormogoneae

Phylum 8. **Cryptophyta**

Phylum 9. **Chloromonadophyta**

Round (1973) modified Classification on F. E. Fritsch (1945) and raised the classes to the rank of phyla. He recognized the presence and absence of true nucleus in algae together with phylogenetic relationships and gave a classification as follows-

PROKARYOTA- Phylum 1. **Cyanophyta**
- a. Cyanophyceae

EUKARYOTA- Phylum 2. **Chrysophyta**
- a. Xanthophyceae
- b. Chrysophyceae
- c. Haptophyceae
- d. Bacillariophyceae

Phylum 3. **Chlorophyta**
- a. Chlorophyceae
- b. Oedogoniophyceae

c. Bryopsidophyceae
d. Conjugatophyceae
e. Charophyceae
f. Prasinophyceae

Phylum 4. **Euglenophyta**

Phylum 5. **Pyrrophyta**

a. Desmophyceae
b. Dinophyceae

Phylum 6. **Cryptophyta**

Phylum 7. **Phaeophyta**

a. Phaeophyceae

Cohorts a. Isogeneratae
b. heterogeneratae
c. Cyclosporae

Phylum 8. **Rhodophyta**

a. Rhodophyceae

Subclasses- a. Bangiophycidae
b. Florideophycidae

Chapman and Chapman (1973) divided algae into prokaryota and eukaryote which were further subdivided into divisions and classes.

Prokaryota

Division- Cyanophyta
Class- Cyanophyceae

Eukaryota

Division- Rhodophyta
Class- Rhodophyceae
Division- Chlorophyta
Class- a. Chlorophyceae
b. Prasimophyceae
c. Charophyceae
Division- Euglenophyta
Class- Euglenophyceae
Division- Chloromonadophyta
Class- Chloromonadophyceae
Division- Xanthophyta
Class- Xanthophyceae
Division- Bacillariophyta

Class-	Bacillariophyceae
Division-	Chrysophyta
Class-	a. Chrysophyceae
	b. Haptophyceae
Division-	Phaeophyta
Class-	Phaeophyceae
Division-	Pyrrophyta
Class-	a. Dinophyceae
	b. Desmophyceae
Division-	Cryptophyta
Class-	a. Cryptophyceae

Salient Features of Important Classes of Algae

1. Chlorophyceae- The Class possesses green algae. Main pigments are chlorophyll a and b, xanthophylls and carotenoids. The cells have well organized nucleus (eukaryotic). Reserve food material is starch rarely oil. Pyrenoid is usually present in the plastid. Motile cells have two isokontae flagella. Sexual reproduction ranges from isogamous to oogamous. The members are mostly fresh water but few forms are marine.

2. Xanthophyceae- Majority of the members are fresh water forms, few are marine. The members are yellow green in colour due to excess of xanthophylls. Major pigments are chlorophyll a and e, β- carotene and xanthophylls. Motile cells are biflagellate with two unequal flagella. Pyrenoids are not present in plastids. Reserve food material is oil. Sexual reproduction is rarely present but if present then it is isogamous.

3. Chrysophyceae- Mostly the members are marine and fresh water forms. The colour of the algae is brown or orange due to the excess presence of phycochrysin. In addition to this other pigments are chlorophyll a and β-carotene. Reserve food material is oil and leucosine. Sexual reproduction is rare as in case of Xanthophyceae and if present then it is isogamous. Motile cells have one flagellum. Sometimes two or three flagella may also be present.

4. Bacillariophyceae- The members of Bacillariophyceae are commonly known as Diatoms. Members are fresh water and marine forms both. The dominant pigment is diatomin and yellow or golden brown in colour. Other pigments are chlorophyll a and c, β- carotene and xanthophylls. Cell wall is impregnated with silica and variously ornamented. The wall is divided into two halves. Pyrenoids are present. Reserve food material is oil, volutin and leucosine. Sexual reproduction is unique.

5. Cryptophyceae- The members are fresh water and marine both. The members are variously coloured (brown, red, olive green, or sometimes bluish green). The cells have two large parietal chloroplasts with pyrenoids. Reserve food material is starch. Motile cells are biflagellate and are unequal in length. Sexual reproduction is isogamous.

6. Dinophyceae- Most of the members are unicellular and motile. Motile cells are biflagellate. Disc shaped chloroplasts are present. Chlorophyll a and c is present. The colour of the members is brown or dark yellow due to the presence of red phycopyrin, dark red peridinin and yellow green chlorophyllin. Reserve food material is starch and fat. Sexual reproduction is rare and if present then it is isogamous.

7. Chloromonadineae- Members are only fresh water forms. Algae of this class are bright green in colour due to the presence of excess xanthophylls and cells have numerous discoid chromatophores. Reserve food material is fat.

8. Euglenophyceae (Euglenineae) - The class includes unicellular flagellates. Flagella are one of two in numbers. Members are fresh water forms or found in saline habitats. Mostly members are free swimming bodies but have tendencies to form gelatinous colonies. Major pigments are chlorophyll a and b, β- carotene and xanthophylls. Reserve food material is polysaccharide paramylon and fats. Reproduction usually takes place by fission.

9. Phaeophyceae- The members are generally known as brown algae. Structurally these are the most complex algae. Pigments include chlorophyll a and c, β- carotene and xanthophylls. The brown colour is due to excess fucoxanthin. Commonly algae are called sea weeds. They are marine forms. Reserve food material is in the form of laminarin and mannitol. Algin and fucoidin is present in cellulosic cell wall. Reproduction is by vegetative and sexual both. Sexual reproduction ranges from isogamy to oogamy. Motile cells are biflagellate with unequal length. Flagella are unequal and are attached laterally.

10. Rhodophyceae- Majority of the forms are marine and only few are fresh water forms. Members are called red algae. Major pigments include chlorophyll a and d, β- carotene, xanthophylls and phycobilins- r-phycoerythrin, r-phycocyanin and allophycocyanin. The colour of algae is red due to the presence of excess r-phycoerythrin. Reserve food material is floridean starch. Thallus is organized and possesses complexity. Plasmodesmata is present in the cells except in the members of Protoflorideae. Sexual reproduction is specialized and oogamous. Motile cells are altogether absent.

11. Cyanophyceae or Myxophyceae- The members are called blue green algae. Members are prokaryotic. Thallus is simple unicellular, colonial or multicellular bodies. Pigments are not in organized bodies as in other cases. Principle pigments are chlorophyll a, α-carotene, β-carotene, xanthophylls and phycobilins- c-phycocyanin and c-phycoerythrin. The colour of algae is due to the presence of excess c-phycocyanin. Reserve food material is cyanophycean starch. The cell wall is made up of mucopeptide. Most of the members are embedded in mucilaginous sheath. False branching and special cells heterocysts are characteristics of several members. Motile cells are altogether absent in life cycle as in the case of Rhodophyceae.

2.5 SUMMARY

1. Cyanophyceae or cyanobacteria (blue green) are prokaryotic in nature while all other algae are eukaryotic.
2. Sexual reproduction is absent in Cyanophyceae.
3. Motile cells are completely absent in Cyanophyceae and Rhodophyceae.
4. Cell wall of cyanobacteria is made up of mucopeptide.
5. The modern concept of classification of algae is based on, type of cell, pigments, flagellation, chemical nature of cell wall, reserve food material and life cycle patterns.
6. Silica is impregnated in the cell wall of the members of Bacillariophhyceae.
7. In Phaeophyceae cell wall contains alginic and fucinic acid.
8. Agar is obtained from red algae.
9. Chlorophyll a is present in all classes of algae.
10. Chlorophyll d is present only in Rhodophyceae
11. Phycobilins are water soluble pigments and are found in Cyanophyceae and Rhodophyceae.
12. Blue green colour of cyanobacteria is due to the predominant pigment c-phycocyanin.
13. Red colour of red algae is due to the presence of predominant pigment r- phycoerythrin.
14. Floridean starch is reserve food material in class Rhodophyceae
15. In Phaeophyceae laminarin and mannitol are reserve food materials.
16. The flagella in algae show 9+2 pattern.
17. In Chlorophyceae, flagella are isokontic.
18. In Xanthophyceae heterokontic flagella are present
19. Tinsel flagella have hair like appendages all over their surface called as flimmers or mastigonemes.
20. Smith classified algae into 7 divisions and divisions into classes.
21. F. E. Fritsch recognized 11 classes of algae.
22. False branching and heterocysts are characteristic features in many blue- green algae.
23. Phaeophyceae possess two unequal flagella which are laterally inserted in the cell.
24. The brown colour of phaeophyceae is due to the excess of pigment fucoxanthin.

2.6 GLOSSARY

- **Anisogamous**- Fusion between dissimilar gametes
- **Carotenoid-** A yellow or orange coloured fat soluble pigment
- **Diplontic**-A life cycle in which main plant body is diplpoid
- **Haplontic**- A life cycle in which main plant body is haploid
- **Isogamous-** Fusion between similar type of gametes
- **Oogamous**- Fusion between motile gamete and non motile gamete
- **Phycobilins**- Red or blue pigment in algae which are water soluble
- **Phycocyanin-** A colouring matter of algae.
- **Phycoerythrin-** The colouring matter of red algae.
- **Pyrenoids**- A protein body in the chloroplasts of algae which are involved in fixation of carbon and starch formation and storage
- **Starch**- a polysaccharide
- **Tinsel flagellum-** Flagellum with minute hairs
- **Whiplash flagellum-** Flagellum with smooth surface

2.7SELF ASSESSMENT QUESTIONS

2.7.1 Multiple choice questions:

1. Motile cells are absent in-
(a) Rhodophyceae (b) Cyanophyceae
(c) Both a and b (d) None of the above

2. Reserve food material in Rhodophyceae is-
(a) Glycogen (b) Starch
(c) Mannitol (d) Floridian starch

3. Allophycocyanin is present in-
(a) Cyanophyceae (b) Xanthophyceae
(c) Chrysophyceae (d) Rhodophyceae

4. Sexual reproduction is absent in the class-
(a) Chlorophyceae (b) Rhodophyceae
(c) Cyanophyceae (d) Phaeophyceae

5. The cells are prokaryotic in-
(a) *Nostoc* (b) *Batrachospermum*
(c) *Sargassum* (d) *Chalamydomonas*

6. Fresh water red alga is-

(a) *Cladophora* (b) *Batrachospermum*
(c) *Polysiphonia* (d) *Ulva*

7. Chlorophyll d is present in-
(a) Cyanophyceae (b) Rhodophyceae
(c) Xanthophyceae (d) Phaeophyceae

8. Fucoxanthin is found in-
(a) Blue-green algae (b) Green algae
(c) Brown algae (d) Red algae

9. The reserve food material in Chlorophyceae is-
(a) Oil (b) Starch
(c) Glucosides (d) Protein

10. Which of the following has floridian starch as reserve food material
(a) *Nostoc* (b) *Volvox*
(c) *Polysiphonia* (d) *Sargassum*

11. Chlorophyll a and b is present in
(a) Chlorophyceae (b) Xanthophyceae
(c) Euglenophyceae (d) Both a and c

12. Reserve food material in Xanthophyceae is-
(a) Leucosine (b) Starch
(c) Floridean starch (d) Laminarin

13. Diatoms are members of-
(a) Xanthophyceae (b) Rhodophyceae
(c) Bacillariophyceae (d) Cyanophyceae

14. Red colour of Rhodophyceae is due to the pigment-
(a) R-phycoerythrin (b) R-phycocyanin
(c) Allophycocyanin (d) Chlorophyll d

15. Paramylon is found in
(a) Rhodophyceae (b) Cryptophyceae
(c) Dinophyceae (d) Euglenophyceae

2.7.2 Fill in the blanks:

a. Chlorophyll a and b is present in………………
b. The brown colour of Phaeophyceae is due to the presence of…………
c. Smith based his classification of algae on two characteristics which are…….and…….
d. The members of class………..are always prokaryotic.
e. In Phaeophyceae the reserve food material is…………..
f. The study of algae is…….
g. Prescott divided algae into…………phyla.
h. F. E Fritsch classified algae into ……….classes.
i. Sexual reproduction is absent in……………..
j. All classes except…………include unicellular forms.
k. Motile cells are absent in class……………and …………..
l. ………………..is the reserve food material in Cyanophyceae.
m. Pantonematic flagellum with terminal fibril is called……………
n. Chlorophyll e is present in………………
o. Heterocyst is present in the members of……………..

2.7.1Answer key:

1-c, 2-d, 3-d, 4-c, 5-a, 6-b, 7-b, 8-c, 9-b, 10-c, 11-d, 12-a, 13-c, 14-a, 15-d

2.7.1Answer key:

a- Chlorophyceae and Euglenophyceae, b- Fucoxanthin, c- Pigments and reserve food material, d- Cyanophyceae, e- Laminarin and mannitol, f- Phycology, g- 9, h- 11, i- Cyanophyceae, j- Rhoodphyceae, k- Cyanophyceae and Rhodophyceae, l- Cyanophycean starch, m- pantoacronematic, n- Xanthophyceae, o- Cyanophyceae

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2.10 TERMINAL QUESTIONS

2.10.1. Very short answer questions:

1. Give the name of pigments found in Cyanophyceae and Rhodophyceae.
2. What kind of flagella is found in Chlorophyceae?
3. How many classes were included by F. E. Fritsch in his classification of algae?
4. What is the basic difference between Cyanophyceae and Chlorophyceae?
5. Why the members of Phaeophyceae are called brown algae?
6. In which class of algae heterokontic, laterally attached flagella are present?
7. How many kinds of pigments are found in algae? Name them.
8. Name the chemical nature of reserve food found in different classes of algae.
9. What are pyrenoids?
10. In which class of algae cell wall is impregnated with silica?

2.10.2. Short answer questions:

1. Describe the following
   a. Flagellation in algae
   b. Algal cell walls
   c. Algal pigments
   d. Reserve food material in algae
2. Write short notes on-
   a. Distinctive characters of Myxophyceae
   b. Characteristic features of Phaeophyceae
   c. Importance of pigments in classification of algae
   d. Distinguishing features of Rhodophyceae
   e. Classification of algae given by Fritsch.
3. Compare the distinguishing features of Myxophyceae and Rhodophyceae
4. Give an account of distinct features of Xanthophyceae, Chrysophyceae and Dinophyceae.

5. Write the importance of nuclear organization and chemical nature of cell wall in classification of algae.
6. Write an outline of classification proposed by Chapman and Chapman.

2.10.3. Long answer questions:

1. What are the main criteria used to classify the algae?
2. Give the classification of algae given by Smith (1955) and mention important characteristics of each class.
3. Describe the distinguishing features of Cyanophyceae, Phaeophyceae, Xanthophyceae, Cryptophyceae, Dinophyceae and Rhodophyceae.
4. Give a detailed account of classification proposed by F. E. Fritsch. Compare his classification by classification given by Chapman (1962).

UNIT-3 FOSSIL ALGAE, BASIC CONCEPT OF CYANOPHAGE, ECONOMIC IMPORTANCE

3.1 OBJECTIVES

After reading this unit student will be able to understand-

- The paleontological account of algae
- The evolutionary history of algae based on the fossil records
- The history, morphology and replication of Cyanophages
- The value of algae in different fields

3.2 INTRODUCTION

Algae are photosynthetic organisms of universal occurrence. Their structure ranges from small, unicellular forms to complex multicellular thallus. They vary in size from micrometers to giant kelps (brown algae) that may attain a length of 60-65 meters. They occur in most habitats, ranging from aquatic to desert land and from hot water springs to snow or ice. Algae are very important producers of organic matter. They contribute food, medicines and other useful industrial and domestic products but at the same time they may be a cause to a mass mortality in the form of water or algal blooms.

Algae are found in the fossil records dating back to approximately 3 billion years in the Precambrian. Modern ultrastructural and molecular studies have provided important information that has led to a reassessment of the evolution of algae. In addition, the fossil record for some groups of algae has hindered evolutionary studies, and the realization that some algae are more closely related to protozoa or fungi than they are to other algae.

In the previous units you have gone through the details about the algal structure, habitats, classifications laid by different scientists time to time. In this unit we will discuss about some general topics on algae such as fossil records of algae on the basis of which we may understand the evolution of algae to some extent, cyanophages and economic importance of algae.

3.3 FOSSIL ALGAE

Algae as being soft and delicate thalloid plants do not undergo fossilization easily. However, a sizable number much of the algal fossil forms have been discovered, identified and preserved. The oldest record of fossil algae meets in the Precambrian era. The oldest algal fossil known is *Archaeosphaeroides barbertonensis*- a blue green alga. It is now accepted that blue-green algae existed in the Archaeozoic era and may be among the earliest algae on earth as considerable number of blue green algal fossils have been discovered from ancient rocks. Only those algae that secreted lime or silica have been preserved successfully.

Algae have been preserved as impressions, petrifactions, coal balls, molds and casts. Largest number of algal fossils belong to Cretaceous period although they have been reported from Paleozoic, Triassic, Jurassic, Silurian, Ordovician periods too. The Paleozoic era has been called as 'Age of Seaweeds' as the warm sea that covered much of the earth of Paleozoic era was very suitable for algal growth.

Blue-green algal forms that were discovered from early Precambrian era were fossil impressions and were unicellular, globular or filamentous. In the middle Precambrian, fossils of coccoid and filamentous forms were reported while in late Precambrian heterocystous cyanobacteria and some eukaryotes from Chlorophyceae, Phaeophyceae and Rhodophyceae were discovered. Fossilized diatoms form thick deposits in various habitats where they found. The large accumulations of fossilized diatoms are called diatomaceous earth. The earliest diatomaceous earth is recorded from late Mesozoic (cretaceous). Among the diatoms, Centrales are older than the Pennales.

Fossils of red algae have been found that are over 2 billion years old. Green algae are as old as red algae. Some scientists consider the red algae, which bear little resemblance to any other group of organisms, to be very primitive eukaryotes that evolved from the prokaryotic blue-green algae (cyanobacteria). Evidence in support of this view includes the nearly identical photosynthetic pigments and the very similar starches among the red algae and the blue-green algae. Many scientists, however, attribute the similarity to an endosymbiotic origin of the red algal chloroplast from a blue-green algal symbiont. Other scientists suggest that the red algae evolved from the Cryptophyceae, with the loss of flagella, or from fungi by obtaining a chloroplast. Dominance of Rhodophycean algae has been reported from Ordovician of Palaeozoic era and hence is called the 'Age of Rhodophyta'.
A large number of algal fossils have been reported from India as well (Punjab, Kashmir, Rajasthan, Madhya Pradesh, Bihar, Chhatisgarh, Andaman and Nicobar, etc.).

Some uses of algal fossils are-

- Algal fossils may indicate the presence of oil deposits.
- Algae fossils help geologists and paleontologists to understand the ancient environments of depositions and ecosystems that existed in the geologic past.
- Algal fossils of different ages help to understand the evolutionary history of algae.
- Algal fossils form limestone which is useful for industrial purposes in various ways.
- Fossilized diatoms that are called diatomaceous earth are economically used.

Table-1

S. No.	Class of Algae	Period in which they appeared
1.	Cyanophyceae (Unicellular and Multicellular) Oscillatoriaceae	 Early Precambrian Middle Precambrian
2.	Rhodophyceae Chlorophyceae (Chlorococcaces) Phaeophyceae Heterocystous Cyanobacteria	Late Precambrian Late Precambrian Late Precambrian Late Precambrian
3.	Rhodophyceae	Cambrian
4.	Chlorophyceae	Ordovician
5.	Charophyceae	Silurian
6.	Bacillariophyceae	Jurassic
7.	Chrysophyceae	Jurassic
8.	Xanthophyceae	Cretaceous
9.	Chrysophyceae	Cretaceous

Table-2 (List of Indian algal fossils)

S. NO.	CLASS	NAME OF THE ALGAL FOSSIL
1.	Cyanophyceae	*Aphanocapsa* *Synechocystis* *Scytonema* *Palaeonostoc* *Archaeonema*
2.	Chlorophyceae	*Dissocladella* *Dictylospora* *Neomeris* *Piania* *Botryococcus* *Palaeochyla* *Oedogonium* *Ulothrix* *Spirogyrites*
3.	Charophyceae	*Chara(Gyrogites)* *Nitellites*
4.	Bacillariophyceae	*Fossil diatoms(diatomaceous earth)*

5.	Rhodophyceae	*Archaeolithothamnion* *Lithothamnion* *Melobsia* *Distichoplax* *Amphira* *Corallina* *Petrophyton* *Solenopora* *Lithophyllum*

3.4 BASIC CONCEPT OF CYANOPHAGE

Cyanophages are the viruses that attack on blue green algae (cyanobacteria). It was Krauss (1961) who for the first time suggest that due to some algal virus disappearance of blue green algae occurred. Lewin (1960) reported a phage which attack on colourless blue green algae, *Spirochaeta rosea*.

For the first time Safferman and Morris (1963) isolated a virus from the waste stabilization pond of Indiana University (U.S.A) that attacked and destroyed the three genera: *Lyngbya, Plectonema* and *Phormidium*. Therefore, they named the virus by using the first letter of the three genera as LPP. Thereafter, several serological strains of LPP were isolated and named as LPP-1, LPP-2, LPP-3, LPP-4 and LPP-5. After the discovery of LPP-1, a large number of cyanophages were discovered and isolated by several phycologists.

Nomenclature- Cyanophages are named according to their hosts. It is done by taking first letters of generic names of hosts followed by Arabic numbers which designate serological sub-groups.
E.g., SM -1
Where SM are hosts (*Synechoccus elongates* and *Microcystis aeroginosa*) and -1 is Serological sub-group (strain NRC-1)

Table-3

Cyanophages	**Host**
LPP-1	*Lyngbya, Phormidium* and *Plectonema*
LPP-2	Same but different serologically
LPP-3	Do
LPP-4	Do
LPP-5	Do
C-1	*Cylindrospermum*
AR-1	*Anabaenopsis circulans* and *Raphidiopsis indica*
	Nostoc muscorum

N-1	*Anabaena variabilis*
A-1	*Anacystic nidulans* and *Synecoccus cedroum*
AS-1	*Tolipothrix, Aulosira, Haplosiphon* and *Nostoc*
TAuHN-1	*Synechoccus elongates* and *Microcystis aeroginosa*
SM-1	Same hosts but serologically different
SM-2	

Structure and composition of Cyanophages

The Cyanophages are composed of nucleic acid and proteins. The nucleic acid is linear, double stranded DNA approximately 45kbps long and its length ranges from 13.2 nm- 24.3 nm. The protein coat (capsid) surrounds the genetic material.

Like other bacteriophages, Cyanophages have a head and a tail made up of proteins. The molecular weight of major head proteins varies between 13000 and 39000 while the major tail protein has a molecular weight of 80,000. The morphology of LPP-1 has been most extensively studied. Lufting and Haselkorn proposed a model of LPP-1. The viral head capsid is a polyhedron, appears hexagonal with 20 facets thus icosahedral symmetry. The diameter of viral head is 600±20Å. The head encloses the genetic material which is always double stranded DNA. The entire head is covered with double membranous coat. The short, hollow cylindrical tail is 20-25 nm (200±25 Å) long and 15nm (150 Å) wide with six fold radial symmetry made up of several (2-4) rings of six subunits. The upper end of tail is attached to the protein head and from the lower end probably protrudes the tail fibers. The tail is non-contractile and is differentiated into an outer tail sheath and inner tail cavity. Tail capital is located at the junction of protein head and the tail. The probable function of the tail capital is uncertain but it is assumed that it function to serve as a joint to fix the tail to the protein head.

Growth cycle of Cyanophages

The growth cycle of Cyanophages comprises five distinct stages that are – attachment, penetration, biosynthesis, maturation and release.

Attachment and Penetration- The attachment site of cyanophage (LPP-1) attaches to a complementary receptor site on the cyanobacterial cell through a chemical interaction. The tail of the cyanophage is an important structure that helps in the attachment process. The tail fibers play an important role in the whole process. The binding of tail fibers to the cell receptor causes the conformational changes in the multiprotein base plate of tail that initiates the contraction on the tail sheath and finally culminates in the transfer of the phage DNA from the capsid to the host cell through tail cavity.

Biosynthesis- Initially the virus uses the host cell's nucleotides and several of its enzymes to synthesize many copies of viral DNA. Later, the biosynthesis of viral proteins begins. The first sign of infection of algal virus is pushing of photosynthetic lamellae to one side and in early stage of infection, many particles, probably α-particles are observed between the photosynthetic lamellae. At later stage, the virogenic stroma is full of developing virus particles. For several minutes after infection, complete cyanophage cannot be found in the host cell. Only separate components- DNA and protein can be detected.

Maturation- The viral DNA moves into the space between the photosynthetic lamellae where DNA helices begin to form. Ultimately these helices move into the virogenic stroma where the final assembly of the viral particles takes place. The protein coat is now built around the DNA helices.

Release- The mature cyanophages are released after the lyses of the cyanobacterial cell. This process of release is important as the cyaophages need to escape from the host cyanobacteria and let their new progenies to disperse in the environment to complete their growth cycle as well.

The replication of SM-1 is slightly different from the replication of LPP-1. It assembles in the nucleoplasm and is rarely seen penetrating the photosynthetic lamellae.

It has been reported that complete lyses of cyanobacteria takes place except the heterocysts. In severe infection lysis starts on the poreside of the heterocyst and heterocyst content is lysed leaving the empty heterocyst wall. It indicates that the phage particles enter through the pores of heterocysts.

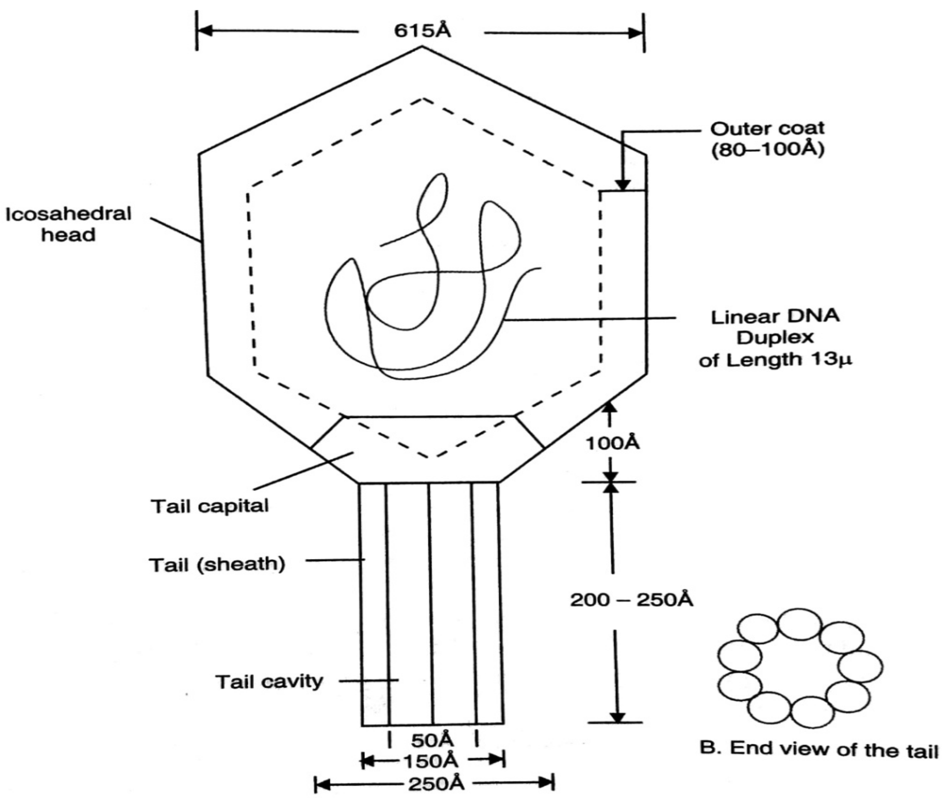

Fig.3.1. Structure of Cyanophage

Significance and importance of Cyanophages- These are as follows-

1. **In controlling algal blooms-** Certain blue green algae such as *Anabaenopsis, Spirulina, Oscillatoria, Microcystis* etc. causes water blooms (algal blooms). By using cyanophages, algal bloom can be destroyed.
2. **In studying plant photosynthesis under viral infection-** The photosynthesis of cyanobacteria is like that of higher plants with slight differentiation. The algal cyanophage system can be adopted as a model to study the plant photosynthesis under viral infection.
3. **In tracing evolutionary closeness-** The cyanophages that infect more than one blue-green algae are said to be more related as the virus has same specificity for them.
4. **In studying the genetic exchange (horizontal gene transfer)-** The significance of the cyanophages gains importance in view of the horizontal gene transfer that has been reported in the case of photosynthetic genes of the cyanophages.
5. **In maintaining ecological balance of the ecosystem-** The seasonal abundance of the cyanophages indicates the ecological poise/equilibrium of the ecosystem and in the maintenance of the biogeochemical cycling and nutritional status of the surroundings thus maintaining the population structure in its appropriate level.

3.5 ECONOMIC IMPORTANCE OF ALGAE

Algae are important to human life in various aspects. These plants have been used for centuries. Although algae are beneficial to us but there are some harmful aspects too.

In this section we will come to know about the role of algae in various fields like industry, agriculture etc. These are as follows-

1. **Agricultural importance-** Blue green soil algae are very important in agriculture as they are capable of nitrogen fixation in the soil. Some important soil cyanobacteria are *Tolipothrix tenius, Aulosira fertilissima, Anabaenopsis, Oscillatoria, Anabaena, Nostoc, Spirulina* and *Cylindrospermum*. P. K. De (1939) has proved that blue green algae are responsible for nitrogen fixation in rice fields. R. .N. Singh (1961) had worked on blue green algae for reclaimation of Usar land and claimed that by inducing a proper growth of cyanobacteria, Usar barren land can be brought to the productive state. Cyanobacteria neutralize the alkalinity and increase fertility of the soil. Sea weeds are used as biofertilizers. The agricultural utilization of sea weeds (large kelps and red algae) as manure has been in practice for centuries chiefly in the land near coastal region. Kelps and red algae are rich in potassium but poor in nitrogen and phosphorus. In France, Ireland and Sri-Lanka vegetables like potatoes, turnips are provided with sea weeds directly. Sea weeds are sometimes burnt and their ashes are sprinkled over the agricultural land as common practice in some countries. In Rajasthan, blue green algae *Spirulina* and *Anabaena* are cultured commercially in Sambhar Lake and are used as manure by local farmers. Concentrated liquid extracts of sea weeds are sold as fertilizers and insecticides also. The grinded form of *Lithothamnion, Lichophyllum* and *Chara* are used in place of lime in some countries.

2. **Role of algae as food and fodder-** Algae synthesize organic food stuffs and are an important food source of fishes and other aquatic animals. As the flesh of the land is dependent upon the activities of the green leaf, so the fish and other aquatic forms of animal life are dependent, directly or indirectly, upon algae. Diatoms, filamentous and some planktonic green algae, and a number of blue-green algae are very often found in the guts of various species of fresh and brackish water fish and they appear to be directly utilized as fish food. Hence, algae are very important source for pisciculture.

Indirectly algae are of great value for man as fishes and other aquatic animals are source of supplementary food for man. In the Pacific Island and Orient many brown, red and green algae form a regular portion of human diet. In India, *Spirogyra* and *Oedogonium* are important genera while *Ulva* is important genus in Europe. *Spirogyra* and *Oedogonium* capture a great market in India as the dried form of these are sold as to prepare soups. In Brazil, *Nostoc* colonies are used as food. Young stipes of *Laminaria* and sporophylls of *Alaria* are also eaten in Pacific island. *Ulva lactuca* was used as salad in Scotland. *Porphyra* (good source of vitamin B and C) is used in large scale as common item of diet in England, China, Japan and South Korea. *Rhodymenia palmata* commonly known as dulse is used as food. The best known and most widely used alga in Western Europe in recent centuries was Irish moss (*Chondrus crispus* a red alga).

Algae are very commonly used as food in China and Japan. Kombu, a Japanese food is prepared by stipes of *Laminaria.* The commonest species used are *Porphyra tenera* (Amanori), *Laminaria*, *Sargassam, Undaria* and *Monostroma* (green algae). In Philippines, *Caulerpa racemosa* is cultivated for food purpose. It has been estimated that approximately 25% of the daily diet in China and Japan consists of sea weeds. The algae are considered rich in proteins, fats and vitamin A, B, C and E. The vitamin A and D which are commercially obtained from the liver of fishes originally come from the synthesis by the planktonic algae. Vitamin B is found in *Ulva, Enteromorpha, Laminaria, Alaria, Porphyra, Nereocystis* and *Chondrus crispus*. Vitamin C is present in *Ulva, Enteromorpha, Alaria* and *Undaria.*

Sea weeds are also used as fodder. Norway, France, USA, Denmark, New-Zealand and Scandenavia sea weeds are commonly used as fodder for animals. Some countries have developed small industries for processing the sea weeds (*Ascophyllum, Fucus, Laminaria* etc) into suitable cattle feed. *Rhodymania palmata* and *Alaria esculenta* are favourable food for goats, cow and sheep in Scotland and Ireland. *Macrocystis* is also used being rich in vitamin A and E. the milk yielding capacity of the cattle is enhanced when dried sea weeds form an ingredient in cow feed.

3. **Algae and space travel-** *Chlorella* (space algae) *Scenedesmus* and *Synchococcus* are used as food source for space travelers. These algae are very rich in proteins (single cell protein)

and multiply rapidly and thus synthesize a rich harvest of food utilizing carbon dioxide and liberating sufficient oxygen as a byproduct for use.

4. **Role of algae in medicine-** Algae has been used for medicinal purposes since time immemorial. Ancient literature of China revealed the use of *Laminaria* sp. for the treatment of goiter. Brown algae being rich source of iodine are employed in the preparation of medicines for goiter. Members of Laminariales have long been used as a surgical tool and also during child birth to expand the cervix. An antibiotic chlorellin is obtained from *Chorella.* Agar agar is an important algal product obtained from red algae used in the manufacture of pills and ointments by pharmaceutical industries. Carrageenin and alginic acid acts as blood coagulant.

Extracts of *Digenea, Codium, Alsidium* and *Durvillea* are effective vermifuge. In Unani medicine system many algae are used in the treatment of lung, kidney and bladder ailments. Extracts of *Cladophora* and *Lyngbya* possess antiviral properties.

5. **Algae as the origin of petroleum and gases**- It is an accepted fact that the fuels such as petroleum and gases have their origin in the organic matter in the marine environment. Planktons captured the energy from sunlight during photosynthesis and transferred to the marine animals in the form of food. Organic compounds derived from the planktons and the animals accumulated in the mud deposits in the shallow water of the ocean floor. In the source, materials were buried by sedimentary action in an oxygen free environment and converted gradually into oil and gas. The natural gas associated with oil is largely methane which is produced by the action of methane producing bacteria upon organic compounds.

6. **Algae and limestone formation-** Many species of algae withdraw calcium from water, both fresh and salt and deposit it in the form of calcium carbonate, in their cell walls. The most significant forms for this purpose are the blue green algae, red algae and to some extent dinoflagellates. Fresh water blue green algae are chiefly responsible for the extensive formation of limestone deposits around hot springs and glaciers. The red algae are the most important calcareous algae of the seas and in particular they play an important role in the formation of coral reefs together with the nedarians (minute sedentary animals that are responsible for the construction of coral reefs). The algae are not only important in the formation of limestone in the seas and fresh water but also they have played important role in the production of beds of limestone rocks.

7. **Role of algae in sewage disposal-** Species of *Chlamydomonas, Chlorella, Scendesmus* and *Euglena* are used in sewage tanks for providing effective, rapid and cheap means of converting the sewage into an odourless and valuable fertilizer. These tanks promote growth of algae in the expense of sewage and these algae photosynthesize and thus produce oxygen for the microorganisms. These microorganisms decompose the organic matter of sewage.

8. **Role of algae in industries-** Algae being source of many commercial products are very useful in industries. The major products derived from algae are agar agar, carrageenin, algin, diatomite and kelp. The industrial utilization of algae particularly sea weeds have been known from hundred of years. These are as follows-

a) **Agar-agar-** It is a mucilaginous product obtained from red algae that is stored in their cell walls along with cellulose. The main source of agar-agar producing algae is *Gelidium, Gracilaria* and *Gigartina.* Other genera which are used for this purpose includes *Camphylophora, Eucheuma, Hypnea, Ahnfeltia* and *Furcellaria.* Agar is a gelatinous, clear nitrogen free extract containing galactose and sulphate from the red algae. Its melting point is between 90-100°F and at lower temperature it changes into solid. It is used extensively in microbiology laboratories as a base for the culture media for bacteria, fungi etc.

In pharmaceutical industries, agar agar is used in the preparation of various medicines, especially as a laxative. It has a great value in the preparation of the food stuffs like breads, pastries, cheese, jellies, deserts and in dairy products as an antidrying agent. In meat industries, agar has proved its effectiveness for temporary preventive for meat and fish canning. Agar is used extensively in the cosmetic, leather, textile and paper industries too.

b) **Algin-** Algin is a carbohydrate (colloidal material) with molecular formula $(C_6H_8O_6)n$ found in the middle lamella and primary walls of brown algae. Algin or alginates are soluble calcium magnesium salt of alginic acid. Alginic acid is insoluble extract. The chief sources of alginic acid are *Ascophyllum, Laminaria, Lessonia, Ecklonia, Macrocystis, Sargassum, Fucus* and *Eisenia.* The alginates having remarkable water absorbing qualities are used as thickeners in the food industry, cosmetics and in textile industry as printing pastes. They are of great use in the production of plastic and artificial fibers. Algin is used as emulsifier in confectionary, dental impression, powders, paints and ice-creams. They are also used in the rubber industry and in latex production. Algin is used in about 80% of commercial products and because of its extensive use in industries the kelp beds are regularly harvested.

c) **Carrageenin-** The chief source of carrageenin is a red alga *Chondrus crispus* (Irish moss). *Gigartina* is also harvested for carrageenin. It is extracted as a mucilaginous polysaccharide from the cell walls of above mentioned genera. It is used as an emulsifying and stabilizing agent in food, textile, pharmaceutical, leather and brewing industries. It is also an important component of tooth pastes, deodorants, cosmetics and paints and also as a remedy for cough.

d) **Diatomite-** Diatomite or kieselguhr is a rock like deposits of indestructible, siliceous cell walls of dead diatoms (fossil diatoms) that had collected over many millions of years on the bottom of seas as sediments. The great deposits of this material, known as diatomaceous earth are found in many parts of the world. The largest beds of diatomaceous earth around 1400 feet thick is found in California of U.S.A. Diatomaceous earth being chemically inert and in having unusual physical properties has become very important for industrial use. It is a whitish and firm substance yet very soft and light. It is highly porous, insoluble, chemically inert, fire proof and highly absorbent. Because of these properties it is used for filtration process in oil refineries, sugar industries and for clearing solvents. It is used as insulator of refrigerators, boilers, hot and cold pipes, hollow tile bricks for construction of constant temperature rooms, sound proof rooms, in packing corrosive chemical liquids, in manufacture of dynamite etc. It is also used as a constituent of tooth pastes, as a base on automobile and silver polishes. Diatomite was also used as an absorbent of nitroglycerine in the manufacture of dynamite before.

e) **Kelp-** Kelp ash (Brown algae) is the source of iodine, soda, and potash. In Japan alone produces approx 100 tons of iodine annually form kelps. The chief genera that are employed for production of iodine are *Laminaria, Fucus, Ecklonia, Ascophyllum, Saccorhiza* and *Eisenia.*

f) **Other industrial uses-** Bromine is obtained from red algae *Rhodomela* and *Polysiphonia.* Glue (funori) is manufactured from red alga *Gleopeltis furcata*.

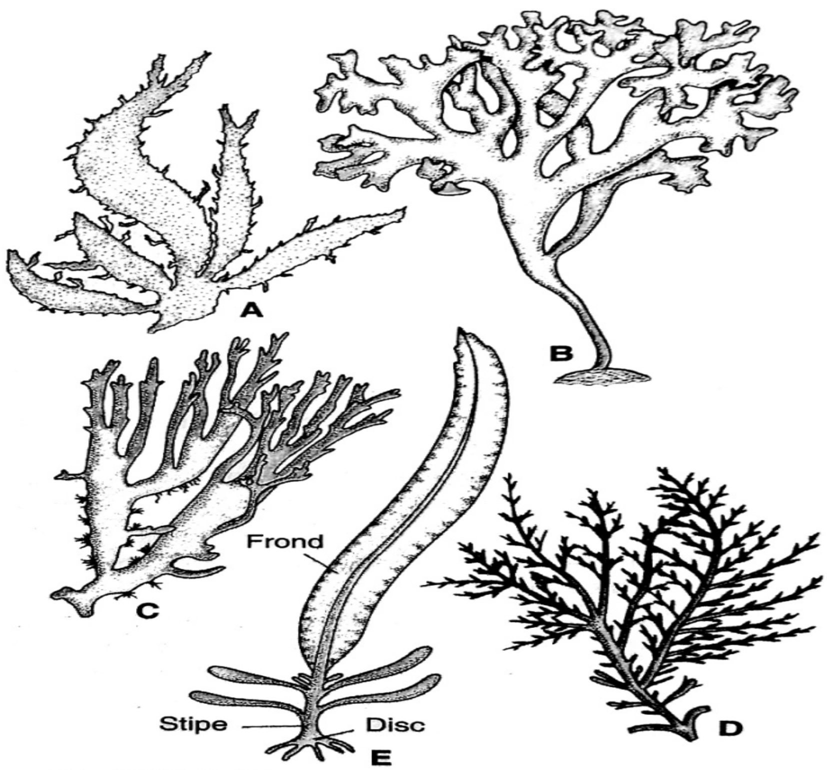

Fig.3.2 Some economically important sea weeds. A. *Gigartina*, B. *Chondrus crispus*, C. *Rhodymenia*, D. *Gelidium*, E. *Alaria*

9. **Algae as indicator of industrial wastes-** Various species of algae are important indicators of industrial wastes such as paper mill wastes, oil wastes, distillery wastes etc. the lists of algae which are employed as the indicators are given below-

a) **Indicators of paper mill wastes-** *Ulothrix zonata, Scendesmus bijuga, Pandorina morum, Oscillatoria splendid, Cymbella vantricosa, Amphora ovalis, Navicula cryptocephala, N. radiosa, Surirella ovata, S. ovata* var. *salina,* and *Synedra ulna.*

b) **Indicators of oil wastes-** *Amphora ovalis, Diatoma vulgaris, Gomphonema herculaneum, Navicula radiosa, Melosera varians, Synedra acus* and *S. ulna.*
c) **Indicators of distillary wastes-** *Chlorogonium gracillima, Chlorobranchis gracillima* and *Chlamydobotrys* sp.
d) **Indicators of copper as wastes-** *Callothrix braunii, Scendesmus obliquus, Chlorococcum botryoides, Stigeoclonium tenue, Navicula viridula, Cymbella ventricosa, C. naviculiformis, Nitzschia palea* and *Acanthes affinis.*
e) **Indicators of iron as wastes-** *Stauroneis phoeniceneteron, Sureilla linearis, S. delicatissima* and *Acanthes affinis.*
f) **Indicators of chromium wastes-** These may be *Euglena acus, E. viridis, E. sociabilis, E. oxyuris, Navicula atomus, N. cuspidate, Tetraspora lubrica, Stigeoclonium tenue* and *Nitzschia sp.*
g) **Indicators of phenoilic wastes-** *Acanthus affinis, Ceratoneis arcus, Cocconeis placentula, Cyclotella kuetzengii, Cymbella naviculiformis, Fragillaria virescens, Gomphonema parvulum.*

10. **Algae and harmful activities-** The algae have negative value as well which can be outlines in following headings-

a) **Parasitic algae-** Parasitic algae cause diseases to economically important plants. Red rust of tea (*Camellia sinensis*) is caused by *Cephaleuros virescens. C. coffea* is known to cause coffee plants.

b) **Toxic algae-** Toxic algae are those that causes sickness or death to aquatic life particularly animals. Some algae are known to secrete harmful/neurotoxic substances that cause illness or death of aquatic animals. Due to algal poisoning, several cases of death from different parts of world have been recorded. Blue green algae *Microcystis toxica* and *Anabaena flos-aquae* are responsible for death of around thousands of cattle, sheep and other animals in South Africa. *Gymnodinium veneficum* is known to be toxic to aquatic animals along the coasts of California and Washington. Not only the animals but human beings are also get affected by algal toxins. Gastrointestinal disorders, severe illness and even death have been reported (Tisdale 1931, Veldee 1931). Gastrointestinal disorder in human beings are known to caused by *Prototheca protoricensis, Oscillatoria intestinii, Anabaena circularis, Aphanomezon* and *Microcystis* (Schwimmer et al. 1964). *Anabaena circularis* and *Lyngbya majuscule* are reported to cause skin diseases and allergic conjunctivitis for swimmers in swimming pools while *Gymnodinium brevis* has been reported to cause respiratory tract irritations.

c) **Water blooms-** In the summers preferably in rainy and spring season, algae particularly green, golden-brown, blue green and diatoms becomes so abundant that the ponds, lakes and reservoirs becomes cloudy and gives fishy smells. Such abundant growth of algae on water surface is called water or algal bloom. The water becomes polluted as the BOD level in these blooms increases. Water bloom imparts fishy smell, oily taste to the drinking water. Water blooms are formed by the abundant growth of solitary alga, rarely by a few algae. The colour of the algae determines the colour of the blooms. The colour of the Red sea is due to the formation of seasonal algal blooms formed by cyanophycean algae *Oscillatoria erythraea* and *Trichodesmium erythraeum.* The algae involved in the development of blooms are generally planktons. Water blooms forming algae belongs to the class Cyanophyceae, Chlorophyceae, Chrysophyceae, Euglenophyceae and Pyrophyceae. Water blooms are formed in fresh water, lakes, and in the seas. It can be temporary or permanent. The water blooms formed during winters and summers are thick while in rainy season these are thin due to sudden splashes of rain water.

In India, the water blooms in temple ponds, lakes, etc. are formed of mainly *Microcystis aeruginosa* and *M. flos-aquae.* The main Cyanophycean algae that form algal bloom include *Anabaenopsis, Spirulina, Oscillatoria, Arthrospira,* etc. *Chlamydomonas, Pandorina, Eudorina, Gonium, Volvox, Cosmarium, Closterium,* etc. are the algae from Chlorophyceae known to form algal blooms. Some other algae are *Euglena* of Euglenophyceae, *Synura* of Chrysophyceae, *Peridinium, Ceratium* and *Gymnodinium* of Pyrrophyceae. *Anabaenopsis* is the main cause of water bloom in Sambhar Lake of Rajasthan.

Water blooms are harmful as some species of algae produce neurotoxins. However, blooms formed by cyanophycean algae are good nitrogen fixers and therefore can be used as fertilizers. Algal blooms can be controlled by the application of copper sulphate or chlorine. Recent researches on Cyanophages have shown that cyanophages can be used to control the algal blooms caused by cyanophycean algae.

3.6 SUMMARY

1. The oldest record of fossil algae meets in the Precambrian era.
2. The oldest algal fossil known is *Archaeosphaeroides barbertonensis,* a blue green alga.
3. Algae have been preserved as impressions, petrifactions, coal balls, molds and casts.
4. The Paleozoic era has been called as ‘Age of Seaweeds’.
5. Diatomaceous earth is fossilized diatoms.
6. It has been found that Centrales are more primitive than Pennales among diatoms.
7. Ordovician period of Palaeozoic Era is regarded as ‘Age of Rhodophyta’.
8. In India a large number of algal fossils have been reported from Punjab, Kashmir, Rajasthan, Madhya Pradesh, Bihar, Chhatisgarh, Andaman and Nicobar etc.
9. Fossil algae are indicators of oil deposits.
10. Cyanophage was isolated first time by Safferman and Morris in 1963 and named as LPP-1
11. Cyanophages are named according to their hosts.
12. Cyanophages are composed of nucleic acid (double stranded linear DNA) and proteins.
13. Growth cycle of Cyanophage is just like Bacteriophages.

14. Cyanophages are important in controlling algal blooms caused by BGA (blue green algae).
15. Blue green soil algae like *Tolipothrix tenius, Aulosira fertilissima, Anabaenopsis, Oscillatoria, Anabaena, Nostoc, Spirulina* and *Cylindrospermum* are responsible for nitrogen fixation in soil.
16. Red rust of tea is caused by *Cephaleuros virescens.*
17. Algae are an important source of food and fodder.
18. Algae are very commonly used as food in China and Japan.
19. Kombu, a Japanese food is prepared by stipes of *Laminaria.*
20. Kelps are used largely as boifertilizers in coastal areas of world.
21. Brown algae are source of iodine and potash.
22. Agar is obtained from red algae.
23. Algin is obtained by brown algae eg. *Ascophyllum, Laminaria, Lessonia, Ecklonia, Macrocystis, Sargassum, Fucus* and *Eisenia.*
24. Various species of algae are important indicators of industrial wastes such as paper mill wastes, oil wastes, distillery wastes etc.
25. The colour of the Red sea is due to the formation of seasonal algal blooms formed by cyanophycean alga *Trichodesmium erythraeum.*

3.7 GLOSSARY

Agar- A mucilaginous substance obtained by red algae.
Algin- A mucilaginous substance found in the middle lamella of cell wall of brown algae.
Algal bloom- A rapid growth of microscopic algae resulting in a coloured scum on the surface of water.
BGA- Blue Green Algae
Biofertilizer- Living organisms used as fertilizers.
Carrageenin- A colloidal extract from seaweeds.
Capsid- Protein coat of viruses.
Coral reef- A ridge of rock in the sea formed by the growth and deposits of coral.
Coccoid- Spherical body shape.
Cyanophage- Viruses infecting blue green algae.
Diatomaceous earth- Fossilized diatoms.
Fossil- Remains of plants or animals
Fossilization- Process by which fossils are formed.
Limestone- A hard sedimentary rock composed mainly of calcium carbonate
Toxic- Poisonous

3.8 SELF ASSESSMENT QUESTION

3.8.1- Multiple Choice Questions-

1. Algin and alginates are obtained from the members of-
(a) Phaeophyceae (b) Rhodophyceae
(c) Cyanophyceae (d) Chrysophyceae

2. Red rust of tea is caused by-
(a) *Cephaleuros virescens* (b) *Ectocarpus*
(c) *Chlamydomnas nevalis* (d) *Ancyclonema*

3. High source of protein are-
(a) *Chlorella* and *Scendesmus* (b) *Chlorella* and *Chlamydomonas*
(c) *Cephaleuros* and *Ectocarpus* (d) *Scendesmus* and *Polysiphonia*

4. Red colour of Red sea is due to-
(a) *Trichodesmium* sp. (b) *Oscillatoria erythraea*
(c) Both a and b (d) None of the above

5. Funori is obtained from-
(a) *Gloiopeltis furcata* (b) *Oscillatoria erythracea*
(c) *Pandorina* sp. (d) *Aulosira*

6. Cyanophages infects the members of-
(a) Rhodophyceae (b) Phaeophyceae
(c) Cyanophyceae (d) Chrysophyceae

7. 'Age of Rhodophyta' is-
(a) Ordovician period (b) Triassic period
(c) Jurassic period (d) Silurian period

8. Cyanophage was discovered by-
(a) Safferman and Morris (b) Bold and Tippo
(c) Twort and Herelle (d) None of the above

9. Which of these was used as an absorbent of nitroglycerine in the manufacture of dynamite-
(a) Diatomite (b) Carrageenin
(c) Agar (d) Algin

10. Cyanophages can control-
(a) Parasites (b) Water bloom
(c) Both a and b (d) None of the above

3.8.2- Fill in the blanks-

a) __________ are the commercial source of bromine.
b) Diatomaceous earth is obtained from algae of class ______________.
c) __________are used by space travelers.
d) Main source of carrageenin is ________.
e) __________ is known as sheep's weed.
f) __________is the common name of *Chondrus crispus*.
g) Kombu is prepared from______.
h) LPP infects_____________.
i) The oldest known fossil alga is___________.
j) Red colour of Red sea is due to___________.

3.8.3. True/false

a) Agar agar is obtained from the algae of class Phaeophyceae.
b) The oldest known fossil alga is *Ancyclonema.*
c) Blue green algae are used as biofertilizers.
d) Carrageenin is obtained from Irish moss.
e) Cyanophages can infect diatoms.
f) *Cephaleuros* is responsible for red rust of tea.
g) Kelps are a good source of iodine.
h) Planktons can form water blooms.
i) Diatoms are fossil algae.
j) Algae of all classes are capable of fixing nitrogen.

3.8.4. Short answer type questions.

a) Discuss the use of algae in agriculture.
b) How algae are useful in pharmaceutical industries? Explain.
c) Can algae be harmful to us? Discuss.
d) Write a note on nitrogen fixation by algae.
e) Discuss the use of algae in sewage disposal.

Answer keys:

3.8.1- 1.(a), 2. (a), 3. (a), 4. (c), 5. (a), 6. (c), 7. (a), 8. (a), 9. (a), 10. (b)

3.8.2- a). red algae, b). bacillariophyceae, c). *Chlorella* and *Scendesmus*, d). *Chondrus crispus*, e). *Rhodymenia palmata,* f). Irish moss, g). *Laminaria*, h). *Lyngbya, Phormedium, Plectonema,* i). *Archaeosphaeroides barbertonensis,* j). *Trichodesmium* sp. And *Oscillatoria erythraea*

3.8.3- a). False, b). False, c) True, d). True, e). False, f). True, g). True, h). True, i). False, j). False

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3.11 TERMINAL QUESTION

3.11.1- Short answer questions:

1- Write short notes on the following-

a) Fossil algae
b) Industrial uses of algae
c) Role of algae in agriculture
d) Structure and replication of Cyanophage
e) Water bloom
f) Toxic algae
g) Role of algae as food and fodder

3.11.2- Long answer questions:

1. Give a detailed account on cyanophage.
2. How algae are useful to us? Describe in detail.
3. Give a detailed account of fossil algae.
4. Algae can be harmful. Discuss it.

BLOCK-2 ALGAE: SALIENT FEATURES OF LIFE CYCLE

UNIT-4 CYANOPHYTA, BACILLARIOPHYTA AND CHAROPHYTA

4.1 OBJECTIVES

After reading this unit you will be able-

- To understand salient features of various members of Cyanophyta like *Oscillaotria*, *Anabena*, *Spirulina*, *Scytonema* and *Rivularia*.
- To know life cycle patterns in Cyanophyta.
- To understand salient features of two important groups of Bacillariophyta Pinnate and Centric diatoms
- To know life cycle patterns in Pinnate and Centric diatoms.
- To understand salient features of various members of Charophyta: *Chara* and *Nitella*.
- To know life cycle patterns in *Chara* and *Nitella*.

4.2 INTRODUCTION

Algae comprise a green group of chlorophyll containing thalloid plants of the simplest type, having no true roots, stems, leaves or leaf like organs. They are placed in the division Thallophyta along with Fungi. They differ from Fungi in the presence of photosynthetic pigment chlorophyll and in their mode of nutrition. Although most of the algae are autotrophic, i.e. they synthesize their food by themselves yet heterotrophic and holozoic forms are not uncommon. Algae account for almost half the photosynthesis on the planet, producing every second breath of oxygen, and shaping the environment for life on earth. Though Algae is a very large diverse colorful group of plants but in this unit you will come to know about three major groups of algae i.e. Cyanophyceae, Bacillariophyceae and Charophyceae. You will enjoy reading this unit as you will see a huge diversity in habitat, habit and life cycle of different members of above algal families.

4.3 SALIENT FEATURES, IMPORTANT GENERA AND LIFE CYCLE PATTERN IN CYANOPHYTA

1. The division Cyanophyta is represented by 1500 species mostly fresh water, some species are free-living while others grow on larger algae or within tissue of other plants.
2. The members of Cyanophyceae or myxophyceae are characterized by the presence of a very rudimentary nucleus and they do not have well organized chromatophores (prokaryotic).
3. The chief pigments are chlorophyll a, B-carotene and c-phycocyanin.
4. The cell wall is made up of mucopolymers.
5. The food reserve is cyanophycean starch.
6. Motile stages are absent but vegetative filaments of some members show gliding movements.
7. Sexual reproduction is absent (recently genetic recombination has been reported).

8. Asexual reproduction is by hormogonia or akinetes.
9. This class comprises of five orders:
   (i) Chroococcales (e.g. *Chroococcus, Gloeocapsa*, *Microcystis*),
   (ii) Chamaesiphonales (e.g. *Chamaesiphon*, *Dermocapsa*),
   (iii) Pleurocapsales (e.g. *Pleurocapsa*),
   (iv)Nostocales (e.g. *Gloeotrichia*, *Nostoc*, *Oscillatoria*, *Rivularia*, *Scytonema*, *Spirulina*), and
   (v) Stigonematales (e.g. *Stigonema*, *Mastigocladium*, *Nostochopsis*)

4.3.1-*Oscillatoria*

Scientific Classification

Division: Cyanophyta
Phylum: Cvanobacteria
Class: Cyanophyceae
Order: Oscillatoriales
Family: Oscillatoriaceae
Genus: *Oscillatoria*

Occurrence

Oscillatoria is a genus of filamentous cyanobacteria (Fig. 4.1.and 4.2). It has more than 100 species. Some of the species are *O. amoena* (Kützing) Gomont, *O. anguiformis* (P. González Guerrero) Anagnostidis, *O. anguina* Bory, *O. prolific* and *O. formosa*. It is named for the oscillation in its movement. Filaments in the colonies can slide back and forth against each other. Thus the whole mass is reoriented to its light source.

It is very common in moist places rich in decaying organic matter. It is commonly found in watering-troughs waters like streams, roadside ditches, drains and sewers. It is mainly blue-green or brown-green. It forms thin blue green mucilaginous coating on the surface of flowing water. It's one species is found in hot springs. Some species like *0. formosa* and *O. princeps* are symbiotic. They form association with the nitrogen fixing bacteria.

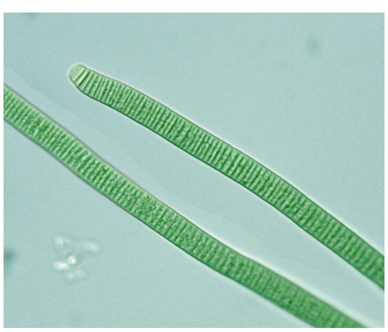


Fig.4.1*Oscillatoria* filaments

Fig.4.2 Apical cell in *Oscillatoria*

Fig. 4.3 Hormogonia

Vegetative structure

Its body is composed of single row of cells. These cells form trichomes. Its trichomes are unbranched filaments. The trichome shows polarity. Some species have narrow trichome. They have cylindrical cells with their length equal or greater than the breadth. They are covered by very thin mucilaginous sheath. Filaments may be either attached or free floating and rarely occur singly. In majority of the species they form compact tangle mass or spongy sheets. The filaments may be interwoven or arranged in parallel rows. All cells of a trichome are similar in shape except apical cells.

The apical cells are convex at the tip. It may be cap like (capitate) or covered by a thick membrane called calyptra. The apical cell may also be conical, dome shaped, acuminate, oval, flattened convex or coiled and accordingly to the shape of the cap cell, the species are identified (Fig.4.2). All other cells arc broader and cylindrical. They are usually smooth but sometimes constricted at the cross walls. In some species, the apical cells may end in subacute point. In some cases, it may have cap or calyptras at the tip.

Cell Structure of *Oscillatoria*

The cells show prokaryotic organization. All cells in the trichome are similar in structure. The cell can be differentiated into two parts: Cell wall and protoplasm.

Cell wall is made of mucopeptide. Ultra structurally it consists mainly a 2000 A° structural layer external to plasma membrane. Outside the structural layer is 160 A° thick another layer and there is a third 90 A° layer loosely wrapped around the two. The structural layer has a series of 700 A° wide pores which terminate at the 160 A° layer. Under an ordinary microscope the protoplasm is distinguishable into a peripheral chromoplasm and a central colourless centroplasm or central body.

Ultrastructure of cell shows that the chromoplasm contains photosynthetic lamellae or single thylakoid which often run parallel to one another. The thylakoids contain photosynthetic pigments like chlorophyll a, carotenes, xanthophyll's and phycobilins (C-phycocyanin, allophycocyanin, c-phycoerythrin). Phycobilins occur in minute vesicles called phycobilisomes.

The centroplasm represents the incipient nucleus called gonophore. It is represented by DNA fibrils. The cell contains many ribosomes but mitochondria, plastids, endoplasmic reticulum and Golgi bodies are absent. Reserve food material is in the form of cyanophycean starch, lipid, globules and cyanophycin. The protoplasm also contains two types of granules α and β, α granules contain proteins and polysaccharides while β granules have lipid. Planktonic species of *Oscillatoria* possess gas vacuoles or pseudovaculoles which are devoid of any membrane. It is made of a number of 'hexagonal' structures called 'gas vesicles' (Fig. 4.4).

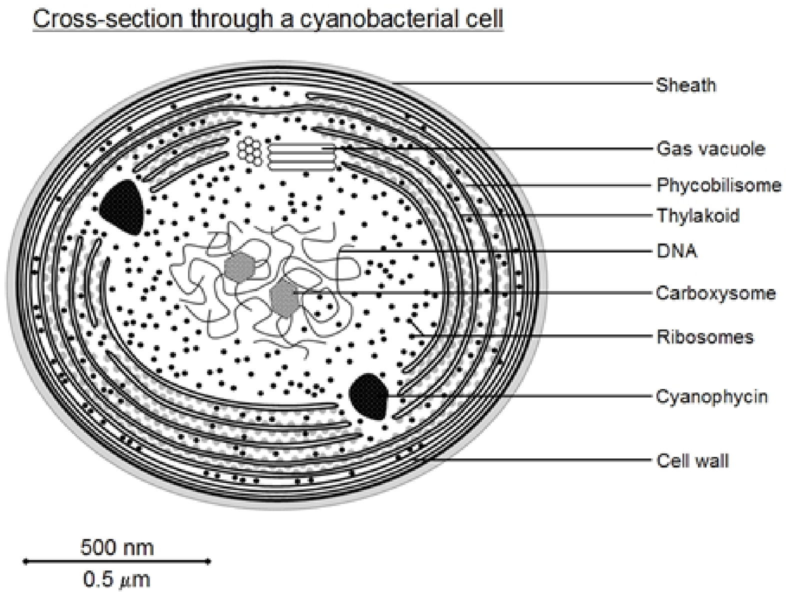


Fig. 4.4 Ultrastructure of a Cyanophycean cell

Reproduction in *Oscillatoria*

Oscillatoria reproduces only be vegetative methods. These are:

1. **By fragmentation**: It occurs due to accidental breakage of the filament, biting of some .insects or animals. Filament divides into small pieces or fragments. Each of these fragments is capable of developing into new individual.
2. **By hormorgonia:** Hormogonia or hormogones are short segments of trichome which consists of few cells. Hormogones are formed due to formation of separation discs. These discs are mucilaginous, pad like and biconcave in shape. These are formed by death of one or more cells of the filament. These mucilage filled dead cells are also called necridia (Fig. 4.3)

Movement in *Oscillatoria*

The name *Oscillatoria* (oscillate, to swing) is given to this alga due to the peculiar movement shown by the trichome. It is called 'oscillatory movement'. These are the jerky, pendulum-like movements of the apical region of the trichome. Some other movements shown by the trichomes of *Oscillatoria* are:

Gliding or creeping movement: The trichome moves forward and backward along its long axis.

Bending movement: The tip of the trichome shows bending.

Oscillatoria sp. is the subject of research into the natural production of butylated hydroxytoluene (BHT), an antioxidant, food additive and industrial chemical.

4.3.2-*Anabaena*

Division: Cyanophyta

Class: Cyanophyceae

Order: Nostocales

Family: Nostocaceae
Genus: *Anabaena*

Occurrence

Anabaena is a genus of filamentous cyanobacteria. It is found as plankton. Many species are known worldwide as major components of the freshwater plankton and also of many saline lakes. Others occur as tychoplankton. There are at least 15 gas-vacuolate species in freshwater, and *A. spiroides, A. circinalis, A. aequalis, A. affinis, A. angstumalis, A. marchita* and *A. flos-aquae* are the most common in the plankton.

Anabaena flos-aquae, has invaded brackish marine environments such as the low-salinity portions of the Baltic Sea. It is known for its nitrogen fixing abilities. They form symbiotic relationships with certain plants, such as the mosquito fern. Some species of *Anabaena* are **endophytes.** They live in the roots of *Cycas* and *Azolla.* Anabaena is found in all types of water. **Blooms** or massive growths can occur in waters with a lot of nutrients. These blooms discolor the water and give it a bad odor when the cells die and decay.

They are one of four genera of cyanobacteria that produce **neurotoxins.** These toxins are harmful to local wildlife, as well as farm animals and pets. Production of these neurotoxins is part of its symbiotic relationships. It protects the host plant from grazing pressure. A DNA sequencing project was undertaken in 1999. It mapped the complete genome of *Anabaena.* Its DNA is 7.2 million base pairs long. The study focused on heterocysts, which convert nitrogen into ammonia. Certain species of *Anabaena* have been used on rice paddy fields. They act as natural fertilizer.

Vegetative Structure/thallus

It has filamentous structure. Its filament resembles the filament of *Nostoc.* Sometimes it becomes difficult to differentiate between trichomes of *Nostoc* and *Anabaena.* There is only one difference. The filaments of *Nostoc* are covered by mucilage and form a colony. It is absent in *Anabaena.* The filament of *Anabaena* consists of string of beaded cells. Several intercalary heterocysts are present in the trichome. Heterocysts are of same shape as of vegetative cell. The filaments are ordinarily straight but they may be circinate or irregular. Filaments occur singly within a sheath (Fig. 4.5). Sheaths are always hyaline and watery gelatinous.

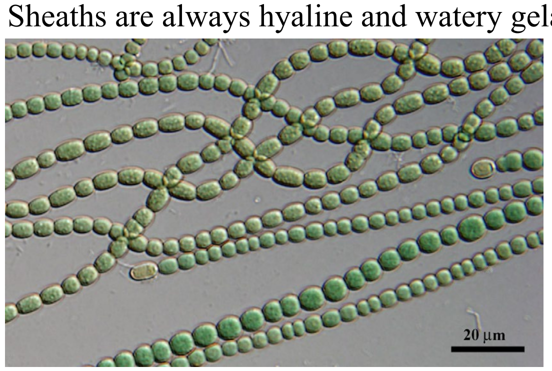


Fig. 4.5 Filaments of *Anabaena*

Trichomes are untapered with conspicuous constrictions at cross- walls. Trichomes may be straight, curved or helically (spirally) formed. The cells are cylindrical, spherical or ovoid (barrel- shaped) and not shorter than broad (or only slightly so), usually ranging in width from about 2 to 10 µm but in some species to over 20 µm. The terminal cells may be rounded, tapered or conical in shape.

Heterocysts (Fig. 4.6) are intercalary or terminal or both. Intercalary heterocysts are nearly spherical to cylindrical with rounded ends; terminal heterocysts are similar or sometimes conical. Akinetes are usually formed, and their position in trichomes differs with the species. A firm individual sheath is absent, but a soft mucilaginous covering is often present. Trichomes, when free of adhesive mucilage, are normally motile (usually <1 µm/s), and colonies are not formed.

Gas vesicles occur in many species; however, they occur mainly in those that are planktonic. They are rarely cylindrical and never discoid. The majority of the cells of a colony are similar in size. Each cell has outer cell wall. This wall consists of three layers. The inner layer is thin cellular layer, medium is pectic layer and outer is mucilage layer.

Protoplasm is composed of Soo riafts. The peripheral part is called chromoplasm. It contains pigments hence it is colored. The central colourless part of protoplasm contains nucleus like material called central body or chromatin granules. The mol% G+C of the DNA of 19 strains ranged from about 35 to 47. Heterocysts are of same shape as of vegetative cell. Golgi bodies, endoplasmic reticulum and mitochondria are absent in their cells.

Nitrogen fixation by *Anabaena*

During times of low environmental nitrogen, about one cell out of every ten differentiates into a heterocyst. The heterocyst then supply neighboring cells fixed nitrogen in return for the products of photosynthesis. Such nitrogen fixing cell cannot perform photosynthesis now. This separation of functions is essential. The nitrogen fixing enzyme in heterocysts is nitrogenase**.** It is unstable in the presence of oxygen.

Nitrogenases are kept isolated from oxygen. Therefore, heterocysts have developed elements to maintain a low level of oxygen within the cell. The developing heterocyst builds three additional layers outside the cell wall. These layers prevent the entrance of oxygen into the cell. It gives heterocyst its characteristic enlarged and rounded appearance. Due to these adaptations, the rate of oxygen diffusion into heterocysts is 100 times lower than of vegetative cells. One layer creates an envelope of polysaccharide layer. The nitrogen is fixed in this oxygen-restricted envelope. To lower the amount of oxygen within the cell, the presence of photosystem II is eliminated.

Heterocyst cells are terminally specialized for nitrogen fixation. The interior of these cells is micro-oxic as a result of increased respiration, inactivation of O_2-producing photosystem (PS) II, and formation of a thickened envelope outside of the cell wall. Nitrogenase, sequestered within these cells, transforms dinitrogen into ammonium at the expense of ATP and reductant—both generated by carbohydrate metabolism, a process supplemented, in the light, by the activity of PS I. Carbohydrate, probably in the form of glucose, is synthesized in vegetative cells and moves into heterocysts. In return, nitrogen fixed in heterocysts moves into the vegetative cells, at least in part in the form of amino acids.

Reproduction:

Only vegetative propagation is found which takes place by-

1. **Fragmentation** of "parental" trichomes into shorter trichomes indistinguishable in cell dimensions from the former trichome.
2. **Hormogonia:** these are frequently formed due to breaking up of trichomes into smaller pieces at the region of heterocysts. On germination, they develop heterocyst and grow into long filaments. They are motile in many species.
3. **Akinetes:** they are formed during unfavorable conditions. Akinetes are thick walled spores with a large amount of reserved food material. Their wall is two to three layers thick. They have granular protoplasm. Akinetes are capable of forming new filaments. The Akinetes can survive in dry conditions. In many species the number and position of akinetes is a specific character i.e; they may be one or two or more in chains. Further, they may be on one or both the sides of a heterocyst or may be disposed away from it. Akinetes are generally cylindrical but may be spherical .On germination, akinetes form new thallus. Nitrogen deficiency appears to be one factor leading to production of akinetes.
4. **By germination of heterocysts:** In a few species, heterocyst germinates to form new thallus. The pigments reappear and cell contents transform into a germling. *Anabaena* possesses motile stage in the vegetative phase and the non motile phase is merely a response to adverse conditions. Fixation of nitrogen has been convincingly demonstrated in species of *A. cylindrica, A. ambigua* and *A. naviculodes*.
5. **Endospore** formation is rare in *Anabaena.*

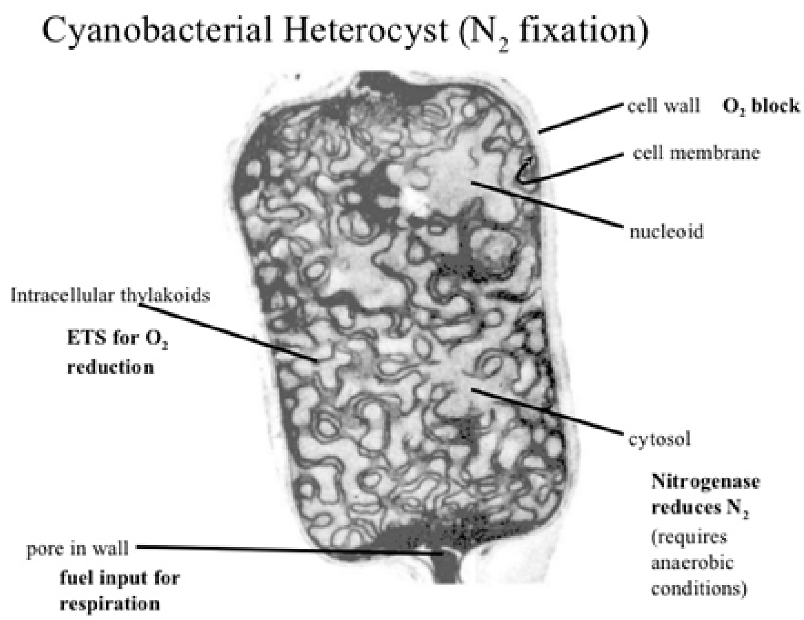


Fig. 4.6 Heterocyst

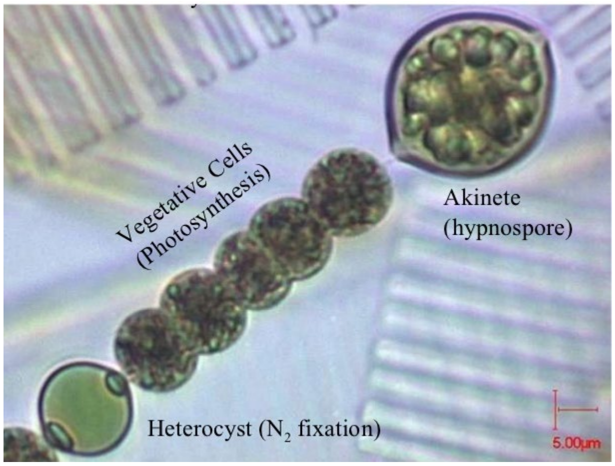


Fig. 4.7 Akinete in *Anabaena*

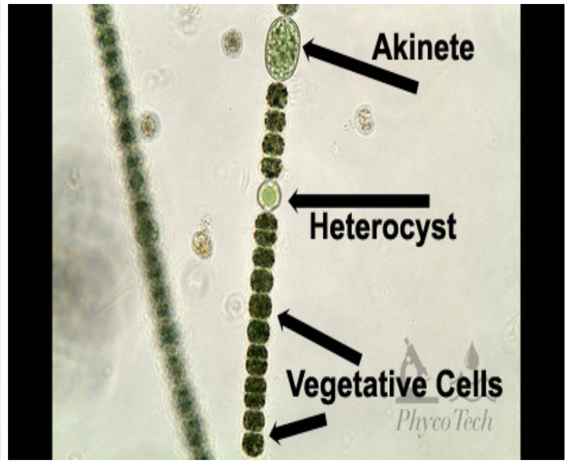


Fig. 4.8 Akinete and heterocyst in *Anabaena*

4.3.3-*Spirulina / Arthrospira*

Division: Cyanophyta
Class: Cyanophyceae
Order: Oscillatoriales
Family: Spirulinaceae
Genus: *Spirulina*

Introduction

Spirulina is a genus of filamentous cyanobacteria with a coil-like shape. 13 species are known some of them are *S. abbreviate, S. albida, S. baltica, S. magnifica, S. abbreviate. S. agilis,* etc. *Spirulina* is also the commercial name for the species *Arthrospira platensis* (previously known as *Spirulina platensis*), which is cultivated around the world as a food source.

It is a very rich source of nutrition. In fact, it was a staple of Aztec cuisine. The genus is also responsible for the flamingo's pink plumage. It is currently popular as a health food in the U.S. and Europe, often taken as a dietary supplement in the form of powder or tablet. It has 55 - 70 % protein, vitamin A, B1 (thiamine), B2 (riboflavin), B3 (niacin), B6 (pyridoxine), B12 (cobalamin), vitamin C, vitamin D, vitamin E, folate, vitamin K, biotin, pantothenic acid, beta carotene (source of vitamin A), inositol, minerals as calcium, manganese, iron, chromium, phosphorus, molybdenum, iodine, chloride, magnesium, sodium, zinc, potassium, selenium, germanium, copper, boron. The cell has amino acids like isoleucine, phenylalanine, leucine, threonine, lysine, tryptophan, methionine, valine, alanine, glycine, arginine, histidine, aspartic acid, proline, cystine, serine, glutamic acid and tyrosine.

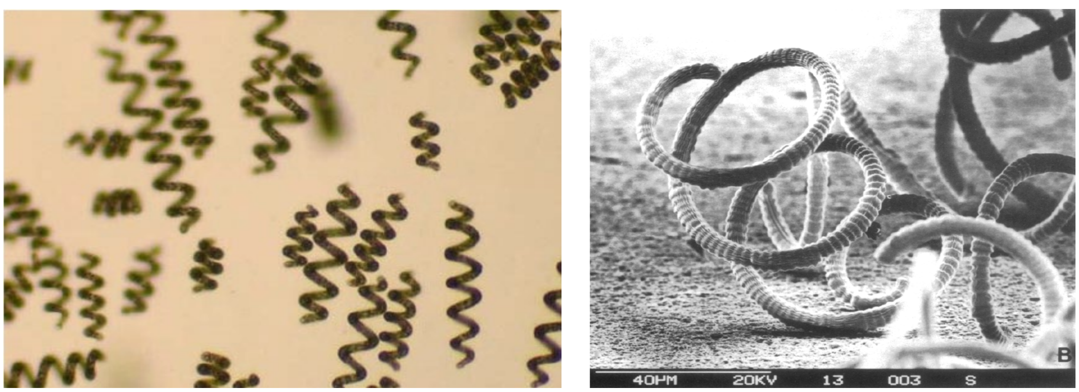
Vegetative structure/thallus

Spirulina is a multicellular, filamentous cyanobacterium. Under the microscope it appears as blue green filaments composed of cylindrical cells arranged in ubranched, helicoidal trichomes (Fig. 4.9).

The filaments are motile, gliding along their axis. Heterocysts are absent. The helical shape of the trichome is characteristic of the genus but the helical parameter (i.e. pitch, length and helix dimensions) vary with the species and even within the same species. The helical shape is maintained only in liquid media. The filaments become true spirals in solid media. The transition from a helix to a flat spiral is slow, where as the reverse occurs almost instantly.

Cell structure

The diameter of the cells ranges from 1-3 µm in the smaller species and from 3-12 µm in the larger. *S. maxima* is characterized by a diameter of the helix of 50-60µm and a pitch of 80 µm. For *S. platensis* these parameters were >35 to 50 and 60 µm respectively. The larger species have a granular cytoplasm containing gas vacuoles and septa. The cell wall is made up of four layers. The septum appears as a thin disk, folded in part. The cells contains phycocyanin, chlorophyll, carotenoids, myxoxanthophyll, zeaxanthin, cryptoxanthin, echinenone and other xanthophylls, gamma linolenic acid, glycolipids, sulfolipids and polysaccharides.



A B

Fig. 4.9 (A-B) Microphotograph of *Spirulina*

Reproduction

The life cycle of *Spirulina* in laboratory culture is simple by hormogonia.

A mature trichome is broken in several pieces through the formation of specialized cells, necridia, that undergo lysis, giving rise to biconcave separation disks.

The fragmentation of the trichome at the necridia produces gliding, short chains (2-4 cells), the hormogonia, which give rise to a new trichome. The cells in the hormogonium lose the attached portions of the necridial cells, becoming rounded at the distal ends with little or no thickening of the walls. During this process, the cytoplasm appears less granulated and the cells assume a pale blue-green color. The number of cells in hormogonia increases by cell fission while the cytoplasm becomes granulated and the cells assume a brilliant blue-green color. By this process trichomes increase in length and assume the typical helicoidal shape. Random but spontaneous breakage of trichomes together with the formation of necridia assures growth and dispersal of the organism.

4.3.4-*Scytonema*

Division: Cyanophyta
Class: Cyanophyceae
Order: Nostocales (Hormogonales)
Family: Scytonemataceae
Genus: *Scytonema* Agardh ex Bornet et Flahault

Occurrence

The word *Scytonema* has been derived from Greek word *skytos*, **"leather" + *nema*, "thread".** *Scytonema* is a genus of photosynthetic cyanobacteria that contains over 100 species. It grows as intricately fused filaments that form dark mats like *S. oscillatum* on wet rocks (Fig. 4.10. a), damps barks of trees etc. Many species are aquatic or semi terrestrial conditions and are either free-floating or grow attached to a submerged substrate, while others species grow on terrestrial rocks, wood, soil, or plants. *S. simplex* is completely submerged forming the undergrowths of ponds and lakes. *Scytonema* is a nitrogen fixer, and can provide fixed nitrogen to the leaves of plants on which it is growing. Some species of *Scytonema* form a symbiotic relationship with fungi to produce a lichen.

Vegetative structure/thallus

The plant body is a uniseriate filament and is surrounded by mucilage sheath, like in other blue green algae. The sheath is lamellated and is of golden yellow or brown, pale blue-green, olive green or even violet colored. The filaments possess either intercalary or terminal heterocysts.
The genus is characterized by its unique type of branching called as "false branching" or "Gemminate branching". The filament breaks up near a heterocyst and the broken end protrudes out of the sheath as a branch. If both the free ends protrude out as branches there will be two branches and it is known-as "gemminate branching". If only one develops into a branch, it is known as "false branching". Later the branches develop their own mucilage sheath. Branching is the result of the following causes:
(1) By the degeneration of Intercalary cell: When one intercalary cell dies, the free ends of cells continue growth resulting in geminate branching.
(2) By the development of separation discs: An intercalary cell in the filament becomes dark in color and thin walled losing its contents. Gradually it becomes biconcave in shape and degenerates ultimately. Soon after, branching follows, producing a pair of branches.
(3) By the formation of Loop: It is also due to the formation of loops resulting in branching of *Scytonema*. The filament bulges out and forms a loop. One of the terminal cells in the loop degenerates and this results 'in two pseudobranches.
(4) By the Heterocysts: The trichome breaks up at the point of' heterocyst and branching follows the usual pattern.

Cell structure

Cells are cylindrical or rectangular in shape. Heterocysts are found in between the vegetative cells. The terminal cell is usually hemispherical. Cells may be longer or shorter than broad. The apical ends of the filaments are not tapered, but the end cells may slightly get rounded or widened. The cells sometimes have constricted cross walls and contain groups of long, cylindrical gas vesicles. The heterocysts are located throughout the filaments and are rectangular and solitary, with darkly-pigmented cell walls. When the period of motility ends, a single terminal heterocyst is formed before cell division and growth resumes. The G+C Mol % is 44.4. *Scytonema* has gained more importance as they produce special chemicals toxins scytovirin an anti-HIV protein.

Reproduction

There is no sexual reproduction and asexual reproduction is brought about by the following methods:

1- Hormogonia: A hormogonium is formed by the formation of two separation discs. Each one consists of several cells and germinates into a new filament.

2- Heterocysts: The trichome breaks up at the point of' heterocyst and branching follows the usual pattern.

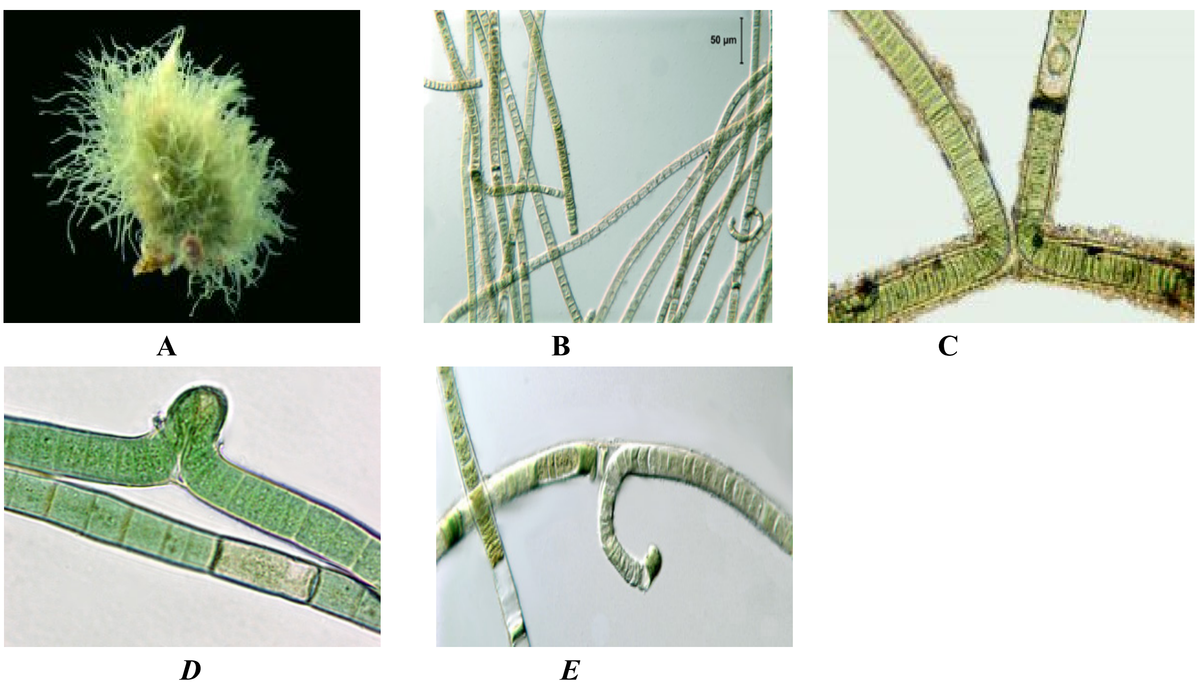


Fig. 4.10.(A-E) Various photographs showing *Scytonema trichomes* and false branching

4.3.5-*Rivularia*

Division: Cyanophyta

Class: Cyanophyceae
Order: Rivulariales
Family: Rivulariaceae
Genus: *Rivularia*
Species: *mehrai*

Occurrence

Rivularia is a genus of cyanobacteria of the family Rivulariaceae. *Rivularia* is found growing on submerged stones, moist rocks, and damp soils near the riverside (Fig. 4.11-A). Some of the species are *Rivularia atra, Rivularia bullata, Rivularia haematites, Rivularia jaoi, Rivularia nitida, Rivularia thermalis. Rivularia* is a colonial form.

The colonies occur in water or on the soil. The aquatic species are fresh water forms which occur either free floating on the surface of water or are attached to submerged plants or stones in the sunny ponds, pools and lakes. *R. bullata* is marine.

Vegetative structure/thallus:

The colonies are macroscopic thalli of various sizes and shapes. They are yellowish brown in color. The colony may be thick and discoid or a spherical, hemispherical or irregularly lobed gelatinous mass. It is soft, sometimes solid.

Each colony contains numerous radially arranged trichomes. The trichomes are loosely arranged in the central portion, but are more or less crowded towards the periphery of the colony. They are unbranched but sometimes exhibit false branching. The numerous trichomes constituting the colony are embedded in the soft, mucilaginous matrix secreted by the cells of the trichomes. The mucilage envelope has more or less a firm boundary to form a definite colony (Fig. 4.11-B)

A B C

Fig. 4.11 (A-B) Colonies of *Rivularia* (C) Filament of *Rivularia*

The trichomes are whip like structures (Fig. 4.11-C). They are straight or slightly curved. Each trichome is broad at the base but gradually tapers further up to terminate in a long, colorless, multicellular hair at its distal end.

The hair is straight or slightly curved rarely irregularly curved and coiled in *R. mehrai*. Situated below the hair is the meristematic region of the trichome. Each trichome has its own mucilage envelope or sheath which is colorless and non-lamellated. The trichome with the surrounding sheath is called the filament. The sheath is indistinct or distinguishable only near the base of the trichome and is diffluent further up. The younger trichomes are pale, blue –green in color and show slight constrictions opposite the septa.

The heterocysts occur singly and at the base of the trichome. The basal heterocyst is spherical, ellipsoidal or cylindrical and normally has a single pore. Two pored heterocysts have been recorded in *R. mehrai*. The contents of the heterocyst are homogenous. Absence of akinete next to the basal heterocyst is a noteworthy feature of *Rivularia*.

Cell structure

The cell as usual, consists of two parts, the cell envelope enclosing the protoplast, the cell envelope is divisible into two regions, the outer sheath and the inner cell wall proper. The latter is usually called the inner investment. It encloses the cell protoplast whereas the cell sheath envelopes the entire trichome. The septa between the cells are formed by the inner investment. Internal to the inner investment is the living plasma membrance which is differentially permeable. The cell protoplast has the same structure as is characterstic of cyanophycean cell. The growth is trichothallic. It takes place by the activity of the meristematic cells of the intercalary meristematic zone located at the base of the terminal hair. The meristematic cells are small in size, have denser granular contents and pseudo-vacuoles.

Reproduction

Rivularia multiplies vegetatively by hormogonia and rarely by heterocyst. No asexual and sexual reproduction is found. At the time of hormogonia formation the cells shed hairs. The delimitation of hormogonia starts in the meristematic zone and gradually extends to the basal portion of the trichome. They are delimited singly or in long series the formation of biconcave separation disc. Each hormogonium consists of two to several living cells. On germination one of the two end cells of a hormogonium becomes modified to form the basal heterocyst. All others divided repeatedly in one place. The daughter cells grow to form the trichome.

4.4 SALIENT FEATURES, IMPORTANT GENERA AND LIFE CYCLE PATTERN IN BACILLARIOPHYTA

Scientific classification

Division: Bacillariophyta
Class: Bacillariophyceae
Order: Pennales
Family: Naviculoideae
Genus: *Pinnularia*
Species: *viridis*

1. Diatoms are a major group of microalgae, and are among the most common types of phytoplankton.
2. Diatoms are unicellular, although they can form colonies in the shape of filaments or ribbons (e.g. *Fragilaria*), fans (e.g. *Meridion*), zigzags (e.g. *Tabellaria*), or stars (e.g. *Asterionella*).
3. The first diatom formally described in scientific literature, the colonial *Bacillaria paradoxa*, was found in 1783 by Danish naturalist Otto Friedrich Müller. Diatoms are producers within the food chain.
4. A unique feature of diatom cells is that they are enclosed within a cell wall made of silica (hydrated silicon dioxide) called a frustule.
5. These shells are used by humans as diatomaceous earth, also known as diatomite. Fossil evidence suggests that they originated during, or before, the early Jurassic period.
6. Diatom communities are a popular tool for monitoring environmental conditions, past and present, and are commonly used in studies of water quality.
7. They are one of the dominant components of phytoplankton in nutrient-rich coastal waters and during oceanic spring blooms since they can divide more rapidly than other groups of phytoplankton.
8. Most live pelagically in open water, although some live as surface films at the water-sediment interface (benthic), or even under damp atmospheric conditions.
9. They are especially important in oceans, where they contribute an estimated 45% of the total oceanic primary production of organic material. Spatial distribution of marine phytoplankton species is restricted both horizontally and vertically.
10. The diatoms are unicellular, sometimes colonial found in every aquatic habitat, some are terrestrial, some occur as epiphyte on other algae [Phaeophyceae and Rhodophyceae].
11. The Cells are surrounded by rigid 2 part box or petri dish pieces like cell wall, composed of Silica and is known as "Frustule".
12. Thus two-part frustules surround the protoplasm. It consist of two halves the smaller or the lower one is known as hypotheca and the larger or the upper one is known as Epitheca.
13. These 2 parts are further made up of two parts a Valve and on two sides of it are connecting bands. The two connecting bands of epitheca and hypotheca together form a Girdle.
14. Sometimes there are one or more additional bands present between valve and girdle these are known as intercalary bands. They are provided with minute teeth and they hold valves together. The protoplasm has a central nucleus suspended by cytoplasmic threads.
15. The chloroplast occupies most of the cell, usually as two parietal plastids or sometimes numerous discs like plastid are present. On either side of the nucleus there is a plate like structure.
16. According to some, these structures act as spindle at the time of division. According to some other these plates are reserve food products. The reserve food material is Chrysolaminarin. It occurs in vesicles.
17. Besides this numerous Mitochondria, Golgi bodies, Endoplasmic reticulum and ribosomes are also present. On one side of the nucleus a centrosome is found.

18. The silica which forms the cell wall has certain patterns on the wall. According to Hendey [1964] there are 4 basic patterns:-

(a) Centric or Radial: - the valves are circular and dots are longer. These are commonly found in sea water [marine]. Here the pattern is along a point. e.g. - *Coscinodiscus*

(b) Frellisoid: - When the pattern is uniform all over the surface without reference to a point or line. e.g.- *Eunotia* (Fig. 4.12).

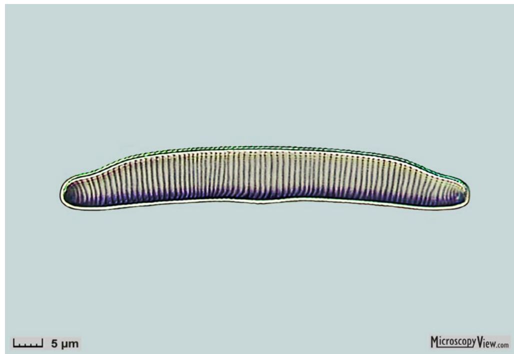


Fig. 4.12. *Eunotia*

(c) Gonoid: - When the pattern is dominated by angles. e.g., *Triceratum* (Fig. 4.13).

(d) Pennate:--The striations are arranged in pennate fashion i.e. arranged symmetrically on two sides of a central line /axial strip. If the axial strip is a plane area then it is called as Pseudoraphe if it possesses a longitudinal slot then it is called as Raphe. The raphe is divided in two parts by means of a central nodule and again at two ends the raphe is terminated by polar nodules one at each end. These nodules are the swelling of the cell wall. Raphe is S-shaped structure and is wider at its outer part and it tapers in the centre. e.g., *Navicula*, *Pinnularia*. The Silica in cell wall is not deposited smoothly throughout. The unthickened areas are called as "Punctae". The unthickened areas are found in form of striations. Sometimes they are found in the form of round pits. When the pits are quite deep they are known as Areolae. These are of 2 types:-

(i) Pores/hole: Simple pore like structures are present in wall.

(ii) Loculus Complex pore: It consists of a hexagonal chamber in the wall which is separated from other loculii by means of vertical spaces. These vertical connections are provided with pores to communicate between adjacent loculii. At one end of the loculus is the sieve membrane and at the other end is a large hole or foramen. The cavity of the foramen is smaller than the main cavity of the loculus. In same diatoms the patterns are similar on both girdle and valves. While in some the pattern is different on both and in some there is no pattern on girdle but only on valve.

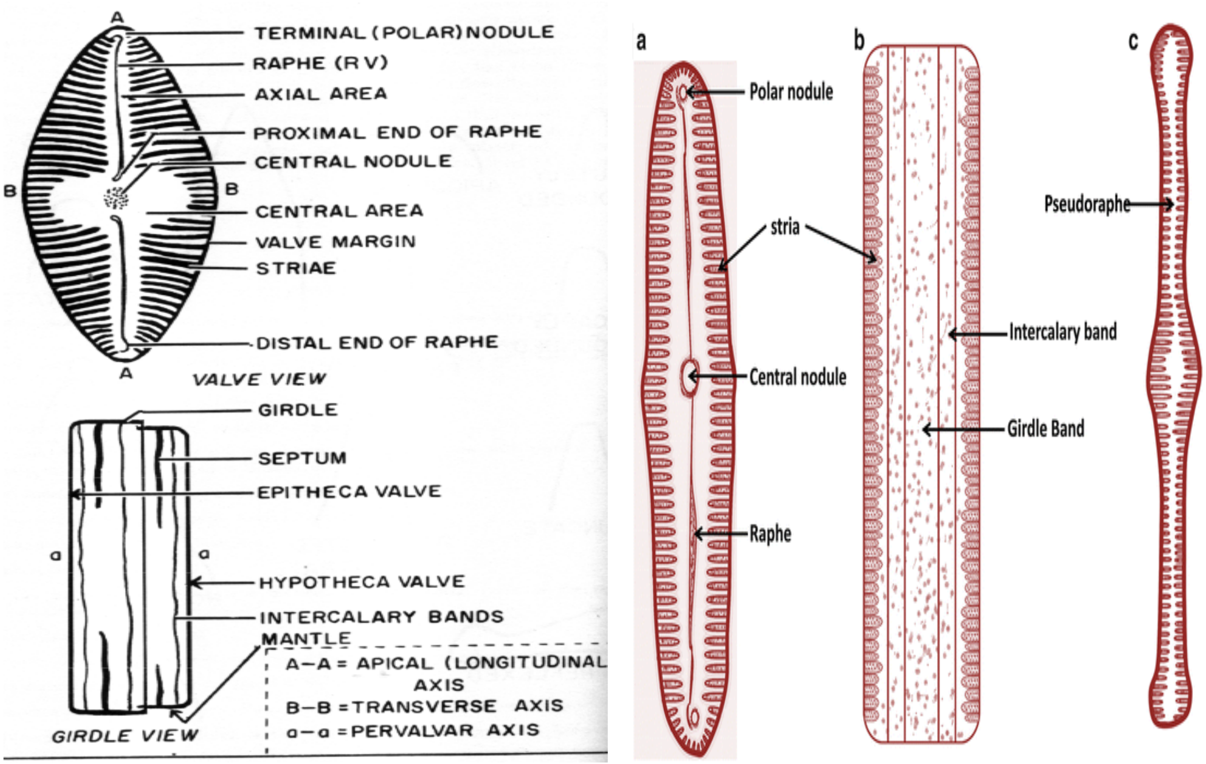


Fig. 4.13 Pennate diatom

19-The chloroplast is enveloped by two membranes of chloroplast and two membranes of chloroplast endoplasmic reticulum [Found only in Bacillariophyceae and Phaeophyceae].

20-The chloroplast, Endoplasmic reticulum is also continuous with the outer membrane of Nuclear envelope as well as with other chloroplast present in the cell.

21-The chloroplast and endoplasmic reticulum has ribosomes attached to it on the outer side. The thylakoids with in the chloroplast are grouped into three to a band and there is a single pyrenoid present. The Chloroplast contains Chl.a, c1 and c2. Fucoxanthin is the main carotenoid and it gives golden brown colour to the cell. A special pigment Diatomin is also present.

22-There are some colourless diatoms also known as Apochlorotic diatoms.

23-They live on decayed marine vegetation and if seen through light microscope plastids are totally absent. If seen through electron microscope some proplastids are seen or underdeveloped plastids are present.

24-The storage product is Chrysolaminarin present in Vesicles.

25-The reserve food material is present in the form of oil and volutin.

26- Motile stage is present in the form of male gametes which are uniflagellate.

27-Characterstic spores are produced known as auxospores.

28-Vegetative reproduction is by means of cell division and sexual reproduction is by fusion.

Classification

Hustedt (1930) divided Division Bacillariophyta Class Diatomatae into two orders-

1. **Centrales**
2. **Pennales**

This classification is followed by Fristch (1935) and most of the other workers.

4.4.1-Pennales

These are mostly fresh water and some are marine water. Pennales includes 4 suborders-

1. Araphideae
2. Raphidineae
3. Monoraphideae
4. Biraphideae

Pennales are bilaterally symmetrical or even asymmetrical valves are present. Araphideae shows colonial nature. Valves boat shaped. Wall markings arranged pinnately in relation to a raphe or pseudoraphe. Many forms exhibit movement. Chromatophores are large and few. Auxospores are normally formed by conjugation except in Araphideae.

a. **Araphideae**: Pseudoraphe is present
b. **Raphidineae**: rudimentary type of raphe. Raphe runs from polar nodule only for short distance. Central nodule is absent.
c. **Monoraphidieae**: fully developed raphe but present only on one side of valve.
d. **Biraphideae**: two well developed raphe systems are present. Forms may be colonial or unicellular. Pennales are mostly freshwater though they are also present in marine water. Colonial forms mostly belongs to Centrales and Araphideae. The cells remains united by means of mucilage which is secreted through large pores present on the valve.

Some special structures associated with diatoms:

Coastae and aerolae are also present. Coastae or ribs are rib like structures and give strength to the wall. The aerolae are box like structures and have air. The movement is observed in those diatoms only in which one or two raphe systems are present. They can perform movement due to sliding of a cell on a substratum that leaves mucilage. The path of the motile cell depends upon the shape of the raphe. The motility can be

1. **Navicula type:** straight movement
2. **Amorpha type:** path is curved
3. **Nitzschia type:** curved path with two different radii.

The movement is faster on a solid substratum than on less solid substratum. Drum and Hopkins (1966) proposed a mechanism for the movement in diatoms known as Drum and Hopkin movement. According to this immediately below the raphe some cryatelloid bodies are present in the cytoplasm. These crystalloid bodies contain mucilaginous material. On an appropriate stimulus the mucilage is released into the raphe system from the area of central or terminal pores. The mucilaginous material runs in the raphe in one direction till it strikes an object to which it is attached to. If the object is fixed then the streaming in the raphe forces the diatoms to move in the opposite direction. Thus the motile diatoms adhere to a substratum in the area of their raphe for the movement to occur.

Sexual reproduction

In pennales sexual reproduction is isogamous. The zygote grows to a special size of spore known as Auxospore. Auxospore formation in pennales takes place by three methods:

1. Gametic union
2. Autogamy
3. Parthenogenesis

1. Auxospore formation by gametic union

This method involves fusion of gametes either

a. there is formation of a single auxospore by two conjugating cells,

b. there is formation of two auxospores by two conjugating cells.

a. Single auxospore formation by 2 conjugating individuals- in this method two diatom individuals come together end to end or laterally and become enveloped in mucilage. The nucleus of both divides meiotically forming 4 haploid nuclei. Later on 3 of the 4 haploid nuclei of each conjugant degenerate. Only one nucleus survives in each protoplast which functions as the gamete. The 2 gametes fuse mid-way between the empty parent frustules after their escape from the same. With the result of fusion the zygote is formed. The zygote or fusion nuclei rest for some time. Thereafter it elongates in a plane parallel to the long axis of the parent frustules and act as an auxospore. Now this auxospore secretes a fresh frustules around it inside its perizonium. This method is isogamous type. Common in *Cocconeis*.

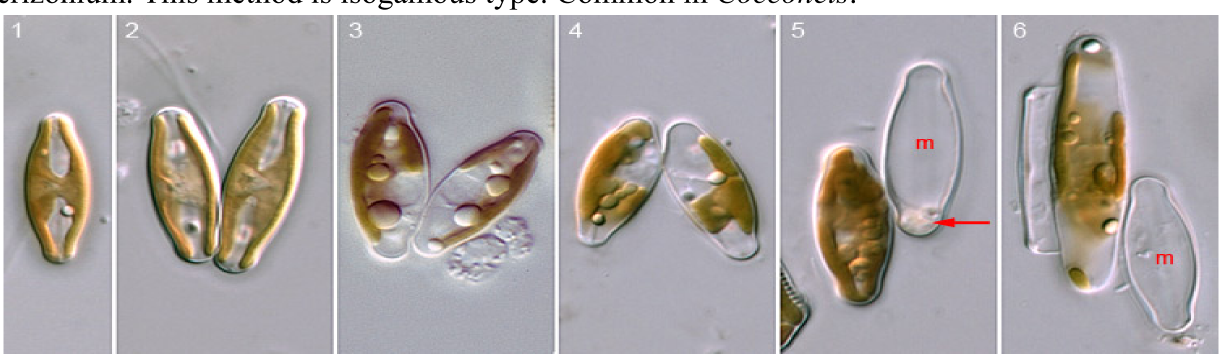


Fig. 4.14 Single auxospore formation from two diatom cells

b. Two Auxospore formations by 2 conjugating individuals- the diatoms taking part in conjugation secrete a common mucilage envelope around them. The diploid nucleus of each individual divides meiotically forming 4 haploid nuclei. Later on 2 of the nuclei in each individual disintegrate. Now the protoplast with the 2 functional haploid nuclei divides into two. This division may be symmetrical or asymmetrical. In symmetrical the gametes are equal (in each conjugant) while in asymmetrical these are unequal. Fusion takes place by any of methods.

(i) Both gametes show amoeboid movement. They come out of frustules (parent) and forms 2 zygotes. E.g. *Cocconeis placentula*. It can be isogamous or anisogamous (Fig. 4.15).

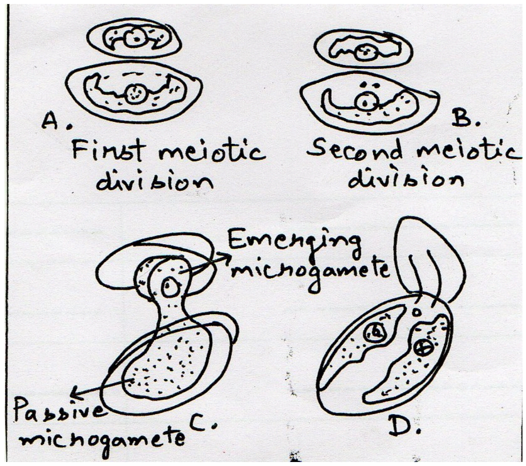


Fig.4.15 Auxospore formation by anisogamy in Cocconeis

(ii) The gametes of one conjugant are motile while those of other are passive. The amoeboid gametes come out actively and fuse in pairs with the passive gametes. Thus one frustule remains empty and other contains 2 zygotes.

(iii) Out of 2 gametes in one conjugant one is amoeboid and other is passive. The amoeboid of each comes out and migrates to the other to fuse with immobile gamete. Thus each frustule has one zygote. Now the zygotes are released they remain dormant for sometime. Later on they elongates and function as auxospore. The auxospore remain enclosed within a silicified pectic membrane known as perizonium. Perizonium is either secreted by the auxospore itself or by the remains of the membrane of the zygote. The auxospore secretes- new frustules around it within the perizonium. It is common in *Cymbella*. This method is more common than first one (Fig. 4.16).

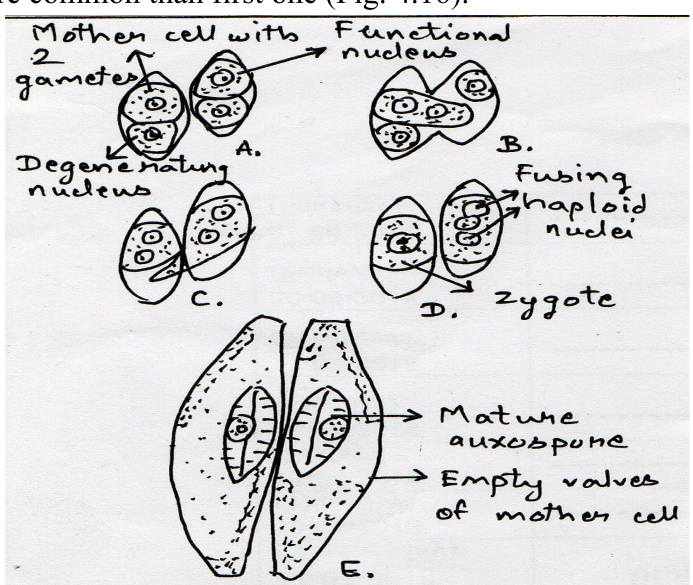


Fig.4.16. Two auxospores formation by two diatom cells

2. **Auxospore formation by autogamy:** according to Geitler (1939) the single diatom cell becomes enveloped in mucilage. The diploid nucleus undergoes meiosis. The 2 haploid daughter nuclei in the protoplast come to lie side by side in a pair and then fuse together. This phenomenon is known as autogamous pairing. The protoplast with a diploid nucleus is released out from the parent frustules which act as an auxospore. Auxospore increases in size and secretes fresh frustules within the perizonium (Fig. 4.17).

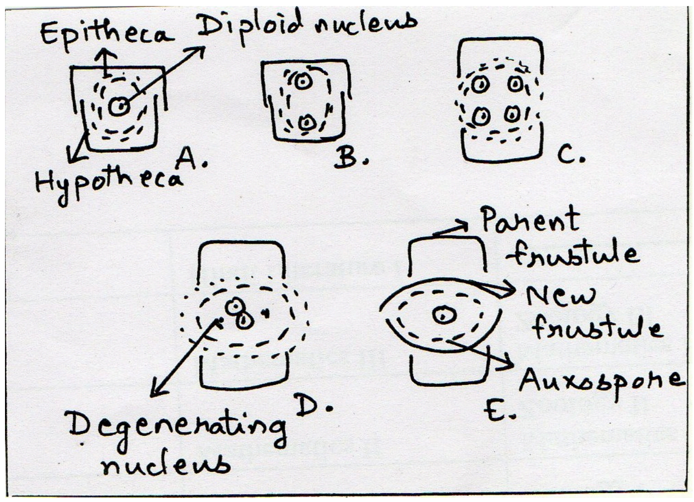


Fig. 4.17 Autogamy

3. **Auxospore formation by parthenogenesis:** in this there is no meiosis in the diploid nucleus. Only mitotic divisions takes place. All the nuclei formed are diploid. Out of these nuclei only one survives and rest degenerates. This single nucleus enlarges and changes into an auxospore which give rise to a single plant. Thus the process do not involved any pairing or fusion. Reported in *Cocconeis* by Geitler.

4.4.2-Centrales

These are mostly marine water and some are fresh water. Mostly found as colonial forms.

Centrales includes 4 suborders

1. Discoideae
2. Solenoideae
3. Biddulphiodeae
4. Rutilariodeae

They are well circular, polygonal or irregular. Ornamentation is radially symmetrical around a central point. Raphe or psedoraphe is absent. No movement due to absence of raphe. Chromatophores are numerous and also spores are formed without conjugation.

a. **Discoideae:** they have cells which have cylindrical or disc shape. Valve circular usually without special processes. e.g., *Cyclotilla*, *Melosira*, *Coscinodiscus.*

b. **Solenoideae:** cells elongate, cylindrical. Girdle complex with numerous intercalary mass. e.g., *Rhizosolenia*.
c. **Biddulphioideae:** cells box shaped and valves mostly provided with horns. e.g., *Triceratum*, *Biddulphia*.
d. **Rutilariodeae:** wall markings radially arranged or irregular. e.g., *Rutilaria*.

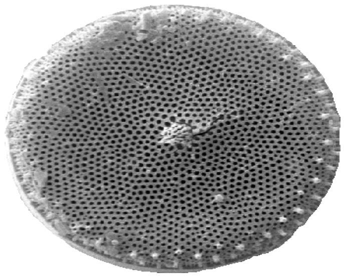


Fig.4.18 Coscinodiscus

Fig. 4.19 Rhizosolenium

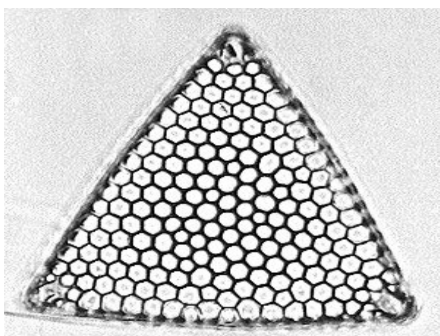


Fig. 4.20 Triceratum

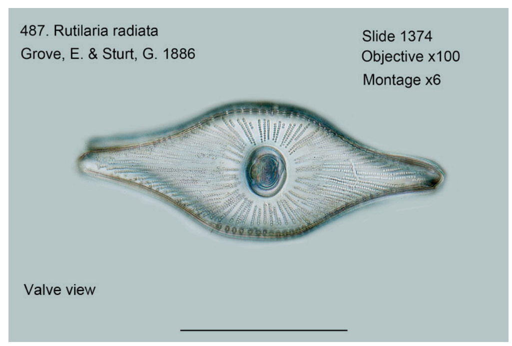


Fig.4.21 Rutilaria

Reproduction

It is by two means-

1- Vegetative: it takes place by cell division. The protoplast slightly increases in diameter and two halves of the cell wall slightly separate from each other. This is followed by mitotic division of the nucleus and then division of the protoplast into two in a plane parallel to the valve. So their one side is naked and on this side a new cell wall is formed. In both cases the new wall formed is always hypotheca, so the size of the cell decreases.

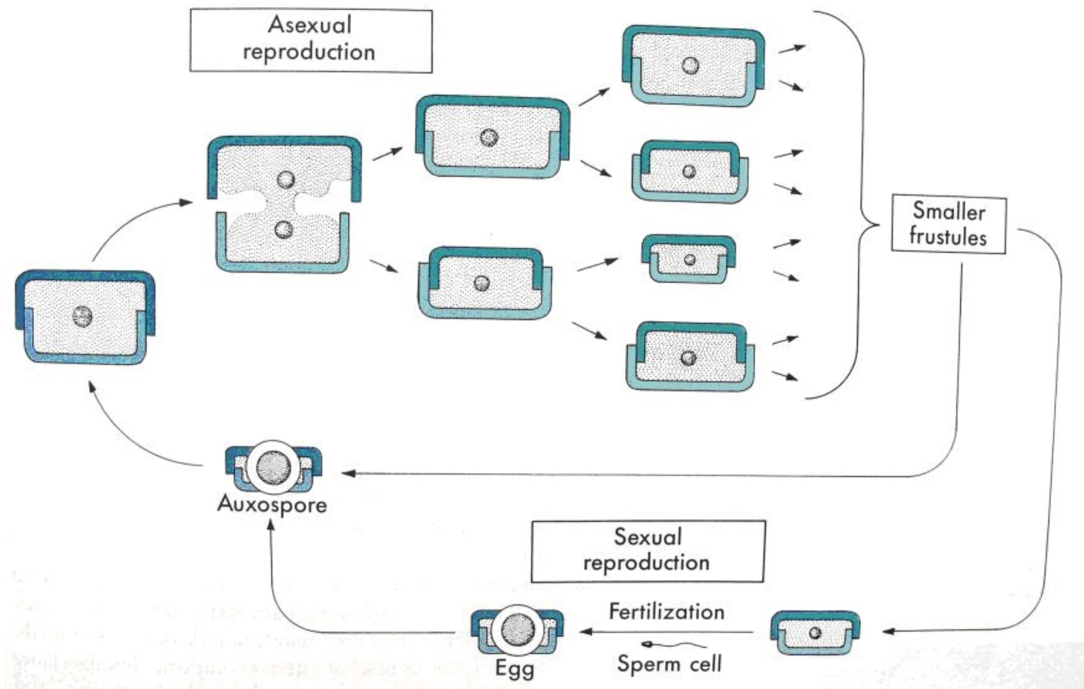
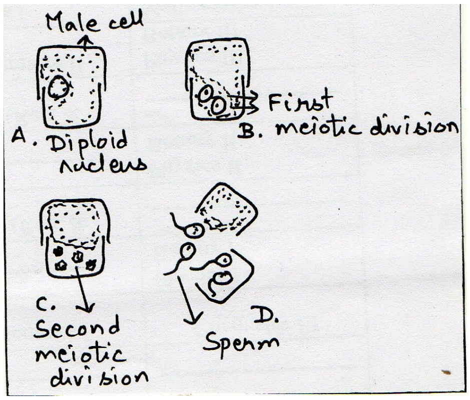


Fig. 4.22 Vegetative propagation in Diatoms

2- Sexual reproduction: It is oogamous. It is influenced by several factors as light, nutrition, temperature. With the exception of *Rhabdonema* all species studied so far are homothallic or monoecious. The zygote grows to a special size of spore known as Auxospore. This type of sexual reproduction is restorative i.e. the original size of size is regained. A single Auxospore is formed within a single individual. The auxospore is formed either by Autogamy or by oogamy.

a. **Autogamy**: at the time of autogamy the cell secrets some mucilage. Epitheca and hypotheca separate slightly and the diploid nucleus divides meiotically to form four nuclei. Two nuclei degenerate and remaining two fuse to form a diploid nucleus. The diploid zygote along with the protoplast comes out from the parent frustule and functions as Auxospore. The auxospore enlarges, secretes an overlapping wall and develops into a new diatom.

b. **Oogamy**: Observed in *Melosira*, *Cyclotella* and *Biddulphia*. A vegetative cell directly functions as an antheridia or spermatogonia. Its protoplasm divides to form 4 to 128 small uninucleate protoplasmic bits. The first division is meiotic one. These are male gametes or spermatozoids. Similarly the female gametes are non-flagellated and are known as eggs. A single egg develops in a single female diatom cell or oogonium. This cell extends slightly with an elongated nucleus. This nucleus divides meiotically forming 4 haploid nuclei. Out of these 4 haploid nuclei 3 degenerates. The male gametes are released from the male cell and swim to an oogonium. One of the spermatozoids penetrates the egg and fuses with it. The plasmogamy is followed by karyogamy. This results in formation of a diploid zygote and this function as auxospore.



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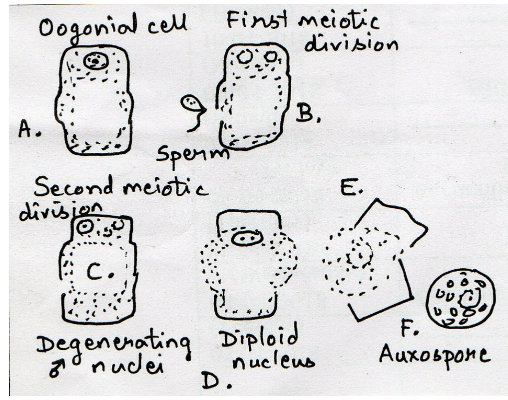

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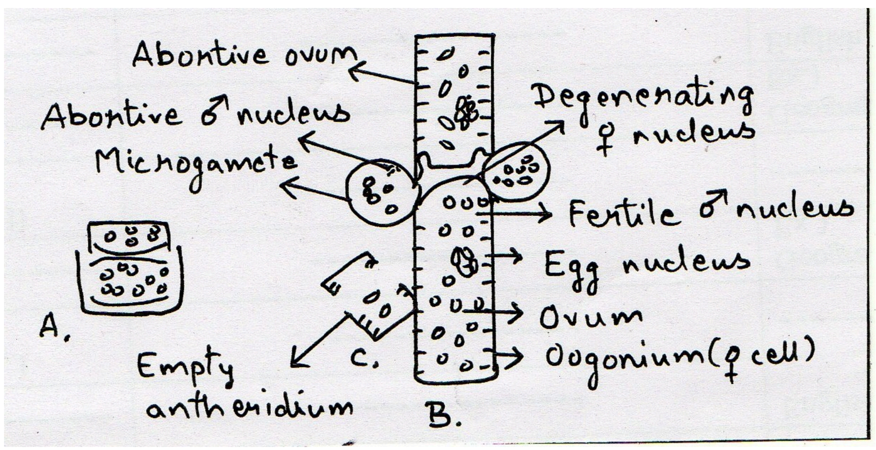


C

Fig.4.23 A- Spermatogonia, B- Oogonium, C- Auxospore

Auxospore in both Centrales and Pennales increases in size and in some as much as 3 times that of the parent cell. Its diploid nuclei undergo 2 mitotic divisions. After first mitotic division one nucleus degerates this nuclei left again divides by mitotic division resulting in the formation of 2 nuclei. Out of these 2 nuclei one degenerates and only a single nucleus is left in a new diatom cell.

4.5 SALIENT FEATURES, IMPORTANT GENERA AND LIFE CYCLE PATTERN IN CHAROPHYTA

1. The green algae included in division Charophyta are best known as Characean algae, commonly called as stoneworts.
2. They are worldwide in distribution.
3. They occur in still, clean water, fresh or brackish water.
4. They flourish in the month of August to March, disappear in hot summers and abundant in cold season in northern India.

5. It has both living and fossil forms. About 294 living species have been reported which are placed under 7 genera *Chara*, *Tolypella*, *Nitella*, *Nitellopsis*, *Lycnothamnus*, *Lamprothamnium* and *Protochara*. About 69 species have been reported from India, Burma, Ceylon and Pakistan.
6. The plant body presents a great elaboration of vegetative structures.
7. It is always erect and consists of long, slender, jointed, green or grey main axis with a regular succession of nodes and internodes.
8. The central axis is branched.
9. At each node arises a whorl of lateral branchlets.
10. Sexual reproduction is oogamous and very complex. They are large enough to be seen with naked eyes. No asexual reproduction is found.
11. The zygote on germination forms protonema which develops into a *Chara* plant.
12. The family Characeae is divided into two sub-families

(a) Nitelloideae: the oogonium has 10 coronal cells. E.g. *Nitella* and *Tolypella*

(b) Charoideae: the oogonium has 5 coronal cells. E.g. *Chara*, *Nitellopsis*, *Lycnothamnus*, *Lamprothamnium* and *Protochara*.

4.5.1 *Chara*

Division: Charophyta
Class: Chlorophyceae
Order: Charales
Family: Characeae
Genus: *Chara*

Occurrence

Chara is represented by 188 species. *Chara* is fresh water; green alga found submerged in shallow water ponds, tanks, lakes and slow running water.

C. baltica is found growing is brackish water and *C. fragilis* is found in hot springs. *Chara* is found mostly in hard fresh water, rich in organic matter, calcium and deficient in oxygen. *Chara* plants are often encrusted with calcium carbonate and hence are commonly called stone wort. *Chara* often emits disagreeable onion like odour due to presence of sulphur compounds. *C. hatei* grows trailing on the soil, *C. nuda* and *C. grovesii* are found on mountains, *C. wallichii* and *C. liydropitys* are found in plains. In India *Chara* is represented by about 30 species of which common Indian species are *C. zeylanica, C. braunii, C. gracilis, C. hatei* and *C. sgymnoptiy* etc.

Vegetative Structure of *Chara* / Thallus

The thallus of *Chara* is branched, multicellular and macroscopic. The thallus is normally 20-30 cm in height but often may be up to 90 cm to l m. Some species like *C. hatei* are small and may be 2-3 cm long. The plants in appearance resemble *Equisetum* hence *Chara* is commonly called as aquatic horsetail. The thallus is mainly differentiated into rhizoids and main axis (Fig. 4.22).

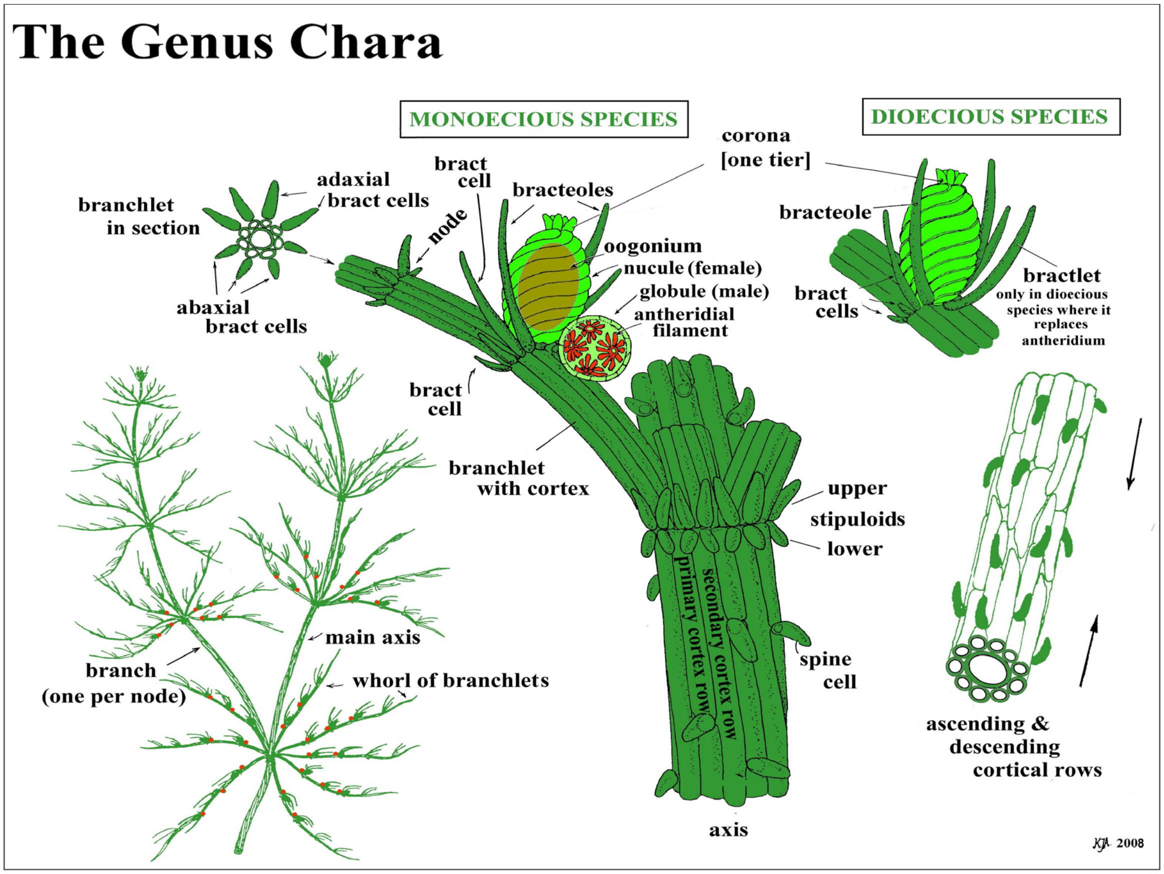


Fig. 4.24 Thallus of *Chara*

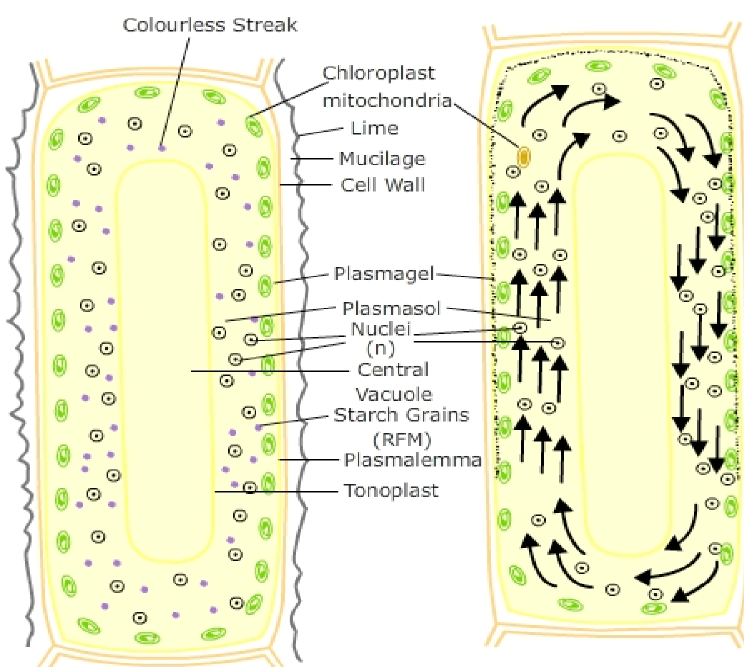


Fig. 4.25 Ultrastructure of *Chara*

Cell structure: The nodal cells are smaller in size and isodiametric. The cells are dense cytoplasmic, uninucleate with few small ellipsoidal chloroplasts. The central vacuole is not developed instead many small vacuoles may be present. The cytoplasm can be differentiated in outer exoplasm and inner endoplasm. The inter-nodal cells are much elongated. The cytoplasm is present around a large central vacuole. The cells are multinucleate and contain many discoid chloroplasts. The cytoplasm is also differentiated into outer exoplasm and inner endoplasm. The endoplasm shows streaming movements. The cell walls between the nodal cell and inter-nodal cells are porous to help in cytoplasmic continuity between cells (Fig. 4.25).

Rhizoids: The rhizoids are white, thread like, multicellular, uniseriate and branched structures. The rhizoids arise from rhizoidal plates which are formed at the base of main axis or from peripheral cells of lower nodes. The rhizoids are characterized by presence of oblique septa. The tips of rhizoids possess minute solid particles which function as statoliths. The rhizoids show apical growth. Rhizoids help in attachment of plant to substratum i.e., mud or sand, in absorption of minerals and in vegetative multiplication of plants by forming bulbils and secondary protonema.

Main Axis: it is erect, long, branched and differentiated into nodes and internodes.
The internode consists of single, much elongated or oblong cell. The inter-nodal cells in some species may be surrounded by one celled thick layer called cortex and such species are called as corticate species. The species in which cortical layer is absent are called ecorticate species. The node consists of a pair of central small cells surrounded by 6-20 peripheral cells. The central cells and peripheral cells arise from a single nodal initial cell. On nodes develop these following four types of appendages:

(i) **Branches of limited growth.** These arise in whorls of 6-20 from peripheral cells of the nodes of main axis or on branches of unlimited growth. These are also called branchlets, branches of first order, primary laterals or leaves. These branches stop to grow after forming 5-15 nodes and hence are called branches of limited growth. The stipulodes and reproductive structures are formed on the node of these branches.

(ii) **Branches of unlimited growth:** They arise from the axils of the branches of limited growth hence these are also called auxiliary branches or long laterals. These are differentiated into nodes and internodes. At nodes they bear primary laterals and these branches look like the main axis. Their growth is also unlimited like main axis.

(iii) **Stipulodes:** The basal node of the branches of limited growth develops short, unicellular oval, pointed single cell outgrowths called stipulodes. In most of the species of *Chara* e.g., *C. burmanica*, the number of stipulodes at each node is twice the number of primary laterals, such species are called as bi-stipulate. Depending upon the arrangement of stipulodes *Chara* can be divided into

- **a.** Haplostephanous (stipules are arranged in single row) *C. brauni*.
- **b.** Diplostephanous (stipules are arranged in two rows) *C. delicatula*.

In some species of *Chara* e.g., *C. nuda* and *C. braunii*, *C. coralline* the number of stipulodes at each node, is equal to number of primary laterals at that node, such species are called unistipulate. When stipulodes are present in one whorl at each node the species are called as haplostephanous and with two whorls on each node are called diplostephanous.

Growth of *Chara* takes place by a dome shaped apical cell (Fig.4.26). The cell undergoes repeated transverse divisions and forms a row of three cells. The upper one remains as apical cell, middle biconcave one forms the nodal initial and the lower one forms the internodal initial. The nodal cell undergoes repeated vertical division and ultimately forms two central cells surrounded by 6-20 peripheral cells. Branches of limited growth are developed from the peripheral cells arranged in single row. The internodal initial does not divide further and elongates much more to form long internodes.

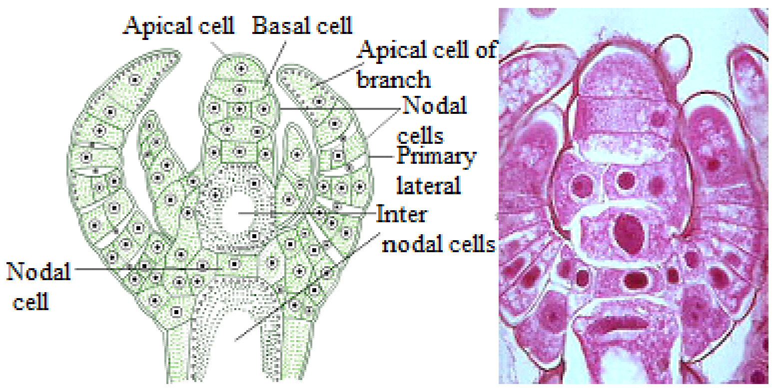


Fig. 4.26 Shoot apex of *Chara*

(iv) **Cortex:** Many species of *Chara* e.g., *C. aspera, C. inferma* have inter-nodal cells of main axis en-sheathed by cortex cells. Such species are called corticated species. The cortex consists of vertically elongated narrow cells. The internode up to half of its length is made up of descending corticating filaments developed from upper node and the lower half of internode is covered by filaments developed from lower node called ascending filaments. The ascending and descending filaments meet at the middle of internode (Fig. 4.26). The species without cortex e.g., C. *corallina, C. succinata, C. wallichii and C. braunii* are called ecorticated species.

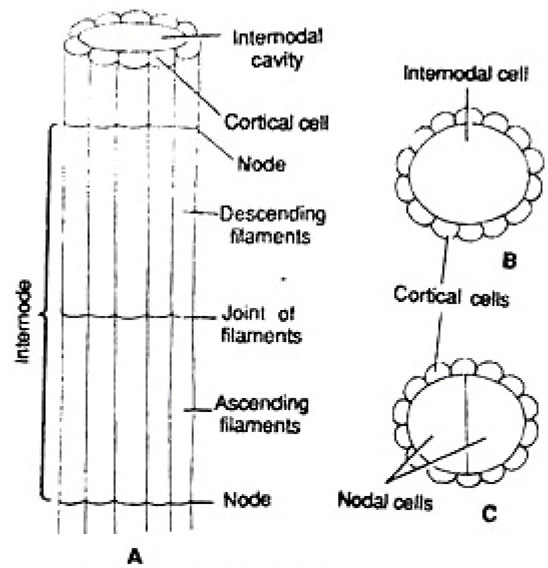


Fig. 4.27 Node and internode of *Chara*

Reproduction

Reproduction in *Chara* takes place by vegetative and sexual methods. Asexual reproduction is absent.

(i) Vegetative Reproduction: It takes place by following methods:

(a) Bulbils: The bulbils are spherical or oval tube-like structures which develop on rhizoids e.g., *C. aspora* or on lower nodes of main axis e.g., *C. baltica*. The bulbils on detachment from plants germinate into new thallus.

(b) Amylum Stars: In some species of *Chara* e.g., *C. stelligna*, on the lower nodes of main axis develop multicellular star shape aggregates of cells. These cells are full of amylum starch and hence are called Amylum stars. The amylum stars on detachment from plants develops into new *Chara* thalli.

(c) Amorphous bulbils: These are group of many cells, irregular in shape which develop on lower node of main axis e.g., *C. delicatula* or on rhizoids e.g., *C. fragifera* and *C. baltica*. The amorphous bulbils are perennating structures, when the main plant dies under unfavorable conditions; these bulbils survive and make *Chara* plants on return of favourable conditions.

(d) Secondary Protonema: These are tubular or filamentous structure which develops from primary protonema or the basal cells of the rhizoids. The secondary protonema like primary protonema form *Chara* plants.

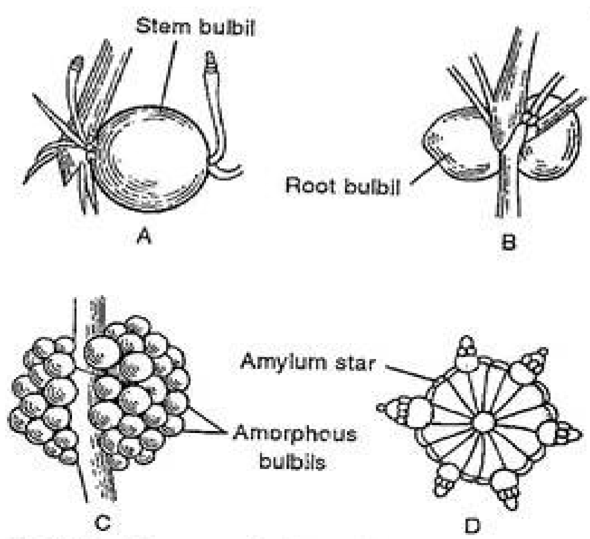


Fig.4.28 Vegetative propagation in *Chara*, A-Stem bulbil, B-Root bulbil, C-Amorphous bulbil, D-Amylum star

Sexual Reproduction in *Chara*

The sexual reproduction in *Chara* is of highly advanced oogamous type. The sex organs are macroscopic and complex in organization. The male sex organs are called antheridium or globule and the female are called oogonium or nucule. Most of the *Chara* species are homothallic i.e., the male and male sex organs are borne on the same nodes, e.g., *C. zeylanica*. Some species e.g., *C. wallichii* are heterothallic i.e., male and female sex organs are borne on different plants. The sex organs arise on the branches of limited growth or primary laterals, the nucule above the globule. The development of globule and nucule takes place simultaneously but in some species globule matures before nucule.

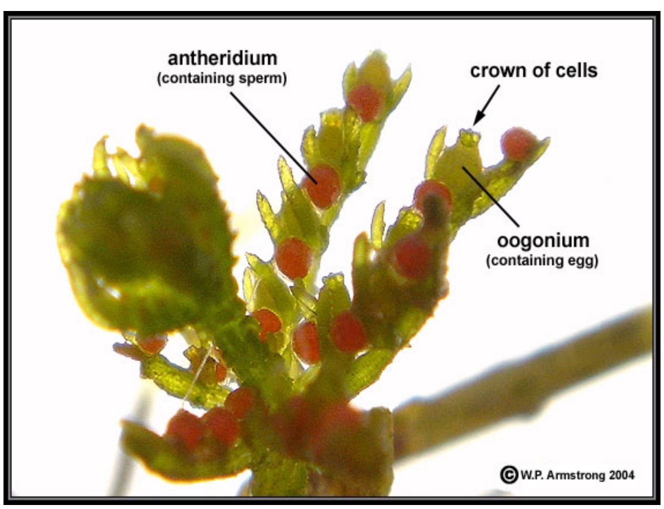


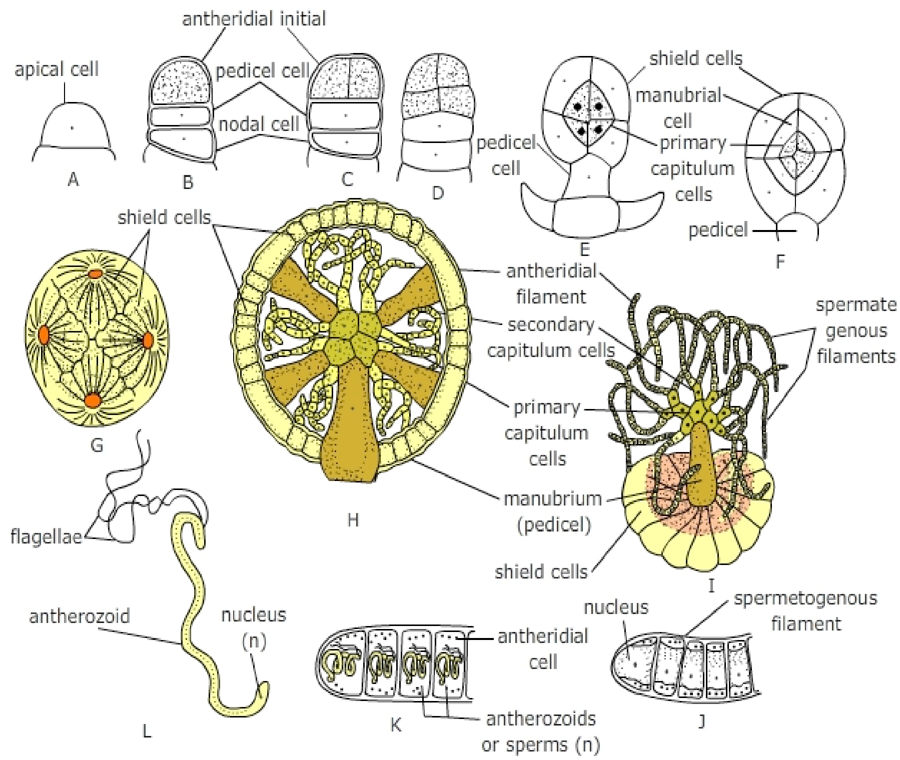
Fig. 4.29 Sexual organs of *Chara*

Globule: It is large, spherical, red or yellow structure (Fig. 4.31).

Development and Structure

The early development of globule and nucule is similar. The peripheral cell of the lower node of the primary lateral divides periclinally to form an inner cell. The outer cell functions as antheridial initial and the lower cell again divides by a periclinal division. Out of these three cells formed, the lowermost functions as inter-nodal cell the middle forms basal node, the uppermost functions as the antheridial initial. The middle basal node cell divides to make 5 peripheral cells. Out of these five peripheral cells, the upper one develops into oogonium; two lateral ones form unicellular bracteoles and two lower ones, one on either side of oogonium forms cortex or remains non-functional.

The antheridial initial divides by transverse division to make basal pedicel cell and a terminal antheridial mother cell. The pedicel cell does not divide further and forms pedicel or stalk of mature antheridium. The antheridial mother cell enlarges and divides by two successive vertical divisions at right angle to each other to make a quadrant. All these four cells divide by a transverse wall to make eight cells or octant stage. Each cell of the octant divides periclinally and forms two layers of eight cells each. The cells of inner or outer layer divide periclinally to make three radial layers of eight cells each. The outermost eight cells enlarge laterally to form a curved plate of eight shield cells. The cells of the middle layer elongate towards centre to make eight rod-shaped manubrial cells. The cells of the inner layer function as eight primary capitulum cells. Each primary capitulum cell divides to form six secondary capitulum cells. Sometimes the secondary capitulum cells divide to make tertiary capitulum cells. Each capitulum cell divides repeatedly to form 2-4 long, multicellular, branched or un-branched antheridial filaments. The antheridial filament has up to 250 uninucleate cells. These cells function as sperm mother cell and each cell gives rise to a single spirally coiled, uninucleate, bi-flagellated antherozoid. The mature globule thus is made up of 8 curved shield cells, 8 elongated manubrial cells, 8 centrally located primary capitulum cells and 48 secondary capitulum cells. The secondary capitulum cells give rise to many antheridial filaments. Each sperm mother cell forms a single bi-flagellated antherozoid. At maturity the shield cells of antheridium separate from each other exposing antheridial filaments in water. The sperm mother cell gelatinizes to liberate the antherozoids.



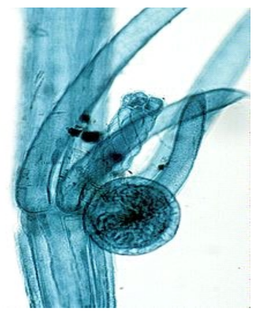


Fig. 4.30 Development of Globule **Fig. 4.31 Globule**

Nucule: The nucule of *Chara* is large, green, oval structure with short stalk. It is borne at the node of the primary lateral. It lies just above the globule in homothallic species.

Development and Structure: The upper peripheral cell of the basal node of the antheridium functions as the oogonial initial. The oogonial initial divides by two transverse divisions to make three celled filament. It has lower pedicel cell, the middle nodal cell and the upper oogonial mother cell (Fig.4.32).

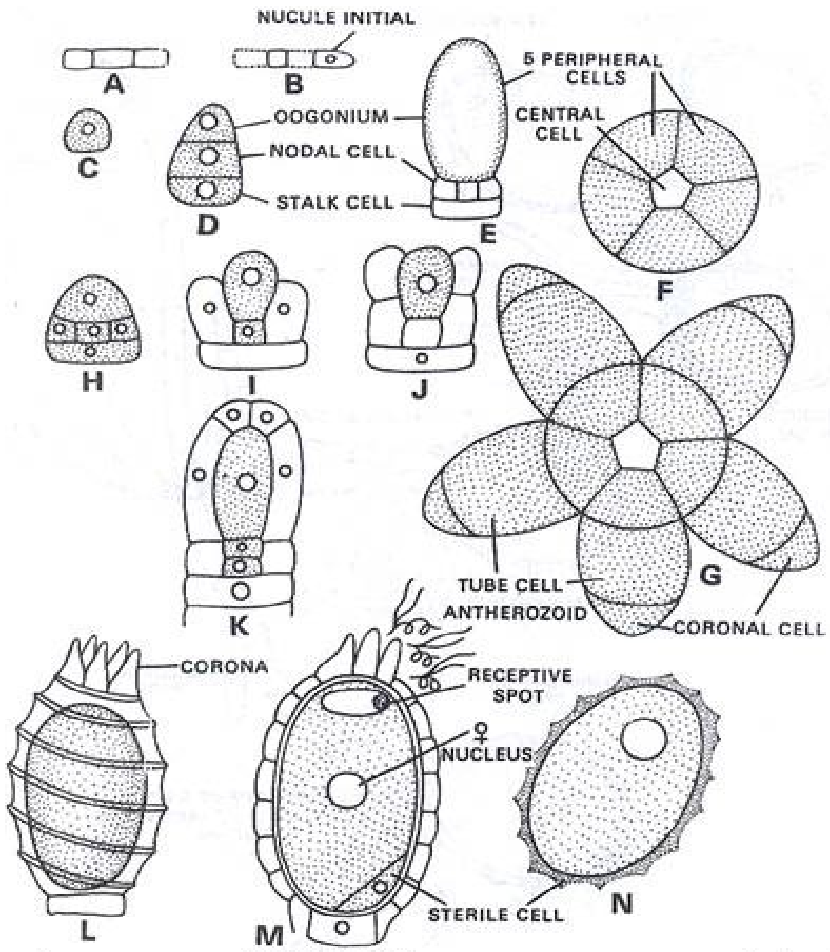


Fig. 4.32. *Chara* sp. Sexual reproduction, A-K, different stages in the Development of Nucule; L-nucule; M-Fertilization; N-Zygote

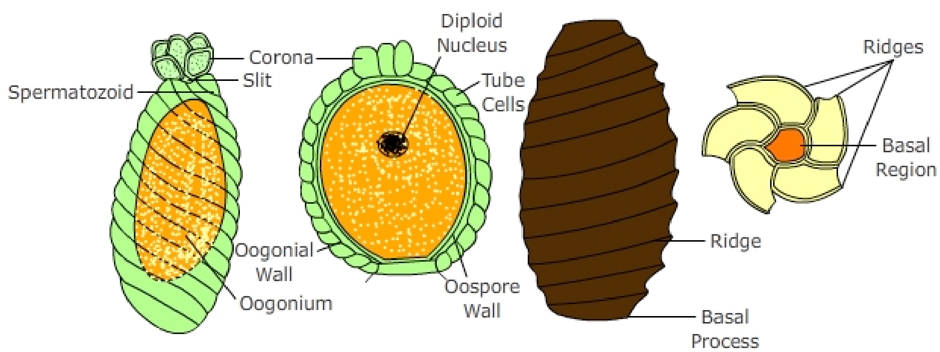


Fig.4.33 L.S. and T.S. of Nucule

The pedicel does not divide further and makes pedicel of the oogonium. The middle nodal cell by many vertical divisions makes five sheath cells or peripheral cell which surrounds the central cell. The central cell does not divide and functions as the node of the oogonium. The oogonial mother cell elongates vertically and divides by transverse division to make lower small stalk cell and an upper large oogonium. The oogonium contains uninucleate ovum or egg. The peripheral cells or five sheath initials elongate and divide by transverse division to make two tiers of five cells each. The five upper tier cells from coronary cells forms the corona of nucule. The five lower tier functions as tube cells, the tube cells elongate and get spirally twisted in clockwise direction. The nucleus migrates on lower side and receptive spot develops at the tip of oogonium. Large amount of starch and oil get deposited in oogonium.

The mature nucule is attached to the node by the pedicel cell. The nucule is surrounded by five tube cells. The tips of tube cells form corona at the top of nucule. The oogonial cell possesses a single large egg or ovum.

Fertilization

When the oogonium is mature, the five tube cells get separated from each other forming narrow slits between them. Antherozoids are chemotactically attracted towards ovum. The antherozoids enter through these slits and penetrate gelatinized wall of the oogonium. Many antherozoids enter oogonium but one of those fertilizes the egg to make a diploid zygote. The zygote secretes a thick wall around itself to make oospore.

Oospore

The mature oospore is hard, oval, ellipsoid structure which may be brown e.g., *C. inferma*, black e.g., *C. corallina* or golden brown e.g., *C. flauda*. The oospore inside contains a diploid nucleus and many oil globules in cytoplasm. On maturity of oospore the inner walls of tube cells get thickened, suberised and silicified. The oogonial as well as oospore walls become thick. The oospore nucleus moves towards the apical region. In advanced stage the outer walls of the envelope or sheath cells fall off and the inner parts remain attached to mature oospore in form of ridges.

The oospore germinates when favourable conditions appear. The diploid nucleus present in apical colourless region divides by meiosis forming four haploid daughter nuclei. At this stage a septum divides oospore into two unequal cells. The upper smaller apical cell contains a single nucleus and the large basal cell contains three nuclei. The three nuclei of basal cell degenerate gradually. The oospore apical cell divides by longitudinal division to make a rhizoidal initial and protonemal initial. The rhizoidal initial shows positive geotropism and forms primary rhizoid, the protonemal initial shows negative geotropism and forms primary protonema. The primary protonema differentiates into nodes and internodes. The peripheral cells of the basal node give rise to rhizoids and secondary protonema. The peripheral cells of the upper nodes give rise to lateral branches.

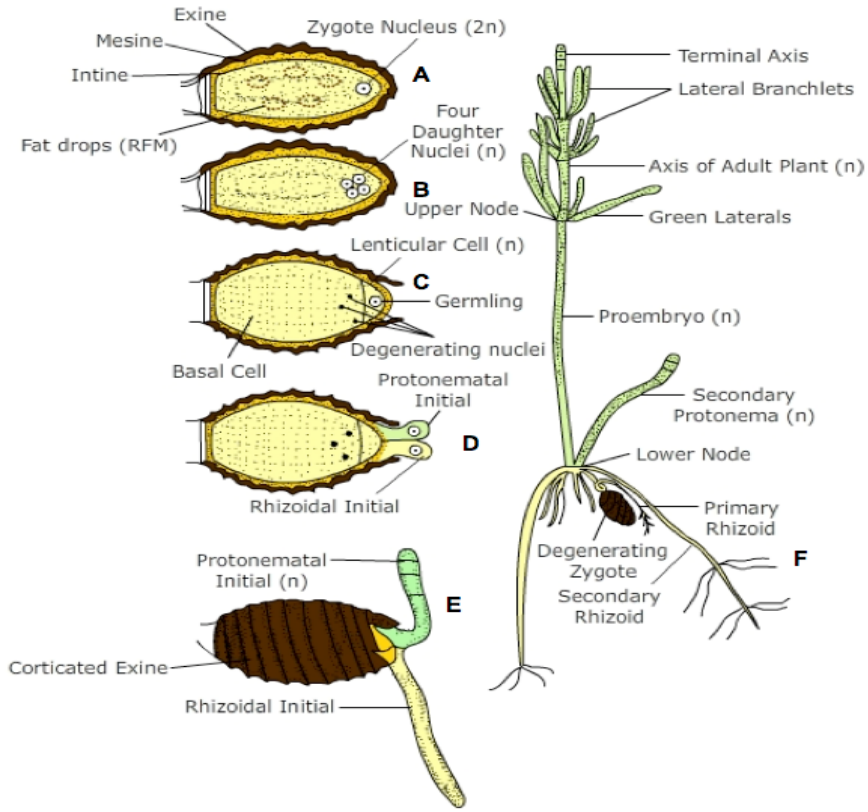


Fig. 4.34 Development of zygote

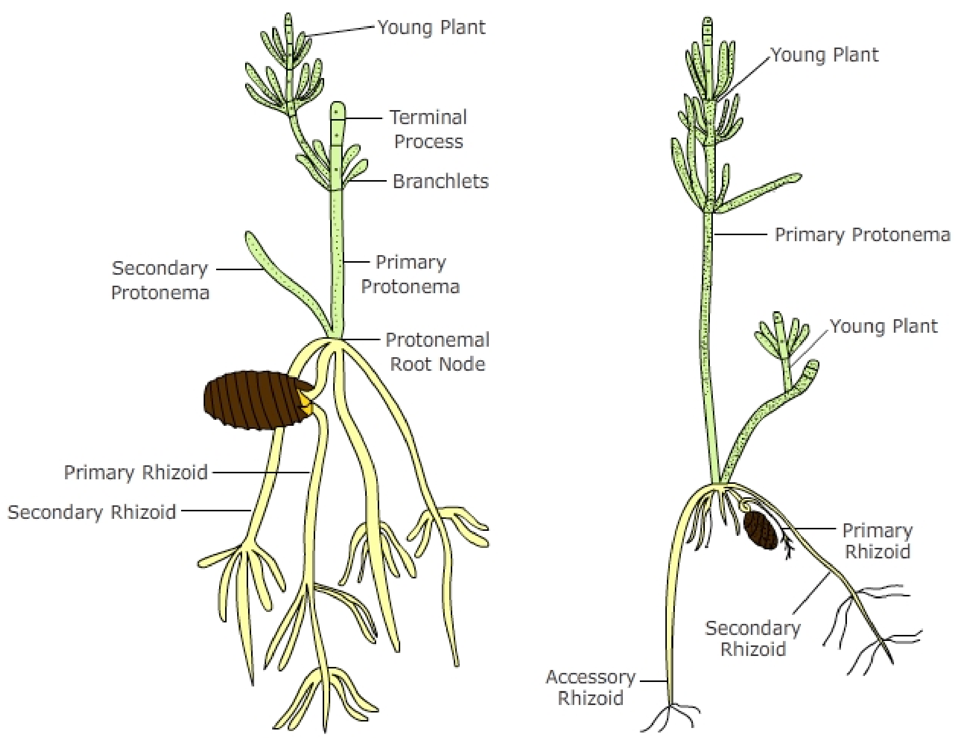


Fig. 4.35 Development of young *Chara* plant

Status of *Chara*

Fritsch (1935) placed *Chara* under the order Charales of class Chlorophyceae. But Smith (1938, 55) Prescott (1965), Bold and Wynne (1978) suggested that Charophyceae occupies an isolated position between green algae and bryophytes due to number of advanced characters like

1. Highly differentiated plant body
2. Elaborate sexual organs
3. Elaborate bi flagellate antherozoids
4. Oogamous reproduction
5. Elaborate post fertilization changes.

   But certain characters make it primitive as

   1. Haploid nature
   2. Unicellular structure of sexual organs
   3. Restricted diploid stage in zygote.

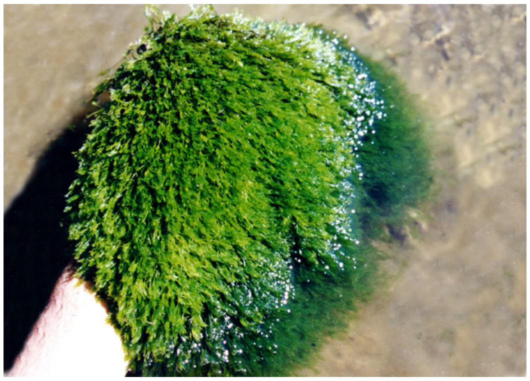
Thus on basis of morphology, cytology and oospore ornamentation Dr. P. Chatterjee, Dr. Sam, Dr. Ruma Pal suggested that the genus *Chara* represents a specialized group and it should be placed under the class Chlorophyceae. According to Church, *Chara* is a remnant of many probable evolutionary tendencies that have failed to attain land habit.

4.5.2- *Nitella*

Division: Charophyta
Class: Charophyceae
Order: Charales
Family: Characeae
Sub-family: Nitelloideae
Genus: *Nitella*
Species: *acuminate*

Occurrence: *Nitella* is represented by 37 species. All of them are aquatic or subaquatic except *N. terrestris* which is found on damp ground. They occur in shallow water along the edges in pools, lakes and slow flowing streams attached to the sandy or muddy substratum (Fig. 4.36).

Vegetative Structure / Thallus: the plant has a jointed central main axis with a whorl of branches arising from each joint (node) (Fig.4.34). It is anchored to the soft substratum by multicellular, branched colorless rhizoids. *N. terrestris* is very small in size as compared to *N. cernua* (about a meter). The main axis is differentiated into well-marked alternating nodes and internodes. The internode is a single, elongated, undivided cylindrical cell several times longer than broad. In *N. cernua* it may reach to a length of 25 cm. The internodal cells are naked as no ensheathing layer is present around them. All species of *Nitella* are ecorticate.



A

Fig. 4.36, A- Thallus of *Nitella*

B C

Fig. 4.37, B-C Microscopic view of thallus of *Nitella*

The node consists of a ring of usually 6, rarely 7 or 8 peripheral cells enclosing two central cells. A whorl of branches of limited growth arises from each node. Their number in the whorls usually varies from 4 to 7. These branches are called as branchlets, laterals or leaves. In addition the stem node bears a long branch of a branchlet in the whorl. In case there are two long branches as in *N. acuminata*, the second branch arises on the inner side of the next oldest branchlet in the whorl. The origin of a long branch or branches on the inner side of branchlets looks like axillary branches. The long branches are thus called as axillary branches. The axillary branch has the same structure as the main axis. There are no stipulodes at the nodes in *Nitella.*

The branchlets in *Nitella* have a characteristic furcated appearance. In *N. accuminata* they are once furcated, twice in *N. terrestris*. They are 2-3 times furcated in *N. flagelliformis* and 3 times, rarely 4 times in *N. furcata*. The furcations are called rays or branchlet rays of first, second, third or higher order depending on the species (Fig. 4.38). The ultimate branchlet rays are called the dactyls. The dactyls may be one celled as *N. flagelliforms* and *N. terrestris* and may be elongate as in *N. acuminata.*

Cell structure: the nodal cells and young intermodal cells have dense cytoplasmic contents. The single nucleus is usually located in the centre of the cell.

There are a number of small discoid chloroplasts, oval in shape and devoid of pyrenoids. They are uniformly distributed in the cytoplasm. Also dispersed in the cytoplasm are a number of small vacuoles. The reserve food is stored as starch.

The cell wall is cellulosic in nature. It has more or less gelatinous superficial layer of unknown composition external to it.

The elongated internodal cell has a large central vacuole with the cytoplasm forming a lining within the cell wall. The nucleus which lies in the peripheral cytoplasm at first becomes lobed and then divides amitotically to form several nuclei. The resultant nuclei lie in the lining layer of cytoplasm and have large nucleoli and scanty chromatin.

The peripheral cytoplasm of the multinucleate intenodal cell is distinguishable into two distinct regions the outer or parental denser region just within the cell wall and the inner less dense part. The former is called ecto or exoplasm and the latter endoplasm. The exoplasm remain stationary.

The chloroplast is present in the stationary exoplasm. They are arranged in well defined longitudinal series. The study of fine structure of the chloroplast revealed that it is limited by a double membrane chloroplast envelope. Within the chloroplast envelope is the matrix which contains 40-100 discs or thylakoids. All of them may form a single stack or band occupying most of the volume of the chloroplast. The more fluid, less denser endoplasm is in a state of constant rotation. This streaming movement of endoplasm is termed cyclosis. It flows up on one side and down on the other the two cytoplasmic streams adjoin a colorless strip or streak of stationary cytoplasm on either flank of the cell. The endoplasm has no velocity gradient in itself. It slides as a whole on the cortex endoplasm interface by a force generated by an unknown mechanism. It is transmitted radially inwards and is responsible for streaming. The extract of microfilaments shows the presence of a contractile protein called actin (just like animals). These are found at ectoplasm-endoplasm interface and are associated with the chloroplast.

The main axis and the axillary branches show indefinite growth. It takes place by the activity of a dome shaped apical cell at the tip. It cuts off a series of segments parallel to its posterior face. Each segment divides by a curved transverse wall into two halves. The lower half is called as internodal initial which is biconvex. It does not divide further but elongates to the length of a mature internode. The upper half is biconcave and is known as nodal initial. It divides to make nodal elements.

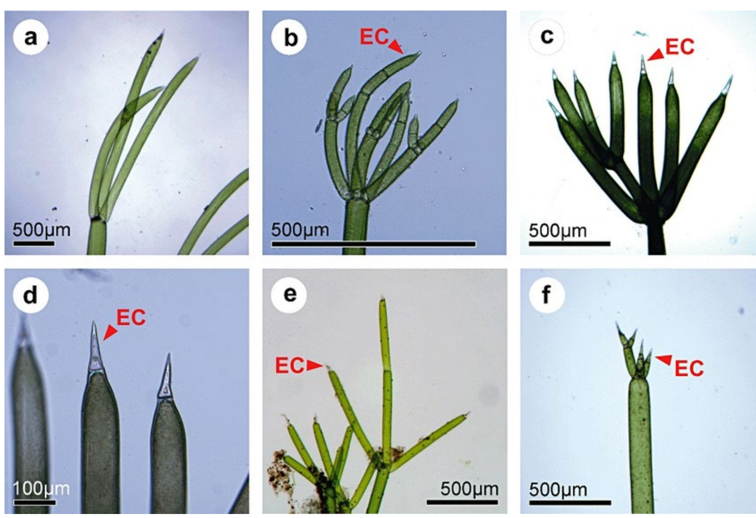


Fig. 4.38, a-f: Development of branchlets in *Nitella*

Development of branchlets

1. **Sterile branchlets:** the peripheral cells at the stem nodes protrude to the outside. Each then divides by a periclinal wall into an inner cell and an outer cell. The inner cell which is called the basal nodal initial divides to develop directly into a basal or basilar node of the branchlet.

It consists of an incomplete ring of two peripheral cells. The ring is open on the abaxial side. The outer cell functions as an apical cell and forms the branchlet. In *N. accuminata* it cuts off only one segment then ceases to divide and elongates to form an elongated dactyl with an acuminate or pointed tip. Meanwhile the segment cut off by the apical cell divides transversely into an upper nodal cell and lower internodal cell. The latter elongates to form the single internode of the branchlet. The nodal cell divides to form the upper node consisting of an incomplete ring of 3 or 4 peripheral cells. It is open on the abaxial side. The peripheral cells of the upper node of the branchlet protrude to the outside and grow into one celled ultimate rays. Each branchlet in *N. acuminata* thus consists of a basal node, and one more node (upper) bearing a whorl of ultimate rays or dactyls. It is thus once furcated. The other species with once furcate branchlets are *N. syncarpa*, *N. cernua*, *N. opeca* and *N. flexilis*. *N. terrestris* tells a slightly different story. The branchlets in *N. terrestris* are twice furacted. It consists of a basal node, and two more nodes which bear branchlet rays of the first and second order. There are species of *Nitella* in which the branchlets may be two to three times furcated as in *N. furcata.*

2. **Axillary branches:** they originate form adaxial peripheral cell of the basal node of the oldest brachlet in the whorl (Fig. 4.39). In case two axillary branches arise from the same node as in *N. acuminata*, the second branch originates from the adaxial peripheral cell of the basal node of the next oldest branchlet. The peripheral cell protrudes out and divides by a periclinal division into an inner cell and the outer hemispherical apical cell. The inner forms the basal node dividing by halving wall followed by curved septa as in the case of the stem node. The basal node comprises 2-4 peripheral cells enclosing 2 central cells. The hemispherical apical cell cuts off a series of successive segments each of which differentiates into an upper nodal initial and lower internodal initial as in the case of the main axis. The apical cells of the axillary branch thus behave in the same manner as the apical cell of the central axis. The axillary branches in *N. acuminata* and *N. terrestris* bear sex organs on special fertile whorls.

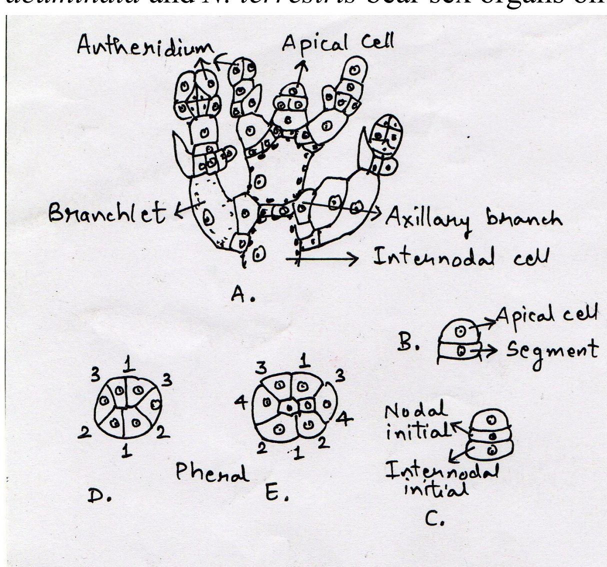


Fig. 4.39 Apical cell of *Nitella* main axis

3. **Rhizoids**: *Nitella* is anchored to the soft substratum by rhizoids. They are developed from the peripheral cells of the lowest node of the main axis and are branched, colorless and multicellular. The septa between the cells are oblique. The rhizoid grows by the activity of an apical cell but show no differentiation into nodes and internodes. At the septa the nodes of the adjoining cells protrude in opposite directions to form a double foot joint. The protruded dilated tip of the upper cell is cut off by an oblique septum to form a segment which divides into a quadrant. From this plate of cells arises a cluster of branched rhizoids. The latter may branch further in the same manner.

Reproduction

Sexual Reproduction

It is an advanced type of oogamy; light intensity plays an important role in the development of sex organs. Some species are monoecious (*N. acuminata, N. furcata, N. terrestris* and *N. hyaline*) and some are dioecious (*N. flagelliformis, N. opaca, N. superba*).

In some species there is no distinction into fertile ad sterile branchlets. In *N. acuminata* and *N. terrestris* however the sex organs are formed on special fertile branchlets which are borne on axillary branches and are different from the sterile branchlets. In the monoecious species the antheridium is terminal at the centre of furcation and oogonium is lateral in position below the antheridium. The antheridium is developed from the apical cell of the branchlet at the furcation. The oogonia are developed from the adaxial peripheral cells of the upper node of the branchlet. It is also called the basal node of the antheridium. The remaining peripheral cells of the node form the branchlet rays. Thus morphologically the oogonium is a modified branchlet ray of the higher order than that of the antheridium. In monoecious forms with more than one furcation all the furcations bear both the sex organs. Final furcation is sterile. The dioecious species bears either an antheridium or oogonium at each furcation.

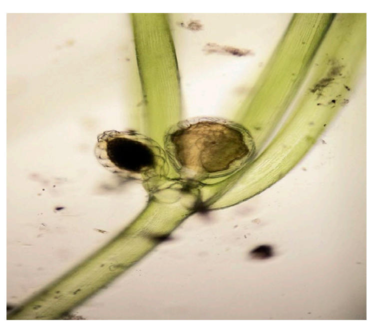


Fig. 4.40 Nucule and globule on the node of *Nitella*

Antheridium: in monoecious species of *Nitella* the antheridium is above the oogonium at the node. The antheridium consists of a jacket layer of 8 closely fitting shield cells. From the middle of each shield cell an elongated manubrium cell projects towards the centre of the antheridium. The manubrium at its distal end bears a terminal cell known as the primary capitulum. The primary capitulum bears about six secondary capitula. Each secondary capitulum terminally develops a pair of long filaments called the antheridial filaments. Each cell of the antheridial filament produces a single antherozoid. The mature antheridium appears stalked. The stalk consists of a pedicel cell which partly projects into the cavity of the antheridia and the stalk cell (there is no stalk cell in the antheridium of *Chara*). The antheridium with a jacket of 8 shields and corresponding number of manubria and head cells is called octoscutate. In *N. terrestris* there are only 4 shield cells such antheridia is called quadriscutate.

Development of antheridium (Fig. 4.41): the antheridium primodia cuts off a cell at its base and then assumes spherical shape to function as antheridial mother cell. The latter undergoes two longitudinal divisions at right angle to one another. The resultant 4 cells constitute the quadrat state. Each quadrat divides transversly to form the octant stage. Each octant undergoes a periclinal division. The outer segment divides again by periclinal division. In this way a row of three cells is formed in each octant. The outer cell of each row grows laterally to form a shield cell. The middle one elongates radially and projects inwards to form the manubrium. The innermost cell of the row constitutes the primary capitulum or head cell. The latter cuts off secondary capitulum cells which form antheridial filaments. In *Nitella* as development of the antheridium proceeds, the basal cell divides transversely into two segments upper and lower. The lower segment remains short and discoid to form the stalk cell. The upper sister segment grows and elongates to form the pedicel cell. A part of the latter remains outside the antheridium.

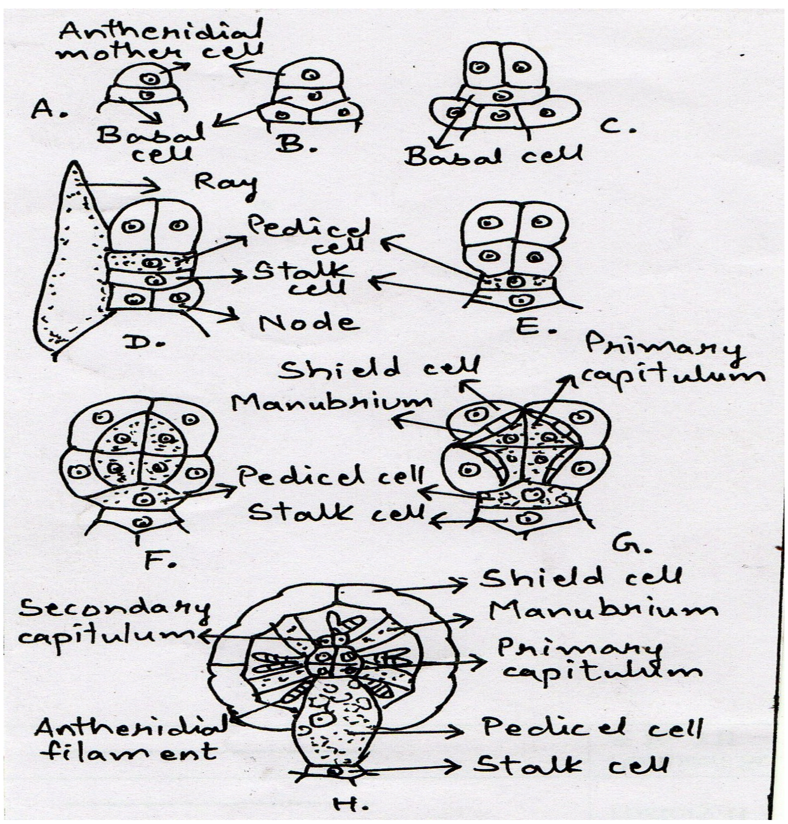


Fig. 4.41Development of Globule in *Nitella*

Oogonium: it is oval in shape and is enclosed by a sheath of five long cells spirally wound around it in a clockwise direction. There are ten small closely fitting cells capping the mature oogonium. They are arranged in two tiers of five cells each and constitute the corona. The corona in *Nitella* is colorless, small, persistent or deciduous and two tiered. They are larger and the corona is persistent, erect and convergent, or divergent and one-tiered. Within the sheath is the oogonium. The protoplast of the oogonium forms a single ovum packed with starch and oil. The nucleus lies at the base. At the apex of the ovum colorless and granular cytoplasm constitutes the receptive spot.

Development of oogonium (Fig. 4.42): it develops from the adaxial peripheral cell of the node below the antheridium; the cell protrudes to the outside and functions as the oogonium initial. After cutting off two segments at its base it becomes the oogonial mother cell. The upper segment undergoes a transverse division to form upper nodal cell and a lower internodal cell. The later along with the lower segment form the stalk of the future oogonium. It consists of two stalk cells. The upper stalk cell is also called the pedicel cell. The nodal cell divides vertically a number of times to give a central cell surrounded by 5 sheath or enveloping cells. Even before sheath cells grow over the oogonial mother cell, the latter cuts off two lens-shaped sterile cells on the side next to the antheridium and one flat sterile cell at its base. As the egg or ovum advances towards maturity the three sterile cells come to lie near its base. Meanwhile each sheath cell grows vertically upward and cuts off a small conical cell, the coronal cell at the top. These five coronal cells constitute the upper tier. Sometimes after each sheath cell cuts off another coronal cell below the upper one. These five small discoid coronal cells constitute the lower tier. The oogonium in *Nitella* thus has a two tiered corona. The cells of the lower tier are comparatively larger and conical. After cutting off the coronal cells the sheath of tube cell, as they grow, twist round the egg or ovum the spirals run from right to the left. Except for a small hyaline area, the receptive spot at the top, the mature egg is packed with reserve food. The nucleus lies at the base.

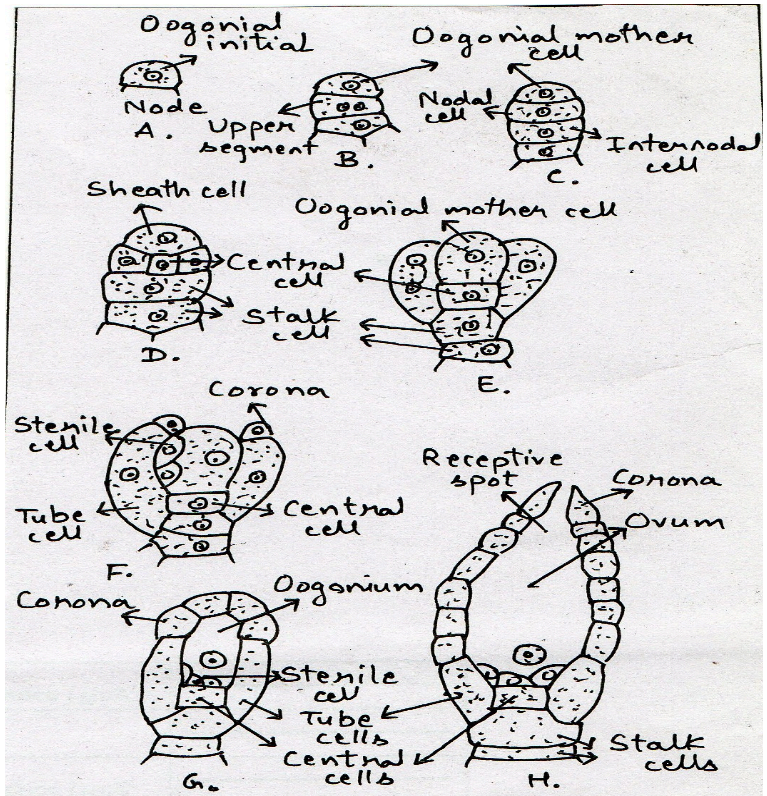


Fig. 4.42 Development of Nucule in *Nitella*

Fertilization

As the sperms mature, the shield cell separate from each other exposing the antheridial filaments. The sperms usually escape in the morning into the surrounding water in which they may continue to swim until the evening. Meanwhile the enveloping tube cells slightly separate from one another at the apex just below the corona of the mature oogonium forming five small slits. Through these slits the sperms penetrate the sheath and the gelatinized wall of the oogonium and thus enters into the ovum at the receptive spot. Within the ovum the sperm nucleus moves down to fuse with the female nucleus at its base.

Oospore: the fertilized egg or zygote enlarges and secrets a thick wall around it to become an oospore. The oospore sinks to the bottom of water. It is hard nut-like body which enters upon a period of rest. It varies in color from light yellow to black and is rounded to ellipsoid in form.

Germination of oospore: after a period of rest (weeks/months) the zygote geminates. Prior to germination the diploid oopsore nucleus migrate to apical pole. There it divides into four daughter nuclei. It is presumed that the division is meiotic. On this presumption the thallus plant is considered to be haploid. The division of the nucleus is followed by asymmetrical division of oospore into a small, uninucleate distal cell and a large, basal trinucleate cell packed with food reserve materials. The basal cells later degenerates. The oospore bursts at the apex exposing the uninucleate cell which now divides vertically to form a rhizoidal initial and a protonematal initial. The two grow in opposite directions, the former developing into a colorless, filamentous rhizoid and the latter into an erect, green, filamentous primary protonema. Both are differentiated into nodes and internodes. The adult plant arises as a lateral branch from the second node of the protonema.

4.6 SUMMARY

The division Cyanophyta or blue green algae or Cyanobacteria, which are the only known oxygen producing prokaryotes. There are about 2500 speices placed under 150 genera. All of them are included in a single class Cyanophyceae or Myxophyceae. These are simplest, autotrophic and microscopic. The flagella is completely absent. The locomotion is of gliding or jerky type. The phycobilin pigments are c-phycocyanin, c-phycoerythrin, along with myxoxanthin and mycoxanthophyll. The chromatophores are not membrane bound. The storage food is myxophycean starch and proteinaceous material cyanophycin. Heterocysts are present in many forms. Sexual reproduction is entirely absent. The members studied in the present unit by you are *Oscillatoria, Anabaena, Spirulina***,** *Scytonema* and ***Rivularia.*** These members are highly useful in nitrogen fixation and are considered best friends of farmers. *Spirulina* is rich in protein and is used as Single cell protein in space expeditions.

The second group studied by you was Bacillariophyceae commonly called as Diatoms. They are the most common types of phytoplankton, unicellular, can form colonies in the shape of filaments or ribbons. Diatoms are producers within the food chain. A unique feature of diatom cells is that they are enclosed within a cell wall made of silica (hydrated silicon dioxide) called a frustule. These frustules show a wide diversity in form, but are usually almost bilaterally symmetrical, hence the group name. Only male gametes of centric diatoms are capable of movement by means of flagella. Diatom communities are a popular tool for monitoring environmental conditions, past and present, and are commonly used in studies of water quality. More than 200 genera of living diatoms are known, with an estimated 100,000 extant species. Diatoms are a widespread group and can be found in the oceans, in fresh water, in soils, and on damp surfaces. They are one of the dominant components of phytoplankton in nutrient-rich coastal waters and during oceanic spring blooms since they can divide more rapidly than other groups of phytoplankton. They are especially important in oceans, where they contribute an estimated 45% of the total oceanic primary production of organic material. Two major groups have been discussed above pennales and centrales. They divide vegetatively and by highly advanced oogamous sexual methods.

The third and most important group studied by you was Charophyta commonly called as the stone worts. These are worldwide in distribution in still, clean, fresh or brackish waters. The order Charales has all living genera. Two members *Chara* and *Nitella* have been discussed above. These plants look like angiospermic plant and sexually highly advanced oogamous type. They also propagate by vegetative methods like Bulbils, Amylum Stars, Amorphous bulbils and Secondary Protonema**.** The male sex organs are called antheridium or globule and the female oogonium or nucule.

4.7 GLOSSARY

Akienete: Akinetes are formed during unfavorable conditions; these are thick walled spores with a large amount of reserved food material

Apochlorotic diatom: colorless diatoms

Filament: The trichome with the surrounding sheath is called the filament.

Gonophore: Incipient nucleus

Hormogonia: Hormogonia or hormogones are short segments of trichome which consists of few cells. Hormogones are formed due to formation of separation discs

Fragmentation: process of breaking in multicellular/colonial organisms, is a form of asexual reproduction

Plankton: diverse free floating collection of organisms that live in large bodies of water and provide crucial source of food.

Tychoplankton: free living/attached benthic organisms.

Endophytes: endosymbiont that lives within a plant for at least some part of its life cycle.

Algal bloom: it is rapid increase/accumulation in the algal population in fresh/marine water which causes discolorization of water, deplete oxygen of water.

Rhizoids: The rhizoids are white, thread like, multicellular, uniseriate and branched structures. The rhizoids arise from rhizoidal plates which are formed at the base of main axis or from peripheral cells of lower nodes. The rhizoids are characterized by presence of oblique septa.

Corticated species: The inter-nodal cells in some species may be surrounded by one celled thick layer called cortex and such species are called as corticate species.

Ecorticate species: The species in which cortical layer is absent are called ecorticate species.

Stipulodes: The basal node of the branches of limited growth develops short, oval, pointed single cell outgrowths called stipulodes

Auxillary branches/long laterals: They arise from the axils of the branches of limited growth hence these are also called auxiliary branches or long laterals. These are differentiated into nodes and internodes. At nodes they bear primary laterals and these branches look like the main axis. Their growth is also unlimited like main axis.

Bi-stipulate: the number of stipulodes at each node is twice the number of primary laterals; such species are called as bi-stipulate.

Haplostephanous: When stipulodes are present in one whorl at each node the species are called as haplostephanous

Unistipulate: In some species of *Chara* e.g., *C. nuda* and *C. braunii*, the number of stipulodes at each node, is equal to number of primary laterals at that node, such species are called unistipulate.

Diplostephanous: When stipulodes are present in two whorls on each node are called diplostephanous.

Branches of limited growth/Branchlets/ branches of first order, primary laterals or leaves**:** These arise in whorls of 6-20 from peripheral cells of the nodes of main axis or on branches of unlimited growth. These branches stop to grow after forming 5-15 nodes and hence are called branches of limited growth.

Bulbils: The bulbils are spherical or oval tube-like structures which develop on rhizoids or on lower nodes of main axis they make new thallus on detachment from plants.

Amylum Stars: They are star shaped developed on the lower nodes of main axis, multicellular aggregates of cells. These cells are full of amylum starch and hence are called Amylum stars. The amylum stars on detachment from plants develops into new *Chara* thalli.

Amorphous bulbils: These are perennating structures made up of group of cells, irregular in shape which develops on lower node of main axis or on rhizoids; these bulbils survive and make *Chara* plants on return of favourable conditions.

Secondary Protonema: These are tubular or filamentous structure which develops from primary protonema or the basal cells of the rhizoids. The secondary protonema like primary protonema form *Chara* plants.

Globule: It is male reproductive organ in *Chara* and *Nitella*, large, spherical, red or yellow structure, highly complex structure.

Nucule: it is female reproductive organ in *Chara* and *Nitella*, oval in shape, has egg nucleus.

Oospore: The zygote develops into mature oospore which is hard, oval; ellipsoid structure may be brown, black or golden brown in color. The oospore inside contains a diploid nucleus and many oil globules in cytoplasm

4.8 SELF ASSESSMENT QUESTION

4.8.1-Multiple choice Questions:

1. Water blooms are usually caused by
(a) Phaeophyceae (b) Myxophyceae
(c) Chlorophyceae (d) Xanthophyceae

2. Nitrogen fixation in soil is done by
(a) Chlorophyceae (b) Phaeophyceae
(c) Myxophyceae (d) Rhodophyceae

3. Diatomin earth is a product of
(a) Chlorophyceae (b) Bacillariophyceae
(c) Xanthophyceae (d) Rhodophyceae

4. Stone wart is common name of
(a) *Chara* (b) *Oedogonium*
(c) *Spirulina* (d) Diatoms

5. Sexual reproduction in *Chara* takes place by

(a) Amylum stars (b) Nucule
(c) Globule (d) Nucule and globule

6. Which of the following has a single polar nodule in the heterocysts
(a) *Volvox* (b) *Oscillatoria*
(c) *Gloeotrichia* (d) *Scytonema*

7. The photosynthetic apparatus, the respiratory apparatus and the genetic apparatus is not bound by membranes in
(a) Chlorophceae (b) Myxophyceae
(c) Rhodophyceae (d) Phaeophyceae

8. Which of the following has prokaryotic cells?
(a) *Chlamydomonas* (b) *Chara*
(c) Diatom (d) *Oscillatoria*

9. Phcyocyanin –c is the dominant pigment in
(a) *Chara* (b) *Nitella*
(c) Diatom (d) *Oscillatoria*

10. The members of Myxophyceae are characterized by
(a) Presence of motile spores and gametes
(b) Sexual reproduction
(c) Fusion and meiosis
(d) Absence of motile reproductive bodies and incipient nucleus

11. *Scytonema* generally reproduces by
(a) Hormogonia and endospores (b) hormogonia and akinetes
(c) Heterocysts and akinetes (d) heterocysts and hormogonia

12. Pseudo vacuoles in cyanophyceae help in
(a) regulate buoyancy (b) store food
(c) store oxygen (d) store CO_2

13. A protein rich alga is
(a) *Chara* (b) diatom
(c) *Gelidium* (d) *Spirulina*

14. Which of the following is known as cyanobacteria?
(a) Blue green algae (b) yeast

(c) Photosynthetic bacteria (d) nitrogen fixing bacteria

15. In *Rivularia* the growth of the filament is due to the activity of -
(a) an apical cell at the apex of the hair (b) intercalary meristem at the base of the hair
(c) all cell of the trichome (d) basal heterocysts

16. The outer portion of the protoplast in a cyanophycean cell is cell chromoplast because of the presence of
(a) colored plasma membrane, (b) chromosomes
(c) pigment (d) chromoplast

17. Manubrium is found in the antheridium of
(a) *Chara* (b) *Chlamydomonas*
(c) *Oedogonium* (d) *Spirogyra*

18- Asexual reproduction by zoospores is completely absent in
(a) *Oedogonium* (b) *Cladophora*,
(c) *Coleochaete* (d) *Chara*

19. Flagella are generally absent in
(a) Charophyta & Rhodophyta (b) Charophyta and Chrysophyta
(c) Rhodophyta and Chlorophyta (d) Rhodophyta and Cyanophyta

20. Auxospore formation is exhibited by
(a) Desmids (b) diatoms
(c) Green algae (d) red algae

4.8.2-True or False:

1. *Chara* is larvicidal
2. *Chara* is free floating green algae
3. Phycocyanin is a pigment found in the blue green algae
4. Blue green algae can occur in free form as well as with mutual relationship with other plants
5. The apical cell of *Oscillatoria* is different from other cells of the filament.

4.8.3-One word answer:

(1) Name one algae of Cyanophyceae which is commercially cultivated for its protein
(2) Name any blue green algae which causes water blooms
(3) Name the algae in which sexual organs are multicellular and sheathed.
(4) Name the group of algae lacking sexual reproduction

4.8.4-Fill in the Blanks:

1. Rhizoids of *Chara* possess______septa
2. There are ________tube cells in nucule of *Chara*.
3. False branching is found in________
4. The male reproductive organ of *Chara* is called as __________
5. The common mode of reproduction in *Oscillatoria* is by_________
6. In Cyanophyceae the site of nitrogen fixation is ___________
7. Water blooms are due to __________
8. In algae the prokaryotic cell is present in the members of _________
9. The algae in which basal heterocyst and akinete are present is___________
10. Stonewart is the common name of _________
11. *Chara* is a ____________aquatic algae.
12. The diatoms have been placed in the class_____________
13. Of the diatoms_________forms are non-motile
14. ________are the characteristic spores of diatoms
15. The structure responsible for locomotion in diatoms is____________

4.8.1-Answer Key: 1(b), 2(c), 3(b), 4(a), 5(d), 6(d) ,7(b), 8(d), 9(d), 10(d), 11(d) ,12(a) ,13(d), 14(a) ,15(b), 16(c), 17(a), 18(c) ,19(d), 20(b)

4.8.2-Answer Key: 1-True, 2-False, 3-True, 4-True, 5-True

4.8.3-Answer Key: 1-*Spirulina*, 2-*Oscillatoria*, 3-*Chara*, 4-Cyanophyceae

4.8.4-Answer Key: 1-Oblique, 2- 5, 3- *Scytonema,* 4-Globule, 5-Fragmentation, 6-Heterocyst, 7- Myxophyceae, 8- Myxophyceae, 9-*Rivularia*, 10- *Chara*, 11- Fresh water, 12-Bacillariophyceae, 13-Centrales, 14- auxospores, 15- Raphe

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4.10 SUGGESTED READINGS

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4.11 TERMINAL QUESTIONS

4.11.1 Short answer questions:

1. Describe binary fission in *Spirulina*.
2. Give vegetative structure of *Rivularia*
3. Draw well labeled diagram of following
   (a) Pinnate diatom
   (b) Globule and nucule of *Chara*
   (c) False branching of *Scytonema*
   (d) Ultrastructure of myxophycean cell
   (e) Heterocyst
4. Differentiate between pinnate and centric diatoms

5. Explain in brief:
(a) Akienete, (b) Hormogonia, (c) Stipulodes, (d) Movement in diatoms, (e) Auxospore
6. Branching in *Scytonema*
7. Economic importance of Blue green algae.
8. Ultrastructure of Cyanophycean cell
9. Affinities of cyanophyceae
10. How cyanophyceae resemble bacteria.
11. In what respect the following are different from each other
    (a) *Oscillatoria* and *Anabaena*
    (b) *Syctonema* and *Rivularia*
    (c) Chlorophyceae and Cyanophyceae
    (d) Hypnospores and akinetes
12. Why it is not necessary to add nitrogen fertilizers to the paddy fields
13. Why blue green algae are considered primitive of all the algae.
14. Name reserve food material in blue green algae.
15. Give characteristic features of *Chara*
16. Vegetative reproduction in *Chara*.
17. Economic importance of diatoms
18. Why does the cell wall of dead diatoms do not decompose

4.11.2 Long answer questions:

1. Give life cycle of *Oscillatoria* and *Spirulina*
2. Explain in detail various life cycle pattern in Pinnate diatoms
3. Give an illustrative account of the method of sexual reproduction in *Chara* and *Nitella*
4. Give life cycles of *Scytonema* and *Rivularia*
5. Describe Centrales with well labeled diagrams.
6. With the help of diagrams describe the sex organs of *Chara*.
7. Describe the life cycle of *Nitella*, how does *Nitella* differ from *Chara*.
8. Give an account of auxospore formation in pennales
9. Describe the distinguishing characters of bacillariophyceae
10. Describe cell structure of cell wall and reproduction in diatoms

UNIT-5 CHLOROPHYTA AND XANTHOPHYTA

5.1 OBJECTIVES

After reading this unit student will be able-

- to know the salient features of Chlorophyta and Xanthophyta.
- to understand the important genera of the Chlorophyta and Xanthophyta.
- to understand the life cycle pattern in Chlorophyta and Xanthophyta.

5.2 INTRODUCTION

In the previous unit you have studied the salient features and life cycle of the Cyanophyta, Bacillariophyta and Charophyta. You also learnt how the cell characters, photosynthetic pigments, reserve food and flagellar characters help in classifying and identifying the different members of the algae. In this unit you will learn some important types and life cycle pattern of the green algae (Chlorophyta) and yellow green algae (Xanthophyta).

5.3 SALIENT FEATURES, IMPORTANT GENERA AND LIFE CYCLE PATTERN IN CHLOROPHYTA

Salient Features of Chlorophyta:

1. The members of class Chlorophyta are primarily aquatic and about 90% members are found in freshwater. Some members are terrestrial while few are found in brackish water.
2. Chlorophyta are also known as "Green Algae" due to green appearance of their thallus. This green appearance is due to the abundance of pigments chlorophyll a and b in their plastids. Other pigments commonly found in these members are lutein, siphonoxanthein and siphonein.
3. Thallus organization in this class ranges from unicellular motile, non-motile, coccoid, palmelloid, filamentous, heterotrichous, siphonaceous, folioceous, to complex habit.
4. Their cell wall is chiefly made up of cellulose, however, in some members xylans and mannons are also found.
5. The chloroplast of these members is usually associated with the pyrenoids. Inside the chloroplast, the thylakoids are grouped always more than two and up to the five in numbers.
6. The pyrenoids are present in the chloroplasts and are surrounded by the starch-sheath.
7. The photosynthetic product starch is formed with in the chloroplast. The chemical composition of starch consists of amylase and amylopectin, similar to the higher plants.
8. In motile forms, the flagella are usually two or in multiple of two and there are usually apically inserted to the cell.
9. Vegetative reproduction occurs by fragmentation while asexual reproduction takes place by motile zoospores, non-motile aplanospore, autospores, and by formation of akinete,

10. Sexual reproduction is isogamous, anisogamous and Oogamous type.
11. Mostly the members are haploid, but some are diploid.
12. Life cycle may be haplontic, diplontic or diplohaplontic.

5.3.1- Haematococcus

Occurrence

The genus occurs in puddles of rainwater, aquaculture ponds, sometime in saline water ponds and salt pans, which they usually impart blood-red color.

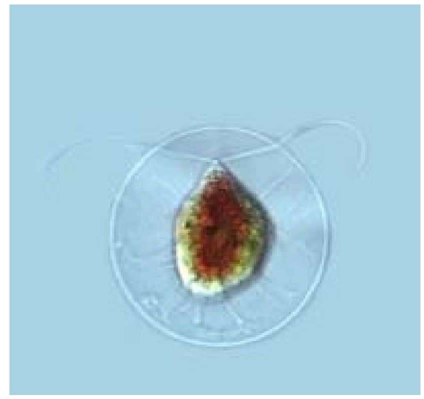

Fig.5.1 ***Haematococcus pluvialis***

Thallus structure

The cells are usually blood red in colour due to the abundance of the pigment haematochrome or astaxanthein lying in the cytoplasm. The thallus is unicellular, ovoid, ellipsoid or nearly globose in shape. The major part of the protoplasm lies at some distance from the cell wall. Some delicate strands of the protoplasm radiate out from the cell into the layer of mucilage. From the anterior end of the cell two flagella arise and penetrate the cell wall. The chloroplast is usually cup-shaped with 1-2 to several pyrenoids and a large eye spot. Nucleus lies centrally in the depression of the chloroplast. The genus contains many contractile vacuoles in the cell.

> *Haematococcus* is economically important alga. It is the source of pigment astaxanthein which a very strong antioxidant. This pigment is used for making herbal dyes and cosmetics. *H. pluvialis* is the most common species of this genus.

Reproduction

Asexual reproduction takes place by formation of zoospores in favorable condition. During unfavorable condition, the cells develop thick-walled aplanospores which later on produce 4-8-or 16 zoospores.

Sexual reproduction is isogamous type. Gametes are biflagellate which after fusion form quadriflagellate zygote. This zygote remains motile for some time and later it loses its flagella and secretes thick cell wall. It undergoes zygotic meiosis and produces 4 vegetative cells which grow in to the adult cells.

5.3.2- *Chlorella*

Occurrence: It is found in freshwater usually in stagnant water or on soil. Some species are found in brackish water while some are marine. *Chlorella* can also occur as endosymbiont in *Paramecium*, gastrovacular cavities of *Hydra* and in some sponges. Some species of *Chlorella* like *C. lichina* associates with fungal partner to form lichen.

Thallus structure

It is unicellular alga which may form a colony like structure. The cells are spherical, sub-spherical, or ellipsoid with or without mucilage, 2-10 µm in diameter and are without flagella. It contains single parietal chloroplast with pyrenoid which is surrounded by starch grains. The cell wall of *Chlorella*, besides cellulose consists of sporopollenin-like substance which is also found in pollen grains of the higher plants.

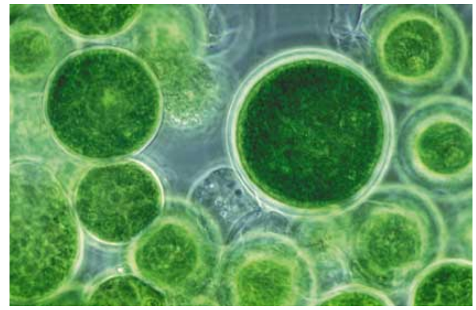

Fig.5.2 *Chlorella*

Reproduction

Chlorella reproduces asexually by **Autospore** formation. Each mother cell produces four autospores which are like miniature of the parent cell. It does not produce zoospores or gametes for sexual reproduction.

Chlorella is of great economic importance. It has high nutritional value. It contains 50% protein, 20% carbohydarates and 20% lipids. It contains all the essential amino acids and dried biomass of the Chlorella is used as single cell protein. *Chlorella* also contains Vitamin A, riboflavin, biotin, folic acid and minerals like Iron and Calcium. It contains an antibiotic chlorelline. The growth of the *Chlorella* is very fast and it is an efficient Oxygen producer hence it is used in spacecrafts to absorb the CO_2 and is also used in oxidation ponds for sewage treatment plants.

5.3.3- *Volvox*

Occurrence

Volvox is freshwater **planktonic** alga which is usually found in stagnant water like pools and ponds during spring and rainy season. On the water surface, its colony appears green, small pin head like structure which are visible to the naked eyes.

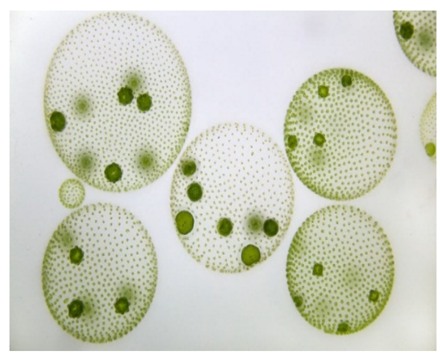

Fig.5.3 *Volvox* colony

Thallus structure

The colony of *Volvox* is composed of many small vegetative cells which form the **coenobia**. A definite number of cells form the globular structure which is held together by highly viscous gelatinous sheath. The coenobia of different species may consist of 500-50,000 cells including reproductive cells or gonidia which are embedded in gelatinous sheath. The individual cells in their general morphology appear like the cell of *Chlamydomonas*. Each cell is ovate in shape having broad posterior and narrow apical end with two apically inserted flagella which are equal in size. Eye spot and two or more contractile vacuoles are present in the anterior region near the base of flagella. The chloroplast is cup-shaped with pyrenoid. Cells are uninucleate. In most of the species, individual cells are held together by prominent cytoplasmic strand. In the coenobium, the cells of the posterior region are usually larger than the anterior end.

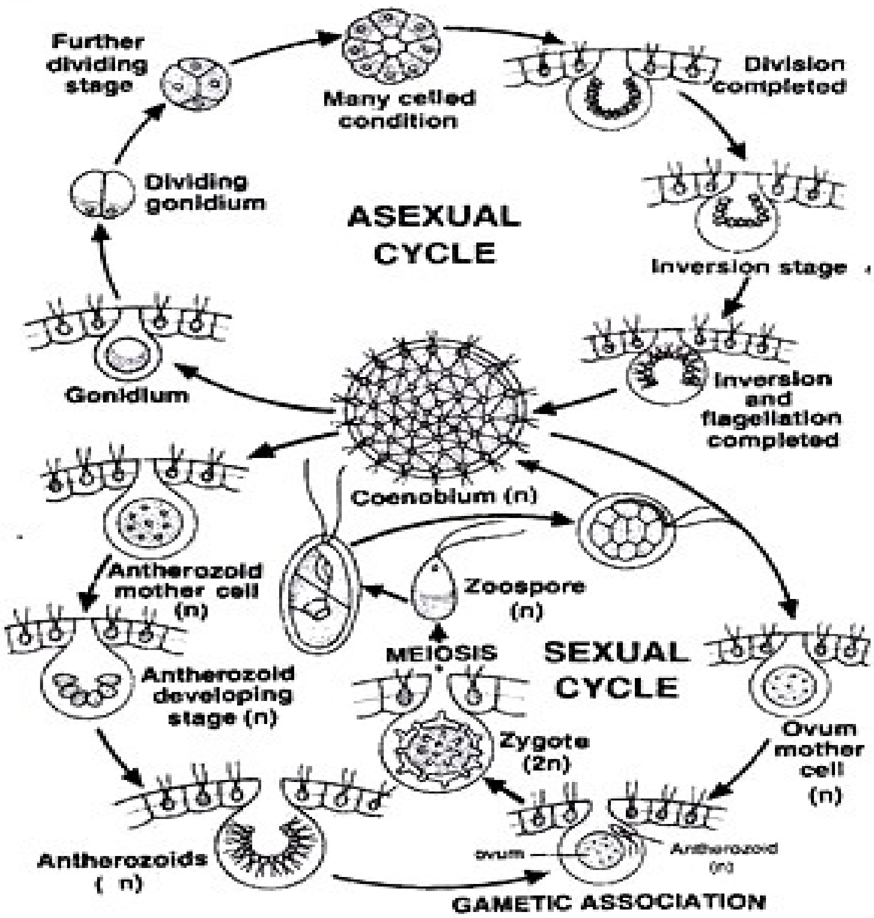

Fig.5.4 ***Volvox*****: Life cycle**

Reproduction

During asexual reproduction, some cells of the posterior region withdraw the flagella, become larger in size and differentiate into asexual reproductive cell called **gonidium.** In a coenobium 2-50 gonidia may be produced. The gonidium divides mitotically several times mostly longitudinally. The group of 8 daughter cells form a curved plate like structure called **Plakea stage**. After the 16-celled stage, the cells are arranged at the periphery of a hollow sphere having an opening called **phialopore.** When the cell division stops, the cells of sphere turn inside out passing through the phialopore by the inversion process. Now the individual cells develop flagella and become the part of a new colony. This new colony may or may not escape from the parent colony.

In *Volvox*, the sexual reproduction takes place during unfavourable season. It is strictly oogamous type. Depending on the species, the coenobia may be monoecious or dioecious.

Monoecious species like *V. globator* produce male and female sex organs in same colony. The monoecious species are protandrous. In dioecious species like *V. aureus*, the male and female sex organs produce in two different colonies. Gametes develop specially from the posterior half of the coenobia. The potential egg cell loses its flagella and enlarges in size during development. It is distinct from the gonidia being flask-shaped, denser and darker than the later. The cell forming male gametangium or antheridium divide successively forming many (16-512) spindle-shaped biflagellate antherozoids similar in manner the development of zoospore, passing through Plakea-stage and by inversion process through the phialopore.

During fertilization, the entire mass of the antherozoids are liberated from the colony which reaches to the egg cell of another coenobium. There individual antherozoids are set free and one of them fuses with the egg cell and form zygote which is called **oospore**. The oospore subsequently, secretes the three-layered wall which may be smooth or spiny depending upon the species. It also accumulates the haematochrome which imparts it orange-red colour. Oospore is released by the rupture of the colony. It is perennating body of the *Volvox*. After a period of rest, During germination, the oosporedivide meiotically to form four nuclei, out of which three degenerate while remaining one divides and re-divides mitotically to form the new coenobium.

5.3.4- *Hydrodictyon*

Occurrence

Hydrodictyon is also known as "water net" alga. It is found growing in freshwater ponds and lakes, rivers in free-floating condition usually in spring or summer season. Sometimes, it becomes so abundant that it may cover entire surface of the water body. *H. reticulatum* is the common species of the India.

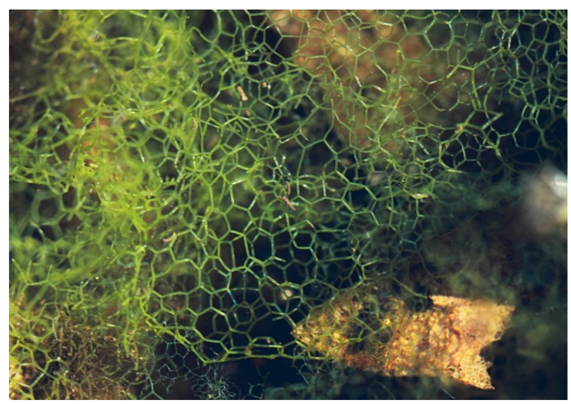

Fig.5.5 *Hydrodictyon* Colony

Thallus structure

The thallus of *Hydrodictyon* is macroscopic nonmotile coenobium.The coenobia form large cylindrical nets which have few hundred to several thousand cells and may reach upto one meter or more in length. Each coenobium consisting of a network of pentagons or hexagons. Each corner of the polygon is made up of fusion of ends of the three large cylindrical cells. These cylindrical cells may be up to 1 cm long. The young cells are uninucleate and have a parietal band-shaped chloroplast with pyrenids but mature cells become multinucleated. The cytoplasm of the cell is restricted to the periphery of the cell by a large vacuole.

Reproduction

Asexual reproduction takes place by **autocolony** formation. The cytoplasm divides up into many uninucleate protoplasts and these lie close together so that each has a polygonal outline. Each protoplast develops into biflagellated zoospore. A single cell of coenobium may form up to 20,000 zoospores, which get associated laterally to each other and thus produce a new net like colony. Each zoospore develops in to cylindrical uninucleate cell and subsequently grow to become the large multinucleate cells of the mature colony. The young colony of the newly formed water net is liberated through the disintegration and dispersion of the parent cell wall.
In some cases, the zoospores instead of assembling to form a new young colony, get liberated from the parent cell and swim freely for some time, then come to rest and surround themselves with the thick wall and turn into a hypnospore. This hypnospore germinate by forming new zoospore. This zoospore settle down into a **polyeder** which is an irregularly shaped cell bearing pointed projections. The content of this polyeder divides into zoospores which are then discharged into a vesicle. Within the vesicle, the zoospores arrange themselves into a spherical net called 'germination net'. Each cylindrical cell of the germination net subsequently produces a daughter net, by the same developmental process described above. As each daughter net takes on the cylindrical shape of the cells in which they are formed, now the daughter net acquires the original cylindrical water net shape of the colony.

Sexual reproduction is isogamous type. The genus is monoecious. The gametes arise in the same way as zoospores but are smaller. The gametes are liberated from the parent cell wall through the hole. The fertilization occurs in water. The zygote undergoes for a period of rest and later divide mitotically into four haploid zoospores. Zoospores escape from the zygote wall and develop in to a non-motile polyhedral cell. This polyhedral cell divides and re-divides to produce numerous zoospores which arrange themselves into a fashion like the *Hydrodictyon* net.

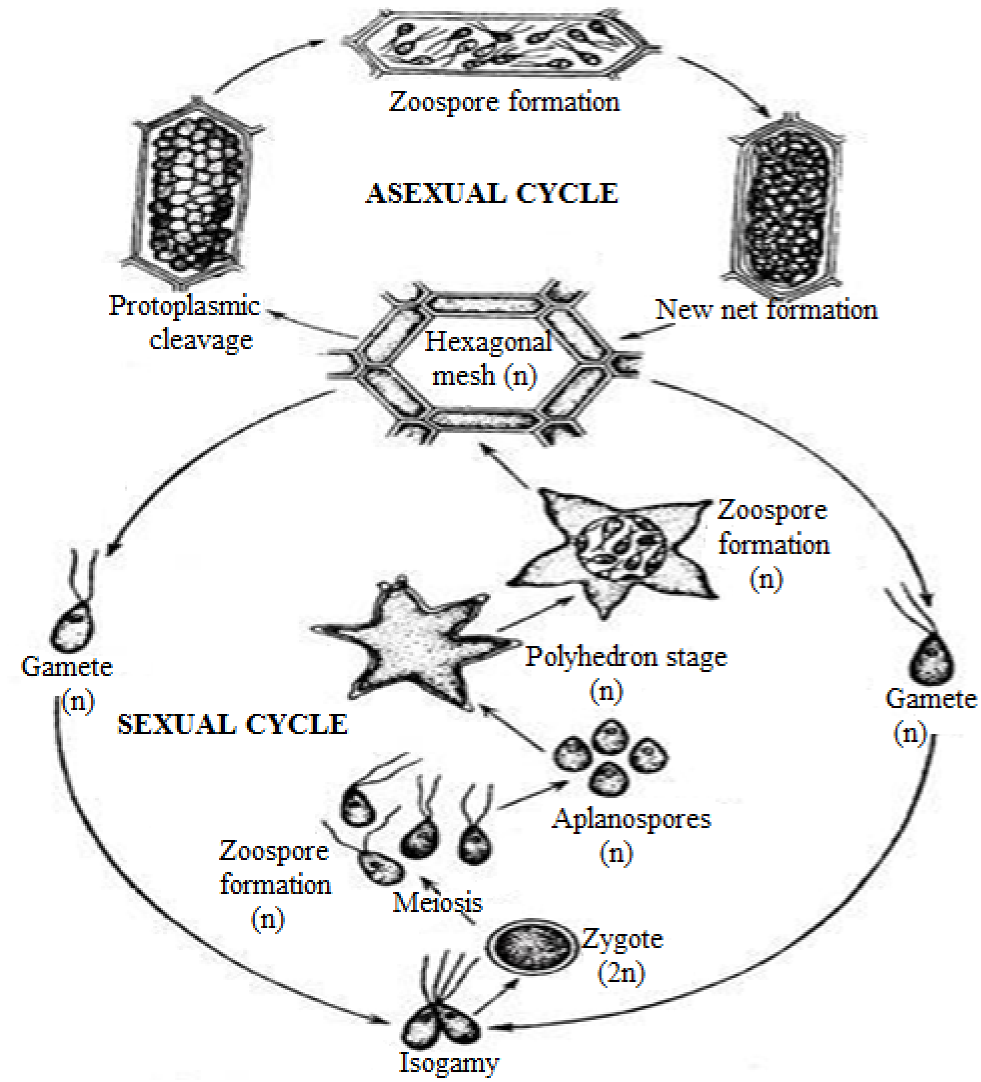

Fig.5.6 Life cycle of *Hydrodictyon*

5.3.5 - *Oedogonium*

Occurrence - It is a common freshwater filamentous unbranched alga and is found attached with the different substrates like stones, wood, leaves of aquatic plants. In the young stage filaments are attached to the substratum with the help of basal holdfast which later may become free. Few species are terrestrial like *O. terrestre*.

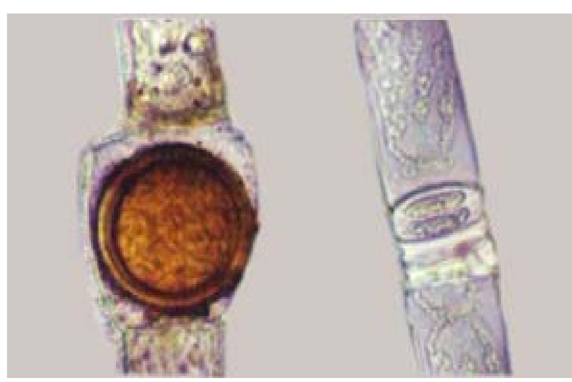

Fig.5.7 *Oedogonium*: Female and male filaments

Thallus structure - Cell wall of this genus is made up of three layers, inner cellulosic, middle pectic and outer chitinous layer. The terminal cell of the filaments is generally rounded and intercalary cells show apical-basal polarity. Most of the cells at distal end possess annular striations at the apical end which are known as **cap cells**. The cells of the filament are cylindrical, uninucleate contain parietal, reticulate chloroplast with several pyrenoids. Mature cells contain a central vacuole.

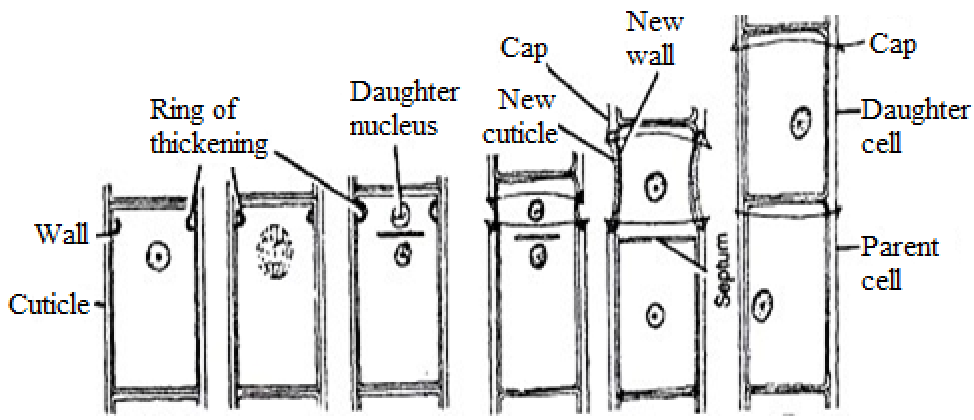

Fig.5.8 Cell division in *Oedogonium*

The process of cell division in *Oedogonium* is unique. Each cell division results in to formation a new cap cell. During cell division the nucleus migrates from middle to distal end and it divides mitotically there. In the early stages of mitosis, just below the apical end of the cell, a ring containing cell wall material develops from the inner cell wall layer. Along with progress in to the cell division this ring grows, thickens and forms a groove like structure which appears like two tubercles. After nuclear division, an unattached floating septum is formed between the two daughter nuclei. The middle and outer cell wall layers external to the ring situated at apical end of the cell ruptures, permitting free elongation of the ring which forms the new cell wall. Now the floating septum moves upward and become fixed near the terminal end of the old cell wall. The membranous striations of the ruptured cell wall at the anterior end of the upper daughter cell becomes the cap and the cell bearing it is called cap cell. The number of caps present on the cell indicated the number of cell divisions that has taken place.

Reproduction - Vegetative reproduction takes place by fragmentation but under unfavourable condition the *Oedogonium* may produce akinetes also.

Asexual reproduction takes place by formation of multiflagellate zoospores. Zoospore formation usually occurs in cap cell. In this process the whole content of the cell gradually metamorphoses in to a single pear-shaped zoospore having a hyaline area at the apex. Surrounding the hyaline area, a ring of flagella develops in the zoospore. Such zoospores are called **stephanokont** zoospores. The zoospore is liberated enveloped in a hyaline sheath from the parent cell through a hole in cell wall. The vesicle soon disappears and the zoospore swim freely for some time and attaches to the substratum by their anterior end. Thereafter, the flagella are withdrawn and the zoospore elongates considerably. The attached end differentiates into holdfast subsequently grow into a new filament.

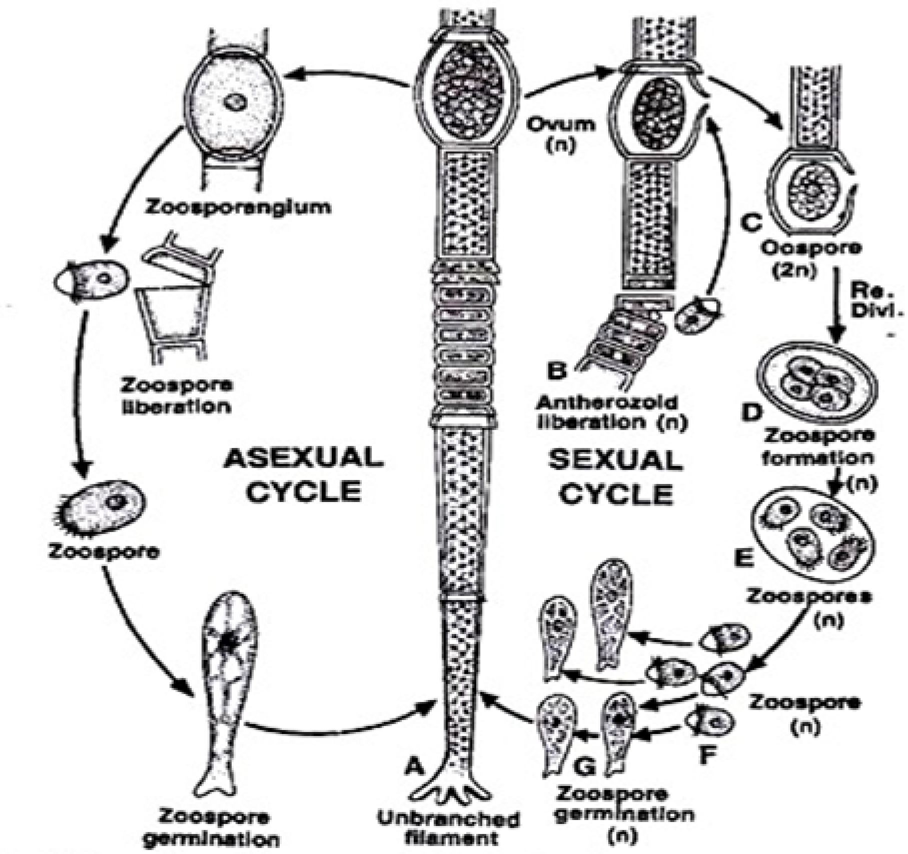

Fig.5.9 Life cycle of macrandrous speceis of *Oedogonium*

Sexual reproduction is oogamous type. Some species are monoecious while others are dioecious. In dioecious species two different categories are found. (i) **macrandrous** type with antheridia produced on normal filament and (ii) **nannandrous** type in which antheridia are produced on dwarf male filament i.e. nannandrium. In monoeciuous species, antheridia are formed in a series by vegetative cells. Protoplasm of each antheridium forms two multiflagellate antherozoids. Oogonia are formed by the division of oogonial mother cell into lower supporting cell or **suffultory cell** and upper oogonium. Oogonium after development enlarges into oval or rounded ball-like structure. A small colorless area appears at one side of the oogonium through which antherozoids enter into the oogoium and reaches up to the egg. After fertilization, zygote develops into the oospore. Oospore secretes the thick wall around it and undergoes a period of rest. It later divides mitotically into four haploid zoospores. In dioecious macrandrous species, out of four, two zoospores form male filament and two form the female filament.

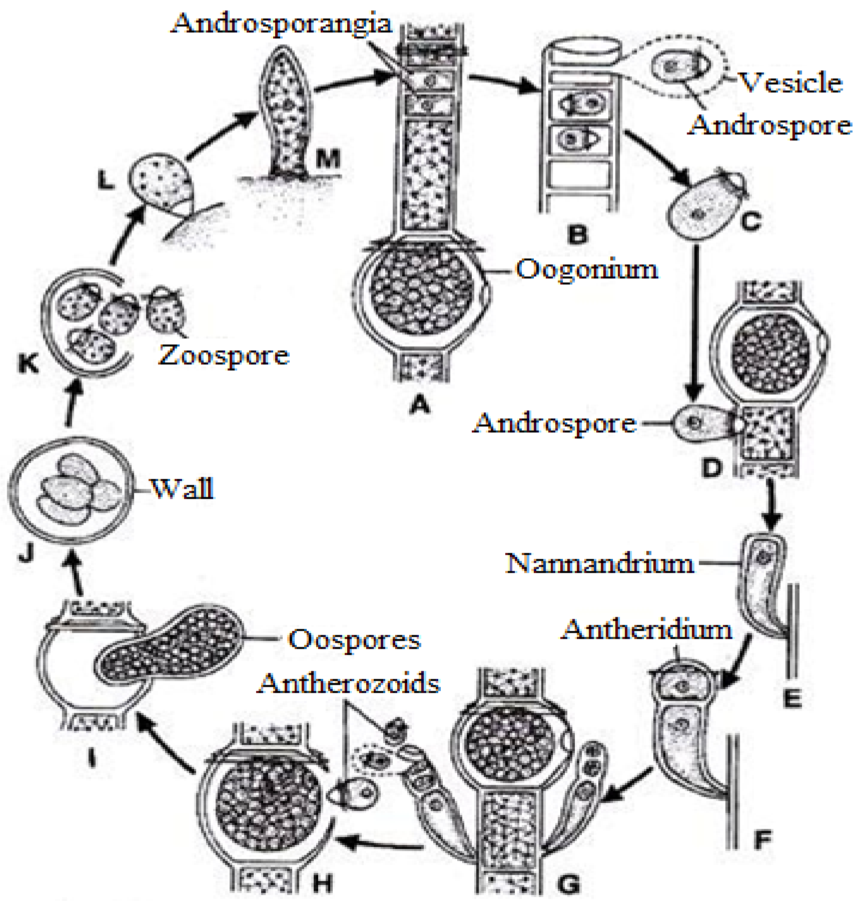

Fig.5.10 Life cycle of nanandrous species of *Oedogonium*

In nannandrous types, the dwarf male filaments are produced from a special type of zoospores called **androspores** which are formed in the **androsporangium**. Androspores are of size between zoospores and antherozoids. Usually the androsporangia are produced on the filaments bearing oogonia and such filaments are called **gynandrosporous** type. In some species, the androsporangia are formed on different filaments which are called **idioandrosprorous** type. The oogonial mother cell of *O. donnellii* produces a pheromone called **circein** which affects the behavior and development of the androspore of *O. donnellii*. Androspores after liberation from androsporangium get attached to the oogonial wall and germinate to form the 2 to 3 celled dwarf male filaments which bear the antheridia. Each antheridium forms two multiflagellatedantherozoids which escape from the antheridium and enter into the oogonium through the aperture. Further process of development and germination are similar to the macrandrous species. If the androspores are subjected to the nitrogen-rich environment it forms a vegetative male thallus that cannot be distinguished from the one which originally released the androspore.

5.3.6 - *Ulva*

Occurrence - It is a marine alga and grows attached to loose shells, rocks and stones in the intertidal zone. It is mainly found in warmer seas, estuaries and coastal areas.

Fig.5.11 *Ulva* thallus

Fig.5.12 Bistromatic thallus

Thallus structure - The thallus is leaf-like or green sheet like which is highly polymorphic and attached to the substratum by means of club-shaped rahizoidal cells which fuse to form the attachment disc. The expanded leaf-like part of the thallus is called blade. Thallus *U. curvata* has curved margins while *U. neapolitana* has narrow, lanceolate ribbon-like blades. The margins of *U. lactuca* are entire and undulate. The shape and arrangement of the cells differ from the basal to middle to apical regions of the blade.

In most of the species the thallus is bistromatic i.e. made up of two cell layers. The individual cells are parenchymatous, somewhat isodiametric and polygonal. Cells are uninucleate. Chloroplast is parietal, cup-shaped with one or two pyrenoids. In *U. lactuca* and *U. curvata* there is one pyrenoid per cell while in *U. rigida* most of the cells have 2-4 pyrenoids per cells in middle and apical region of the thallus. The chloroplast may also be notched or have irregular margins. The growth of the thallus is diffused.

Reproduction - Vegetative reproduction takes place by fragmentation of the thallus. In *Ulva* the dominant phase of life cycle is sporophyte.

Asexual reproduction takes place by quadriflagellated zoospores which are formed by the meiosis. The fertile cells are situated at the margin of the thallus. These zoospores germinate and develop into gametophytes which are morphologically similar to sporophyte.

The gametophyte produces iso-or anisogametes which fuse to form the zygote. This diploid zygote first develops into filamentous form to tubular form and eventually gives rise to leafy sporophyte. Thus, *Ulva* exhibits isomorphic alternation of generation.

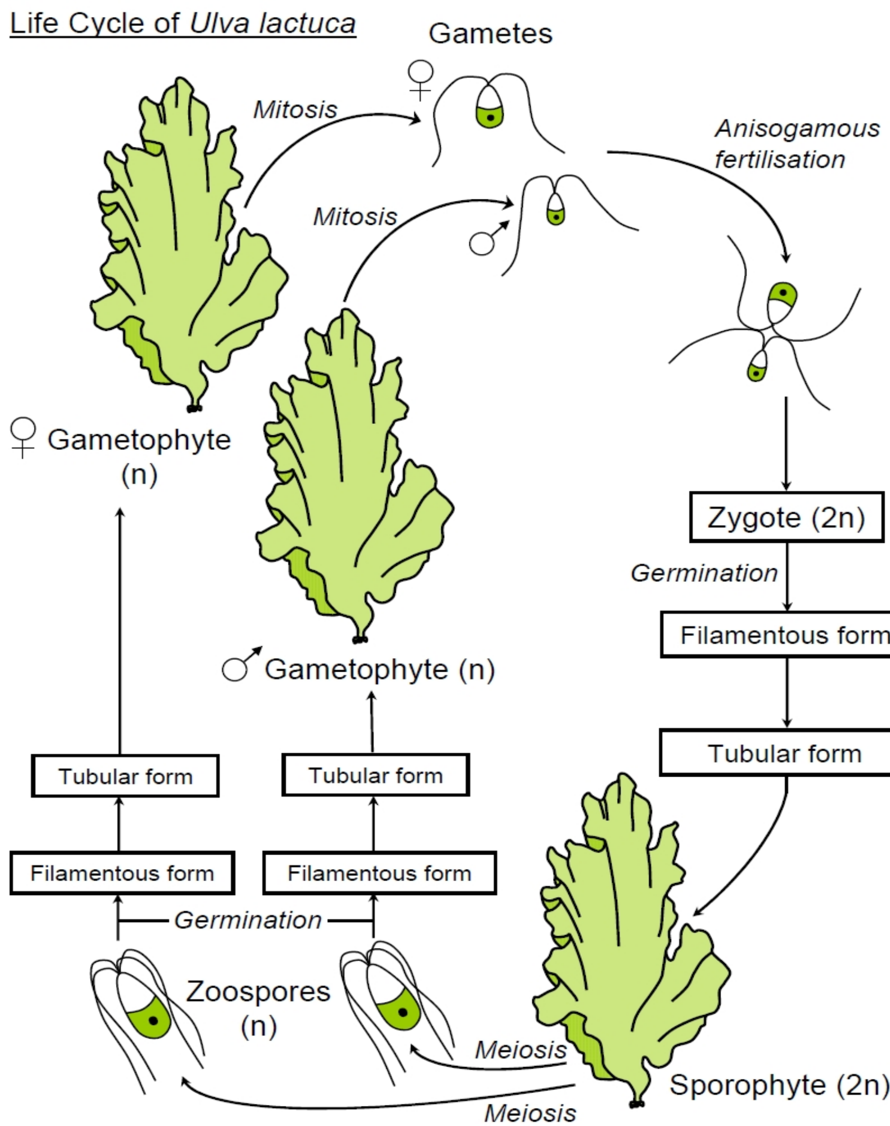

Fig.5.13 Life cycle of *Ulva*

5.3.7 – *Cladophora*

Occurrence - *Cladophora* occurs in diverse habitats like in freshwater, brackish water and in marine habitats either free-floating or attached to rocks or as epiphyte or attached on shells of molluscs. Some species of *Cladophora* grow so profusely that they form dense mat-like structures while some others form a hollow ball-like structure called as '**aegagropiloid habit**'. *C. glomerata* is a typical, most abundant freshwater alga which is found in streams throughout the world. The excessive growth of the alga may cause nuisance due to cultural eutrophication of the water bodies.

Thallus structure–The thalli are dark green, entangled aggregates which may grow up to 4 cm in diameter. The filaments arebranched which usually grow attached with long horizontal branches. The branching is usually dichotomous and they arise below the septa. The branching is usually lateral but appears dichotomous due to pushing aside of the original axis of the branch.

Fig.5.13 *Cladophora*: Aegagropiloid habit

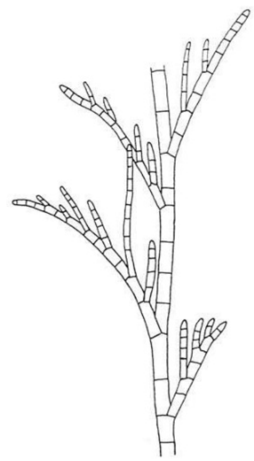

Fig.5.14 *Cladophora:* Pattern of branching of thallus

This process is called **evection**. Cells are elongated with thick, stratified cell wall. Each cell consists of many discoid chloroplasts at periphery which unit to form a reticulate structurewith numerous pyrenoids. Cells are multinucleate.

Reproduction - During unfavourable condition, the rhizoidal branches act as perennating organ which grow into new plant after advent of favourable condition. Some freshwater species also tide over the unfavourable condition by forming akinetes.

Asexual reproduction takes place by formation of quadriflagellated zoospores which are formed in zoosporangium situated usually at terminal branches. After liberation from zoosporangium the zoospores germinate to form new filament.

During sexual reproduction, zoospore like isogametes are formed from the two different thalli in gametangium which fuse to form the zygote. Zygote, without undergoing a period of rest germinates and grows to form the diploid sporophytic thallus. The diploid sporophytic thallus of the *Cladophora* produces haploid zoospores after the meiosis which develops to produce the haploid gametophytic thalli, which are morphologically similar to the diploid sporophytic thalli. Thus, *Cladophora* exhibits isomorphic alternation of generation. However, in *C. glomerata*, both gametes and zoospores are produced on diploid thalli but meiosis occurs only during gamete formation. Hence in this species the life cycle is diplontic type.

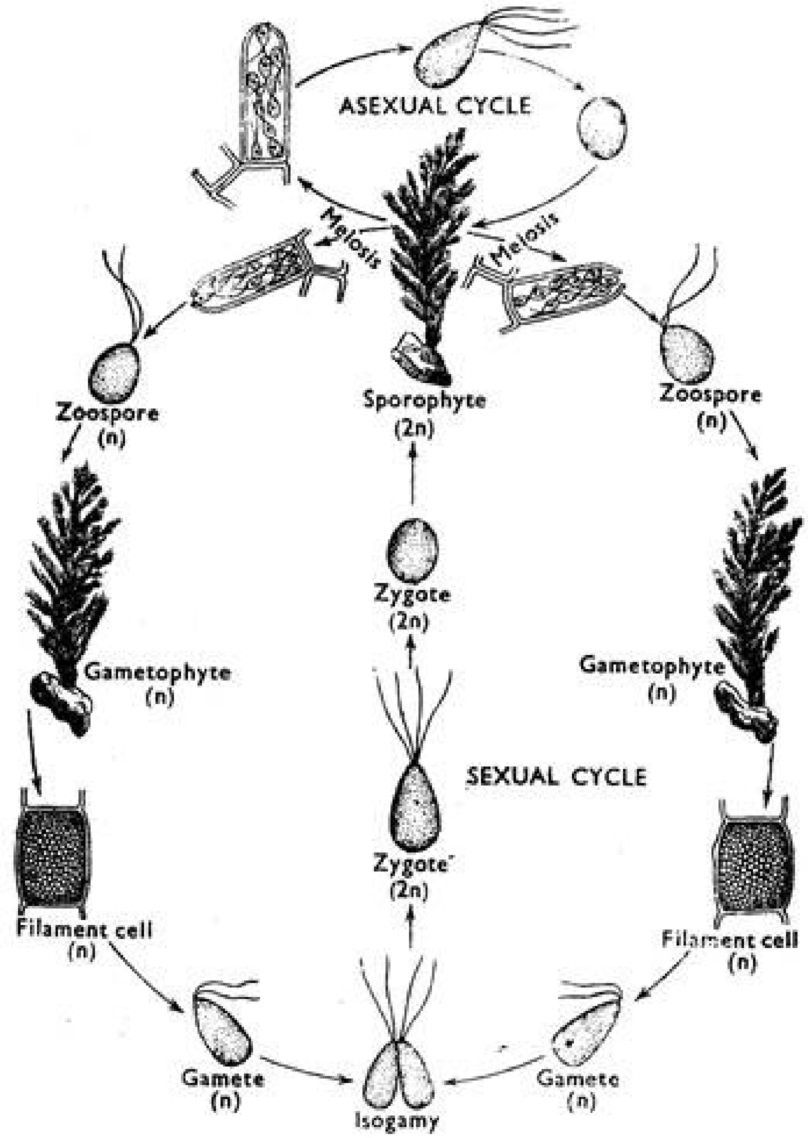

Fig.5.15 Life cycle of *Cladophora*

5.4 SALIENT FEATURES, IMPORTANT GENERA AND LIFE CYCLE PATTERN IN XANTHOPHYTA

Salient Features of Xanthophyta

1. The members of Xanthophyta are also known as Yellow-Green Algae.
2. The members of this group are primarily freshwater and terrestrial, few are marine.
3. This class is characterized by the motile cells having anteriorly directed **tinsel** flagellum and a posteriorly directed **whiplash** flagellum.

4. The chloroplast consists of chlorophyll a, and c, and appear yellowish-green. The major carotenoids found in this group are diadinoxanthin, heteroxanthin and vaucheriaxanthin.
5. In the chloroplast, the thylakoids group in to bands of three. In many genera, there is a single pyrenoid in the chloroplast. The eyespot in motile cells are always present in the chloroplast. The chloroplast is surrounded by the two membranes of **chloroplast-endoplasmic-reticulum** (c.e.r). The outer membrane of c.e.r. is usually continuous with outer nuclear membrane.
6. The reserve food material in this group of the algae are mannitol, ß-1,3 linked glucans similar to the paramylon and lipids.
7. Vegetative and asexual reproduction takes place by fragmentation and by zoospore, aplanospore or by akinete formation. The zoospores are pyriform, without cell wall, and biflagellated with anterior large tinsel and posterior small whiplash flagella.
8. Sexual reproduction is known only in *Vaucheria*, *Tribonema* and *Botrydium*. In *Vaucheria* it is oogamous type while in rest two both the gametes are biflagellated.

5.4.1 – *Vaucheria*

Occurrence - *Vaucheria* occurs in wide habitats; found growing on ranging from damp soils towalls, in freshwater, and muds of salt marshes. Many species are amphibious which form thick, dark green felt-like structure on moist soils. Some species are marine also.

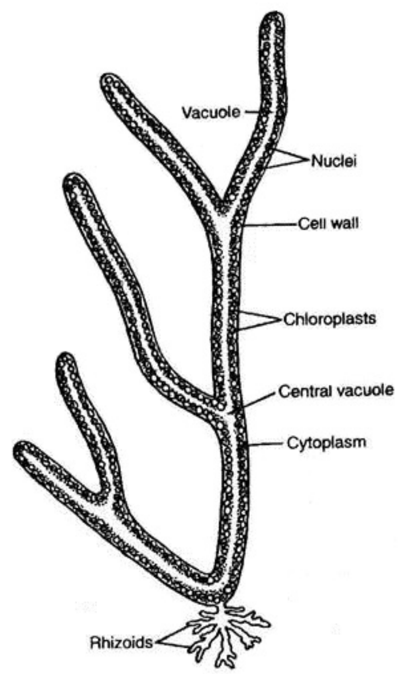

Fig.5.16 *Vaucheria*: Thallus

Thallus structure - The thallus of *Vaucheria* is filamentous, aseptate, siphonaceous tube-like and sparingly branched. In terrestrial species the genus is attached with the substratum with the help of rhizoidal branches. Cell wall is relatively thin,made up of cellulose. The protoplasm consists of a central vacuole which runs throughout the thallus and with surrounding cytoplasm. The peripheral region of the protoplasm consists of discoid chromatophores with pyrenoids while lying close to the vacuole are found numerous nuclei. The central region of protoplast near the vacuole shows cytoplasmic streaming movement which involves the nuclei, mitochondria and golgi. The thallus grows is restrictedthe at apex and takes place by simple elongation of the terminal portions of the branches. Transverse septa may develop due to injury that separated the injured portion from rest part of the thallus.

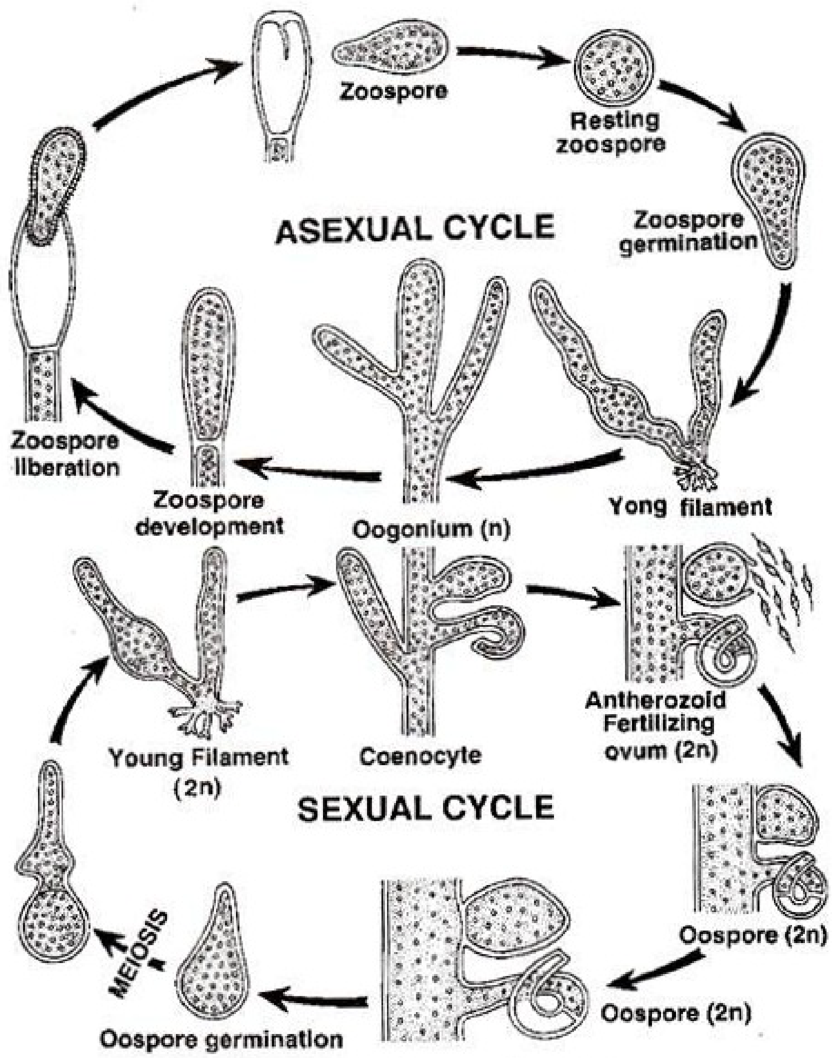

Fig.5.17 *Vaucheria*: Life Cycle

Reproduction - Vegetative reproduction in *Vaucheria* takes place occasionally by fragmentation of the filaments.

Asexual reproduction involves the formation of zoospores in club-shaped zoosporangia which are formed at the tip of the filaments. Zoospores are multinucleate and multiflagellate. There is formation of septa at the base of zoosporangium during its development and it is cut off from rest of the thallus. The protoplasm of the zoosporangium gets metamorphosed into the single large zoospore having numerous peripheral unequal flagella in pairs covering the entire surface of zoospore. Such type of multiflatellated zoospore of *Vaucheria* is called ‘compound zoospore’ or ‘**synzoospore**’ resulting from failure of the sporangial protoplast into the segments of biflagellate uninucleate zoospores as in case of other members of Xanphophyceae. The zoospore is liberated by gelatinization of the apical wall the zoosporangia. After swimming for some time, the zoospore settles down the substratum, the flagella are withdrawn, and a wall is secreted around. The germinating zoospore gives rise to several germ tubes which develop into new young thallus. Low light intensity, high humidity, transfers from running to still water and low nutrient availability induces the formation of zoopospores.

In terrestrial species, asexual reproduction occurs by formation of aplanospore or hypnospores which are non-motile and thick-walled spores. Aplanospores are formed singly in club-shaped aplanosporangia and are liberated through apical pores. During hypnospore formation, entire thallus gets segmented by formation of transverse septa and the protoplasm of each unit gets converted in to the hypnospore. At this stage the thallus of *Vaucheria* looks like another alga *Gongrosira*, hence this stage is also known as '**Gongrosira stage**'. The hypnospores either germinate directly or divide into a number of small cysts. During germination, the protoplasm of each cyst comes out of the cyst wall through a pore, exhibit amoeboid movement for some time, and later it develops into a young thallus.

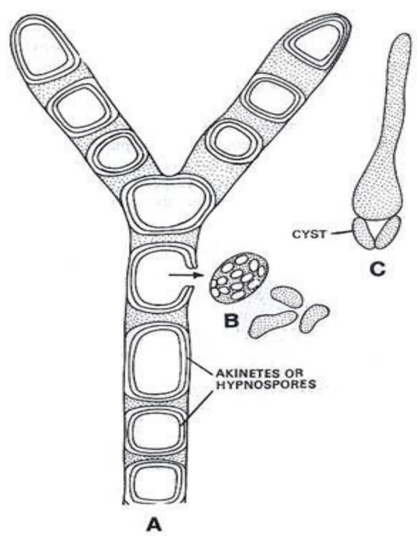

Fig .5.18 - A. *Vaucheria*: Gongrosira stage, B. Amoeboid cyst, C. Germination of cyst

Sexual reproduction in *Vaucheria* is oogamous type. The thallus is usually homothallic but rarely heterothallic. Antheridia and oogonia are borne adjacent to each other on the same branch or on the adjacent branches. Both the sex organs develop as a swelling on the branches. In the *Vaucheria*most of the species are protandrous. The sex organs are cut off by a septum. The oogonium has a single egg filled with the oil and chloroplasts. The mature oogonium produces a beak like structure, which gets gelatinized forming an aperture for the entry of spermatozoids. The antheridium usually develops as a curved cylindrical appendage. Its protoplasm divides into a large number of uninucleate biflagellate spermatozoids. With the gelatinization of the antheridial tip the spermatozoids are released. Each spermatozoid is cylindrical posteriorly but has a flattened proboscis in the anterior end. It has one forwardly projecting tinsel flagellum and a slightly longer backwardly directed whiplash flagellum. Fertilization takes place by fusion of a spermatozoid with egg nucleus. Zygote secretes thick wall and converts into oospore which gets coloured by accumulation of oil droplets and due to degeneration products of the chlorophyll. It remains dormant for few months. Before germination, meiosis takes place and it develops into a haploid thallus.

5.4.2 - *Botrydium*

Occurrence - It is a terrestrial alga found commonly growing on the muddy or damp soil near the bank of rivers, streams, ponds or pools. It grows like pinhead vesicles and usually forms a mat of thick yellowish-green coating over the soil surface.

Thallus structure - The thallus of *Botrydium* is unicellular, coenocytic, consisting of usually globose or cylindrical vesicle-like aerial portion and lower subterranean highly branched colorless rhizoidal portion. The rhizoidal portion helps in attachment of the thallus with substratum. The vesicle contains a central vacuole and peripheral protoplasm. The protoplasm consists of numerous discoid chromatophores with naked pyrenoids and nuclei. The chromatophores lie close to the cell membrane while nuclei lie close to the vacuole. Sometimes the thallus may become heavily encrusted with the calcium carbonate. Rhizoids are also multinucleate and nuclei are scattered in vacuolated and non-vacuolated cytoplasm. The cell wall is chiefly made up of cellulose and the oil and leucosin are the reserve food material.

Fig.5.19 *Botrydium*

Reproduction

Vegetative reproduction is rare if occurs it takes place by budding of the mature vesicles.

Asexual reproduction takes place with the help of biflagellated zoospores or by formation of aplanospores or hypnospores. Zoospore formation occurs during favourable condition like high humidity and free water. The coenocytic protoplasm of the vesicle is fragmented into the uninucleate units and each unit develops into a pyriform biflagellate zoospore having unequal flagella. Zoospores generally differentiate to produce the normal thallus. But sometimes they behave like gamete and are involved in sexual reproduction. Under certain conditions when plant fails to produce zoospores, it produces non-motileuni or multinucleate aplanospores. Both, uni and multinucleate aplanospores germinate to produce new thalli. During adverse environmental conditions, these aplanospores get modified into the thick walled uninucleate or multinucleate hypnospores. The uninucleate hypnospores behave like aplanospores in respect of germination but multinucleate hypnospores produce uninucleate aplanospores or zoospores which eventually produce new thalli.

During sexual reproduction, biflagellate gametes are produced, which are morphologically similar to the zoospores and are formed in the way similar to the zoospores. The gametes may be **isogamous** or **anisogamous** and after fusion, they form zygote. The zygote divides meiotically and form four haploid biflagellate zoospores. Each zoospore germinates to produce new thallus of *Botrydium*.

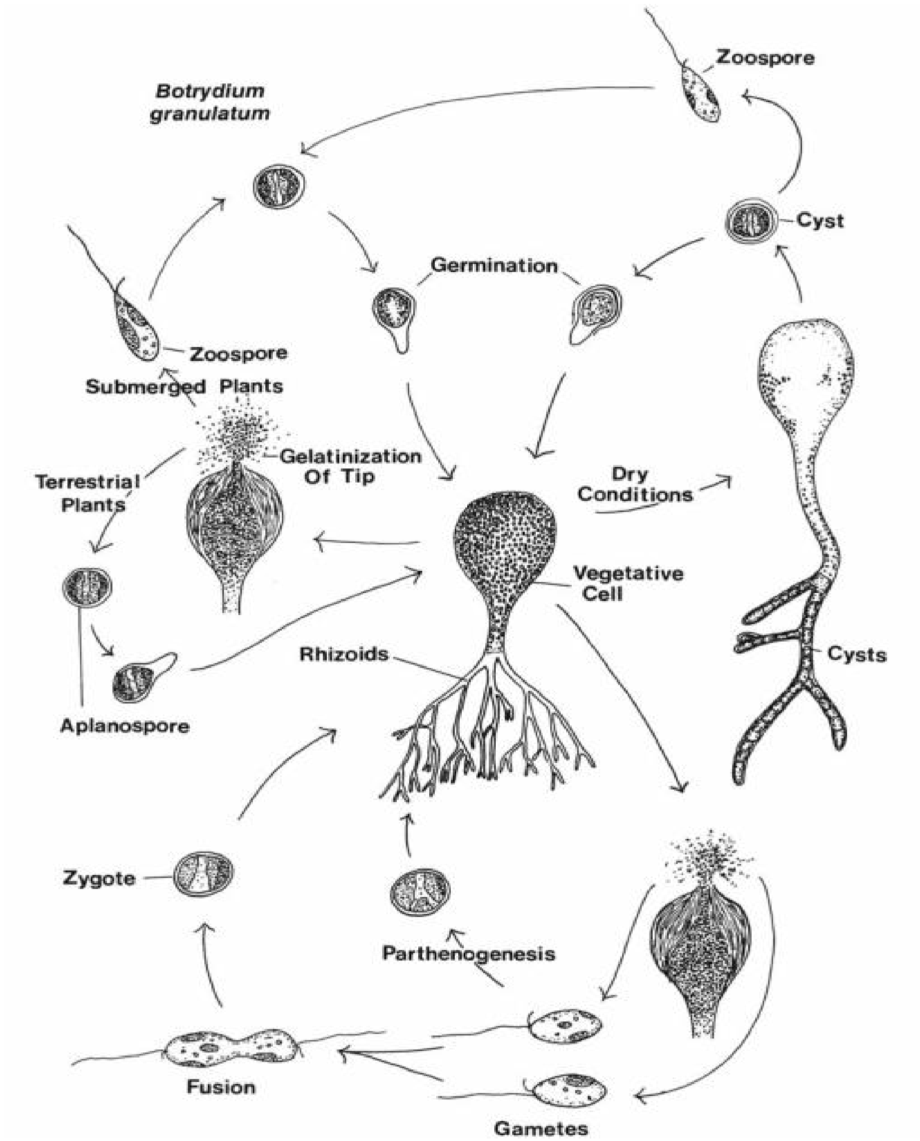

Fig.5.20 Life cycle of *Botrydium*

5.5 SUMMARY

In this unit we have discussed the general characters of class Chlorophyta and Xanthophyta. We also learnt about habit, habitat, identifying features and life cycle of some important genera of these classes. Let us sum up key points of this chapter.

1. Members of class Chlorophyceae are generally known as “green algae” which are primarily aquatic and freshwater inhabitants.
2. Their main photosynthetic pigment is chlorophyll a and b.
3. The pyrenoids are present in the chloroplast and starch is their reserve food material.
4. Motile cells usually contain two apically inserted equal whiplash flagella
5. They reproduce asexually by means of zoospores, aplanospore, autospores, hypnospores and by formation of akinete.
6. Sexual reproduction is isogamous, anisogamous and oogamous type
7. Members of class Xanthophyta are called “yellow green algae” which may be terrestrial, freshwater or marine in habitat.
8. Principal pigments are chlorophyll a and c.
9. Reserve food material in this group of the algae are mannitol, ß-1,3 linked glucans
10. Chloroplast is surrounded by two membranes of chloroplast endoplasmic reticulum.
11. Zoospores in Xanthophyta are pyriform, biflagellated with one tinsel and another whiplash flagellum
12. Sexual reproduction, if present, it is oogamous type.

5.6 GLOSSARY

Akinete: Thick walled asexual spores filled with reserve food material.

Anisogamous : A type of sexual reproduction involving morphologically two different gametes

Aplanospores : Non-motile spores

Autocolony: A newly formed coenobium having the similar form as the parent colony

Autospore: Aplanospore having similar shape as the parent cell

Chloroplast-endoplasmic-reticulum: Endoplasmic reticulum present outer to the chloroplast

Chromatophore: A chloroplast with some other colour than green

Eutrophication: A process of continuous increase of nutrients especially Nitrogen and Phosphorus in to the water bodies which leads to excessive growth of the algae

Gonidium: Asexual reproductive non-motile cell that divides to form a daughter colony in *Volvox*

Hypnospores : Thick walled aplanospores

Isogamous: A type of sexual reproduction involving morphologically similar gametes

Oogamous: Sexual reproduction involving fusion of non-motile eggwith small motile male gamete

Paramylon: A reserve food material of some algae composed of ß 1, 3 linked glucose molecules

Phialopore: A hole in inverted daughter colony in the *Volvox*
Plakea stage: A flat plate-like structure of cells found in *Volvox*
Pyrenoids: Proteinaceous area in chloroplast associated with formation of starch
Stephanokont: Condition in which flagellated cells have crown of flagella
Synzoospore: Compound, multiflagellate, multinucleate zoospore found in *Vaucheria*
Tinsel: Flagellum with hair
Whiplash: Flagellum without hairs on its surface

5.7 SELF ASSESSMENT QUESTIONS

5.7.1 Very short answer questions

1. Members of class Chlorophyta are also known as?
2. Which group of algae is also known as yellow green algae?
3. What is the reserve food material of class Chlorophyta?
4. Astaxanthein is commercially obtained from which alga?
5. Aplanospore having similar shape as the parent cells are called as?
6. Plakea stage is the characteristic stage of which alga?
7. Which alga is also known as water net alga?
8. Formation of cap cells during cell division is identifying feature of which alga?
9. What is the common name of *Ulva*?
10. Gongrosira stage is found in life cycle of which alga?
11. What is the preferred habitat of the *Botrydium*?
12. What are the principal pigments of class Xanthophyta

5.7.2 Multiple choice questions:

1. The flagella in Chlorophyta are:
(a) Two, equal in size and apically inserted (b) Two, unequal in size and laterally inserted
(c) One apically inserted (d) One laterally inserted

2. Chloroplast of green algae are surrounded by
(a) One chloroplast endoplasmic reticulum (b) Two chloroplast endoplasmic reticulum
(c) Three chloroplast endoplasmic reticulum (d) No chloroplast endoplasmic reticulum

3. Red colour of the thallus of *Haematococcus* is due to the presence of
(a) Chlorophyll a and b (b) Chlorophyll a and c
(c) Haematochrome (d) Violaxanthein

4. In *Chlorella*, the reproduction takes place by means of
(a) Zoospore (b) Akinete

(c) Autospore (d) Hypnospre

5. The zoospores of *Oedogonium* are also known as
(a) Isokontae (b) Heterokontae
(c) Akontae (d) Stephanokontae

6. The thallus of *Hydrodictyon* is
(a) Macroscopic nonmotile coenobium (b) Microscopic nonmotile coenobium
(c) Macroscopic motile coenobium (d) None of the above

7. Aegagropiloid habit is found in
(a) *Volvox* (b) *Cladophora*
(c) *Vaucheria* (d) *Chlorella*

8. The thallus of *Ulva* is
(a) Monostromatic (b) Bistromatic
(c) Tristrmatic (d) Tetrastromatic

9. The reserve food material of class Xanthophyta is
(a) Starch (b) Mannitol
(c) Sucrose (d) Glucose

10. Siphonaceous habit of the thallus is found in
(a) *Volvox* (b) *Cladophora*
(c) *Ulva* (d) *Vaucheria*

11. The thallus of *Botrydium* is
(a) Unicellular coenocytic (b) Unicellular uninucleate
(c) Filamentous coenocytic (d) Filamentous siphonaceous

12. Heterotrichous habit in algae consists of
(a) Prostrate filaments (b) Erect filaments
(c) Both prostrate and erect filaments (d) None of these

5.7.3 Fill in the following blanks

1. The cell wall of Chlorophyta is usually made up of …………
2. Starch consists of ………………..and ……………….
3. The number of flagella present in *Haematococcus* are ……..
4. Antibiotic chlorelline is obtained from ……………….
5. The alternation of generation of *Ulva* is ………………
6. Asexual reproductive cells as gonidium is found in ………….
7. Dwarf male filaments of *Oedogonium* are produced from …………….. spore.

8. Filaments of *Oedogonium* producing adrosprorangia other than the filaments producing oogonia are called……………….
9. The development of branching process in *Cladophora* is called …………….
10. The shape of zoospores in class Xanthophyta is……………………………….
11. Formation of septa in thallus of *Vaucheria* takes place during………………..
12. The preferred habitat of *Botrydium* is ………………………………………

5.7.1 Answer key: 1. Green algae, 2. Xanthophyta, 3. Starch, 4. *Haematococcus*, 5. Autospores, 6. *Volvox*, 7. *Hydrodictyon*, 8. *Oedogonium*, 9. Sea Lettuce, 10. *Vaucheria*, 11. Damp soil, 12. Chlorophyll a and c

5.7.2 Answer key: 1.(a), 2.(d), 3. (c), 4. (c), 5. (d), 6. (a), 7. (b), 8. (b), 9. (b), 10. (d), 11. (a), 12. (c)

5.7.3 Answer Key: 1. Cellulose, 2. Amylose and amylopectin, 3. Two, 4. Chlorella, 5. Isomorphic, 6. Volvox, 7. Androsporangia, 8. Idioandrosporus, 9. Evection, 10. Pyriform, 11. Reproduction, 12. Damp soil

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5.10 TERMINAL QUESTIONS

1- Describe *Hydrodictyon* with labeled diagram of life cycle.
2- Discuss about the reproduction in *Oedogonium* with diagram.
3- Give salient features of Chlorophyta and discuss about *Volvox*.
4- Describe about *Ulva* with well labeled diagram of its life cycle.
5- Give salient features of Xanthophyta and discuss about *Vaucheria*.

UNIT-6 PHAEOPHYTA AND RHODOPHYTA

6.1 OBJECTIVES

After reading this unit students will be able-

- to know The salient features of Phaeophyta and Rhodophyta.
- to understand about the important genera of the Phaeophyta and Rhodophyta.
- to know about the life cycle pattern in Phaeophyta and Rhodophyta.

6.*2 INTRODUCTION*

In the previous unit you have studied the salient features and life cycle of the Chlorophyta, and Xanthophyta. You also learnt how the cell characters, photosynthetic pigments, reserve food and flagellar characters help in classifying and identifying the different members of the algae. In this unit you will learn some important types and life cycle pattern of the Brown algae (Phaeophyta) and Red algae (Rhodophyta).

6.3 SALIENT FEATURES, IMPORTANT GENERA AND LIFE CYCLE PATTERN IN PHAEOPHYTA

Salient Features of Phaeophyta

1. The members of class Phaeophyceae are generally known as "Brown Algae" due to abundance of a golden brown coloured pigment '**fucoxanthin**' which masks the green colour of the chlorophyll and pigments.
2. This class contains 265 genera and 15,000 species out of which 31 genera and 141 species are known from the coasts of India.
3. Most of the members are marine predominately in temperate or cold water growing in littoral zone of the sea or oceans. However, four are freshwater viz. *Heribaudiella, Pleurocladia, Bodanella* and *Sphacelaria* genera.
4. Cell wall is composed of two layers; inner cellulosic and outer layer is pectin layer. Alginic acid and fucoidin are also located in intercellular spaces. Cell wall calcification is found in *Padina*.
5. Chloroplasts are discoidal or ellipsoidal in shape. They have three thylakoids per band and are surrounded by the chloroplast envelop and two membranes of chloroplast-endoplasmic-reticulum. The outer membrane of chloroplast-endoplasmic reticulum is continuous with the outer nuclear membrane in most of the genera.
6. Pyrenoids occur singly, naked, stalked and projected from the chloroplast.
7. Photosynthetic pigments include chlorophyll a, c_1, c_2, with major carotenoid being fucoxanthin.

8. Long term reserve food material is laminarin, however, accumulation of sugar alcohol D-mannitol has also been reported.
9. Cells are generally uninucleate, with prominent nucleoli.
10. Motile cells (only gametes and zoospores) have one long anterior tinsel or pantonematic flagellum and a short backwardly directed whiplash or acronematic flagellum. Posterior flagellum along with eyespot helps in phototaxis movements.
11. Schimidt (1888) discovered fucosan vesicles or physodes which are only found in cells of members of Phaeophyceae. These are colourless, refracting bodies contain pholorotannins. It is an acidic fluid which gets oxidized in the air and turn black in colour due to formation of phycophaein.
12. The thallus ranges from heterotrichous filamentous through pseudoparenchymatous forms to true parenchymatous forms. No unicellular and simple filamentous thalli are found in this group of algae.
13. Vegetative reproduction takes place by fragmentation, while asexual reproduction by formation of zoospores which develop in unilocular or pleurilocular sporangia. Unilocular sporangia develop only on sporophytic plants after the meiosis and produce haploid zoospores. Tetrasporangia are also found on sporophytes some genera.
14. Sexual reproduction is isogamous, anisogamous and oogamous type.
15. Alternation of generation is isomorphic or heteromorphic.

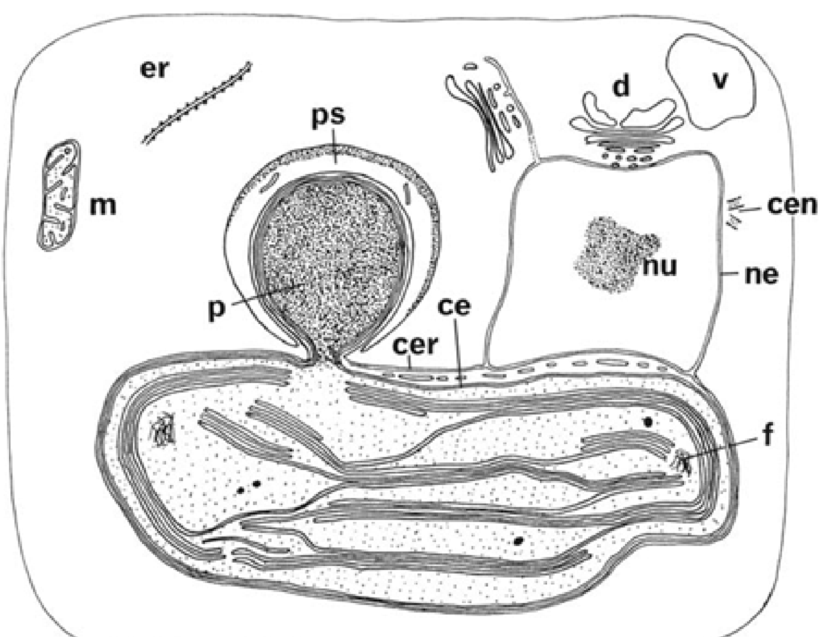

Fig.6.1: Diagram of a hypothetical brown algal cell.(ce) Chloroplast envelope; (cen) centrioles; (cer) chloroplast endoplasmic reticulum; (d) dictyosome; (er) endoplasmic reticulum; (f) DNA fibrils; (m) mitochondrion; (ne) nuclear envelope; (nu) nucleolus; (p) pyrenoid; (ps) pyrenoid sac

6.3.1-*Ectocarpus*

Occurrence

This marine alga has wide distribution range, ranging from tropic to temperate oceans. It is found growing as epiphyte or epilithic tufts in littoral and sublittoral zone.

Thallus structure

Thallus of *Ectocarpus* is branched uniseriate filamentous and heterotrichous in nature, differentiating into prostrate and erect filaments. The erect system is much branched than the prostrate system. Branches arise generally just below the septum and usually terminate into a hair. The thallus is attached to the substratum with the help of branched rhizoids arising from the lower cells of the lower branches.

The cells have ribbon-like or plate-like chloroplasts with or without pyrenoids. But these chloroplasts are absent in end branches of the thallus which are long, tapering and hyaline. Cells are uninucleate. Mature cells have large vacuoles which develop by merging the small vesicles of the cell.

Fig.6.2 Thallus of *Ectocarpus*

Reproduction

Asexual reproduction takes place by formation of zoospores which are formed in sporangia. The sporophyte bears the elongated plurilocular sporangia and globose or ellipsoidal unilocular sporangia which develop from the terminal cells of the lateral branches. The protoplast of each plurilocular sporangium divides mitotically into a number of units, consists of vertical rows of many small cuboidal chambers of locules. The protoplast of each locule gets transformed into pear-shaped diploid zoospores which possess two laterally inserted unequal flagella. The zoospores are released by through a pore in cell wall of the locule. After little swimming the zoospores settle down on the substratum and develop into a new sporophytic thallus. The protoplast of the unilocular sporangia divides first by meiosis and then by mitosis producing 32-64 haploid nuclei. Each nucleus with little protoplast get transformed into biflagellated, pear-shaped, haploid zoospore. These zoospores are liberated in mass through the terminal pore of the unilocular sporangium. The haploid zoospores develop into the gametophyte or sexual plants.

Sexual reproduction is isogamous or anisogamous type. Some species of *Ectocarpous* are heterthallic like *E. siliculosus*. The gametophic thalli bear plurilocular sporangia in similar manner to the sporophytes and each locule of the sporangia differentiates into a gamete which are morophlogically similar to the zoospores. In physiological anisogamous species, like *E. siliculosus* some gametes behave like female gamete being passive and sluggish than the other gametes which swim actively like male gametes. In *E. secundus* the female gametangia are larger than the male gametangia and accordingly produce lager female gametes. The female gametes settle down after liberation and start secreting a volatile sexual hormone called 'ectocarpene' [cis-1-(cycloheptadiene-2′, 5′-y1)-butene]. Many male gametes surround a female gamete through their flagellar ends under the influence of sex hormone and eventually, any one closer to the female gamete fuses with it through their apical end and form zygote. The zygote develops into a new sporophytic thallus. If the gametes fail to fuse with another gamete may germinate into a gametophytic thallus.

Thus, the life cycle of *Ectocarpous* has two isomorphic generations. The gametophytes are dioecious and form only plurilocular gametangia while the sporophytic thalli produce both unilocular and plurilocular sporangia. Zoopores derived from the unilocular sporangia produce after meiosis which germinates to give rise the gametopytes while that of plurilocular sporangia produce diploid zoospores after mitosis which continue the sporophytic generation.

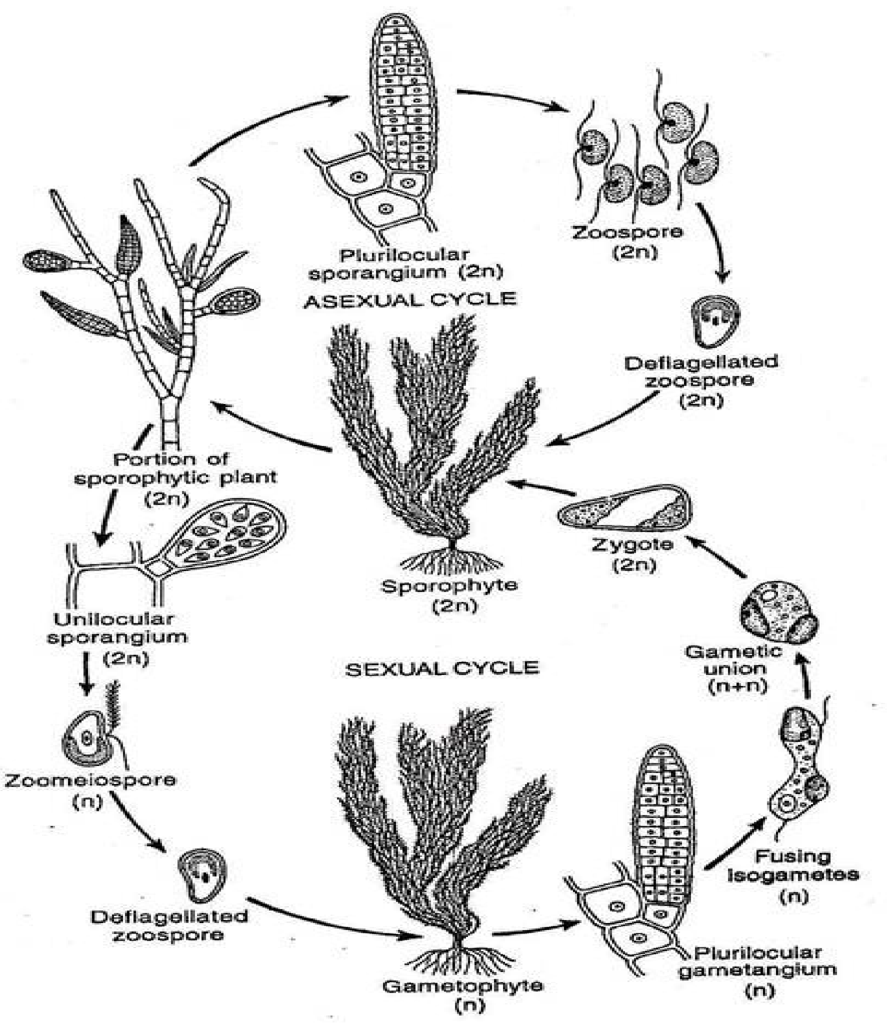

Fig.6.3 Life cycle of *Ectocarpus*

6.3.2- *Dictyota*

Occurrence

This genus grows commonly in rock pools of littoral and sublittoral zone of marine water. It is widely distributed in tropical, subtropical to temperate oceans.

Thallus structure

Fig.6.4: Thallus of *Dictyota*

The thallus of the *Dictyota* is flattened, divided into many branches having bushy erect fronds. The branching is dichotomous and may be in same plane. In some species branching is pinnate rather than dichotomous. The plants are attached to substratum with a tuft of rhizoids. The growth of the thallus takes place by a prominent apical lenticular cell, situated at the tips of the fronds. This apical cell cuts segments basally and gradually these segments broaden from apex towards base. These segments undergo division by two curved walls resulting into inner larger medullary cell and a layer of small cortical cells on both the sides. In a mature thallus, a layer of large medullary cell in which few or no chloroplasts are found. This layer is surrounded on both sides by a layer of small cortical cells. These cells are densely covered by the chloroplasts. True hairs arise in tufts on this layer which are scattered on the surface. The branching takes place by equal vertical longitudinal division of apical cell.

Reproduction

Vegetative reproduction takes place by detachment and subsequent regeneration of the detached part into new thalli. The reproductive structures in *Dictyota* develop on the lower portions and along the margins of the fronds in form of sori or patches. Light and tidal rhythms influence the sexual reproduction cycle in this genus. In *D. dichotoma* the gametangia develop during the neap tide periods in summer, but formation of sporangia is not correlated with the tidal periodicity. The male gametophytes bear plurilocular sporangia (antheridia) arranged in sori on both the surfaces of the fronds. Some vegetative cells near the sori divide and re-divide to form a protective covering surrounding the antheridium. Each chamber of the antheridium produces a uniflagellate male gamete. The oogonia are also produce in groups but single oogonium produces only one non-motile female gamete or oosphere. It is enclosed in gelatinous matrix when released from the oogonium and eventually it gets released from the matrix also. After the fertilization, the zygote attaches to the substratum and germinate into a new sporophyte.

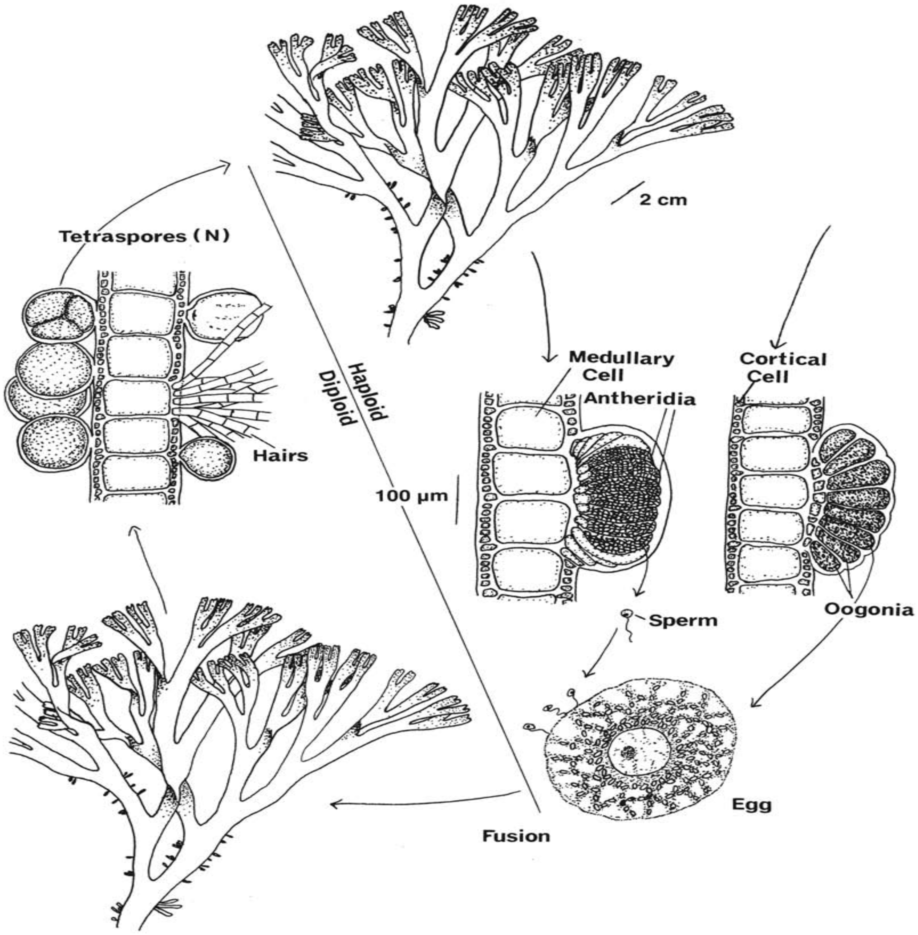

Fig.6.5: Life cycle of *Dictyota*

6.3.3- *Laminaria*

Occurrence

The alga generally grows in sub-littoral zone in temperate water, therefore, no member is found in Indian coasts. They grow attached on rocks as lithophytes. Some members are epiphytes. The genus is perennial in nature.

Thallus structure

The sporophyte is large, bulky with highly differentiated parenchymatous organization.It may reach up to the length of 3 meters or more. The thallus is differentiated into upper blade or lamina, middle stipe or cauloid and lower holdfast or haptera. The holdfast adheres to the crevices of the substratum very firmly.

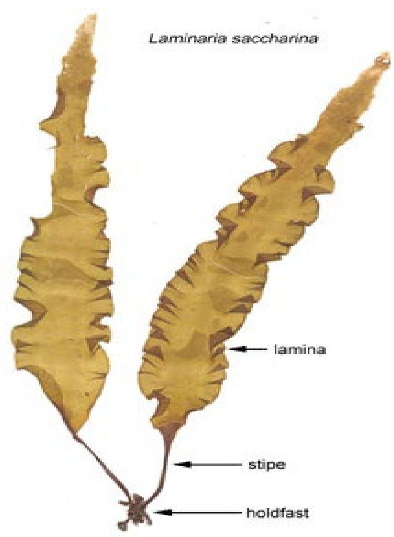

Fig.6.6: Thallus of *Laminaria*

Stipe connects the main thallus with holdfast. In some species like *L. sinclairii* there may be more than one stipe in a thallus. The lamina is leathery leaf-like or ovate. It may have vertical splits. The growth in length of the thallus occurs by the activity of the intercalary meristoderm, which is generally present at the junction of stipe and blade. Meristematic activity of meristem results into formation of three layers of the tissues, viz. a central medulla which is surrounded by the outer and inner cortex. The outer most cortex is the actively dividing layer of the thallus and is called meristoderm. The medulla layer forms certain characteristic cross-connecting hyphae, some of which are dumbbell shaped, which are called as 'trumpet hypahe'. On the inner side the trumpet hyphae bear sieve plate like structure traversed by the cytoplasmic strands similar to the phloem cells of higher plants. In the blade and sometimes in stipe, an interconnected system of mucilage canals is found in cortex. These canals are filled with mucilage and have secretary cells.

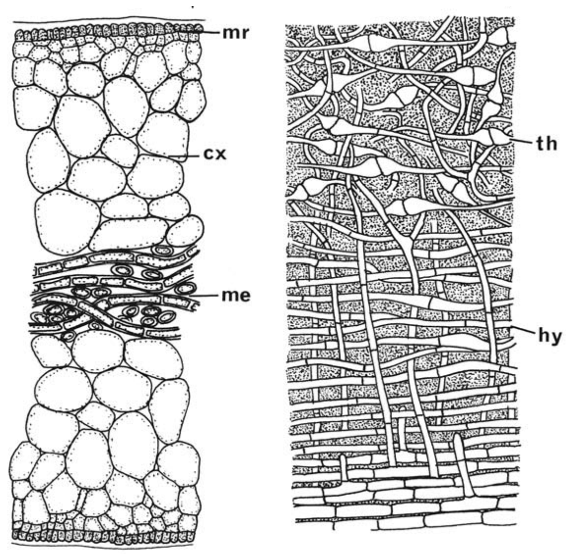

Fig.6.7 Sections of lamina (left) and the central portion of a stipe (right) of a member of the Laminariales. (cx) Cortex; (hy) hyphae; (me) medulla;(mr) meristoderm; (th) trumpet hyphae.

Reproduction

Vegetative reproduction takes place by the regeneration of detached pieces of lamina or from old holdfasts. In sporophye, the asexual reproduction takes place by formation of zoospores, which are formed by unilocular sporangia. These sporangia aggregate to form the sori. Sori are formed on both the surfaces of the thallus and are associated with the hair-like structure called paraphyes. The upper ends of the paraphyses are swollen and mucilaginous and form covering over the sporangia. After meiosis, the unilocular sporangia form about 32 haploid zoospores. The zoospores are biflagellated having unequal laterally inserted flagella and single chloroplast. Zoospores swim for some time and germinate in to a microscopic, filamentous, heterotrichous male or female gametophyte. These gametophytes can survive in dark for longer periods.

In *Laminaria*, the sexual reproduction is oogamous type. During sexual reproduction the male gametophyte which has smaller cells and more branched than the female gametophyte, produce antheridia singly or in groups. These antheridia develop from the terminal cells of the projecting threads or as a lateral outgrowth. Each antheridium produces a biflagellated, pear-shaped, antherozoid which is liberated through the pore at the apex. Female gametophyte produces elongated oogonium from any of the cell of the gametophye. Each oogonium produces single egg cell which remains attached to the oogonial wall and fertilization takes place in this position. The zygote starts germinating without undergoing a period of rest and eventually develops in to a sporophyte.

Thus, the life cycle of *Laminaria* exhibits heteromorphic alternation of generation. The sporophytic thallus is large, macroscopic which produces haploid zoospores after meiosis. Zoospores develop in to small microscopic filamentous male or female gametophytes. These gametophytes produce gametes which fertilize to restart a new sporophytic generation. Environmental factors like temperature and light influence much to the life cycle of *Laminaria*.

> Members of order Laminariales are generally called as 'Kelps'. They form the 'kelp forests' in the shallow ocean floor. Kelps are the good source of alginates which has good water retention property and is used as emulsifier. The kelp ash has good amount of Iodine.

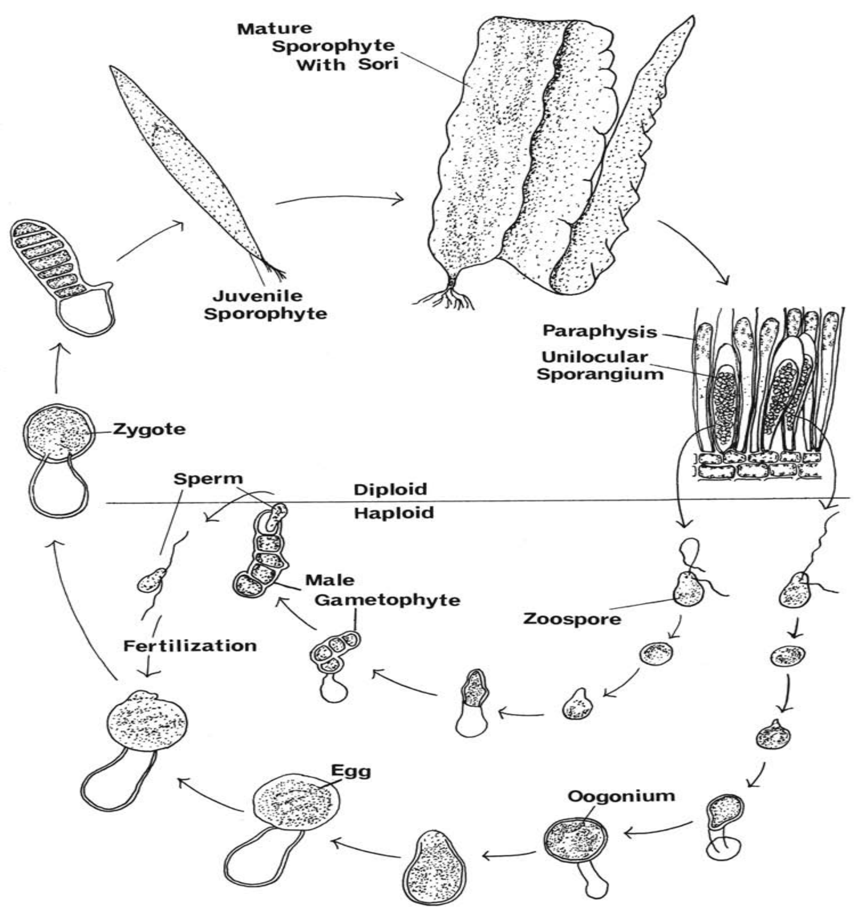

Fig.6.8 Life cycle of *Laminaria*

6.3.4- *Fucus*

Occurrence

Fucus occurs in temperate and arctic oceans and is found growing attached to the rocks in littoral zone. This genus is also not found in Indian coasts.

Fig.6.9 Thallus of *Fucus*

Thallus structure

The plant body is diploid sporophyte, usually less than 0.5 meters in length. It is differentiated into flattened leathery strap-shaped blade or frond, short and narrow stipe and basal discoid holdfast. The holdfast helps the thallus to attach with the substratum. The blade is dichotomously branched with distinct midrib. On the surface of thallus are found scattered dot like pits which are called sterile conceptacles or cryptostomata or cryptoblast. The opening of cryptoblast is called cryptoblamata. They possess hairs called paraphyses. In some species like *F. vasiculosus*, paired air bladders are present on the blade. These air bladders help in buoyancy of the thallus. The tips of the branches are swollen to form receptacles which contain fertile concepatacles. Anatomically, the plant body is divisible into outermost layer of the meristoderm (epidermis). Cells of this layer are filled with several chloroplasts. Meristoderm is followed by cortex and medulla. The growth takes place by an apical cell which is present at apical notch or pit. A maure apical cell is more or less pyramidal with four cutting faces. The apical cell divides to form cells of meristoderm, cortex and later on medullary cells. The sterile and fertile conceptacles are formed by the superficial cells of the thallus known as conceptacle initial. This initial cell divides into upper tongue cell and lower basal cell. The tongue cell degenerates, while the basal cell forms the floor of conceptacles. In fertile conceptacles, the fertile floor is formed by the repeated division of the basal cell. At maturity the conceptacle becomes spherical or oval in shape having an opening called ostiole. The neck region of conceptacle is surrounded by the unbranched hairs called paraphyses. At the basal region, these paraphyses are branched and bear sex organs.

Reproduction

Vegetative reproduction takes place by fragmentation of the thallus. Asexual reproduction is not known. Sexual reproduction is oogamous type. The thallus may be dioecious or monoecious depending on the species. In monoecious species, the antheridia and oogonia may develop in same or different conceptacles. Antheridia are small, unilocular, and elongated. In each antheridium after meiosis, followed by mitosis 64 pear-shaped, biflagellated antherozoids are formed. After maturity, the wall of antheridium ruptures and the antherozoids are liberated into the sea water in a gelatinized covering which later on dissolves in to the sea water to set the antherozoids free in to the water. In antherozoids, a part of the flagellar apparatus is incorporated in upper surface as proboscis. Oogonia are borne directly on fertile floor of the female conceptacles. Each oogonium is a spherical or oval structure and has a short stalk cell. After meiosis, followed by the mitosis 8 eggs are formed in each oogonium. The wall of mature oogonium is 3 layered viz. exochite, mesochite and endochite. After maturity of the oogonium, exochite ruptures, eggs surrounded by mesochite and endochite are released in sea water. Mesochite ruptures apically and slips backwards exposing eggs covered with endochite. The endochite gets gelatinized after some times and eggs are released in to water. The eggs secrete a chemical 'fucoserratin' which attract the swimming antherozoids for fertilization. After fertilization, diploid zygote is formed. Spherical zygote germinates to form initially a cylindrical structure. Lower cell develops rhizoids while terminal cell from hairs. Soon a prominent apical cell is formed and division of cells in all planes results in mature sporophytes.

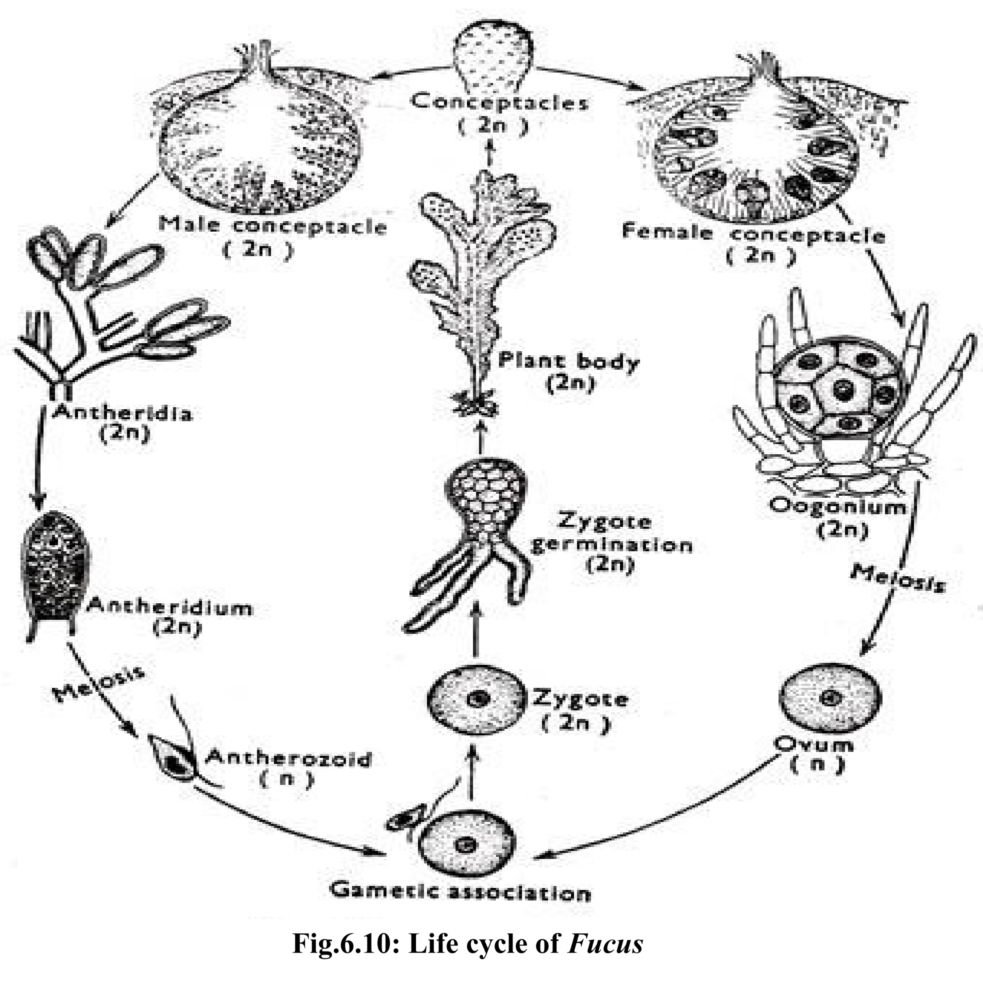

Fig.6.10: Life cycle of *Fucus*

6.4 SALIENT FEATURES, IMPORTANT GENERA AND LIFE CYCLE PATTERN IN RHODOPHYTA

Salient Features of Rhodophyta

1. Division Rhodophyta is one of the oldest groups of eukaryotic algae. Members of this group are commonly known as 'Red Algae'. The red colour of the thallus is due to the excess of pigment phycoerythrine.
2. Most of the red algae are marine, generally growing in littoral and sub-littoral zones upto a depth of 200 meters or so on. About 200 species are found in freshwater.
3. The flagellated motile cells are not found in any lifecycle stage.
4. Thallus may be unicellular or multicellular filamentous, pseudoparenchymatous.
5. The cell wall consists of outer mucilaginous pectin layer and inner cellulose. It also contains amorphous polysulphated esters of carbohydrates as phycocolloids known as agar and carrageenans. Some members show calcification in cell wall also.
6. The cells are usually uninucleate but in advanced members mature cells become multinucleate.
7. The chloroplast may be axile stellate or parietal plate like with a central naked pyrenoid having only proteinaceous body and there is no starch sheath. Chloroplast has one thylakoid per band and no chloroplast endoplasmic reticulum. Photosynthetic pigments are chlorophyll a, phycobilins like r-phycocyanin, r- phycoerythrine and allophycocyanin.
8. Red algae have the ability for complementary chromatic adaptation i.e. altering the proportions of different pigments in response to differing qualities of incident light.
9. Certain red algae show marked blue or green iridescence when observed in refracted light due to presence of iridescent bodies in cell wall.
10. Secretary vesicular cells occur in certain red algae which contain a large central vacuole and store high concentrations of Iodine.
11. Pit connection is present between the cells of filamentous genera. Primary pit connection is found between two cells derived from same mother cell while secondary pit connection is found between adjacent cells of two neighboring filaments. Pit connections provide mechanical strength to the thallus.
12. Reserve food material is Floridian starch; sorbitol and mannitol are also found in some genera.
13. Sexual reproduction is advanced oogamous type. Male gametes are called spermatia which are formed singly in spertmatangium. Male gametes are passively transported to the female gamete or egg cell lodged in female reproductive structure carpogonia, through the trichogyne. There are distinct post-fertilization developments which are found exclusive in this group of algae.
14. Life cycle is triphasic haplobiontic or triphasic diplobiontic.

6.4.1- *Gelidium*

Occurrence

It is widely distributed marine alga found growing attached to the littoral zone. Six species are known from the coasts of India.

Thallus structure

The thallus consists of entangled mass of highly branched polymorphic axes, which are sometimes leathery. The basal part of the thallus consists of dorsiventral, creeping stolon from which clusters of erect fronds arise on the upper side. The axes are pseudoparenchymatous and uniaxial. Fronds are cartilaginous, compressed, dichotomous twice or thrice pinnately branched. Growth takes place by a prominent apical cell. Internal hyphae are commonly present in many species and provide the mechanical strength.

Fig.6.11: Thallus of *Gelidium*

Reproduction

Vegetative reproduction takes place by detachment of stolon or fronds. The thallus is dioecious. Male and female plants are morphologically similar. Sexual reproductive structures are formed from the cortical cell of upright fronds. Spermatangia are found in the form of irregular patches on the thallus. Cells of the lateral filaments are transform into two spermatangial mother cells. Each of them by transverse division forms two spermatangia. Each spermatangium give rise to a single non-motile male gamete called spermatium. In female plants, carpogonia are formed in derpression behind apical notch of specialized branches known as 'fertile area'. The carpogonium is cut off from pericentral cells. It is terminal in position. The trichogyne may project above the surface of the thallus. Carpogonial branch is single celled. Small nutritive filaments develop from the basal cell of lateral filament. After fertilization, the carpogonium may fuse with the cells of nutritive filaments. Gonimoblast filaments develop from the fusion cells. Generally, a single gonimoblast filament originates which may be branched and bears terminal carposporangia. The wall of mature cystocarp develops two pores or ostioles opening on either side of thallus. Carpospores on germination develop into a free independent stage known as tetrasporophyte. Tetrasporophyte is similar to the gametophye. In these plants, tetrasporangia ar formed. Each tetrasporangia after reduction division forms four haploid tetraspores. The arrangement of tetraspore is curciate. Out of four tetraspores two germinate into male gametophyte and remaining two form female gametophyte. Life cycle is triphasic diplobiontic.

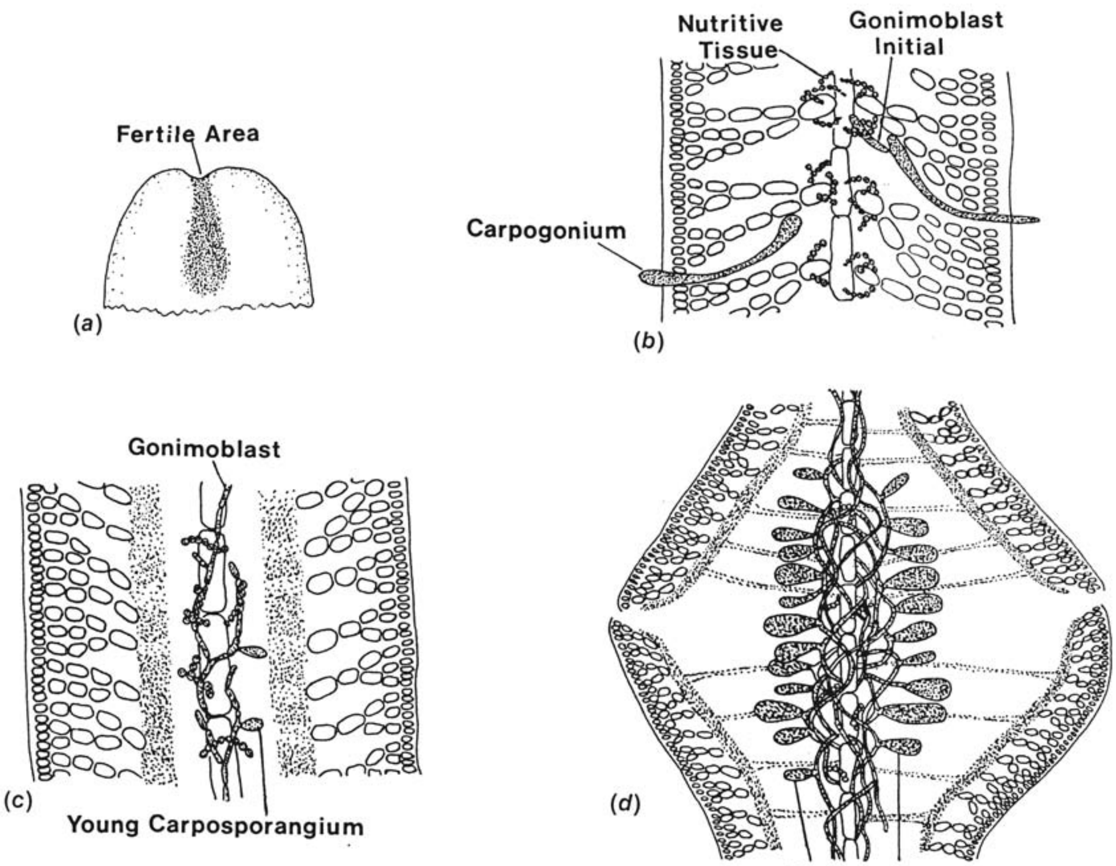

Fig.6.12: *Gelidium cartilagineum.* (a) Apex of fertile thallus. (b) Longitudinal section of thallus showing carpogonium. (c) Gonimoblast producing young carposporangia. (d) Carposporophyte with mature carposporangia.

Geladium is an important genus of agarophyte through which the commercial agar is obtained. Agar is composed of two polysaccharide viz. agarose and agaropectin. Agar is insoluble in cold water but readily dissolves in hot water. 1.5% aqueous solution of the agar gives a clear solid elastic gel which does not dissolve again below temperature 85^0 C. agar is mainly used in food industries and pharmaceutical industries. It is also used as stiffening agent for growth media in microbiology and mycology.

6.4.2- *Batrachospermum*

Occurrence

It is a freshwater red alga which is found in cold running water streams, ponds and lakes. It is widely distributed in tropical, subtropical and temperate regions. It is also known as 'frog-spawn alga'.

Thallus structure

The thallus appears soft gelatinous branched axes with characteristic beaded appearance. The colour may vary between shades of blue-green, olive, violet or red, depending on the habitat. The thallus has a main primary axis through which numerous braches of limited and unlimited growth arise in whorls. The apical cell forms primary axis, which cuts off a series of segments at its base. Each segment produces four lateral projections which are cut off as pericentral cells. The axial cells do not divide further and continue to increase in length and width. Each pericentral cell forms lateral branches of limited growth. This arrangement of branches differentiates the main axis into nodes and internodes. The braches of unlimited growth contain the same feature of nodes and internodes similar to the main axis and possess cells longer than the cells of limited growth. Besides the laterally projecting filaments, from the lower most cells of the nodal branches arise corticating filaments which bend downwards and surround the axial cell, giving the central axis a multicellular appearance. The cells are uninucleate. Chloroplasts are parietal lobe shaped with single naked pyrenoid.

Fig.6.13: A part of thallus of *Batrachospermum*

Reproduction

Plants are dioecious or monoecious. Sexual reproduction is oogamous type. Spermatangia develop in groups at the tip of lateral branches, which bear a single spermatium. Carpogonia are borne on 3-4 celled carpogonial branches. The carpogonium has a basal dialated portion which contains female nucleus and a projected long neck called, the trichogyne. The wall of trichogyne dissolves when spermatium comes in contact with it and nuclei of both the gametes fuse. The trichogyne disappears after the fertilization. The diploid nucleus of zygote divides mitotically. Gonimoblast initials develop from the carpogonium in form of lateral outgrowth. Each gonimoblast initial cell divides mitotically and form branched, thread-like gonimoblast filaments. The terminal cell of each gonimoblast filaments develop into carposporangium. Each carposporangium forms a single non-motile carpospores. The whole structure, consisting of gonimoblast filaments, carposporangia, and carpospores is called carposporophyte, which is parasitic on female gametophyte. Some enveloping threads also develop from base of the carpogonium which ensheath the carposporophyte. Now, the entire structure is termed as fruiting body or cystocarp. After liberating from the carposporangia, the carpospores germinates into a microscopic, heterotrichous filament which is called 'Chantrantia stage'. This filaments chantrantia stage bears monosporangia which produce single monospore. These spores again develop in to a new chantrantia stage. The filaments also produce erect filaments which elongate by apical growth.

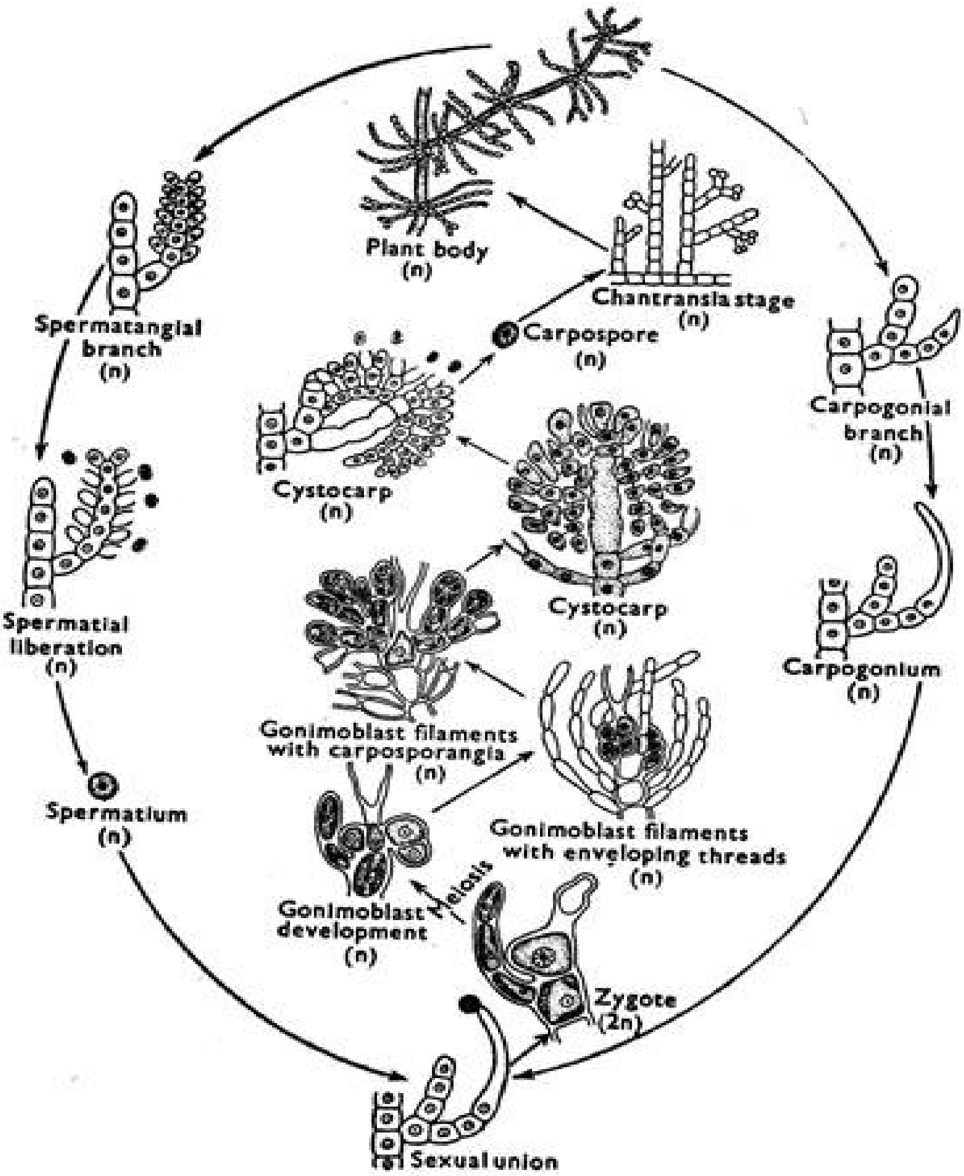

Fig.6.14: Sexual cycle of the *Batrachospermum*

The apical cell of these erect filaments divides meiotically forming four haploid nuclei. Out of four three degenerate and one remains functional. Now this haploid apical cell grows into new gametophyte. The macroscopic plant is thus composed of basal diploid cells on a haploid plant.

6.4.3- *Gracilaria*

Occurrence

The genus is widely distributed in tropical and temperate oceans. It is quite common in intertidal zones thriving in turbid, shallow lagoons near freshwater inflows rich in nutrients.

Thallus structure

The thallus is large, dark red in colour, may reach up to 60 cm in length. It consists of a perennial disc which bears numerous cylindrical upright branches every year. The branches are dichotomous or trichotomously branched, cylindrical, terete or broadly flattened having a cartilaginous texture. The main axis may possess or lack sinusoidal constrictions. The thallus is uniaxial. It consists of large isodimetric cells in medulla and small cortical cells with numerous ribbon-shaped chloroplasts. A single apical cell is found at the tip of each branch. Some species may have unilateral branchlets in rows along the main axis. Some species may have hair cells also.

Fig.6.15: Thallus of *Gracilaria*

Reproduction

Vegetative reproduction occurs by detachment of the branches. The sexual reproduction is oogamous type. Plants are dioecious. Male plants produce spermatia in spermatangia which are formed in shallow depressions of the thallus. The female plant bears a supporting cell derived from the medulla and it bears two-celled carpogonial branch and a number of laterals. All of the cells of procarp become multinucleate and develop into nutritive cells except carpogonium and a cell beneath it. After fertilization, carpogonium fuses with one of the nutritive cells called auxiliary cell and convert into the fusion cell. Subsequently, this fusion cell fuses with other multinucleate nutritive cells. Simultaneously, the cortical cells near the procarp divide and re-divide to form the cystocarp wall. The gonimoblast filaments develop from the fusion cell after is fusion with auxiliary cell. They develop outside the thallus and are covered by the pericarp. The cystocarp is hemispherical, dome-shaped structure, projecting out from the surface of the thallus. The carpospores are released from the opening of the cystocarp called ostiole. The carpospores germinate to produce parenchymatous disc that produce tetrasporophytes which are almost morphologically similar to the female gametophytes. Inside the cortex of tetrasporophytes, cruciate haploid tetrasporangia are formed after meiosis. Tetraspores germinate to form a parenchymatous disc which produces erect gametophytes.

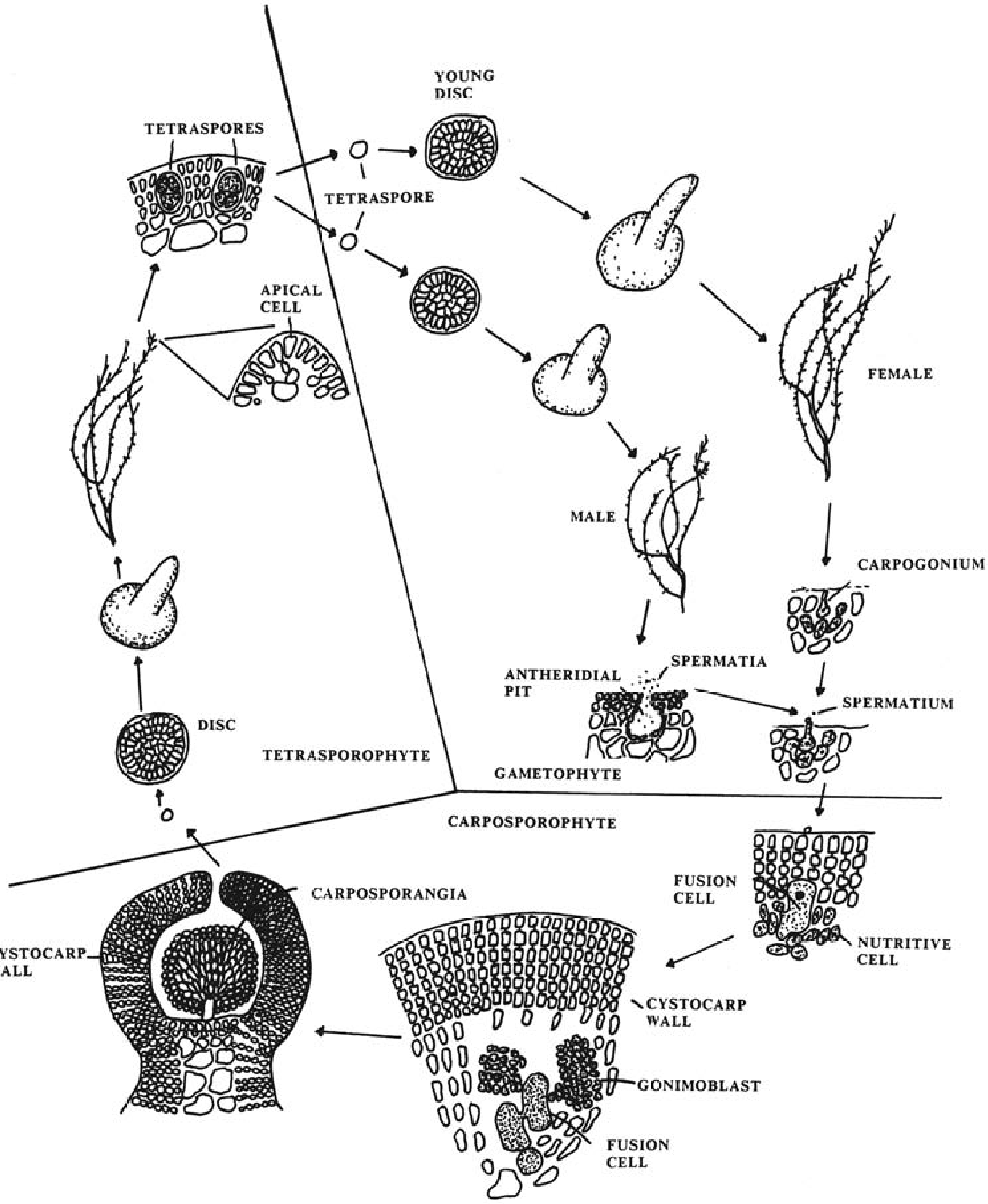

Fig.6.16: The life cycle of *Gracilaria*

Gracilaria is also a major agarophyte, which provides more than fifty percent supply of the agar. It is also found in Indian coasts. In Taiwan, it is cultivated for agar and as a food source.

6.4.4- *Polysiphonia*

Occurrence

The genus is widespread in distribution throughout the sea. They prefer quite shallow water and thallus appears brownish-red to purple in colour. Mostly they are lithophytes, but epiphytes are also quite common.

Thallus structure

The plant is bushy in appearance, freely branched having polysiphonus thallus. The main thallus consists of a central siphon, surrounded by 4-24 pericentral siphon of pericentral cells. The lateral branches are of two types, the ordinary branches and the trichoblasts. Ordinary branches are similar to the main axis, polysiphonus and with unlimited growth. The trichoblasts are hair-lile, uniseriate, usually colourless and bear sex organs. From lower part of the thallus, rhizoids evelope which possess mucilaginous pads or thick walled lobed rhizoids for firm attachment with substratum. Mature vegetative cells are uninucleate with one chloroplasts, usually without pyrenoids.

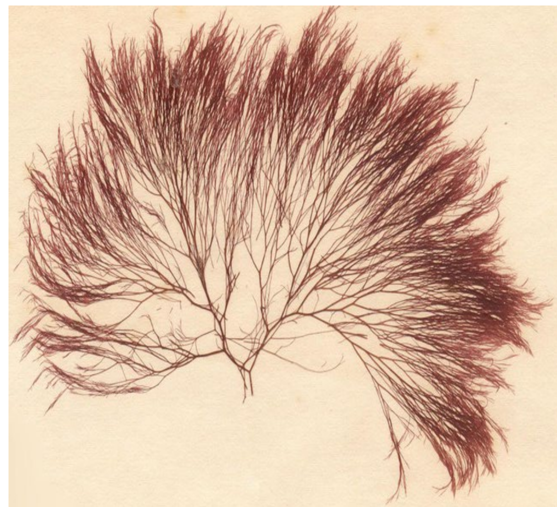

Fig.6.17: Thallus of *Polysiphonia*

Reproduction

Plants are usually dioecious. The spermatangia develop in groups as antheridial sori on trichoblast consisting of two celled stalk. Spermatangial branches are dichotomously branched and only one branch becomes the fertile. The carpogonia develop on four-celled caropogonial branch located on the fertile trichoblast. At the base of the carpogonial branch, supporting cell is situated. After the fertilization, the auxiliary cell is cut off from the supporting cell which fuses with the carpogonium. Now the zygotic nucleus divides mitotically and one of the diploid nucleus passes into the auxillary cell which subsequently fuses with the supporting cell and form fusion cell. gonimoblast initials develop from the fusion cell and form a number of gonimoblast filaments. The terminal cell of these gonimoblast filaments develop into pear-shaped carposporangia which bear carpospores. Simultaneous with these developments, the lateral sterile cells near the carpogonium grow out to form sterile filaments which form one to two layered wall of pericarp which surround the carposporangia. The entire structure appears urn-shaped which is termed as cystocarp. Cystocarp has an opening at apical end, called ostiole.

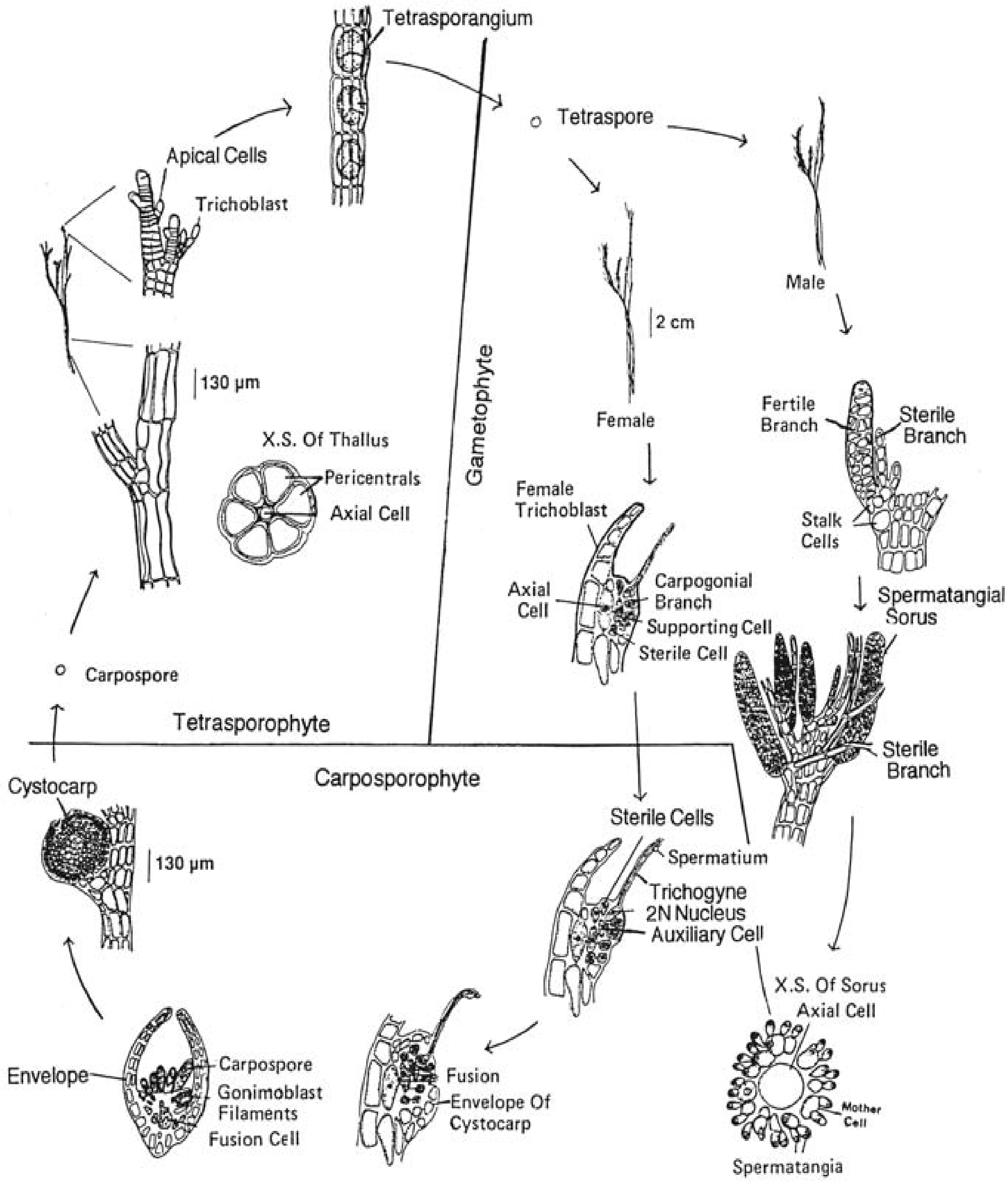

Fig.6.18 Life cycle of *Polysiphonia*

The carpospores germinate to form tetrasporphyte plant which is morphologically similar to the gametophytic plant. Tetrasporophytes produce four tetraspores after meiosis which are arranged tetrahedrally. Out of four tetraspores, two germinate in to female and two into male gametophytic plants. The life cycle is thus diplobiontic triphasic, where the haploid gametphytic plant alternates with diploid tetrasporophytic plant and the diploid carposporophyte is dependent on the gametophyte.

6.5 SUMMARY

In this unit we have discussed the general characters of class Phaeophyta and Rhodophyta. We also learnt about habit, habitat, identifying features and life cycle of some important genera of these classes. Let us sum up key points of this chapter.

13. Members of class Phaeophyceae are generally known as "Brown algae" which are mostly marine except few.
14. Their main photosynthetic pigment is chlorophyll a, c and fucoxanthin. Chlorplasts have three thylakoids per band and two chloroplast endoplasmic reticulum layers.
15. Besides the cellulose, the cell wall contains alginic acid and focoidin in intercellular spaces.
16. Motile cells of in brown algae are usually pyriform, and with two unequal, laterally inserted flagella.
17. Reserve food material is laminarin and mannitol.
18. They reproduce asexually by means of zoospores, which are formed in unilocular and plurilocular sporangia.
19. Sexual reproduction is isogamous, anisogamous and oogamous type
20. Life cycle is diplobiontic isomorphic or heteromorphic.
21. Members of class Rhodophyta are called "Red algae" which are primarily marine.
22. Principal pigments are chlorophyll a, c and r-phycoerythrine.
23. Chloroplast is without chloroplast endoplasmic reticulum and has one thylakoid per band.
24. Pyrenoids are naked, projected, outside the chloroplast.
25. Reserve food material in this group is floridian starch.
26. Motile stages are entirely absent from the life-cycle.
27. Sexual reproduction is oogamous type, by means of non-motile male gamete spermatia and female reproductive structure is flask-shaped carpogonia.
28. Post-fertilization changes are complex. Most of the genera consist of a carposporophytic phase which is dependent on gametophyte.
29. Life cycle in diplobiontic diphasic or triphasic.

6.6 GLOSSARY

Carposporophyte: In red algae, a separate phase of life cycle, parasitic on gametophyte.
Cystocarp: Fruiting body of red algae, aggregate structure consisting of carposporangia and sterile covering cells.
Diplobiontic: Type of life cycle having two free-living morphological phases.
Fusion cell: In red algae, the cell produced by the fusion of auxiliary cell with one or more neighboring cells.
Gonimoblast filaments: A filament of diploid/haploid cells that produce carpospores.
Intertidal: Sea littoral

Iridescence: The play of colours caused by refraction and interference of light waves at the surface.
Lagoon: Shallow Lake of salt or brackish water, separated from sea
Lenticular: Lens shaped
Lithophytes: Algae which are found growing on submerged rocks or stones
Littoral : Occurring between levels of high and neap tide (=intertidal)
Ostiole: Opening of a cavity
Plurilocular sporangia: Sporangium composed of tiers of cells producing zoospores by mitosis in Phaeophyta
Procarp: In red algae, the compact female reproductive tissue, consisting of short carpogonial branch borne by supporting cell.
Sub-littoral: Zone between low tide marks to 200 meters depth in sea
Terete: Cylindrical in shape, taprering from bottom to top
Tetraspore: Spore formed in tetrasporangium, usually after meiosis
Tetrasporophyte: Usually diploid plant forming tetraspores in red algae
Trichoblast: Uniseriate, colourless hair bearing sex organs in red algae
Triphasic: Life cycle completing in three distinct phases
Unilocular sporangia: Sporangium composed of single cell producing zoospores by meiosis

6.7 SELF ASSESSMENT QUESTIONS

6.7.1 Very short answer questions

Q.1. Red colored of thallus of Rhodophyta is due to excess of pigment?
Q.2.Which group of algae are also known as Brown algae?
Q.3. Alginic acid is found in intercellular spaces of cell wall of which group of algae?
Q.4. Flagella are entirely absent in life cycle of which group of algae?
Q.5. How many chloroplast endoplasmic reticulum are found in Phaeophyta?
Q.6. Reserve food material in Phaeophyata is?
Q.7. Alginate is obtained from which group of algae?
Q.8. The volatile sex hormone secreted by the *Ectocarpus* is?
Q.9. Life cycle of *Laminaria* is?
Q.10. Heterortrichous, filamentous gametophyte of *Batrachospermum* is called?
Q.11. Main reserve food material of Rhodophyta is?
Q.12. Male gametes of red algae are called as?
Q.13. Carpogonia as female reproductive structure is found in which group of algae?
Q14. Agar is obtained from which group of algae?
Q.15. Mature fruiting body of red algae is called as?
Q.16. Which alga is also known as ‘Frog spawn alga’

6.7.2. Multiple choice questions

1. The flagella in Phaeophyta are:
(a) Two, equal in size and apically inserted (b) Two, unequal in size and laterally inserted
(c) One apically inserted (d) One laterally inserted

2. The main photosynthetic pigment in Phaeophyta are:
(a) Chlorophyll a, b, and fucoxanthin (b) Chlorophyll a, c, and fucoxanthin
(c) Chlorophyll b, c, and fucoxanthin (d) Chlorophyll b, d and fucoxanthin

3. Which one among the followings is a freshwater brown alga?
(a) *Laminaria* (b) *Ectocarpus*
(c) *Sphacelaria* (d) *Dictyota*

4. Which among the following brown alga has calcium deposition in its cell wall?
(a) *Padina* (b) *Laminaria*
(c) *Ectocarpus* (d) *Fucus*

5. Fucosan vesicles or fusodes are found in which group of the algae
(a) Chlorophyta (b) Xanthophyta
(c) Pheophyta (d) Rhodophyta

6. In Phaeophyta, the haploid zoospores are formed in
(a) Unilocular sporangia (b) Plurilocular sporangia
(c) Both of the above (d) None of the above

7. Trumpet hyphae is found in
(a) *Ectocarpus* (b) *Fucus*
(c) *Laminaria* (d) All of the above

8. Life cycle of *Ectocarpus* is
(a) Isomorphic diplobiontic (b) Heteromorphic diplobiontic
(c) Isomorphic triphasic (d) Hetermorphic triphasic

9. Which among the following algae shows heteromorphic diplobiontic life cycle
(a) *Ectocarpus* (b) *Padina*
(c) *Fucus* (d) *Laminaria*

10. In *Fucus*, the wall of mature oogonium is
(a) One layered (b) Two layered
(c) Three layerd (d) Naked

11. Which among the followings are agarophytes
(a) *Ectocarpus* and *Fucus* (b) *Gelidium* and *Gracilaria*
(c) *Laminaria* and *Sphacelaria* (d) *Batrachospermum* and *Dictyota*

12. Photosynthetic pigments phycobilisomes are found in
(a) Cyanophyta (b) Rhodophyta
(c) Both of the above (d) None of the above

13. The gonimoblast filaments are found in
(a) Gametophyte of Phaeophyta (b) Sporophyte of Phaeophyta
(c) Gametophyte of Rhodophyta (d) Tetrasporophyte of Rhodophyta

14. Which among the followings red algae, the carpogonial branch is single celled
(a) *Gelidium* (b) *Gracilaria*
(c) *Batrachospremum* (d) *Polysiphonia*

15. Preferred habitat for *Batrachospermum* is
(a) Intertidal zone (b) Littoral zone
(c) Freshwater streams (d) Rocky Mountains

16. Thallus of *Gracilaria* is
(a) Heterotrichous filamentous (b) Uniseriate filamentous
(c) Foliose parenchymatous (d) Terete and branched

17. In red algae, the cystocarp consists of
(a) A part of gametophytic thallus, gonimoblast filaments and carposporangia
(b) Gonimoblast filaments, and carposporangia only
(c) Only carposporangia
(d) None of the above

18. In Rhodophyta, carposporangia are formed from
(a) Basal cell of gonimoblast filaments (b) Apical cell of gonimoblast filaments
(c) Intercalary cells of tetrsporophyte (d) Apical cell of tetrasoprophyte

19. In *Polysiphonia*, the gametangia develop from
(a) Tetrasporophytes (b) Carposporophytes
(c) Gonimoblast filaments (d) Trichoblast filaments

20. Which among the following statement is true about carposporophytes –
(a) It is a life cycle stage of Chlorophyta (b) It is a life cycle stage is Xathophyta

(c) It is a life cycle stage of Phaeophyta (d) It is a life cycle stage of Rhodophyta

6.7.1 Answer key: 1.Phycoerythrine, 2. Phaeophyta, 3. Brown algae, 4. Rhodophyta, 5. Two, 6. Laminarin, 7. Red algae, 8. Ectocarpene, 9. Heteromorphic, 10. Chantrantia stage 11. Floridian starch, 12. Spermatia, 13. Red algae, 14. Red algae 15. Cystocarp 16. *Batrachospermum*

6.7.2 Answer key: 1.(b), 2.(b), 3.(c), 4.(a), 5.(c), 6.(a), 7.(c), 8.(a), 9.(d), 10.(c), 11.(b), 12.(c), 13.(c), 14.(a), 15.(c), 16.(d), 17.(a),18.(b), 19.(d),20.(d)

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6.10 TERMINAL QUESTIONS

6.10.1- Long answer type questions

Q.1. Compare the morphological characters of Phaeophyta and Rhodophyta along with cytological details.
Q.2. "Reporduction in Rhodophyta is the most complex among all the groups of algae". Justify the statement giving suitable examples.
Q.3. Describe the reproductive behavior of the gametophytic and sporophytic generations of the *Ectocarpus*.
Q.4. Why *Laminaria* is considered as highly evolved genus of the Phaeophyta? Explain in detail.
Q.5. Giving suitable example, describe the heteromorphic life cycle of an alga belonging to Phaeophyta.
Q.6. Describe the triphasic life cycle pattern found in Red algae with suitable diagrams.

6.10.2 Short answer type questions

Q.1. Describe the different types of sporangia found in *Ectocarpus*.
Q.2. Give details about the thallus organization of *Laminaria*.
Q.3. Write a short note on economic importance of brown algae.
Q.4. Describe the habit and habitat of *Dictyota*.
Q.5. Describe reproductive structures of genus *Fucus*.
Q.6. Write comments upon agarophytes.
Q.7. Write short note on structure and development of carposporophytes.
Q.8. Give an account on different types of spores found in red algae.
Q.9. What are tetrasporophytes? How do they differ from carposporophytes?
Q.10. Describe the post-fertilization changes found in genus *Polysiphonia*.
Q.11. Give a comparative account on morphological features of *Gracilaria* and *Gelidium*.
Q.12. Differentiate the thallus structure of *Batrachospermum* and *Polysiphonia*.

BLOCK-3 BRYOPHYTES

UNIT-7 GENERAL CHARACTERISTICS, DISTRIBUTION, REPRODUCTION, ECONOMIC AND ECOLOGICAL IMPORTANCE

7.1 OBJECTIVES

After reading this unit students will be able-

- to Identify the main characteristics of Bryophytes
- to know about Origin of Bryophytes.
- to know about Distribution and habitat of the bryophytes
- to Describe the events in the bryophyte lifecycle
- to understand What is the ecological importance of Bryophytes?
- to Draw a life cycle diagram of a Bryophyte
- to Describe vegetative and sexual reproduction in Bryophytes.

7.2 INTRODUCTION

Bryophytes (nonvascular plants) are the only embryophytes (plants that produce an embryo) whose life history includes a dominant gametophyte (haploid) stage. They are an ancient and diverse group of non-vascular plants. Bryophyta (Gr. Bryon = mass; phyton = plant), a division of kingdom Plantae comprises of Mosses, Hornworts and Liverworts. They are groups of green plants which occupy a position between the thallophytes (Algae) and the vascular cryptogams (Pteridophytes). Bryophytes produce embryos but lack seeds and vascular tissues. They are the most simple and primitive group of Embryophyta. Bryophytes grow in two habitats i.e. water and land so known as amphibians of plant kingdom. They are said to be the first land plants or non-vascular land plants. They cannot reproduce without sufficient moisture because without water sex organs neither matures nor dehisces. Presence of swimming antherozoids is an evidence of their aquatic ancestory. They comprise three main taxonomic groups: mosses (Bryophyta), liverworts (Marchantiophyta or Hepatophyta) and hornworts (Anthocerotophyta) which have evolved quite separately.

Most bryophytes have erect or creeping stems and tiny leaves, but hornworts and some liverworts have only a flat thallus and no leaves. There are possibly 25,000 species of mosses and liverworts all over the world.

Origin of Bryophytes

Nothing definite is known about the origin of Bryophytes because of the very little fossil record. There are two views regarding the origin of Bryophytes.

These are:

(i) Algal hypothesis of the origin of Bryophytes.

(ii) Pteridophytean hypothesis of the origin of Bryophytes.

(i) Algal Hypothesis of Origin:

There is no fossil evidence of origin of Bryophytes from algae but Bryophytes resemble with algae in characters like-amphibious nature, presence of flagellated antherozoids and necessity of water for fertilization.This hypothesis was supported by Bower (1908), Fritsch (1945) and Smith (1955) etc. According to Fritsch (1945) and Smith (1955) Bryophytes have been originated from the heterotrichous green algae belonging to the order Chaetophorales for e.g., Fritschiella, Coleochaete and Draparnaldiopsis.

(ii) Pteridophytean Hypothesis of Origin:

According to this hypothesis Bryophytes are descendent of Pteridophytes. They are evolved from Pteridophytes by progressive simplification or reduction.This hypothesis is based on certain characters like-presence of type of stomata on the sporogonium of Anthoceros and apophysis of mosses similar to the vascular land plants, similarly in the sporophytes of some Bryophytes (e.g., Anthoceros, Sphagnum, Andreaea) with some members of Psilophytales of Pteridophytes (e.g., Rhynia, Hormophyton etc.)This hypothesis was supported by Kashyap (1919), Christensen (1954), Proskaner (1961), Mehra (1969) etc.

7.3 GENERAL CHARACTERISTICS

1. Small group of primitive land dwellers having small leafy or thalloid green plant body.
2. Like thallophytes plant body is gametophytic, independent, dominant, autotrophic, either thalloid (i.e., thallus like, not differentiated into root, stem and leaves) or foliose, containing a rootless leafy shoot.
3. Plant body is very small and ranges from a few mm too many cm. Zoopsis is the smallest bryophyte (5 mm.) while the tallest bryophyte is *Dawsonia* (50-70 cm.).
4. Leaves and stems found in vascular plants are absent, these **'leaf'** and **'stem'** like structures as **'axis'** and **'phylloid'** respectively.
5. Roots are absent. Functions of the roots are performed by rhizoids. Cells are also capable to absorb moisture directly from the ground or atmosphere. Therefore, Bryophytes can also survive on the moist soils.
6. Rhizoids may be unicellular, un-branched (e.g., *Riccia, Marchantia, Anthoceros*) or multicellular and branched (e.g., *Sphagnum, Funaria*).
7. In members of order Marchantiales (e.g., *Riccia, Marchantia*) scales are present. These are violet coloured, multicellular and single cell thick. They protect the growing point and help to retain the moisture.
8. Vascular tissue (xylem and phloem) is completely absent. Water and food material is transferred from cell to cell. However, in some Bryophytes (e.g., mosses) a few cells in groups of 2-3 are present for conduction of water and translocation of food (photo assimilate). These

cells are known as hydroid (collectively hydrom) and leptoids respectively. Cuticle and stomata are absent.

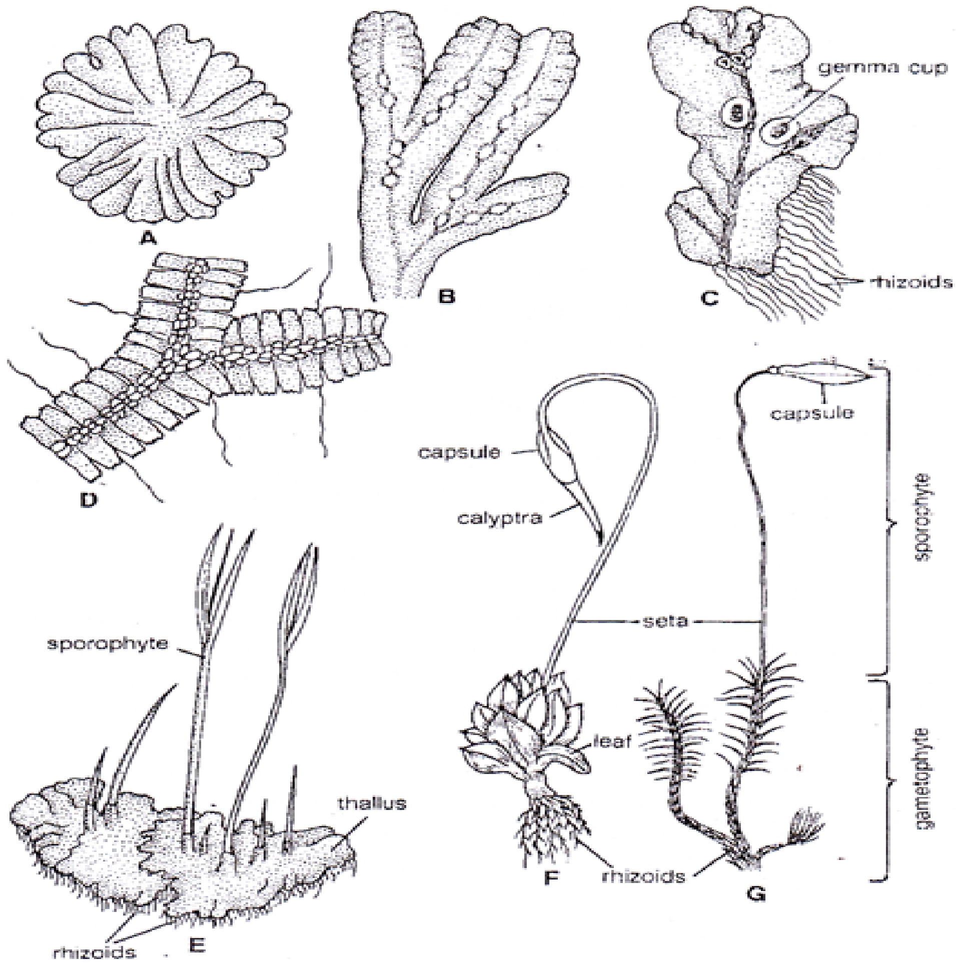

Fig.7.1. External Features of Bryophytes (A) *Riccia* rosette (B) *Riccia* Thallus (C) *Marchantia* (D) *Porella* (E) *Anthoceros* (F) *Funaria* (G) *Polytrichum*

9. Sexual reproduction is invariably highly oogamous. The sex organs are jacketed and multicellular while in algae they are non-jacketed and unicellular.
10. Female sex organ is archegonium appears for the first time in bryophytes.
11. Sperms are biflagellate and both the flagella are of whiplash type.
12. Fertilization takes place in the presence of water or moisture.
13. Fertilized egg remains in the venter of the archegonia. It neither becomes independent from parent gametophyte nor passes into resting period. In both these respect the bryophyte differs from algae.
14. Zygote undergoes repeated divisions to form an undifferentiated multicellular structure called the embryo.
15. First division of the zygote is transverse and the apex of the embryo develops from the outer cell. Such embryogenesis is called exoscopic.

16. The venter wall enlarges to produce a protective multicellular envelop called calyptra.
17. The embryo by further division and differentiation produce a relatively small spore producing structure which is not independent. It is called sporogonium (sporophyte).
18. Sporophyte is rootless and consists of foot, seta and capsule. In some seta is absent (Corsinia) and rarely the both foot and seta (Riccia).
19. Sporophyte remains attached with gametophyte throughout its life and also depends on it partially or wholly for nutrition.
20. Sporophyte produces spores which are wind disseminated, non-motile and cutinized, also called meiospores.
21. Morphologically all the meiospores in a given species are alike, thus known as homosporous.
22. Each spore under suitable conditions germinates to give rise gametophyte plant directly or indirectly as lateral bud from protonema.
23. Heterologous type of alternation of generation in the life cycle of bryophytes while in algae it is of homologous type.

7.4 DISTRIBUTION

Bryophytes are distributed throughout the world, from polar and alpine regions to the tropics. Water must, at some point, be present in the habitat in order for the sperm to swim to the egg. Bryophytes do not live in extremely arid sites or in seawater, although some are found in perennially damp environments within arid regions and a few are found on seashores above the intertidal zone. A few bryophytes are aquatic. Bryophytes are most abundant in climates that are constantly humid and equable. The greatest diversity is at tropical and subtropical latitudes. Bryophytes (especially the moss *Sphagnum*) dominate the vegetation of peatland in extensive areas of the cooler parts of the Northern Hemisphere.

The geographic distribution patterns of bryophytes are similar to those of the terrestrial vascular plants, except that there are many genera and families and a few species of bryophytes that are almost cosmopolitan. Indeed, a few species show extremely wide distribution. Some botanists explain these broad distribution patterns on the theory that the bryophytes represent an extremely ancient group of plants, while others suggest that the readily dispersible small gemmae and spores enhance wide distribution. The distribution of some bryophytes, however, is extremely restricted, yet they possess the same apparent dispersibility and ecological plasticity as do widespread bryophytes. Others show broad interrupted patterns that are represented also in vascular plants.

Bryophytes are represented by 960 genera and 25,000 species. They are cosmopolitan in distribution and are found growing both in the temperate and tropical regions of the world at an altitude of 4000-8000 feet.In India, Bryophytes are quite abundant in both Nilgiri hills and Himalayas; Kullu, Manali, Shimla, Darjeeling, Dalhousie and Uttarakhand are some of the hilly regions which also have a luxuriant growth of Bryophytes. Eastern Himalayas have the richest in

bryophytic flora. A few species of Riccia, Marchantia and Funaria occur in the plains of U.P., M.P. Rajasthan, Gujarat and South India.
In hills they grow during the summer or rainy season. Winter is the rest period. In the plains the rest period is summer, whereas active growth takes place during the winter and the rainy season. Some Bryophytes have also been recorded from different geological eras e.g., *Muscites yallourensis* (Coenozoic era), *Intiavermicularies, Marchantia* spp. (Palaeozoic era) etc.

7.5 HABITAT

Bryophytes grow densely in moist and shady places and form thick carpets or mats on damp soils, rocks, bark of trees especially during rainy season. Small in size, but they can be very conspicuous growing as extensive mats in woodland, as cushions on walls, rocks and tree trunks, and as a pioneer colonists of disturbed habitats.

Majority of the species are terrestrial but a few species grow in fresh water (aquatic) e.g., *Riccia fluitans, Ricciocarpos natans, Riella* etc. Bryophytes are not found in sea but some mosses are found growing in the crevices of rocks and are being regularly bathed by sea water e.g., *Grimmia maritime.* Some bryophytes also grow in diverse habitats e.g., *Sphagnum*-grows in bogs, Dendroceros-epiphytic, *Radulaprotensa*-epiphyllous, *Polytrichum juniperinum*- xerophytic, *Tortula muralis*-on old walls. *Tortula desertorum* in deserts, *Porella platyphylla*-on dry rocks, *Buxbaumia phylla* (moss) and *Cryptothallus mirabilis* (liverwort) are saprophytic.

7.6 LIFE CYCLE

The life cycle of bryophytes shows two distinct phases namely a haploid gametophytic phase and a diploid sporophytic phase alternating with each other. The adult plant body represents the gametophyte. A short-lived sporophyte occurs as a parasite on the gametophyte.

Gametophyte: A stage in the life cycle of bryophyte that undergoes alternation of generations. It is a haploid multicellular organism that develops from a haploid spore that has one set of chromosomes. The gametophyte is the sexual phase in the life cycle of bryophytes. It develops sex organs that produce gametes, haploid sex cells that participate in fertilization to form a diploid zygote in which each cell has two sets of chromosomes. Cell division of the zygote results in a new diploid multicellular organism, the second stage in the life cycle known as the sporophyte, the function of which is to produce haploid spores by meiosis.

In bryophytes (mosses, liverworts, and hornworts), the gametophyte is the most visible stage of the life cycle. The bryophyte gametophyte is longer lived, nutritionally independent, and the sporophytes are typically attached to the gametophytes and nutritionally dependent on them. It is the adult plant body in bryophytes. It is either thalloid or in the form of a leafy shoot with stem-like and leaf-like structures. Roots are absent and instead thread-like rhizoids are present. Vascular tissues xylem and phloem are absent. Water and food are directly transported from a cell to cell. Vegetative reproduction may sometimes occur by fragmentation. However, sexual reproduction is common and is of oogamous type. The mature gametophyte bears male reproductive organs called antheridia and female reproductive organs called archegonia. The antheridia have a club-shaped body and a stalk. They produce flagellated male gametes called antherozoids or sperms. The archegonia are flask-shaped with a well-defined venter and neck. The venter encloses a venter canal cell and an egg cell while the neck encloses a variable number of neck canal cells.

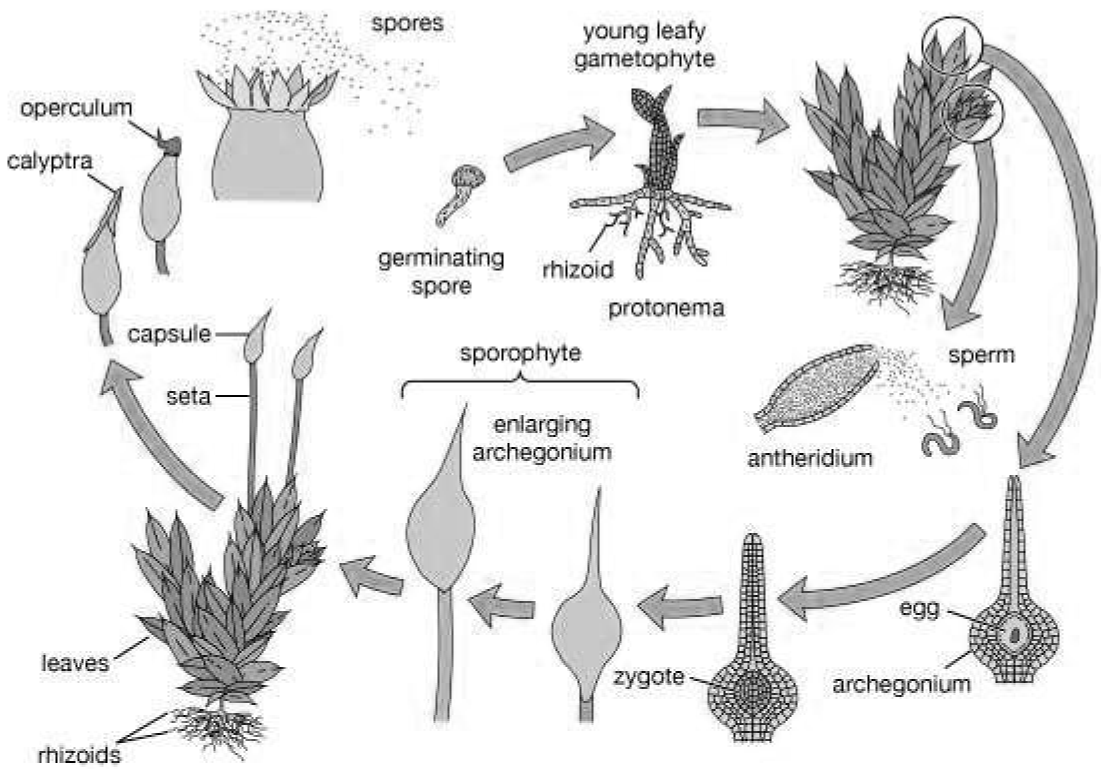

Fig.7.2.Moss Life Cycle

The antherozoids liberated from antheridia, swim in a film of water and reach the archegonia. They are attracted into the archegonia to bring about fertilization. The zygote develops into the sporophyte.

Sporophyte: Zygote represents the first cell of the sporophytic phase. It divides and develops into a sporophytic plant body called sporogonium. It is neither independent of the parent gametophyte nor passes into the resting phase. In both respects differs from the zygote of green algae. Further development of zygote into embryo occurs within venter of the archegonium. Zygote undergoes segmentation without a resting period into multicellular, undifferentiated structure called embryo. Embryo by further segmentation and differentiation finally develops into full-fledged sporophyte called sporogonium. The wall of venter forms a protective covering to the sporogonium, called calyptra. Sporogonium in bryophytes is leafless and rootless. Most often, the sporogonium is differentiated into a foot, a seta and a capsule. It remains attached throughout its life to the gametophytic host with the help of foot. It absorbs nutrients directly from the gametophyte. In some bryophytes the foot is much reduced and its function is performed by haustorial collar which develops from the junction of reduced foot and seta. Seta conducts the absorbed food to the capsule. The terminal capsule is considered equivalent to fern sporangium is mainly concerned in the production of spores which are nonmotile and wind disseminated.

The sporogonium produces haploid spores (meiospores) which get released from the capsule. Spores are highly specialized cells differentiated from the diploid spore mother cell by meiosis. They are thus haploid cells. The spores represent the first cells of gametophytic generation. They germinate under suitable condition to produce new gametophytes either directly or through a juvenile stage called protonema.

Another remarkable feature in the lifecycle of bryophyte in which they differ from thallophytes is the complete absence of asexual spores called the mitospores in the life cycle. Asexual reproduction takes place only by the vegetative method of fragmentation and gemmae.

7.7 REPRODUCTION IN BRYOPHYTES

Bryophytes reproduce only by vegetative and sexual means. Asexual reproduction is absent in these.

A. Vegetative Reproduction in Bryophytes:

Bryophytes possess a characteristic feature and that is their tendency towards extensive vegetative reproduction. The vegetative reproduction takes place in favourable season for vegetative growth. Majority of the bryophytes propagate vegetatively and it is brought about in many ways.

1. By Death and Decay of the Older Portion of Thallus or by Fragmentation: In Bryophytes the growing point is situated at the tip of the thallus. The basal, posterior or older portion of the thallus starts rotting or disintegrating due to ageing or drought. When this process of disintegration or decay reaches up to the place of dichotomy, the lobes of the thallus get separated. These detached lobes or fragments develop into independent plants by apical growth. This is the most common method of vegetative reproduction in *Riccia, Marchantia, Anthoceros* and some mosses like *Sphagnum.*

2. **By Persistent Apices:** Due to prolonged dry or summer or towards the end of growing season the whole thallus in some bryophytes (e.g., *Riccia, Anthoceros, Cyathodium*) dries and get destroyed except the growing point. Later, it grows deep into the soil and becomes thick. Under favourable conditions it develops into a new thallus.

3. **By Tubers:** Tubers are formed in those species which are exposed to desiccations (drying effect of the air). Towards the end of the growing season, the subterranean branches get swollen at their tips to from the underground tubers. On the periphery of a tuber are two to three layers of water proof, corky, hyaline cells develop.

These layers surround the inner cells which contain starch, oil globules and albuminous layers. During the unfavorable conditions the thallus dies out but the dormant tubers remain unaffected. On the return of the favourable conditions each tuber germinates to form a new plant e.g., *Riccia*, *Anthoceros*, *Fossombronia* etc. Thus, tubers also serve as organ of perennation.

4. By Gemmae: Gemmae are multicellular reproductive bodies of various shapes and colours. These are produced in gemma cups, on the surface and axil of the leaves, on stem apex or even inside the cells. They get detached from the parent plant and after falling on a suitable substratum gemmae give rise to a new individual directly (e.g., *Marchantia*) or indirectly (e.g., Mosses).

5. By Adventitious Branches: The adventitious branches develop from the ventral surface the thallus e.g., *Riccia fluitans* and *Anthoceros*. On being detached from the parent plant these branches develop into new thalli. In *Marchantia, Dumortiera* these branches develop from archegoniophore while in *Pellia* these branches arise from the dorsal surface or margins of the thallus called automnal fronds.

6. **By Regeneration:** The liverworts possess an amazing power of regeneration. Part of the plant or any living cell of the thallus (e.g., rhizoid, scales) are capable of regenerating the entire plant. e.g., *Riccia, Marchantia* etc.

7. **By Innovation:** In *Sphagnum* one of the branches in the apical cluster instead of forming drooping branches or divergent branches, develop more vigorously than the others and continues the growth upwards. This long upright branch has all the characteristics of main axis. It is called innovation. Due to progressive death and decay of the parent plant these innovation become separated from the parent plant and establish themselves as parent plants.

8. By Primary Protonema: Primary protonema is the filament like stage produced by the developing spores of the mosses. It produces the leafy gametophores. It breaks into short filament of cells by the death of cells at intervals. Each detached fragment grows into a new protonema which bears a crown of leafy gametophores e.g., *Funaria*.

9. By Secondary Protonema: The protonema formed by other methods than from the germination of spores is called secondary protonema. It may develop from any living cells of the leafy gametophore i.e., from leaf, stem, rhizome, injured portion of the leafy gametophore, antheridium, paraphysis or archegonium. From this arise the leafy gametophores or lateral buds in the same manner as in primary protonema e.g., *Funaria, Sphagnum.*

10. By Bulbils: These are small resting buds develop on rhizoids. Bulbils are devoid of chlorophyll but full of starch. On germination bulbils produce a protonema which bears leafy gametophores

11. By Apospory: The production of diploid gametophyte from the unspecialized sporophyte without meiosis is known as apospory e.g., *Anthoceros*. In *Funaria* green protonemal filaments may arise from the unspecialized cells of the various parts of sporogonium. These protonemal filaments bear lateral buds which develop into leafy gametophores.

12. By Rhizoidal Tips: The apical part of the young rhizoids divide and re-divide to form a gemma like mass of cells e.g., *Riccia glauca*. These cells contain chloroplast and are capable to develop into new thallus.

B. Sexual Reproduction in Bryophytes

1. Sexual reproduction is highly oogamous.
2. Male and female sex organs are known as antheridia (Sing, antheridium) and archegonia (Sing, archegonium), respectively.
3. Sex organs are jacketed and multilayered.
4. Antheridium is stalked, pear shaped or oblong and has an outer one cell thick jacket which encloses a mass of fertile cells called androcytes. Each androcyte metamorphoses into biflagellate antherozoid.
5. Archegonium is stalked, flask shaped structure. It has a basal swollen portion called venter and an elongated neck. The neck is filled with many neck canal cells whereas venter has a large egg cell and a small venter canal cell.
6. Antherozoids are attracted towards the neck of the archegonium chemotactically by certain substances (like sugars, malic acid, proteins, inorganic salts of potassium etc.) present in the mucilaginous substance formed by the degeneration of neck canal cells and venter canal cell.
7. Water is essential for fertilization.
8. The fertilized egg or zygote is the beginning of the sporophytic phase. It is retained within the venter of the archegonium.

Sporophyte

1. Without resting period, the zygote undergoes repeated divisions to form a multicellular structure called the embryo.
2. The first division of the zygote is always transverse and the outer cell develops into embryo. Such an embryogeny is called exoscopic.
3. Embryo develops into a sporophyte or sporogonium.
4. The sporophyte is usually differentiated into foot, seta and capsule. In certain cases it is represented only by capsule (e.g., *Riccia*) or by foot and capsule (e.g., *Corsinia*).
5. Sporophyte is attached to parent gametophytic plant body throughout its life. It partially or completely depends on it for nutrition.
6. Foot is basal, bulbous structure. It is embedded in the tissue of parent gametophyte. Its main function is to absorb the food material from the parent gametophyte.
7. Seta is present between the foot and capsule. It elongates and pushes the capsule through protective layers. It also conducts the food to the capsule absorbed by foot.
8. Capsule is the terminal part of the sporogonium and its function is to produce spores
9. All Bryophytes are homosporous i.e., all spores are similar in shape, size and structure

10. Capsule produces sporogenous tissue which develops entirely into spore mother cells it e.g., *Riccia*) or differentiated into spore mother cells and elater mother cells (e.g., *Marchantia* and, *Anthoceros*).
11. Spore mother cells divide diagonally to produce asexually four haploid spores which are arranged in tetrahedral tetrads.
12. Elater mother cells develop into elaters (e.g., *Marchantia*) or pseudo elaters (e.g., *Anthoceros* which are hygroscopic in nature. Elaters are present in liverworts and absent in mosses.
13. Venter wall enlarges with the developing sporogonium and forms a protective multicellular layer called calyptra (gametophytic tissue enclosing the sporophyte).

Young Gametophyte

1. The meiospore (spore formed after meiosis) is the first cell of the gametophytic phase.
2. Each spore is unicellular, haploid and germinates into young gametophytic plant (e.g., *Riccia* or *Marchantia*) or first germinates into a filamentous protonema on which buds are produced to give rise to a young gametophytic plant, (e.g., *Funaria*).

Alternation of Generation: The life-cycle of a bryophyte shows regular alternation of gametophytic and sporophytic generations. This process of alternation of generations was demonstrated for the first time in 1851 by Hofmeister. Thereafter in 1894 Strassburger could actually show the periodic doubling and halving of the number of chromosomes during the life-cycle.

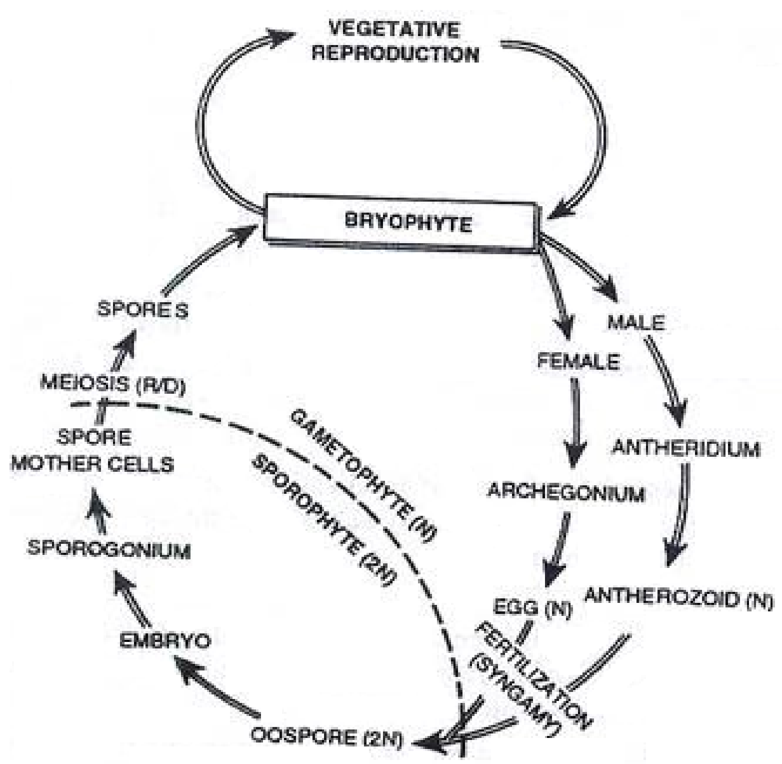

Fig.7.3. Bryophytes life cycle (Graphic Representation)

The haploid phase (n) is the gametophyte or sexual generation. It bears the sexual reproductive organs which produce gametes, i.e., antherozoids and eggs. With the result of gametic union a zygote is formed which develops into a sporophyte. This is the diploid phase (2n). The sporophyte produces spores which always germinate to form gametophytes.
During the formation of spores, the spore mother cells divide meiotically and haploid spores are produced. The production of the spores is the beginning of the gametophytic or haploid phase. The spores germinate and produce gametophytic or haploid phase which bear sex organs.

Ultimately the gametic union takes place and zygote is resulted. It is diploid (2n). This is the beginning of the sporophytic or diploid phase. This way, the sporophyte generation intervenes between fertilization (syngamy) and meiosis (reduction division); and gametophyte generation intervenes between meiosis and fertilization.

Resemblance with Algae

1. Thalloid plant body.
2. Absence of roots.
3. Absence of complex vascular bundles.
4. Autotrophic mode of nutrition.
5. Need of water during fertilization.
6. Presence of chlorophyll pigments.
7. Reserve food material is true starch.
8. Cell wall consists of cellulose which surrounds by a pectic layer containing galacturonic acid.

Difference between Bryophytes and Algae

S.No.	Bryophytes	Algae
1-	Grow in moist and shady places as well as in water and called ‘Amphibians of plant kingdom.	They are usually aquatic in habitat.
2-	Tissue differentiation is well developed	Tissue differentiation is found only in higher forms.
3-	Only oogamous type of sexual reproduction is present.	Isogamous, anisogamous and oogamous type of sexual reproduction.
4-	Sex organs are multicellular covered by sterile jacket layer.	Sex organs are unicellular not covered by sterile jacket layer.
5-	Female sex organ is archegonia.	Female sex organ is oogonia.
6-	Zygote remains enclosed in the archegonium	Zygote liberated from the plant.
7-	Gametophyte phase is dominant.	Usually sporophyte phase is dominant.

8-	Sporophyte is dependent upon gametophyte.	Sporophyte is independent of gametophyte.
9-	Embryo is produced from zygote.	Embryo is never produced.
10-	Sporophyte is differentiated into foot, seta and capsule.	There is no such differentiation.
11-	Microspore absent.	Microspore usually present.

7.8 ECONOMIC IMPORTANCE

Economically bryophytes are very important and are used in many ways:

1. Sphagnum is the chief constituent of peat, which is used as fuel, in preparation of ethyl alcohol, peat tar, ammonia, paraffin etc. In horticulture to improve the soil texture and even in surgical dressings.
2. Sphagnum has the capacity to retain the water for long period of time and is used to cover the plant roots during transportation.
3. Some mosses which grow in pools settle to bottom on their death and this helps in soil formation in water bodies. Even in rocks as well they help in soil formation.
4. Some bryophytes are used as bed for animals.
5. Also used as seed bed due to water retention capacity.
6. Bryophytes are used as soil binders when grow in aggregation.
7. Some bryophytes are used as fodder for animals.
8. Peat tar known as sphagnol is used in skin disease.
9. Many species having antibiotic activity so used against microorganisms.
10. Also used as experimental material for example- the mechanism of sex determination in plants was discovered in a liverwort *Sphaerocarpus*.
11. Bryophytes are very good atmospheric and water pollution indicators as well
12. Some bryophyte species are reliable indicators of mineralization.

7.9 ECOLOGICAL IMPORTANCE

1. Bryophytes are of great ecological importance due to following reasons:

(a) Pioneer of the land plants- Bryophytes are pioneer of the land plants because they are the first plants to grow and colonize the barren rocks and lands.

(b) Bryophytes prevent soil erosion- They usually grow densely and hence act as soil binders. Mosses grow in dense strands forming mat or carpet like structure.

They prevent soil erosion by:

(i) Bearing the impact of falling rain drops

(ii) Holding much of the falling water and reducing the amount of run-off water.

(c) Formation of soil- Mosses and lichens are slow but efficient soil formers. The acid secreted by the lichens and progressive death and decay of mosses help in the formation of soil.

(d) Bog succession- Peat mosses change the banks of lakes or shallow bodies of water into solid soil which supports vegetation e.g., *Sphagnum*

(e) Rock builders- Some mosses in association with some green algae (e.g., *Chara*) grow in water of streams and lakes which contain large amount of calcium bicarbonate. These mosses bring about decomposition of bi-carbonic ions by abstracting free carbon dioxide. The insoluble calcium carbonate precipitates and on exposure hardens, forming calcareous (lime) rock like deposits.

2. Formation of Peat: Peat is a brown or dark colour substance formed by the gradual compression and carbonization of the partially decomposed pieces of dead vegetative matter in the bogs. Sphagnum is an aquatic moss. While growing in water it secretes certain acids in the water body. This acid makes conditions unfavorable for the growth of decomposing organisms like bacteria and fungi. Absence of oxygen and decomposing microorganisms slows down the decaying process of dead material and a large amount of dead material is added year by year. It is called peat (that is why Sphagnum is called peat moss).

3. As Packing Material: Dried mosses and bryophytes have great ability to hold water. Due to this ability the bryophytes are used as packing material for shipment of cut flowers, vegetables, perishable fruits, bulbs, tubers etc.

4. As Bedding Stock: Because of great ability of holding and absorbing water, in nurseries beds are covered with thalli of bryophytes.

5. In Medicines: Some Bryophytes are used medicinally in various diseases for e.g.,

(a) Pulmonary tuberculosis and affliction of liver—Marchantia spp.

(c) Acute hemorrhage and diseases of eye—Decoction of Sphagnum.

(d) Stone of kidney and gall bladder—Polytrichum commune.

(e) Antiseptic properties and healing of wounds—Sphagnum leaves and extracts of some bryophytes for e.g., Conocephalum conicum, Dumortiera, Sphagnum protoricense, S. strictum show antiseptic properties.

6. In Experimental Botany: The liverworts and mosses play an important role as research tools in various fields of Botany such as genetics. For the first time in a liverwort, Sphaerocarpos, the mechanism of sex determination in plants was discovered.

7. As Food: Some Bryophytes e.g., mosses are used as food by chicks, birds and Alaskan reindeer etc.

7.10 SUMMARY

1. Bryophytes are photosynthetic non vascular land plants (terrestrial) with some aquatic forms. Thalloid and attached to the substratum by hair-like structures called rhizoids (true roots are

absent) or is differentiated into stem-like (caulalia) and leaf-like structures (phyllids), true stems and leaves lacking.

2. The bryophytes show alternation of generations - the haploid gametophyte alternates with diploid sporophyte.
3. Gametophytes homothallic or heterothallic. The gametophyte generation is dominant, conspicuous and independent.
4. Vegetative reproduction may sometimes occur by fragmentation. However, sexual reproduction is common and is of oogamous type.
5. The mature gametophyte bears male reproductive organs called antheridia and female reproductive organs called archegonia.
6. They produce flagellated male gametes called antherozoids or sperms. The archegonia are flask-shaped with a well-defined venter and neck. The venter encloses a venter canal cell and an egg cell while the neck encloses a variable number of neck canal cells.
7. The antherozoids liberated from antheridia, swim in a film of water and reach the archegonia. They are attracted into the archegonia to bring about fertilization.
8. The zygote develops into the sporophyte. The diploid sporophyte usually consists of a basal foot, an elevating seta and a terminal sporangium - the capsule. The sporophyte is attached and dependent upon the gametophyte for nutrition i.e. is parasitic on the gametophyte.
9. Spores are produced as a direct result of meiosis. Spores dispersed by a mechanism which ensures dispersal in dry weather only.

7.11 GLOSSARY

Abaxial – facing away from the axis of plant

Antheridium – The male sex organ of the Cryptogam

Androcyte – Antherozoid mother cell.

Antherozoid – Small, motile male gamete with flagella

Archegonium – The female sex organ of bryophytes, pteridophytes and gymnosperms containing the egg inside a cellular jacket.

Archesporium – Group of cells from which the spores of a sporangium are derived.

Autoecious – Having the male and female reproductive organs on the same plant but in separate branches.

Bryophyte: a non-vascular, green plant with a gametophyte generation that is free-living and a comparatively ephemeral sporophyte; a collective name for mosses, liverworts and hornworts.

Calyptra (pl. **calyptrae**)**:** a membranous or hairy hood or covering that protects the maturing sporophyte; derived largely from the archegonial venter.

Capsule: the terminal, spore-producing part of a moss sporophyte.

Cushion: a more-or-less hemispherical or rounded moss colony, with stems generally erect and tightly clustered but radiating somewhat to form a tuft.

Dehiscent: *of capsules*, splitting open by means of an annulus, operculum or valves

Dimorphic: of two distinct forms, e.g. leaves, male and female plants.
Diploid: a cell, individual or generation with two sets of chromosomes (*2n*); the typical chromosome level of the sporophyte generation.
Dorsiventral: flattened with distinct upper and lower surfaces.
Endothecium: in most mosses, the inner embryonic tissue of a capsule which gives rise to all tissues interior to the outer spore sac. In *Sphagnum* it also produces the columella.
Epiphyllous: a plant that grows on the living leaves of another plant.
Epiphyte: a plant that grows on the surface of another plant.
Elater – elongate sterile cells, usually hygroscopic, admixed among spores of most hepatics and hornworts.
Embryo – the early developmental stage of a sporophyte.
Embryophyta – plant that bears an embryo.
Filamentous: thread-like.
Foot: the basal organ of attachment and absorption for the bryophyte sporophyte, embedded in the gametophyte.
Gametangium (pl. gametangia): an antheridium or archegonium; a structure forming gametes (ovum, spermatozoid).
Gemma (pl. **gemmae**)**:** uni- or multi-cellular, globose, clavate, filiform, cylindrical or discoid structures, borne on the aerial part of the plant and functioning in vegetative reproduction.
Habit: general appearance.
Heteroicous: having several forms of gametangia on the same plant; also called polygamous, polyoicous.
Hornwort: a member of class Anthocerotopsida.
Oogamy – fusion of two dissimilar gametes, a small, motile male gamete with the large, immotile female gamete
Peristome: a circular structure generally divided into 4, 8, 16 or 32 teeth arranged in single or double (rarely multiple) rows around the mouth of the capsule and visible after dehiscence of the operculum.
Polyploid: a plant or tissue with more than 2 complete sets of chromosomes.
Prosenchyma: a tissue consisting of narrow, elongate cells with overlapping ends.
Protandrous: maturation of the antheridia prior to the archegonia.
Protonema (pl. **protonemata**)**:** a filamentous, globose or thallose structure resulting from spore germination and including all stages up to production of one or more gametophores. The protonema varies in the amount of chlorophyll present and the degree of obliqueness of its end walls, and in its branching.
Paleozoic – pertaining to an era occurring between 570 and 230 million years ago, characterized by the advent of fish, insects and reptiles
Permian – a period of geologic time beginning approximately 280 million years ago and lasting 55 million years.
Triassic – a period of geologic time beginning 225 million years ago and lasting 35 million years

Rhizoid: a hair-like structure that anchors a moss to the substratum; multicellular with oblique cross walls, often pigmented, and sometimes clothing the stem.
Rhizome: a slender horizontal, subterranean stem giving rise to erect secondary stems; e.g. in *Dawsonia* and *Rhodobryum*.
Saxicolous: growing on rock.
Scleroderm: a tissue of thick-walled cells in the central cylinder of stems and branches of *Sphagnum*.
Seta (pl. **setae**)**:** the elongated portion of the sporophyte between the capsule and the foot.
Spore: a minute, usually spherical, haploid cell produced in the capsule as a result of meiosis; its germination gives rise to the protonema.
Spore sac: a spore-containing cavity in a moss capsule.
Sporocyte: a diploid cell that undergoes meiosis in the capsule to produce 4 haploid spores; sometimes called a spore mother cell.
Sporophyte: the spore-bearing generation; initiated by the fertilization of an ovum; consists of foot, seta and capsule; attached to and partially dependent on the gametophyte.

7.12 SELF ASSESSMENT QUESTION

7.12.1 Multiple Choice Questions:

1. Which one of the following is a non-vascular embryophyte?
(a) Thallophyta (b) Bryophyta
(c) Pteridophyta (d) All the above

2. The largest bryophyte is-
(a) *Funaria* (Moss) (b) *Marchantia*
(c) *Megaceros* (d) *Dawsonia*

3. Who amongst the following is regarded as the "Father of Indian Bryology"
(a) Prof. K.C. Mehta (b) Prof. D.D. Pant
(c) Prof. S.R. Kashyap (d) Prof. P.N. Mehra

4. Heteromorphic alternation of generation is commonly found in
(a) Algae (b) Fungi
(c) Bryophyta (d) All the above

5. Venter is the part of
(a) Sporogonium (b) Sporangium
(c) Antheridium (d) Archegonium

6. Archesporium is
(a) A diploid tissue responsible for the formation of sporogenous tissue
(b) A part of archegonia
(c) A haploid tissue responsible for the formation of gametophytic cells
(d) None of the above

7. In which of the following groups would you place a plant which produces spores and embryos but lacks seeds and vascular tissue
(a) Fungi (b) Bryophytes
(c) Pteridophytes (d) Gymnosperms

8. Bryophytes are of-
(a) Great economic value (b) No value at all
(c) Great ecological importance (d) A lot of aesthetic value

9. Among the following which is not characteristic feature of Bryophyta
(a) Motile sperms (b) Presence of archegonium
(c) Water essential for fertilization (d) Photosynthetically independent sporophyte

10. Last stage of gametophytic generation is
(a) Gametes (b) Zygote
(c) Spore mother cells (d) Spores

11. Which one of the following is true moss?
(a) Club moss (b) Reindeer moss
(c) Irish moss (d) Bogg moss (*Sphagnum*)

12. Bryophytes differ from pteridophytes in
(a) Swimming antherozoids (b) An independent gametophyte
(c) Archegonia (d) Lack of vascular tissue

13. Along the sea-coast which of the following is least likely to be found
(a) Brown algae (b) Red algae
(c) Mosses (d) All the above

14. Elaters are present in sporogonium of
(a) *Riccia* (b) *Marchantia*
(c) *Selaginella* (d) *Dawsonia*

15. Gametophytic generation is dominant in

(a) Pteridophyta (b) Bryophyta
(c) Angiosperms (d) Gymnosperms

7.12.1 Answer Key:

1- (b)	2- (d)	3- (c)	4- (c)	5- (d)
6- (a)	7- (b)	8- (c)	9- (d)	10- (b)
11- (d)	12- (d)	13- (c)	14-(a)	15- (b)

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7.15 TERMINAL QUESTIONS

7.15.1 Short answers questions:

1. What are the main characteristics of bryophytes?
2. Why can bryophytes be considered the “amphibians of the plant world”?
3. What are the main groups of bryophytes?
4. The Plant body of bryophytes is a gametophyte or a sporophyte? Explain.
5. Define habit and habitat of bryophyte.

7.15.2 Long answer questions:

1. Describe the distinguishing features of bryophytes in detail.
2. Define alternation of generation in bryophytes.
3. In what respect do bryophytes differ from algae and resemble with algae.

UNIT-8 MODERN SYSTEMS OF CLASSIFICATION OF BRYOPHYTES

8.1 OBJECTIVES

After reading this unit students will be able-

- to learn the Characters used in classification of bryophytes.
- to understand the Classification of bryophytes given by different workers.
- to know Important characteristics of different classes.
- to learn about the Adaptation of bryophytes as land plant.
- to know Why bryophytes are amphibians of plant kingdom

8.2 INTRODUCTION

The word **bryophyte** is the collective term for mosses, hornworts and liverworts and **bryology** is the study of bryophytes. While there are marked differences between these three groups of organisms, they are related closely enough to warrant a single term that includes all three. So a moss is a bryophyte, a liverwort is a bryophyte and a hornwort is a bryophyte. These are all plants, scientifically classified within the Plant Kingdom. They are spore-producing, rather than seed-producing, plants and they are all without flowers. Like any living organisms bryophytes are classified hierarchically. Related species are grouped into genera; related genera are grouped into families and so on.

In a **moss** plant leaves growing from stems and in many moss species solid-stalked spore capsules growing out from the leafy part of the plant. In other species the spore capsule will be stalkless. **Hornworts** are not leafy. The main part of the plant consists of a greenish, flattish sheet - which may be lobed or somewhat wrinkled. This sheet-like form is called a thallose growth habit. In hornworts the capsules are thin, tapering "horns" or needles that grow out from the thallose part. Here is a hornwort with a few immature capsules growing up from the thallose base. The photo shows a hornwort colony with numerous immature but more advanced capsules and here are mature capsules, now brown in their upper parts. **Liverworts** come in two growth forms, with both thallose species and leafy species - with the latter having leaves on stems, just like mosses. Spore capsules are produced in various ways. In the thallose liverwort genus *Riccia* the capsules are embedded in the thallose sheet and a couple of empty cavities within the thallose growth. Those are spore capsules which have opened and from which most of the spores have been dispersed. In leafy liverworts and a number of thallose liverworts the capsules are atop stalks.

Many people are familiar with the thallose liverwort species *Lunularia cruciata*. It can form large colonies in glasshouses and in flower pots. However, while a few of the thallose liverwort species are quite conspicuous, there are far more leafy species than there are thallose species of liverworts.

In mosses and leafy liverworts the leaves are fairly small and in some cases the stems can be quite short as well. That section is devoted to explaining what you see when you look at a moss, liverwort or hornwort. There you'll find out about the features you can see with the naked eye as well as some of the finer detail that a microscope reveals.

8.3 MODERN SYSTEMS OF CLASSIFICATION OF BRYOPHYTES

Various characters are used for the classification of bryophytes.

Some important characters are:

(i) External and internal structure of the thallus.

(ii) Types of rhizoids.

(iii) Types of scales.

(iv) Position of sex organs.

(v) Structure and nature of sporophyte.

(vi) Degree of sterilization in the sporophyte.

Classification of Bryophytes

The term Bryophyta was first introduced by Braun (1864); however, he included algae, fungi, lichens and mosses in this group. Later, algae, fungi and lichens were placed in a separate division Thallophyta and liverworts, mosses in division Bryophyta.

Eichler (1883) was the first to divide bryophyta into two groups:

Group I. Hepaticae

Group II. Musci.

Engler (1892) recognized Hepaticae and Musci as two classes and divided each class into the following three orders:

Division- Bryophyta:

Class I. Hepaticae:Divided into three orders:

Order 1. Marchantiales

Order 2.Jungermanniales

Order 3. Anthocerotales

Class II. Musci:Divided into three orders:

Order 1.Sphagnales

Order 2.Andreaeales

Order 3.Bryales.

International code of Botanical Nomenclature (ICBN) suggested in 1956-that the suffix-opsida should be used for the classes and such usage had already been proposed by Rothmaler (1951) for the classes of Bryophytes.He changed the class names as:

Class I. Hapaticae as Hepaticopsida.

Class II. Anthocerotae as Anthoceropsida

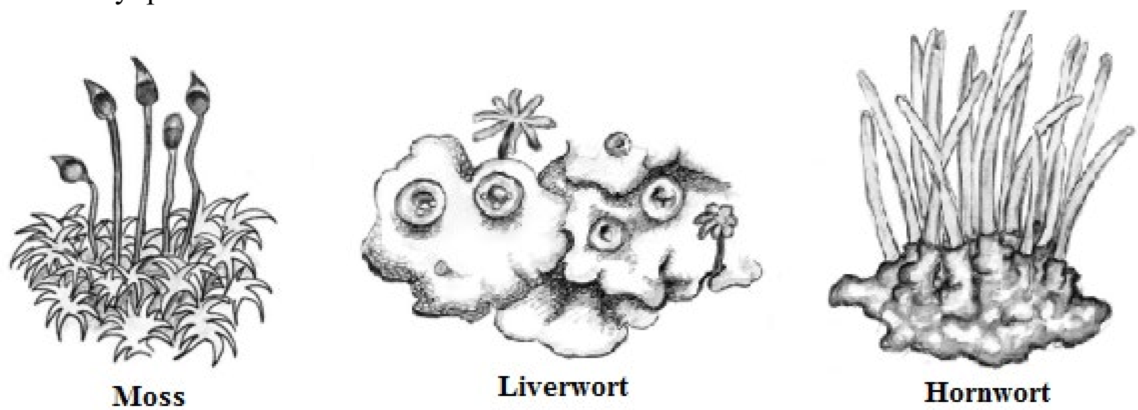
Class III. Musci as Bryopsida.

Proskauer (1957) suggested that the class name Antheoceropsida should be Anthocerotopsida. Parihar (1965) and Holmes (1986) followed Proskauer's classification and divided Bryophyta into three classes:

Clase I. Hepaticopsida

Class II. Anthocerotopsida

Class III. Bryopsida.



Class I. Hepaticopsida (Liverworts):

General Characters:

1. This class includes about 280 genera and 9500 species.
2. The name of this class is derived from a Latin word Hepatica which means liver. Hence members of this class are commonly known as liverworts.
3. Plant body is gametophytic and the gametophyte is either thalloid or foliose.
4. Thalloid forms are prostrate, lobed, dorsiventral and dichotomously branched.
5. In foliose forms, **'leaves'** are entire, lobed or divided and without **'midrib'**. 'Leaves arranged in two to three rows on the axis.
6. Rhizoids are unicellular and branched.
7. Photosynthetic cells contain many chloroplasts.
8. Pyrenoids are absent.
9. Sex organs are borne dorsally or apically, superficial or embedded in gametophytic tissue
10. Members may be monoecious or dioecious.
11. Sporophyte is either simple or represented by capsule only (e.g., *Riccia*) or may differentiated into foot, seta and capsule (e.g., *Marchantia*).
12. Archesporium is endothecial in origin.
13. Sporogenous tissue either forms only spores (e.g., *Riccia*) or is differentiated into sterile elater mother cells and fertile spore mother cells.
14. Columella is absent in the capsule.
15. Elaters are unicellular, hygroscopic with spiral thickenings.
16. Capsule wall is one to several layers thick and without stomata.
17. Dehiscence of the capsule is irregular or in definite number of valves.

18. Spores on germination form the gametophytic plant body.
19. Plants show heteromorphic alternation of generation.

Schuster (1957) divided the class Hepaticae into two sub-classes:

Sub-class 1. Jungerinanniae. It includes four orders:

Order 1.Calobryales (e.g., *Calobryum*)
Order 2.Takakiales (e.g., *Takakia*)
Order 3.Jungermanniales (e.g., *Pellia*)
Order 4.Metzgeriales (e.g., *Metzgeria*)

Sub-class 2. Marchantiae: It includes three orders:

Order 5.Sphaerocarpales (e.g., *Sphaerocarpos*)
Order 6. Marchantiales (e.g., *Marchantia*).

All these 6 orders have their characteristic features and all these are described here. The important features of these orders are:

1. Order-Calobryales (2 genera-*Calobryum* (8 spp.) and *Haplomitrium* (1 spp.):

The characteristic features are as follows:

1. They possess erect leafy gametophytes with leaves in three vertical rows.
2. The leaves are dorsiventrally flattened.
3. They have a pale, subterranean, sparingly branched rhizome from which arise erect leafy branches.
4. Erect branches bearing sex organs have the uppermost leaves close together and in more than three rows.
5. They are devoid of rhizoids.
6. The antheridia are ovoid, stalked, and borne at the apex of the stem.
7. The jacket of the neck of archegonium has only four vertical rows of cells.
8. The sporophyte bears an elongate capsule whose jacket layer is only one cell in thickness except at the apex.
9. The number of chromosomes is-n=9.

Since there is single family Calobryaceae the characters are similar to that of the order. Two genera-*Calobryum* and *Haplomitrium*.

2. Order-Takakiales (1 genus; 2 species):

The characteristic features are as follows:

1. They possess cylindrical, rhizomatic and erect gametophores.
2. They are devoid of rhizoids.
3. They possess copious beaked or non-beaked mucilage hairs on them.

4. They possess bifid-trifid-quadrifid leaves or phyllids.
5. The gametophores are about 1 to 1.5 cm. in height.
6. The leafless branches facing downward known as 'flagella' or 'stolons' may be present.
7. Asexual reproduction is not known.
8. Only female (archegonial) shoots are known. They bear conspicuous pedestalled archegonia.
9. The male (antheridial) shoots and the sporophytes are not known.
10. They have lowest chromosome number (i.e., n=4).
11. They are supposed to be most primitive and sometimes known as living fossil. There is one family Takakiaceae, and one genus Takakia.

3. Order-Jungermanniales (220 genera; 8, 500 species):

The characteristic features of this order are as follows:
1. The gametophyte is differentiated into stem and leaves; the leaves are borne in a regular spiral succession along the stem.
2. The apical cell is pyramid-like with three cutting faces.
3. The stem generally bears three rows of leaves; two rows are lateral and consist of leaves of normal size; the third row consists of the underleaves which are generally smaller than the lateral leaves called amphigastrium.
4. The archegonia are always restricted to the apices of the axis and its branches.
5. The sporophytes are always terminal in position.
6. The antheridia are borne singly or in groups in the axis of leaves.

Family-Porellaceae (single genus-*Porella*):
1. The leaves are arranged in three rows on the stem; ventral leaves are well developed and usually decurrent at the base.
2. The rhizoids are scarce and arise from the lower side of the stem in tufts generally near the base of underleaves (ventral leaves).
3. The archegonia are borne in terminal cluster on small lateral branches; the archegonia remain surrounded by a large inflated perianth.
4. The spherical capsule dehisces by four valves which split only to half way down.

Family-Frullaniaceae (three genera; important genus *Frullania*):
1. The thallus is pinnately branched and differentiated into stem and leaves.
2. The leaves are arranged in three rows two laterals unequally lobed and a ventral lobule.
3. The ventral leaves are bifid and trumpet-shaped.
4. The archegonia develop in a group.

4. Order- Metzgeriales (23 genera; 550 species):

The characteristic features of this order are as follows:
1. The gametophyte may be thalloid or differentiated into stem and lateral leaves.

2. In most cases the gametophytes are without internal differentiation of tissues but certain genera have a central strand of thick-walled cells.
3. The ventral surface of a gametophyte bears smooth-walled rhizoids.
4. The sex-organs are found to be scattered on dorsal surface of thallus.
5. The archegonia arise from the young segments cut off by the apical cell.
6. The mature sporophytes lie some distance back from the growing apex of a gametophyte.
7. The sex organs (antheridia and archegonia) are produced on any branch of the gametophyte or only on special branches.

Family-Pelliaceae (Three genera- *Pellia*, *Noteroclada* and *Calycularia*):
1. The thallus is prostrate, dorsiventral and very often lobed by irregular incisions.
2. The rhizoids are simple, non-septate, smooth and thin-walled. The scales are absent.
3. The sex organs (antheridia and archegonia) remain scattered on the dorsal surface of the thallus.
4. The archegonial cluster always remains surrounded by an involucre which is an outgrowth of the thallus.
5. The capsule (sporogonium) is globose or oval in shape. It possesses a basal elaterophore.

Family-Riccardiaceae (two genera):
1. The gametophytes are wholly thallose or have thallose terminal branches.
2. The cells of thallus possess finely segmented oil bodies.
3. The sex organs (antheridia and archegonia) are borne on short lateral branches.
4. A well-developed calyptra is present but there is no involucre.
5. A distal apical elaterophore is present to which some elaters are attached.
6. The capsule is ovoid to cylindrical and dehisces longitudinally into four parts extending to the base.

Family-Fossombroniaceae (4 genera; *Fossombronia*, *Simodon*, *Petalophyllum* and *Sewardiella*):
1. Thallus is distinctly foliose.
2. The thallus is dorsiventral and prostrate.
3. The stem is branched. Growth of the main axis and of its branches is by means of an apical cell with two cutting faces.
4. The leaf is thin, one cell-thick except the basal portion which is 2 or 3 cells in thickness.
5. Antheridia develop in acropetal succession singly or in small groups.
6. Archegonia occur in small groups.
7. Young sporophyte remains surrounded by a calyptra and which is ensheathed by a cuplike involucre.
8. The mature sporophyte is surrounded and protected by a bell-shaped sheathing perianth.
9. Important genus-*Fossombronia*.

5. Order-Sphaerocarpales (3 genera)-two families:

1. Family-Sphaerocarpaceae - *Sphaerocarpos* (seven species) and Geothallus (single species).
2. Family-Riellaceae-*Riella* (17 species).

The characteristic features of the order are as follows:

1. Vegetative structure of gametophyte is similar to that of order-Metzgeriales, but in which development and structure of sex organs, as well as the structure of sporophyte are similar to those of order-Marchantiales, and because of this the genera are placed in separate order Sphaerocarpales.
2. The main diagnostic feature by which the order is recognized is the presence of globose or a flask-like envelope or involucre around each of the sex organs (i.e., antheridia and archegonia).

6. Order-Marchantiales (32 genera; 400 species):

The characteristic features are as follows:

1. The ribbon-like, dichotomously branched and dorsiventral thalli grow prostrate upon suitable substrata.
2. Excluding *Dumortiera*, *Monoselenium* and *Monoclea*, the rest of the genera possess internally differentiated air chambers on the dorsal side of the thallus; such chamber opens outside by an air pore of a particular design.
3. The ventral portion of the thallus consists of parenchyma which acts as storage tissue; oil and mucilage cells may be present in this region.
4. The scales and rhizoids are present on the ventral side of the thallus; the rhizoids are of two types (smooth-walled and tuberculate).
5. The antheridia and archegonia may be found directly on the dorsal surface of the thallus or they may be present on the special branches known as antheridiophores and archegoniophores respectively.
6. In most of cases the capsules of the sporophytes possess single layered jacket.
7. The capsule may be simple as in *Riccia* or it may be differentiated into foot, seta and capsule as in *Marchantia.*
8. The elaters may or may not be present. According to Campbell (1940), there are five families in this order. The characteristic features of two families are given here:

I. Family-Ricciaceae (3 genera; 140 species):

1. The gametophyte consists of a rosette-like dichotomously branched thallus.
2. In the thallus, the dorsal portion consists of chlorophyllous strips which may or may not have air canals among them; the ventral portion of the thallus is parenchymatous and acts as storage tissue.
3. The sex organs (antheridia and archegonia) are found in the longitudinal groove on the dorsal side from the growing apex to backward in basipetal succession.
4. The sporogonium consists of a simple capsule which is not differentiated into foot, seta and capsule.

5. Elaters not present.
6. The archesporium produces only the spores.
The important genera are-*Ricciocarpus* and *Riccia*.

II. Family-Marchantiaceae (23 genera; 250 species):

1. The thallus is dorsiventral; it has distinct assimilatory and storage regions.
2. The assimilatory region remains divided into several chambers and each chamber contains branched assimilatory filaments.
3. The pores of the thallus may be simple or barrel-shaped.
4. The archegonia are borne upon special erect, stalked, vertical branches, the archego-niophores.
5. The antheridiophores may or may not present; however, in *Marchantia*, the antheridia are borne upon these erect, stalked antheridiophores.
6. The typical sterile elaters are found in the sporogonium mixed with the spores. The important genera are - *Conocephalum, Cryptometrium, Lunularia, Marchantia*, etc.

Class II. Anthocerotopsida (Hornworts):

General Characters:

1. This class is represented by about 6 genera and 300 species.
2. Plant body is flat, dorsiventral, thalloid, gametophytic and variously lobed.
3. Smooth walled rhizoids are present.
4. Tuberculated rhizoids and scales are absent.
5. Internally the thallus is not differentiated into zones.
6. All cells are alike.
7. Air chambers or air pores are absent.
8. Each cell has a single chloroplast and each chloroplast contains one to many pyrenoids.
9. Mucilage cavities open on the ventral surface by slime pores.
10. Sex organs are embedded in the thallus.
11. Antheridia develop either singly or in groups in closed cavities called antheridial chambers.
12. The sporophyte is differentiated into foot, an intermediate zone or meristematic zone and capsule.
13. Due to the presence of the meristematic zone, the sporophyte shows indeterminate growth i.e., it continues to grow indefinitely.
14. Archesporium is amphithecial in origin.
15. Sporogenous tissue forms the fertile spores and sterile elaters. Elaters do not have spiral thickenings and are known as pseudo elaters.
16. Capsule wall is four to six layered thick and epidermis has the stomata.
17. Capsule matures from apex to base and usually dehisce by two valves.

The class Anthocerotopsida has only a single order Anthocerotales. Muller (1940), Proskauer and Reimers (1954) divided the order Anthocerotales in two families:

Family 1.Anthocerotaceae (e.g., *Anthoceros*)

Family 2.Notothylaceae (e.g., *Notothylas*).

Family-Anthocerotaceae (4 or 5 genera; important genus *Anthoceros*):

1. The capsule is linear and vertical.
2. The stomata are present on the wall of capsule.
3. The archesporium develops from amphithecium.
4. The elaters are four-celled, smooth or thick-walled; thickening band may or may not be present.

Family-Notothylaceae (single genus-*Notothylas*):

1. The capsule is cylindrical and horizontal.
2. The stomata are not found on the wall of capsule.
3. Archesporium arises from endothecium and amphithecium.
4. Elaters are short and stumpy; they have irregular thickening bands.

Class III. Bryopsida (Mosses):

General Characters:

1. It is the largest class in bryophyta and includes about 700 genera and 14,000 species.
2. The main plant body is gametophytic and can be differentiated into two stages-juvenile stage and leafy stage or gametophore.
3. Juvenile stage is represented by green, filamentous branched structures called protonema. It develops from the germination of the spore.
4. Gametophores are erect leafy branches which develop on the protonema.
5. Gametophores can be branched or un-branched and can be differentiated into three parts-rhizoids, **'stem'** and **'leaves'**.
6. Branches arise below the **'leaves'**.
7. **'Leaves'** are with midrib, un-lobed and arranged spirally in three to eight rows on the axis or
8. Rhizoids are multicellular, filamentous, branched with oblique septa.
9. The axis is differentiated into central conducting strand enclosed by cortex.
10. The sex organs (antheridia and archegonia) develop from the superficial cells of the gametophore.
11. The sporophyte is green in early stages and can be differentiated into foot, seta and capsule.
12. The seta is usually elongated and rigid.
13. The capsular wall remains interrupted by stomata at several places.
14. Columella is usually present and endothecial in origin.
15. Archesporium (spore forming tissue) is differentiated only in spores.
16. Elaters are absent.

17. Dehiscence of capsule takes place by separation of lid or operculum.
18. Peristome helps in the dispersal of spores.
19. Spores on germination produce the protonema.

The class Bryopsida (Musci) has been divided into three sub-classes
(1) Sphagnobrya (Sphagnidae); (2) Andreaeobrya (Andreaeidae) and (3) Eubrya (Bryidae).

I. Sub-class:Sphagnobrya:

The sub-class has a single order, the Sphagnales and a single family, the Sphagnaceae. (Single genus *Sphagnum* with 326 species). The characteristic features are as follows:

1. They are called 'bog mosses' or 'peat mosses'.
2. The protonema is broad and thallose; it produces one gametophore; the leaves or gametophores lack mid-rib and usually composed of two types of cells-(i) the narrow living green cells and (ii) large hyaline dead cells.
3. The branches arise in lateral clusters in the axis of the leaves borne on the stem.
4. The antheridia are borne in the axis of leaves on the antheridial branch.
5. The archegonia are terminal and formed acrogenously.
6. The sporogenous tissue of a sporophyte develops from the amphithecium.
7. The sporogonium remains elevated above the gametophyte due to elongation of a stalk of gametophytic tissue, the pseudopodium.

II. Sub-class. Andreaeobrya:

This sub-class has a single order, the Andreaeales, and a singly family, the Andreaceceae. The important genus is *Andreaea*. The characteristic features are as follows:

1. The gametophores are brittle, and can easily be broken.
2. There is practically no tissue differentiation in plant body.
3. The leaves are generally large, erect and convolute.
4. The archesporium and colonmella develop from the endothecium.

III. Sub-class Eubrya (650 genera; 14,000 species):

This sub-class has been further divided into three cohorts and fifteen orders. The true mosses are included in this sub-class. The characteristic features are as follows:

1. The leaves of the gametophores are more than one cell in thickness and possess midrib on them.
2. The protonema is filamentous.
3. The sporophyte bears a well differentiated, elongated seta which pushes out the capsule from the gametophore.
4. The sporogenous tissue is derived from the endothecium.
5. The archesporium does not overarch the columella; the columella continues upto the apex of the capsule; both columella and archesporium have been derived from the endothecium.

6. In between spore sac and columella, the partitioned air spaces are present.
7. The mature capsule possesses the complex structure made of many tissues.
8. The capsule opens at its apex by an operculum; the spore dispersal is regulated by teeth like apparatus, the peristome.

Order-Funariales (26 genera; 356 species):
Characteristic features:
1. The plants are terrestrial; they are small in size and may be annual or biennial.
2. The leaves possess distinct mid-ribs and arranged in rosettes at the apex of the gametophyte.
3. The capsule is wide and provided with an unbeaked operculum.
4. The peristome of the capsule is double and consists of inner and outer peristome called endostome and exostome respectively.
5. There are five families in this order, of which Funariaceae is most important.

Family-Funariaceae (9 genera; 200 species):
1. The leaves are one cell in thickness except at the mid-rib region.
2. The small mosses form the velvety appearance on the surface of the sustratum.
3. The calyptra is soon detached from the opercula of the capsules; the calyptra is provided with long beaks.
4. The capsules are pyriform and situated on the long, elongated setae.

Order-Polytrichales:
Characteristic features:
1. The gametophyte is perennial and tall.
2. The leaves are narrow and possess longitudinal lamellae on the upper surface of the midrib.
3. The capsule is terminal.
4. The single annular series of cells gives rise to a peristome in the inner zone of the amphithecium.
5. There are 32 to 64 pyramidal teeth in peristome; the tips of the peristome teeth remain joined above to a thin membrance, the epiphragm covers the mouth of the capsule.
6. There is a single family, the Polytrichaceae in this order; the important genera of this family are — *Polytrichum* and *Pogonatum.*

Adaptations of Bryophytes to Land Habit:

Bryophytes are first land plants. Evidences support that Bryophytes are evolved from Algae. During the process of origin they developed to certain adaptations to land habit.

These are:
1. Development of compact plant body covered with epidermis.
2. Development of organs for attachment and absorption of water e.g., rhizoids.
3. Absorption of carbon dioxide from atmosphere for photosynthesis e.g., airpores.

4. Protection of reproductive cells from drying and mechanical injury i.e., jacketed sex organs.
5. Retention of zygote within the archegonium.
6. Production of large number of thick walled spores.
7. Dissemination of spores by wind.

Bryophytes: Amphibians of Plant Kingdom

Bryophytes are also known as amphibians of plant kingdom because water is needed to complete the life cycle. In animal kingdom class Amphibia (Gr. Amphi = two or both; bios = life) includes those vertebrates which are amphibians in nature i.e., they can live on land as well as in water. Similarly, majority of the bryophytes are terrestrial but they are incompletely adapted to the land conditions.

They are unable to grow during dry season and require sufficient amount of water; for their vegetative growth. Water is absolutely essential for the maturity of sex organs ar. fertilization. Without water they are unable to complete their life cycle. On account of their complex dependence on external water for completing their life cycle, Bryophytes along with Pteridophyte are regarded as amphibians of plant kingdom.

Apogamy and Apospory in Bryophytes

Bryophytes are endowed with a remarkable regeneration capacity. Parts of the plant or any living cell of the thallus are capable of regenerating the entire plant. The sporophytic cells regenerate to form a protonema on which appear gametophytes. This regeneration of diploid gametophyte from a sporophyte without the formation of spores is called apospory.

Conversely a gametophyte may form a mass of cells which may regenerate a sporophyte. This regeneration of a diploid sporophyte from a gametophyte, without the formation of gametes is called apogamy. Aposory and apogamy are rarely found in life cycle of bryophytes.

Rhizoids and Scales in Bryophytes

Rhizoids:

In Bryophytes roots are absent and the functions of the root i.e., anchorage and absorption is performed by the filamentous structures known as rhizoids.Rhizoids may be unicellular, un-branched in thallose forms of Hepaticopsida and Anthocerotopsida (e.g., *Riccia, Marchantia*, *Anthoceros*) or multicellular and branched in foliose forms of Bryopsida (e.g., *Funaria*, *Polytrichum*). Multicellular rhizoids possess oblique cross walls.

Unicellular rhizoids are of two types smooth-walled and tuberculated. The members of order Marchantiales (e.g., *Riccia, Marchantia*) possess both types of rhizoids while Anthocerotales (e.g., *Anthoceros*) possess only smooth walled rhizoids. In thalloid forms rhizoids are borne on the ventral surface along the mid rib, however, in foliose forms rhizoids arise from the base of the **'stem'**. In aquatic Bryophytes (e.g., *Riccia fluitans, Ricciocarpus natans*) rhizoids are absent.

Scales:

Scales are present only in the members of order Marchantiales and absent in all bryophytes. The scales are multicellular, violet coloured and single cell thick. They are violet in colour due to the presence of the pigment anthocyanin. Scales develop on the ventral surface of the thallus.

They may be arranged in one row (e.g., young thallus of *Riccia*) or in two rows on each side of the mid rib (e.g., *Targionia*) or in two to four rows on each side of the mid rib (e.g., *Marchantia*) or irregularly distributed over the entire ventral surface (e.g., *Corsinia*).

In *Riccia* the scales are ligulate while in *Marchantia* the scales are of two types-ligulate and appendiculate (divided by a narrow constriction into two parts—body and appendage). Scales protect the growing point by covering their delicate cells and secreting slime to keep them moist. The scales are absent in some aquatic members of order Marchantiales e.g., *Riccia fluitans*.

8.4 SUMMARY

Mosses, **hornworts and liverworts** are often collectively referred to as bryophytes. Bryophytes require water to reproduce sexually, produce spores rather than seeds and lack the vascular tissue found in ferns and "higher" plants. Bryophytes are classified in three categories: Mosses, hornworts and liverworts.

Mosses are found in a range of habitats, although moist and shady habitats are more common. Mosses are often epiphytes. The dominant phase of the moss life cycle is the gametophyte (haploid). The plant is called a thallus, they may be erect or prostrate (axis along the ground).The gametophyte has a stem like axis with spirally arranged leaves, which are known as phyllids. It lacks xylem and phloem. All mosses have a sporic (diplohaplontic) life cycle that is oogamous. For sexual reproduction, the moss gametophyte produces gametangia. The male and female gametangia may be on the same thallus (homothallic or monoecious) or on separate gametophytes (heterothallic or dioecious).Both the antheridium and archegonium have a sterile jacket of cells, which better protects the gametes against desiccation in the terrestrial environment. After fertilization, the sporophyte grows out of the archegonium, and nutrients for the developing sporophyte are provided by the gametophyte.

Hornworts (Anthocerotophyta) have irregular lobed or branching bodies, known as thalli, the tissue of which is not organized into organs. Guard cells form on the underside of the thallus. Cavities form under these that are typically filled with cyanobacteria. Only one species of hornwort has been found in Iceland, *Carolina phaeoceros* (*Phaeoceros carolinianus*). Its distribution is confined to geothermal areas.

Liverworts are odd little plants that appear as small, flat green patches attached to the ground, although they may form large masses in favorable habitats such as moist, shaded rocks or soil, tree trunks or branches and a few even grow directly in water. Liverworts have three unique traits:

- Most have special structures known as oil bodies in their leaf cells.
- Their spore-shedding generation is not green and lives only a short time.
- Their spore capsules swell and the spores mature before the capsule's stalk starts to lengthen.

There are two main types of liverwort: Leafy liverworts have leaves and thalloid liverworts do not have leaves – they are sheets of cells.

If they are thick and have internal air spaces with pores to the outside, they are called complex thalloid liverworts. If they are thin and have no air spaces or pores, they are called simple thalloid liverworts. Liverworts lack specialized conducting tissues, cuticles, and stomata, and their rhizoids are always unicellular. The gametophytes arise directly from spores in most species. Most liverworts (75%) have nine chromosomes in their haploid cells. There are two kinds of liverworts based on body form: thallose and leafy.

8.5 GLOSSARY

Apophysis – Swollen Sterile tissue at the base of the capsule where it joins the seta

Archesporium – Group of cells from which the spores of a sporangium are derived.

Autoecious – Having the male and female reproductive organs on the same plant but in separate branches.

Bistratose: consisting of two cell layers, e.g. a leaf lamina two cells thick.

Bryophyte: a non-vascular, green plant with a gametophyte generation that is free-living and a comparatively ephemeral sporophytel; a collective name for mosses, liverworts and hornworts.

Calcicolous: a plant that grows best in habitats or on substrata with high levels of calcium.

Calyptra (pl. calyptrae)**:** a membranous or hairy hood or covering that protects the maturing sporophyte; derived largely from the archegonial venter.

Capsule: the terminal, spore-producing part of a moss sporophyte.

Cilia (sing. cilium)**:** a delicate, hair-like or thread-like structure, usually one cell thick and unbranched; in peristomes, a structure that occurs singly or in groups alternating with the segments of the inner endostome; hair-like appendages fringing leaves or calyptrae. adj.

Cushion: a more-or-less hemispherical or rounded moss colony, with stems generally erect and tightly clustered but radiating somewhat to form a tuft.

Dimorphic: of two distinct forms, e.g. leaves, male and female plants.

Diploid: a cell, individual or generation with two sets of chromosomes (*2n*); the typical chromosome level of the sporophyte generation.

Embryo: the developing sporophyte phase normally generated from a zygote; in mosses it usually consists of a foot, seta and capsule.

Endothecium: in most mosses, the inner embryonic tissue of a capsule which gives rise to all tissues interior to the outer spore sac. In *Sphagnum* it also produces the columella.

Foliose: leafy or leaflike; covered with leaves.

Foot: the basal organ of attachment and absorbtion for the bryophyte sporophyte, Foot – the base of the sporophyte that attaches it to the gametophore

Gametangium (pl. **gametangia**)**:** an antheridium or archegonium; a structure forming gametes (ovum, spermatozoid).

Gametophyte: the haploid, sexual generation; in bryophytes the free-living, dominant generation.

Hornwort: a member of Class Anthocerotopsida.

Oogamy– fusion of two dissimilar gametes, a small, motile male gamete with the large, immotile female gamete

Protonema: the filamentous juvenile stage that precedes the formation of gametophore (=first hair)

paraphyses (sing. **paraphysis**)**:** sterile hairs composed of uniseriate cells, coloured or hyaline, associated with antheridia and sometimes archegonia.

Peristome: a circular structure generally divided into 4, 8, 16 or 32 teeth arranged in single or double (rarely multiple) rows around the mouth of the capsule and visible after dehiscence of the operculum.

Polyploid: a plant or tissue with more than 2 complete sets of chromosomes.

Prostome: a rudimentary structure outside and usually adhering to the main peristome teeth; e.g. in Pterobryaceae.

Prostrate: lying flat on ground; creeping.

Protonema: a filamentous, globose or thallose structure resulting from spore germination and including all stages up to production of one or more gametophores. The protonema varies in the amount of chlorophyll present and the degree of obliqueness of its end walls, and in its branching.

Venter: the expanded portion of the archegonium that encloses the egg

Rhizoid: a hair-like structure that anchors a moss to the substratum; multicellular with oblique cross walls, often pigmented, and sometimes clothing the stem.

Rhizome: a slender horizontal, subterranean stem giving rise to erect secondary stems; e.g. in *Dawsonia* and *Rhodobryum*.

Seta: the elongated portion of the sporophyte between the capsule and the foot.

Sporophyte: the spore-bearing generation; initiated by the fertilization of an ovum; consists of foot, seta and capsule; attached to and partially dependent on the gametophyte.

8.6 SELF ASSESSMENT QUESTION

8.6.1 Multiple Choice Questions:

1. Bryophytes are classified as which type of the following plants?

(a) Flowering (b) Non-flowering

(c) Vascular (d) Non vascular

2. Antherozoid mother cells are:
(a)Androgonia (b) antherozoids
(c) Androcytes (d) None

3. The basal swollen portion of the archegonium is:
(a) Venter (b) Neck
(c) Jacket (d) Oospere

4. Which plant does belong to Hepaticopsida?
(a) *Funaria* (b) *Polytrichum*
(c) *Porella* (d) *Anthoceros*

5. Which plant does belong to Anthoceropsida?
(a) *Funaria* (b) *Polytrichum*
(c) *Porella* (d) *Anthoceros*

6. Which plant is a moss?
(a) *Marchantia* (b) *Polytrichum*
(c) *Porella* (d) *Anthoceros*

7. Meristematic tissues are present in:
(a) *Marchantia* (b) *Polytrichum*
(c) *Porella* (d) *Anthoceros*

8. Protonema is found in:
(a) *Marchantia* (b) *Polytrichum*
(c) *Porella* (d) *Anthoceros*

9. Which of the followings is absent in bryophytes?
(a) Archegonia (b) Oosphere
(c) Zoospore (d) Antheridia

10. The structure not involved in asexual reproduction is:
(a) spore (b) Tuber
(c) (lemma (d) None

11. A structure is present in the centre of the capsule called:
(a) elaters (b) spores
(c) columella (d) pseudoelaters

12. A narrow region encircles the columella. This region contains spores and:
(a) elaters (b) spores
(c) columella (d) pseudoelaters

13. Endothecium divides to form:
(a) elaters (b) spores
(c) columella (d) pseudoeaters

14. Amphithecium divides to form:
(a) archesporium (b) spores
(c) columella (d) pseudoelaters

15. The leaves adjacent to the sex organs are called:
(a) bracts (b) paraphylls
(c) Tubers (d) lemma

16. The inner medullary cells are large and thin-walled. The superficial cells of the stem give rise to:
(a) bracts (b) paraphylls
(c) involucre (d) Gemma

17. The archegonia and bracts forms structure called:
(a) bracts (b) paraphylls
(c) involucre (d) Gemma

18. Pseudofoot is present in:
(a) *Funaria* (b) *Polytrichum*
(c) *PoreIla* (d) *Anthoceros*

19. The hypobasal cell does not divide further and forms:
(a) elaters (b) spores
(c) columella (d) haustorium

20. Rhizome is present in:
(a) *Funaria* (b) *Potytrichum*
(c) *PoreIla* (d) *Anthoceros*

8.6.1 Answers Key: 1. (d), 2. (c), 3. (a), 4. (c), 5. (d), 6. (c), 7. (d), 8. (c), 9. (c), 10. (a), 11. (c), 12. (a), 13. (c), 14. (a), 15. (a), 16. (b), 17. (c), 18. (c), 19. (d), 20 (b)

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8.9 TERMINAL QUESTIONS

8.9.1 Short Answer Question

1. Explain classification of bryophytes given by Engler.
2. Explain the adaptation of bryophytes in land.
3. How do we call bryophytes as amphibians?
4. Write important general characters of mosses.
5. Define the general characteristics of liverworts.

8.9.2 Long Answer Questions

1. Give an account of classification of bryophytes in detail.
2. Give an account of classification of bryophytes.
3. Describe in detail about the general features of Hepaticopsida.
4. Define the characteristic feature of Anthocerotopsida.
5. Describe the salient features of class bryopsida.

UNIT-9 SPHAEROCARPALES, MARCHANTIALES, JUNGERMANNIALES, METZGERIALES AND CALOBRYALES

9.1 OBJECTIVES

This section is based on the following objectives:

- Identify the main characteristics of order Sphaerocarpales and Sphaerocarpus.
- Distribution, habitat and general features of *Marchantiales* and *Marchantia*.
- Describe the events in the lifecycle of Jungermaniales and its members.
- Draw a life cycle diagram of order Metzgeriales and its members.
- Describe vegetative and sexual reproduction in Calobryales.

9.2 INTRODUCTION

Hepatophyta are commonly called *liverworts*– a term derived from the liver-shaped outline of their gametophyte. Liverworts are the simplest of all extant plants. They thrive in moist habitats and are less well known than the mosses. Like that of mosses, the gametophyte of liverworts lacks xylem and phloem, and therefore true leaves, stems, and roots are absent. However, both gametophyte form and a less complex sporophyte distinguish liverworts from mosses. The liverwort gametophyte, called a thallus, takes on one of two forms—either the ribbon-shaped or lobed form of "thallose" liverworts or the leafy shoot system of "leafy" liverworts. Both forms usually are flattened and grow prostrate on substrates.

The gametophyte bears stalked reproductive organs (archegonia and antheridia) on the upper surface and fine hair like unicellular rhizoids project from the lower surface. All liverwort thalli lack the mucous-filled cavity present in hornworts. The thallose liverwort *Marchantia* grows on stream banks, among mosses on rocks, and in wet ashes after fires. Although all liverworts lack a cuticle (the waxy, water-resistant layer present in mosses and hornworts), *Marchantia* is one of numerous thallose liverworts characterized by a thallus with internally differentiated tissues, which exchange gases through barrel-shaped pores that open into air chambers within the thallus. Liverwort pores differ in form from the stomata of vascular plants. Liverwort sporophytes lack air pores. Liverwort rhizoids are single-celled in comparison with moss rhizoids, which are always multicellular. Rhizoids both anchor the thallus and help move water and dissolved minerals via capillary action. Many thallose liverworts have a midrib, a thickened region that runs down the center of each thallus lobe. The thallus lacks vascular tissue, although some species have specialized tissue to aid in conduction. In height, liverworts seldom exceed 5 cm.

Liverworts reproduce sexually (with gametes) and asexually (by spores, fragmentation, and gemmae), in broad outline like mosses. The liverwort egg is produced in the archegonium of the gametophyte by mitotic division. On a separate thallus (male gametophyte), antheridia produce motile, antherozoid. Sperm transported by rain drops fertilize the egg. The liverwort embryo develops a sporophyte from the resulting diploid zygotes. The liverwort sporophyte is

permanently attached by a minute stalk to the female gametophyte. The sporophyte consists of a capsule (sporangium), seta (stalk), and foot.
Meiotic cell division takes place at the sporophyte tip, leading to the production of haploid spores. After the capsule opens, spores are discharged by elaters, helical coils that twist as they dry and then snap suddenly, releasing spores. Hornworts have cells similar to elaters, but mosses do not. Wind, animals, and water aid in spore dispersal. A spore germinates directly into a young thallus or, in a few genera; a filament of cells precedes the thallus. This haploid gametophyte differentiates gametangia and the life cycle begins again. The haploid-dominated life cycle characterizes all mosses, liverworts, and hornworts.

In asexual reproduction by gemmae, liverworts reproduce haploid organisms that are genetically identical with the parent plant. In some thallose liverworts, small cup-shaped organs called cupules form on the upper surface of the thallus. Within the cupules, little green spheres called gemmae grow. When gemmae are dispersed by raindrops to suitable damp soil, they grow into new haploid liverworts.

Most of the 6000 liverwort species live in tropical regions throughout the world, on rock, shaded trees, fallen logs, and soil. Liverworts are often found in waterfalls and other rapidly running freshwater and as epiphytes, organisms that grow on other organisms but are not symbiotic. A number of species are known in Antarctica, where they may survive harsh environmental conditions by production of "antifreeze."During the middle Ages, liverworts were believed to be useful in treating liver ailments. At that time, plants that looked like an organ were used to treat medical conditions affecting that organ called 'Doctrine of signature'. Liverworts are not currently credited with therapeutic value and are not eaten. Their value lies in their function as pioneer plants in burned areas and other inhospitable habitats.

Sporophyte is a dependent and diploid phase in the life cycle of bryophytes. It is always attached to the gametophyte and nutritionally dependent on gametophyte due to lack of chloroplast. They are relatively small. They have no lateral appendages or branching as found in gametophyte. There is no mean of apical growth hence they are of determinate growth. However in hornworts the sporophyte is of indeterminate growth due to basal meristematic zone. The main function of the sporophyte is to produce spores as well as to disperse them to distant places for successful completion of life cycle. Accordingly they have adapted such morphology which is well suited to perform their ultimate function. The term sporogonium is often used for the bryophyte capsule as well as for whole bryophyte sporophyte.

As far as nutritional dependency of sporophyte on gametophyte is concerned, the sporophytes are described as totally dependent on gametophyte and at times parasite on gametophyte also but it is not exactly true as chloroplasts occur in the capsule wall, seta and foot cells also (Watson 1964).In liverworts, the sporophytes are more dependent on gametophyte as they are poor in chlorophyll contents and they lack stomata. However, there are many liverworts in which the sporophytes are capable for photosynthesis at least in early stages of development as chloroplasts are present in foot, seta and capsule wall cells e.g. *Marchantia polymorpha, Dumortiera hirsuta, Riella americana, Sphaerocarpos texanus, Monoselenium tenerrum, Pellia epiphylla* etc. (Bold 1938).

In some liverworts the seta is very small, narrow, highly reduced to few celled broad as in *Sphaerocarpus, Corsinia* and *Riella.* It does not elongate even after the maturity. While in majority of liverworts the seta is small at initial stage but after the maturity of the capsule it elongates rapidly pushing the capsule outside the protective coverings: calyptra, perianth, perichaetium or involucre and helps in the spore dispersal e.g. members of order Jungermanniales and Metzgeriales.

Liverworts are usually regarded as the most basal group in bryophytes. Among them, *Marchantiales* and Jungermanniales have no water-conducting cells (Kobiyama and Crandall-Stotler, 1999). However, an internal strand of water-conducting cells is present in Calobryales and Metzgeriales (Burr *et al*., 1974; Hébant, 1977). In Metzgeriales, the water-conducting cells show thick cell walls with helicoidal pits, reminiscent of tracheids.

9.3 SALIENT FEATURES OF IMPORTANT GROUPS WITH EMPHASIS ON THE GIVEN GENERA

According to Campbell, Smith, Takhtajan and others, the bryophyta has been divided into three classes- Hepaticae, Anthocerotae and Musci. In this section we are going to deal with the members of Class Hepaticae.

1. The gametophytes are dorsiventrally differentiated. They may be thalloid (thallose) or differentiated into leaves and stem (foliose).
2. In foliose types the leaves are arranged in two or three rows on the axis and are always without mid-rib.
3. The sex organs develop from superficial cells on the dorsal side of the thallus, except when they are terminal in position.
4. The sporophyte may be simple, or differentiated into foot and capsule, or into a foot, seta and capsule.
5. The sporogenous cells develop from the endothecium of sporogonium.
6. The sporophyte is completely dependent on gametophytes for its nutritive supply.
7. The wall of sporogonium is one to several layered thick. The stomata are not present on the wall of sporogonium.

8. The dehiscence of sporogonium is irregular.The class Hepaticopsida is further divided into several orders - (1) Sphaerocarpales; (2) *Marchantia*les; (3) Metzgeriales; (4) Jungermanniales; (5) Calobryales and (6) Takakiales.

A detailed description of order Sphaerocarpales, *Marchantia*les, Metzgeriales and Jungermanniales has been given in this unit.

9.4 MORPHOLOGY, ANATOMY AND REPRODUCTION OF SPHAEROCARPALES

Sphaerocarpales is an order of plants within the liverworts. Approximately twenty species are in this order which is sub-divided into three families: Sphaerocarpaceae and Riellaceae. The characteristic features of the order are as follows:

1. Vegetative structure of gametophyte is similar to that of order-Metzgeriales, but in development and structure of sex organs, as well as the structure of sporophyte are similar to those of order-*Marchantia*les, and because of this the genera are placed in separate order Sphaerocarpales.
2. The main diagnostic feature by which the order is recognized is the presence of globose or a flask-like envelope or involucre around each of the sex organs (i.e., antheridia and archegonia).
3. Plant body thalloid, scales absent on ventral surface and smooth walled rhizoids present.
4. Antheridium and archegonium enclosed within involucre.
5. Sporophyte having small foot, seta and a globose capsule. Capsule wall is unilayered and elaters are absent.
6. Capsule is cleistocarpous and dehiscence is irregular.

9.4.1 Sphaerocarpos

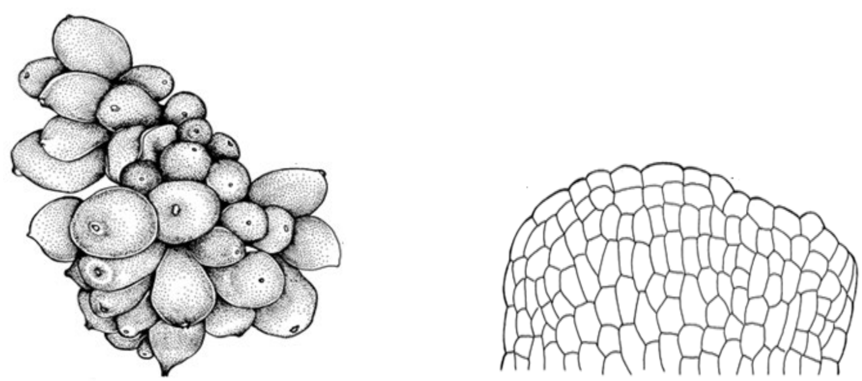
Kingdom	:	Plantae
Division	:	Bryophyta
Class	:	Hepaticiopsida
Order	:	Sphaerocarpales
Family	:	Sphaerocarpaceae
Genus	:	*Spherocarpos*

Family Sphaerocarpaceae has two genera Sphaerocapos and Geothallus. The genus is not present in India and mostly found in USA. It is mostly found in moist and colder region and morphology varies as per the climatic condition. The simplest type of thallus organization can be seen in the genus Sphaerocarpos.

Gametophyte: Plant body is thalloid and the thallus is prostrate, dorsiventral, small, green and dichotomously branched. Growing point is present at the apical notch. Prominent mid rib looks like an axis is also found. The thallus having a central multistratose cushiony midrib portion and thin, delicate, unistratose wing portion.

Dorsal surface of the thallus is very smooth and no air pores are present as in *Marchantia*. On the ventral surface scales are not present except at the apex, near the growing point. Mucilage hairs are also present near the apical notch and the apical end of each mucilage hair has large swollen terminal cell. The rhizoids are simple and confined to the central thick portion of the thallus.Plants forming small, whitish-green rosette, fragile and translucent and up to 8 mm in diameter.

Thallus Anatomy: Thallus is very simple in anatomy as well and is not differentiated in the photosynthetic or storage zones. Simply multistratose mid rib region and unistratose leaf lobes are present. Chloroplast is present in every cell except the rhizoidal cells.



A B

Fig.9.1.*Sphaerocarpos*: (A) Thallus (B) Leaf Anatomy

Reproduction: Sphaerocarpos reproduces by both methods i.e. vegetatively and sexually.

1. Vegetative Reproduction: It takes place either by adventitious branches, or dichotomous branches. Plant is capable to give rise many new branches from the lower region and every branch is able to give rise a new plant.

2. Sexual reproduction: Inspite of being so simple in morphology and anatomy, the thalli are very unique in having the sex organs in a specialized involucre. Each of the sex organs (antheridium and archegonium) is protected by bottle shaped or pear shaped involucre. Plants are unisexual, the male plants much smaller than the female and rarely observed.

Male Plant: Antheridial plants generally 0.1--0.3 times smaller than the archegonial. The dorsal surface having several involucres and each involucre is one layered thick. Antheridium has a single cell thickening and it has biflagellate, spindle or coiled antherozoids. Development of antherozoid is similar to *Marchantia*.

Female Plant: Archegonial plants 2--15 mm in diameter; lobes 1-stratose, not divided or lobed, generally succubous. The inflated female (archegonial) involucres hiding a small thallus-like axis with ruffled lobe-like leaves at margins, the leaves rounded distally, margins crisped and ascending. Archegonial involucres conspicuous, bottle- or flask-shaped, 1-2 mm high, flaring open at the mouth, some partially hidden by the ruffled thallus, appearing in late summer or fall. Capsules form inside the archegonial involucres but are not visible without dissection. Cells lacking trigones, quadrate to hexagonal. Sporangia ovoid, seta very short with no elongation and of 4 celled rows. Spores large, spore wall reticulate or not, faces aerolate; aerole with or without tubercles, lamellae or spines.

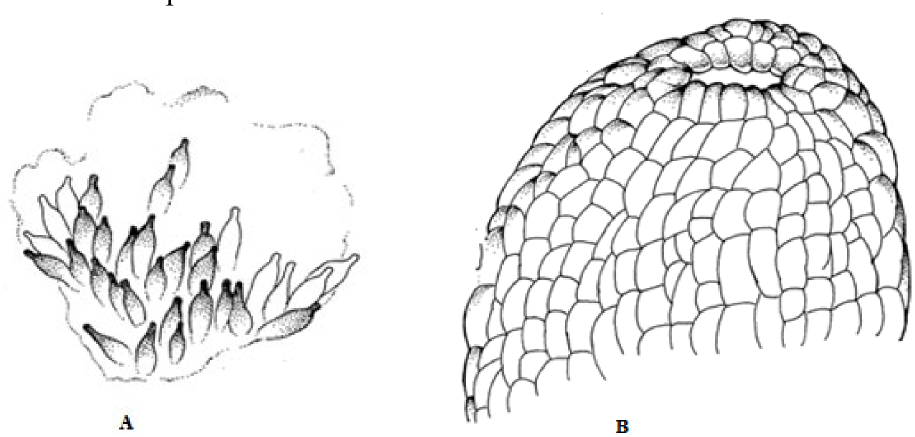


Fig.9.2.*Sphaerocarpos*: (A) Male Involucre (B) Female Involucre

Fertilization: It takes place when male and female thalli grow near each other. Water is essential for fertilization. In the mature archegonium the venter canal cell and neck canal cells disintegrate and form a mucilaginous mass. It absorbs water, swells up and comes out of the archegonial mouth by pushing the cover cells apart. This mucilaginous mass consists of chemical substances.

The antherozoids are splashed by rain drops. They may fall on the nearby female receptacle or swim the whole way by female receptacle. Many antherozoids enter the archegonial neck by chemotactic response and reach up to egg. This mechanism of fertilization is called splash cup mechanism. One of the antherozoids penetrates the egg and fertilization is affected. The fusion of both male and female nuclei results in the formation of diploid zygote or oospore. Fertilization ends the gametophytic phase.

Sporophyte: A sporophyte develops from an egg, held within a flask-like **archegonium** that has been fertilized. The fertilized egg grows by the formation of additional cells. In the great majority of species the embryonic sporophyte elongates and one part becomes a **foot** that penetrates the gametophyte and anchors the embryonic sporophyte to the gametophyte. The opposite end will develop into the spore-bearing capsule (and also the supporting stalk, or **seta**, in species in which the mature capsule is stalked). The embryonic sporophyte is often protected by a **calyptra**, a covering that develops from the wall of the archegonium.

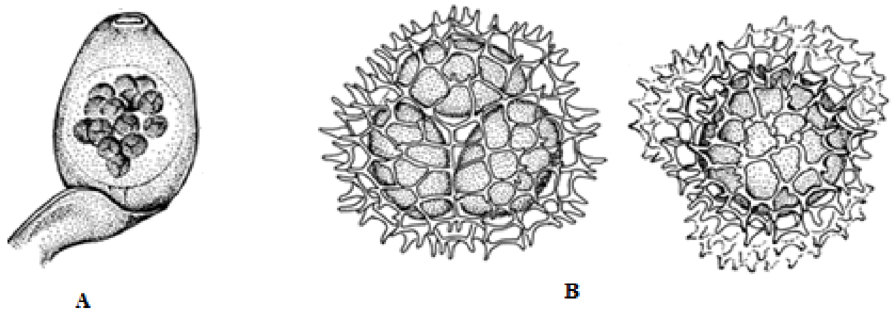


Fig.9.3. ***Sphaerocarpos*: (A) Sporophyte (B) Spore Tetrad**

The sporophyte of Sphaerocarpos has three parts:

a) **Foot: It** penetrates the gametophyte and anchors the embryonic sporophyte to the gametophyte and is responsible for absorption of food from the gametophyte.

b) **Seta:** Seta elongates only when the spore capsule has matured, quite the opposite to what happens in mosses. Liverwort setae elongate by cell expansion and so are fairly flimsy and are also colourless. Seta very short, not elongating, of 4 cell rows in height.

c) **Capsule:** Upper most part of sporophyte and is one cell layered and is derived from amphithecium. It contains chloroplasts and the cavity of capsule is filled by spores and nurse cells, produced from endothecium. The diploid endothecium cells divides meiotically to form spore mother cell. While few diploid cells fail to act as spore mother cell and they become sterile, their nature changes and called nurse cells. These cells contain chlorophyll whichprovide nourishment to the developing spores.

Spores: Spore tetrads germinate and produce two male and two female plants after germination. A germ tube appears through the germ pore. It divides by a transverse wall at terminal end and forms two unequal cells. The lower cell forms the rhizoidal cell and the upper terminal cell having dense cytoplasm divides again transversally and longitudinally. It gives rise a two cell thick and about four cell height short filamentous gametophytic plants body.

9.5 MORPHOLOGY, ANATOMY AND REPRODUCTION OF *MARCHANTIA*LES

The characteristic features of order *Marchantiales* are as follows:

1. The ribbon-like, dichotomously branched and dorsiventral thalli grow prostrate upon suitable substrata.

2. Excluding *Dumortiera, Monoselenium* and *Monoclea*, the rest of the genera possess internally differentiated air chambers on the dorsal side of the thallus; such chamber opens outside by an air pore of a particular design.
3. The ventral portion of the thallus consists of parenchyma which acts as storage tissue; oil and mucilage cells may be present in this region.
4. The scales and rhizoids are present on the ventral side of the thallus; the rhizoids are of two types (smooth-walled and tuberculate).
5. The antheridia and archegonia may be found directly on the dorsal surface of the thallus or they may be present on the special branches known as antheridiophores and archegoniophores respectively.
6. In most of cases the capsules of the sporophytes possess single layered jacket.
7. The capsule may be simple as in *Riccia* or it may be differentiated into foot, seta and capsule as in *Marchantia*.
8. The elaters may or may not be present.

9.5.1-Marchantia

Division	–	Bryophyta
Class	–	Hepaticopsida
Order	–	Marchantilaes
Family	–	*Marchantia*ceae
Genus	–	*Marchantia*

Marchantia, the most important genus of family *Marchantia*ceae is represented by about 65 species. The name *Marchantia* was given in honour of Nicolas Merchant, director of botanical garden of Gaston d' Orleans in Blois, France. All species are terrestrial and cosmopolitan in distribution. The species prefer to grow in moist and shady places like wet open woodlands, banks of streams, wood rocks or on shaded stub rocks. These grow best after the forest fire in the burnt soil. In India, *Marchantia* is represented by about 11 species (Chopra, 1943). These species are commonly found growing in the Himalayan region at an altitude of 4000-8000 feet. Some species are also found growing in plains of Haryana, Punjab, Uttar Pradesh and hilly regions of South India.

Some of the common Indian species are *M. palmata, M. polymorpha, M. simlana etc. M. polymorpha* is most widely distributed species. The thalli with gemma cups are found throughout the year whereas the thalli with sex organs occur abundantly during February to March in Himalayas and October to November in hills of South India.

Gametophytic Phase of *Marchantia*: The plant body is gametophytic, thalloid, flat, prostrate, 2-10 cm. long and dichotomously branched. Dorsal surface is dark green. It has a conspicuous midrib and a number of polygonal areas called areolae. The midrib is marked on the dorsal surface by a shallow groove and on the ventral surface by a low ridge. Each polygonal area re-presents the underlying air chamber. The boundaries of these areas represent the walls that separate each air chamber from the next. Each air chamber has a central pore. The midrib ends in a depression at the apical region forming an apical notch in which growing point is situated.

Dorsal surface also bears the vegetative and sexual reproductive structures. The vegetative reproductive structures are gemma cup and develop along the midrib. These are crescent shaped with spiny or fimbriate margins and are about one eighth of an inch in diameter. Sexual reproductive structures are borne on special stalked structures called gametophores. The gametophores bearing archegonia are called archegoniophores and that bearing antheridia are called antheridiophores.

The ventral surface of the thallus bears scales and rhizoids along the midrib. Scales are violet coloured, multicellular, one cell thick and arranged in 2-4 rows. Scales are of two types:
(i) Simple or ligulate
(ii) Appendiculate.
Appendiculate scales form the inner row of the scales close with midrib. Ligulate scales form the outer or marginal row and are smaller than the appendiculate scales.

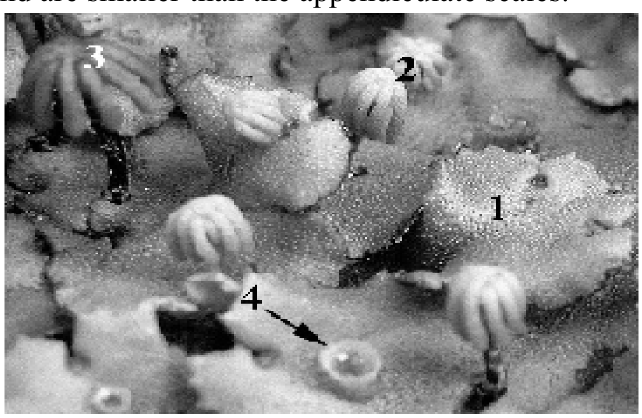


Fig.9.4. ***Marchantia*** **Thallus Showing: 1-Thallus; 2-young archegoniophore; 3-mature archegoniophore; 4-gemma cups; (Photo Ted van Gaalen)**

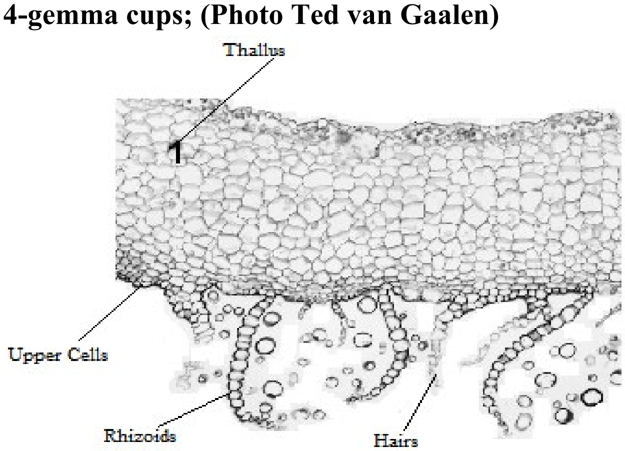


Fig.9.5 ***Marchantia*** **Thallus- Anatomical Features**

Rhizoids are unicellular, branched and develop as prolongation of the lower epidermal cells. They are of two types:
(i) Smooth-walled rhizoids,
(ii) Tuberculate rhizoids.
In smooth-walled rhizoids both the inner and outer wall layers are fully stretched while in tuberculate type rhizoids appear like circular dots in surface view. The inner wall layer modifies into peg like in growth which projects into the cell lumen. The main functions of the rhizoids are to anchor the thallus on the substratum and to absorb water and mineral nutrients from the soil.

Anatomy of the Gametophyte: A vertical cross section of the thallus can be differentiated photosynthetic zone and lower storage zone.

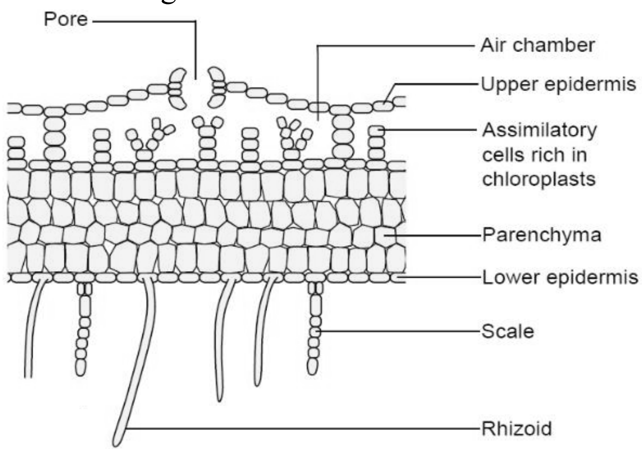


Fig.9.6. Anatomy of *Marchantia* Thallus (Detailed View)

Upper Photosynthetic zone: The outermost layer is upper epidermis. Its cells are thin walled square, compactly arranged and contain few chloroplasts. Its continuity is broken by the presence of many barrel shaped air pores. Each pore is surrounded by four to eight superimposed tiers of concentric rings with three to four cells in each tier.Air pores are compound in nature. The lower tier consists of four cells which project in the pore and the opening of the pore looks star like in the surface view. The walls of the air pore lie half below and half above the upper epidermis.

Just below the upper epidermis photosynthetic chambers are present in a horizontal layer. Each air pore opens inside the air chamber and helps in exchange of gases during photosynthesis.These chambers develop schizogenously and are separated from each other by single layered partition walls. The partition walls are two to four cells in height. Cells contain chloroplast. Many simple or branched photosynthetic filaments arise from the base of the air chambers.

Storage zone: It lies below the air chambers. It is more thickened in the centre and gradually tapers towards the margins. It consists of several lasers of compactly arranged, thin walled parenchymatous isodiametric cells. Intercellular spaces are absent. The cells of this zone contain starch. Some cells contain a single large oil body or filled with mucilage. The cells of the midrib region possess reticulate thickenings. The lower most cell layer of the zone forms the lower epidermis. Some cells of the middle layer of lower epidermis extend to form both types of scales and rhizoids.

Reproduction in *Marchantia*: *Marchantia* reproduces by vegetative and sexual methods.

A. **Vegetative Reproduction:** In Marchantia it is quite common and takes place by the following methods:

1. By Gemmae: Gemmae are produced in the gemma cups which are found on the dorsal surface of the thallus. Gemma cups are crescent shaped, 3 mm. in diameter with smooth, spiny or fimbriate margins. Mature gemmae are found to be attached at the base of the gemma cup by a single celled stalk. Intermingled with gemmae are many mucilage hairs. Each gemma is autotrophic, multicellular, bilaterally symmetrical, thick in the centre and thin at the apex. It consist parenchymatous cells, oil cells and rhizoidal cells. It is notched on two sides in which lies the growing point.

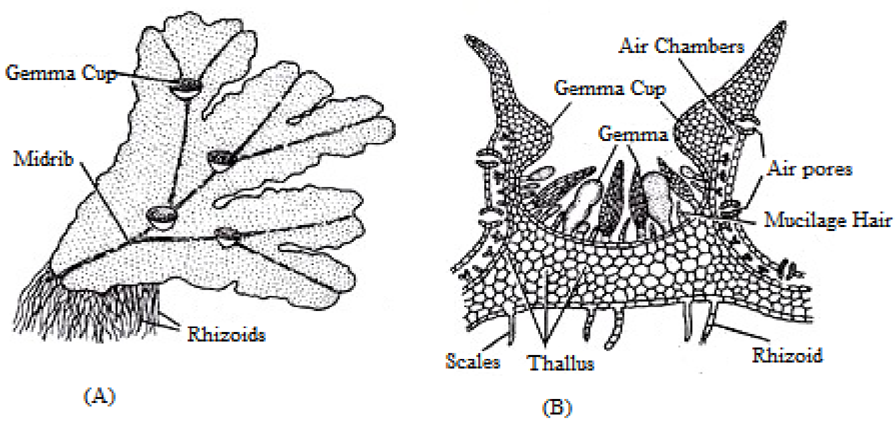


Fig.9.7.*Marchantia,* (A) Gemma Cup on Dorsal Surface, (B)-Vertical Section View

All cells of the gemma contain chloroplast except rhizoidal cells and oil cells. Rhizoidal cells are colourless and large in size. Oil cells are present just within the margins and contain oil bodies instead of chloroplast. Mucilage hairs secrete mucilage on absorption of water. It swells up and presses the gemmae to get detached from the stalk in the gemma cup. They may also be detached from the stalk due to the pressure exerted by the growth of the young gemmae. The gemmae are dispersed over long distances by water currents.

Germination of Gemmae: After falling on suitable substratum gemmae germinate. The surface which comes in contact with the soil becomes ventral surface.The rhizoidal cells develop into rhizoids. Meanwhile, the growing points in which lie the two lateral notches form thalli in opposite directions. Thus, from single gemmae two thalli are formed. Gemmae which develop on the male thalli form the male plants and those on the female thalli form the female plant.

Development of Gemma: The gemma develops from a single superficial cell. It develops on the floor of a gemma cup. It is papillate and called gemma initial. It divides by a transverse division to form lower stalk cell and upper cell. The lower cell forms the single celled stalk.The upper cell further divides by transverse division to form two cells. Both cells undergo by similar divisions to form four cells. These cells divide by vertical and horizontal division to form a plate like structure with two marginal notches. It is called gemma.

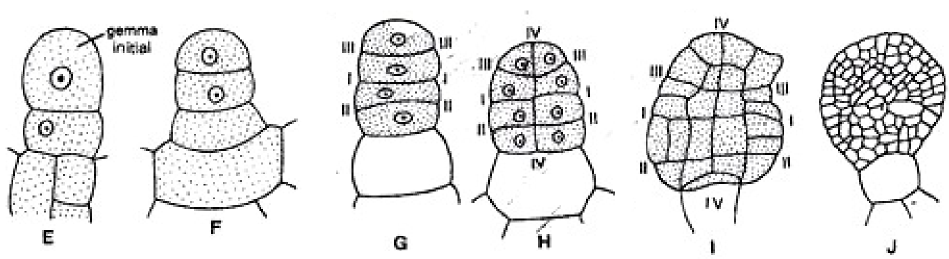


Fig.9.8. Different Stages in the Development of Gemma

2. Death and decay of the older portion of the thallus or fragmentation:
The thallus is dichotomously branched. The basal part of the thallus rots and disintegrates due to ageing. When this process reaches up to the place of dichotomy, the lobes of the thallus get separated. The detached lobes or fragments develop into independent thalli by apical growth.

3. By adventitious branches:
The adventitious branches develop from any part of the thallus or the ventral surface of the thallus or rarely from the stalk and disc of the archegoniophore in species like *M. palmata* (Kashyap, 1919). On being detached, these branches develop into new thalli.

B. **Sexual Reproduction:** Sexual reproduction in *Marchantia* is oogamous. All species are dioecious. Male reproductive bodies are known as antheridia and female as archegonia. Antheridia and archegonia are produced a special, erect modified lateral branches of thallus called antheridiophore and archegoniophore respectively.

Internal structure of Antheridiophore or Archegoniophore:

Its transverse section shows that can be differentiated into two sides: ventral side and dorsal side. Ventral side has two longitudinal tows with scales and rhizoids. These grooves, run longitudinally through the entire length of the stalk. Dorsal side shows an internal differentiation of air chambers.

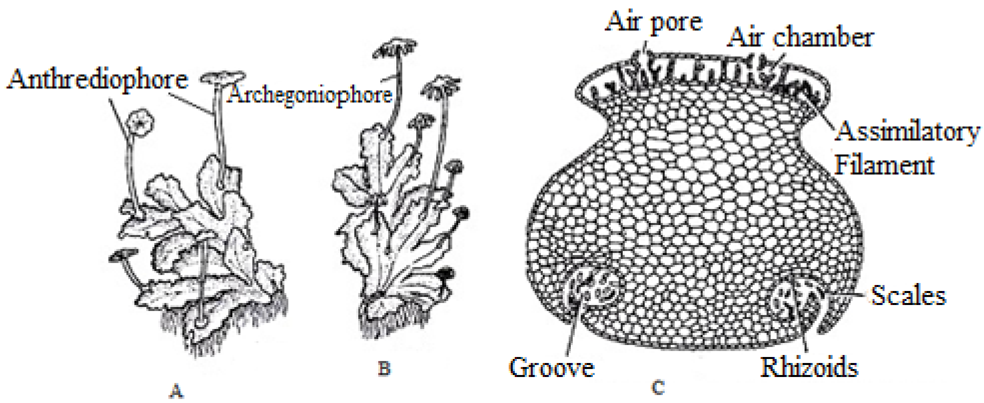


Fig.9.9.*Marchantia*: (A) Thallus Bearing Antheridiophore (B) Female Thallus with Archegoniophore (C) V.T.S. Gametophore

Antheridiophore: It consists of 1-3 centimeter long stalk and a lobed disc at the apex. The disc is usually eight lobed but in *M. geminate* it is four lobed. The lobed disc is a result of created dichotomies.The disc consists of air chambers alternating with antheridial cavities. Air chambers are more or less triangular and open on upper surface by a pore called ostiole. Antheridia arise in acropetal succession i.e., the older near the center and youngest at the margins.

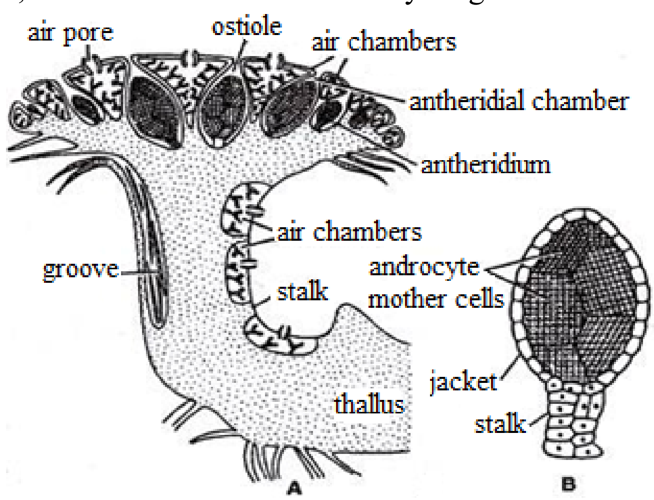


Fig.9.10. *Marchantia* Antheridia (A) Vertical Section (B) Mature Antheridia

A mature antheridium is globular in shape and can be differentiated into two parts stalk and body. Stalk is short multicellular and attaches the body to the base of the antheridial chamber. A single layered sterile jacket encloses the mass of androcyte mother cells which metamorphosis into antherozoids. The antherozoid is a minute rod like biflagellate structure.

Development of Antheridium: The development of the antheridium starts by a single superficial cell which is situated on the dorsal surface of the disc, 2-3 cells behind the growing point. This cell is called antheridial initial. The antheridial initial increases in size and divides by a transverse division to form an outer upper cell and a lower basal cell.Basal cell remains embedded in the tissue of the thallus undergoes a little further development and forms the embedded portion of the antheridial stalk. Outer cell divides to form a filament of four cells. Upper two cells of the four celled filament are known as primary antheridial cells and lower two cells are known as primary stalk cells.

Primary stalk cells from the stalk of the antheridium. Primary antheridial cells divide by two successive vertical divisions at right angle to each other to form two tiers of four cells each. A periclinal division is laid down in both the tiers of four cells and there is formation of eight outer sterile jacket initials and eight inner primary androgonial cells.Jacket initials divide by several anticlinal divisions to form a single layer of sterile antheridial jacket. Primary androgonial cells divide by several repeated transverse and vertical divisions resulting in the formation of large number of small androgonial cells. The last generation of the androgonial cells is known as androcyte mother cells. Each androcyte mother cells divides by a diagonal mitotic division to form two triangular cells called androcytes. Each androcyte cell metamorphoses into an antherozoid.

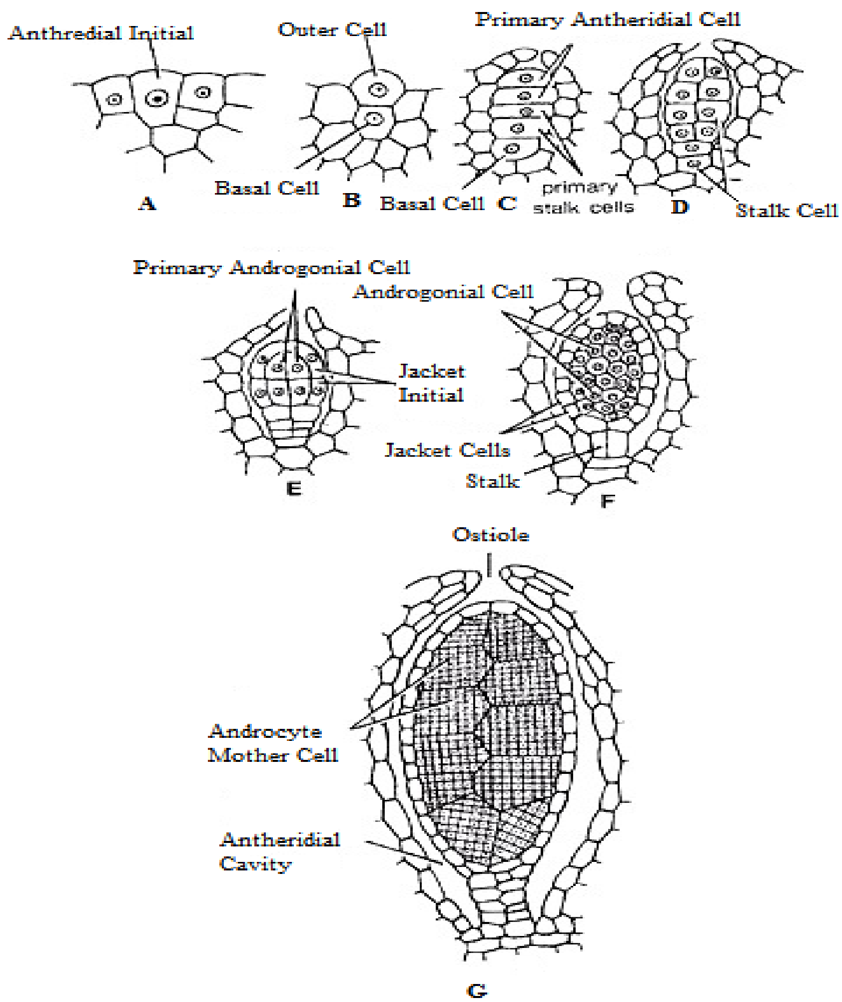


Fig.9.11.*Marchantia* Antheridia Developmental Stages (A-G)

Spermatogenesis: The process of metamorphosis of androcyte mother cells into antherozoids is called spermatogenesis.It is completed in two phases:
(1) Development of blepharoplast.
(2) Elongation of androcyte nucleus.

Archegoniophore or Carpocephalum: It arises at the apical notch and consists of a stalk and terminal disc. It is slightly longer than the antheridiophore. It may be five to seven cm. long. The young apex of the archegoniophore divides by three successive dichotomies to form eight lobed rosette like disc.
Each lobe of the disc contains a growing point. The archegonia begin to develop in each lobe in acropetal succession, i.e., the oldest archegonium near the centre and the young archegonium near the apex of the disc. Thus, eight groups of archegonia develop on the upper surface of the disc. There are twelve to fourteen archegonia in a single row in each lobe of the disc.

Development: The development of the archegonium starts on the dorsal surface of the young receptacle in acropetal succession. A single superficial cell which acts as archegonial initial enlarges and divides by transverse division to form a basal cell or primary stalk cell and an outer cell or primary archegonial cell.
The primary stalk cell undergoes irregular divisions and forms the stalk of the archegonium. The primary archegonial cell divides by three successive intercalary walls or periclinal vertical walls resulting in the formation of three peripheral initials and a fourth median cells, the primary axial cell.Each of the three peripheral initials divides by an anticlinal vertical division forming two cells. In this way primary axial cell gets surrounded by six cells. These are called jacket initials. Six jacket initials divide transversely into upper neck initials and lower venter initials. Neck initial tier divides by repeated transverse divisions, to form a tube like neck.

Mature Archegonium: A mature archegonium is a flask shaped structure. It remains attached to the archegonial disc by a short stalk. It consists upper elongated slender neck and basal globular portion called venter. The neck consists of six vertical rows enclosing eight neck canal cells and large egg. Four cover cells are present at the top of the neck.

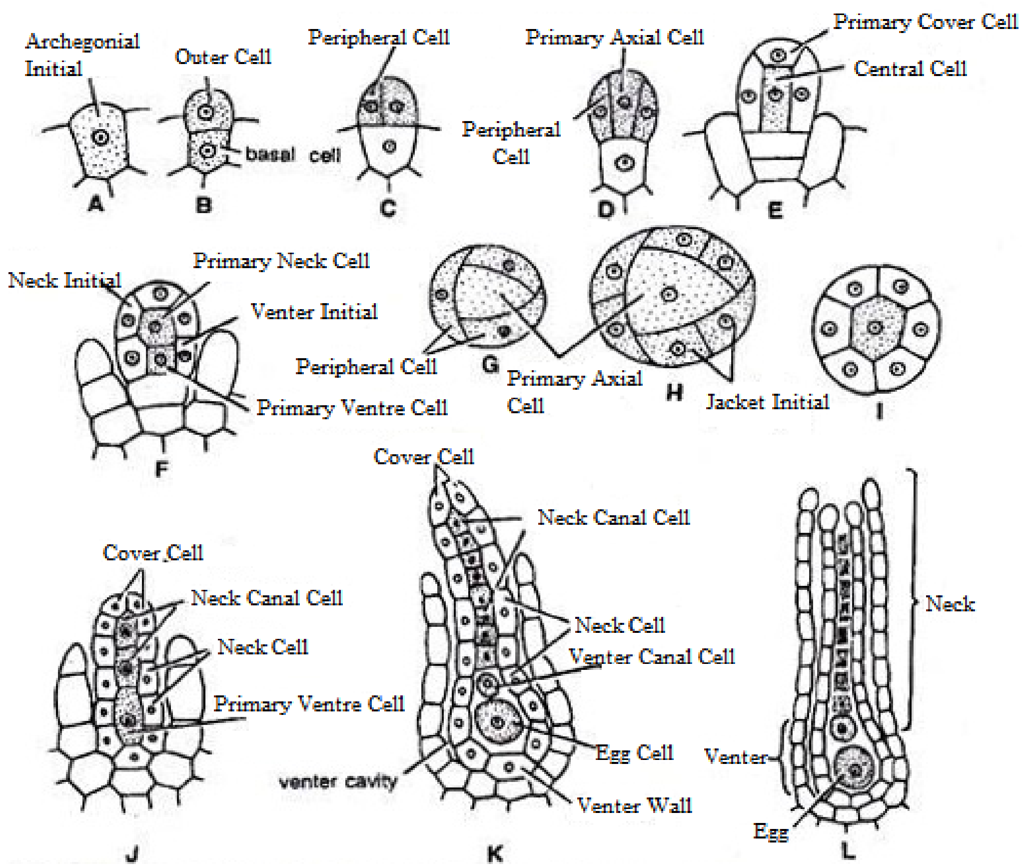


Fig.9.12. ***Marchantia*****: Successive Stages in the Development of Archegonia (A-L)**

Fertilization in *Marchantia*: Fertilization takes place when male and female thalli grow near each other. Water is essential for fertilization. The neck of the archegonium is directed upwards on the dorsal surface of the disc of the archegoniophore. In the mature archegonium the venter canal cell and neck canal cells disintegrate and form a mucilaginous mass. It absorbs water, swells up and comes out of the archegonial mouth by pushing the cover cells apart. This mucilaginous mass consists of chemical substances.

The antherozoids are splashed by rain drops. The flattened surface of male disc have shallow splash cups which discharge sperms on the water surface in the splash cup mechanism. They may fall on the nearby female receptacle or swim the whole way to female receptacle. It is only possible if both the male and female receptacles are surrounded by water. Many antherozoids enter the archegonial neck by chemotactic response and reach up to egg. This mechanism of fertilization is called splash cup mechanism. One of the antherozoids penetrates the egg and fertilization is affected. The fusion of both male and female nuclei results in the formation of diploid zygote or oospore. Fertilization ends the gametophytic phase.

Sporophytic Phase: The young sporogonia are protected by three sheaths developed from the tissue of female receptacle. These layers are perigynium, calyptra and perichaetium. Development of the capsule is accompanied by the development of foot and seta. After Fertilization the zygote starts dividing within 48 hours of fertilization and produces an epibasal and a hypobasal cell. Globular embryo shows exosporic development and quadrant and octant stages come one by one. Four epibasal cells form capsule while four hypobasal cells form foot and seta.Periclinal division takes place in the capsular region separating single layer amphithecium and inner endothecium. Amphithecium divides further to give rise capsule wall. The archesporial cells divide simultaneously and produce a massive sporogenous tissue. These cells are alike in the beginning but after sometime differentiated into elater mother cell and spore mother cell.

After spore maturation seta elongates slightly and the capsule breaks through the calyptra. It projects beyond the perigynium and perichaetium and the apical cell of capsule dries up and ruptures. Capsule wall splits open along 4 to 6 lines. The hygroscopic elaters facilitate dispersal of spores. Elaters coil and uncoil due to changes in the moisture content so that elaters stretch and twist undergoing wriggling movements. Spore after germination produces a new gametophyte.

9.5.2-*Plagiochasma*

Division	–	Bryophyta
Class	–	Hepaticopsida
Order	–	Marchantilaes
Family	–	Rebouliaceae
Genus	–	*Plagiochasma*

Plagiochasma is a thalloid liverwort represented by 30 species (Bischler, 1978), but in India only 10 species have been reported, viz., *Plagiochasma appendiculatum*, *Plagiochasma articulatum*, *Plagiochasma bicornutum*, *Plagiochasma cordatum* and *Plagiochasma cordotii*, *Plagiochasma intermedium*, *Plagiochasma martensii*, *Plagiochasma nepalensis*, *Plagiochasma pauriana* and *Plagiochasma quadricornutum* (Parihar *et al*., 1994). Out of these taxa *P. appendiculatum* abundantly grows in India.

It is widely distributed in Western, Eastern Himalayas, Central India and South India and generally grows to an altitude up-to 8000 ft. from sea level. The species grow in xeric and mesic conditions in all continents, they are absent in areas of equatorial and continental climate (Bischler, 1978, 1979).

Vegetative Structure: Thallus is long, lobed, and flat, dorsiventrally differentiated, dichotomously branched and with undulated margins. Apex of the thallus is notched. Dorsal surface is dark-green. Ventral surface is purplish and bears scales and rhizoids. Midrib is inconspicuous and gradually passing into the lamina. Dorsal epidermis mostly lacking chloroplast, thick- or thin-walled, roughened or smooth and with or without waxy granular deposit externally. Air pores simple, sometimes ± stellate, minute and very inconspicuous or larger and slightly raised, encircled by 1 ring or by 2(3) concentric rings of (4)5-8 cells in each, radial walls of cells often forming continuous lines which may be thickened, pores leading below into small, compact, empty air chambers in several irregular layers, bounding walls chlorophyllous.

Some scattered cells nearly filled with a single oil body, also present in storage tissue, where cells are closely packed: rhizoids ventral, some smooth, others pegged. Scales purple, red to violet, in 2 forwardly directed ventral rows, large, extending beyond thallus margins or not. Basal portion broadly ovate, apically with 1 or 2(3) appendages, variable in shape, linear-lanceolate or ovate to orbicular, sometimes constricted or folded at base, containing a few scattered oil cells: scale margin entire and with papillae in subgenus *Plagiochasma.*

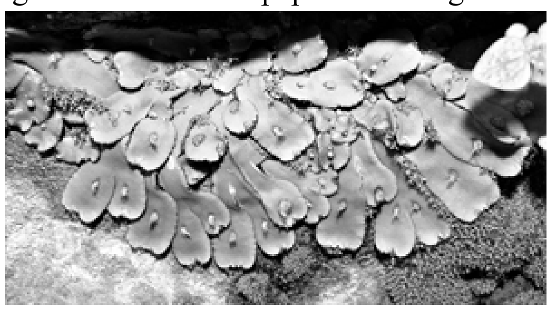


Fig.9.13.*Plagiochasma* Thallus

In T.S. of the thallus, the following layers are noticed:

(a) Upper epidermis with simple pores,

(b) Dorsal air-chambers,

(c) Parenchymatous cell zone,

(d) Ventral layer with multicellular scales and rhizoids which are unicellular, smooth-walled and tuberculate.

The photosynthetic zone consists of 3-4 layers of empty air chambers. Chloroplast is confined to partition wall of the chamber. Photosynthetic filaments are absent in the chambers. Upper photosynthetic zone comprises half barrel shaped air pores. Storage region is well developed and made up of mostly thin walled parenchymatous cell having starch grains as reserve food. Few oil cells are also present and crystals of calcium oxalate are also present in some cells.

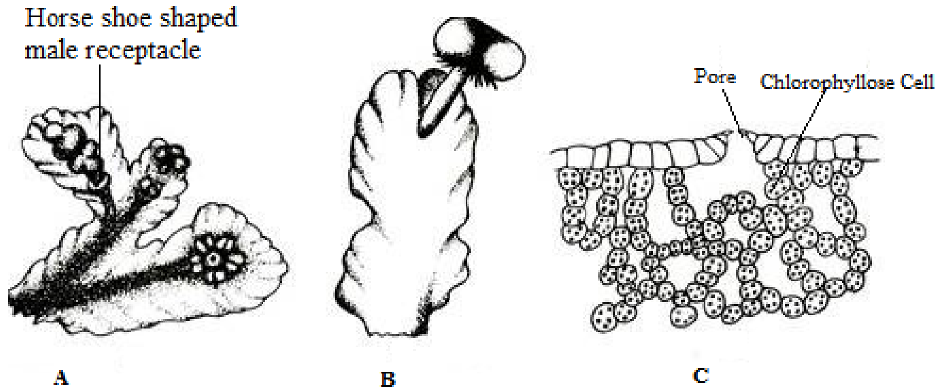


Fig.9.14.*Plagiochasma*: (A) Male Gametophyte (B) Female Gametophyte (C) V.T.S. Thallus

Reproductive Structure: Plants are of both types i.e. monoecious and dioecious. Receptacles are always located at apex to begin with, becoming dorsal by the formation of apical adventitious shoots.

Antheridia: Male receptacle is formed one after another, or a male receptacle may be followed by a female receptacle. Male receptacle is sessile, horse-shoe-shaped and surrounded by linear scales. Receptacle bears two types of chambers i.e. air-chambers with simple pores lie between the antheridia and antheridial chamber. Antheridial chambers contain single large globose antheridium and having an opening called ostiole.

Archegonia: Female receptacle is also sessile when young, but at maturity stalked. The stalk arises from the dorsal side of the thallus, and is devoid of rhizoidal furrow, but has scales at base and apex. The disc of archegoniophore has only air chambers and each chamber has barrel shaped air pores as in *Marchantia*. Female receptacle is more or less concave on the dorsal surface, with barrel-shaped pores and is 2 – 9 lobed. It is surrounded by involucres which are large, inflated, and bivalved and margin folded inwardly. Each involucre contains one archegonium. The development, structure and fertilization is similar to *Marchantia*.

Sporophyte: Sporophyte has large globose capsule, short seta and a reduced foot. Capsule is spherical with single-layered jacket and an operculum on its anterior side. Inside the capsule spore and elater are present. Spores are yellowish and reticulate-lamellate. Elaters are short and bi-or trispiral. During dehiscence of capsule the operculum throw off and the rest of the capsule splits in several valves. Spore liberates and a new gametophyte is developed in a suitable substratum

9.5.3-*Conocephalum*

Division	–	Bryophyta
Class	–	Hepaticopsida
Order	–	Marchantilaes
Family	–	Conocephalaceae

Genus – *Conocephalum*

Conocephalum conicum is one of our most common 'thallose' (i.e. not leafy) liverworts, often forming large colonies on damp, shady stonework and on ditch sides and in damp woodland. Plants mainly found in high altitude of mountains. It grows on the faces of rocks, in the river, commonly the water flows over these rocks and the *Conocephalum* is behind a small waterfall.

Vegetative Structure: Plant body is thalloid in nature and the thallus is large, dichotomously branched and dorsiventrally differentiated. As is typical of the *Marchantia*les, the gametophyte thallus is dichotomously branched and many cells thick. Dorsal surface of the thallus is dark green, but ventral surface is pale green. Midrib is very conspicuous. There are few scales arranged in two rows on ventral surface by the side of midrib, along with unicellular, smooth-walled and tuberculate rhizoids.

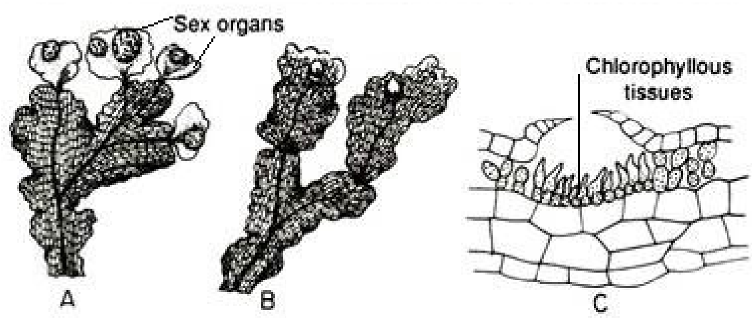


Fig.9.15. A & B *Conocephalum* Dorsal Thallus View, (C) V.T.S. Through Gametophyte

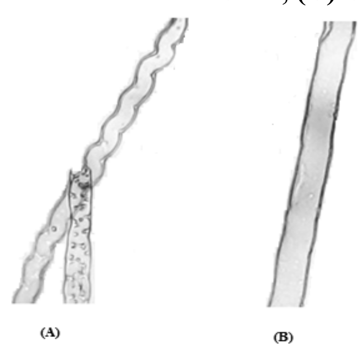


Fig.9.16.*Conocephalum* Rhizoids (A) Tuberculate or Pegged (B) Smooth Walled

Internal Structure

The tissue differentiated into the chlorenchyma - an upper region of small cells containing chloroplasts, and a lower parenchyma of larger cells containing starch grains. Single-layered upper epidermis with simple elevated air pores (areolate) which are visible to the naked eye. Areolae are very distinct and mostly hexagonal. These air pores are somewhat analagous to stomata in the sporophyte generation of vascular plants. In *Conocephalum* these air pores are surrounded by 4-6 concentric rings of thin-walled cells, making the pores easily visible to the naked eye.

Presence of dorsal layer with large air-chambers, where filamentous, chlorophyllous cells arising from the floor are produced into pointed beaks. Parenchymatous storage tissue and lower epidermis with scales and 2 types of rhizoids are present.

Reproduction:

A. Asexual reproduction

1. **Fragmentation:** New plants are produced by regeneration from broken pieces of thallus, the thallus being brittle and no doubt easily transported by water.
2. **Gemmae:** Gemma is seen in some thalloid liverworts, sometimes they develop on the lower surfaces of senescent thalli.
3. **By Tubers:** Tubers are formed in those species which are exposed to desiccation (drying effect of the air). Towards the end of the growing season, the subterranean branches get swollen at their tips to from the underground tubers. On the periphery of a tuber are two to three layers of water proof corky, hyaline cells develop.

   These layers surround the inner cells which contain starch, oil globules and albuminous layers. During the unfavorable conditions the thallus dies out but the dormant tubers remain unaffected. On the return of the favourable conditions each tuber germinates to form a new plant. Thus, tubers also serve as organ of perennation

B. Sexual Reproduction: *Conocephalum* is, however, dioecious (male and female gametes produced on separate plants) and colonies will often be of a single sex. This species frequently produces receptacles at the thallus apices.

Antheridia: The male receptacle (containing the antheridia) is sessile, green or tinged violet. Male receptacle is disciform, papillose, sessile and situated near the apex of a branch, or sometimes apparently lateral in a cup formed by the growth of the thallus laterally and posteriorly. Each antheridial chamber has single antheridium and opens outside through an opening called ostiole. The structure development and dehiscence of antheridium is similar as in *Marchantia*.

Archegonia: The female receptacle (containing the archegonia) is stalked, like a tiny umbrella, the stalk sometimes elongating to up to 10 cm. Archegonia are produced on female receptacle which has two distinct part stalk and disc. Female receptacle is nearly terminal, long-stalked and located in a pit. It is obtusely conical, almost entire and composed of 5-8 tubular involucres on the underside, each enclosing a single capsule. Parianth is absent. The dorsal surface of female disc is lined up by air chambers having barrel shaped air pores.

(A) (B)

Fig.9.17. *Conocephalum*: (A) Sporophyte over Gametophyte (B) Single Sporophyte

Sporophyte: It is composed of foot, seta and capsule. Sporophyte is present on short feebly developed lobes of female disc. Thus number of sporophyte depends on the number of lobes. Each sporophyte is protected by tubular involucre. Capsule has a rather long pedicel and it is clavate-pyriform in shape. It dehisces at maturity by throwing off an apical cap, and the remaining part of jacket splitting longitudinally by 4 to 8 reflexed valves. Spores are large, papillose and many-celled. Elaters contain 2-4 spiral and bluntly fusiform thickening bands. The multilocular spore when come in contact with rocky soil, germinates into gametophyte thallus.

9.6 MORPHOLOGY, ANATOMY AND REPRODUCTION OF JUNGERMANNIALES

The Jungermanniales or 'leafy Liverworts', e.g. *Lophocolea, Lophozia* and *Frullania*, is the largest order of liverworts and contrast with thalloid liverworts such as *Marchantia* and *Pellia* and with mosses and hornworts which collectively make up the bryophytes. Liverworts are the simplest of all extant plants. They thrive in moist habitats and are less well known than the mosses. The gametophyte bears stalked reproductive organs (archegonia and antheridia) on the upper surface and fine hair like unicellular rhizoids project from the lower surface. All liverwort thalli lack the mucous-filled cavity present in hornworts.

The characteristic features of this order are as follows:

1. The gametophyte is differentiated into stem and leaves; the leaves are borne in a regular spiral succession along the stem.
2. The apical cell is pyramid-like with three cutting faces.
3. The stem generally bears three rows of leaves; two rows are lateral and consist of leaves of normal size; the third row consists of the under leaves which are generally smaller than the lateral leaves.

4. The archegonia are always restricted to the apices of the axis and its branches.
5. The sporophytes are always terminal in position.
6. The antheridia are borne singly or in groups in the axis of leaves.
7. Archegonium arises from a single surface cell and is a minute flask-shaped structure, with a rounded base or venter containing the single egg cell and a ventral canal cell.
8. A narrow neck whose canal is initially plugged by 5 (in most Jungermanniales) neck canal cells.

Frullaniaceae is a family of leafy liverworts characterized by creeping plants, median to robust, forming branched tufts, usually epiphytic in habit. The leaves are incubous, with usually inflated lobes, often transformed into water sacs, and the stylus is multiform (Stotler 1970; Yuzawa 1991; Konrat et al. 2012). This family is distributed worldwide, achieving greater richness and diversity in tropical regions (Gradstein et al. 2001). Frullaniaceae spores are large and brownish and some species show precocious and endosporic germination (Crandall-Stotler et al. 2009).

9.6.1-*Frullania*

Division	–	Bryophyta
Class	–	Hepaticopsida
Order	–	Jungermanniales
Family	–	Frullaniaceae
Genus	–	*Frullania*

There are about 800 species of *Frullania* liverworts and many grow as epiphytes on the bark of trees and shrubs where the humidity is high. Epiphytic plants take nothing from the host plants they grow on, so this liverwort does no harm to trees. It can look very lacy and fern like at times. Sometimes it reminds of the beautiful fan corals found on distant coral reefs. . *F. dilatata* and *F. tamarisci* are both common British species; *F. tamarisci* grows on rocks, on the ground, or less frequently on trees, while *F. dilatata* generally grows on trees.

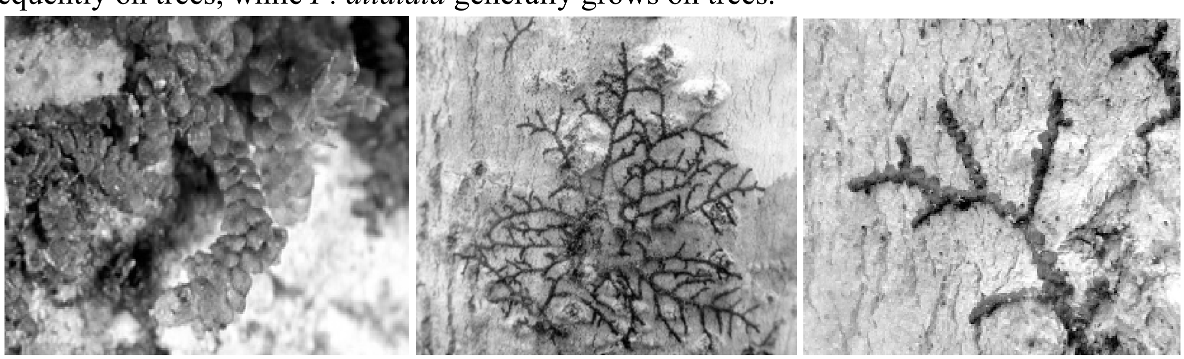


Fig.11.18. Different Species of *Frullania* on Trees & Rocks

Gametophyte: ***Frullania* is a** genus of leafy liverworts; the thallus is pinnately branched and differentiated into stem and leaves. The plants are small and olive-green. The thallus is often dark green to copper-brown or purplish in colour. It has a characteristic type of leaf. The very small leaves of the *Frullania* liverwort were strung together like beads in few species. The leaf lobe apices are rounded, acute and especially on younger shoots. The lobules are remote from stem and they are attached to stem in a matter that they tilted outwards, clavate-cylindric, somewhat dorsiventrally compressed near mouth in comparison with the gibbous upper half with an obtuse apex.

The leaves are arranged in three rows two laterals unequally lobed and a ventral lobule. Each leaf consists of 2 parts, the smaller of which is pitcher-like; these tiny pitchers hold water and often contain a characteristic microscopic fauna, including rotifers, which may in some way aid in the nutrition of the liverwort The under leaves of leading stems are very small, distant, and as wide as the stem, longer than wide. The leaf lobes are composed of relatively large cells.

Anatomy of Stem & Leaf: Little tissue differentiation is seen and even no clear epidermis is seen. Stem is divided in cortical and central medullary zone. Cells of cortical zone are smaller but with thick wall while the cells of medullary zone are larger and with thin wall. No conducting tissue is present. Leaf is one layered and the cells comprise chloroplast and few oil bodies as well. Leaf has no mid rib and stomata and air pores remain absent.

Reproduction

a) Vegetative Reproduction:

(i) By Fragmentation: Older part of branched stem die of old age and the branches thus separated as fragment by apical growth develops into new plant.

(ii) By Cladia: These are the small or broad detachable branches which help in vegetative reproduction. These are of two types: **(i) Leaf cladia:** Arising from the individual cell of the leaf e.g., *Frullania fragilifolia* etc. **(ii) Stem cladia**: Arising from the individual cell of the stem.

b) **Sexual Reproduction:** The species is presumably dioecious but few species are monoecious and others are dioecious. Sex organs are present on special lateral branches. The antheridia are borne on special lateral branches. The archegonia are borne on the main shoot or a branch terminally. A mature sporophyte has a blunt foot, short and broad seta. The capsule encloses the spores.

In monoecious species sex organs are present on separate branches of the same plant. The leaves borne on fertile branches are called bracts. These differ in shape and size from the vegetative leaves. Bracts occurring on the male branch are called the perigonial bract and those occurring on the female branch are called perichaetial bracts.

Antheridia: It occurs on special short branches called male branches or androecia. Each antheridium is a minute more-or-less spherical structure borne on a long stalk in the shelter of each concave scale-like leaf on the catkin-like male shoot. Each male branch bears 2-5 or more

pairsof usually concave, close set of perigonial bracts, which are bilobed. Two lobes are almost equal in size. Usually two antheridia develop at the axil of each bract.
Antheridium is differentiated into stalk and a globose body. Stalk has double row of cells and the antheridial body is surrounded by a jacket layer surrounding central mass of androcyte cells. Each androcyte mother cell divides by a diagonal division into two androcytes and each androcyte metamorphoses into biflagellate antherozoids.

Archegonia: Gynoecia on short or elongate shoots, each with 2-5 archegonia. Perianth flattened or inflated, with 0-14 keels, the mouth contracted into a beak. Mature archegonium is flask shaped having venter and a long narrow neck. Venter encloses the egg cell and a ventral canal cell. Neck is made up of five vertical rows of neck cells surrounding an axial row of up to eight neck canal cells.

Fertilization: It takes place in the presence of water. When ripe, the antheridia release the flagellated **antherozoids**, or male gametes, which swim across the surface film of moisture, attracted to chemicals released by the egg cell (or possible associated tissues). The perianth may assist this by holding water. In the ripe archegonium, the ventral canal cell and neck canal cells break down into mucilage which takes in water and expands, opening the flask-like archegonium ready for an antherozoid to swim down to the egg where fertilisation occurs.

Sporophyte: The diploid zygote typically develops into the **sporophyte**. One of the archegonia at the female shoot tip will develop into the sporophyte after fertilisation. It grows out from the perianth as a stalk topped by spore capsule, which is usually darkly coloured and glossy when mature and may be more-or-less spherical but is usually elongated. In some forms, the young sporophyte begins its development completely enclosed in gametophyte tissue which grows up from the stem to enclose the sporophyte, forming a **marsupium**. This protective sheath of stem tissue may bear leaves or bracts and may replace a perianth in some forms which lack this structure and may occur at the end of the shoot or hang down from the branch at right angles and may be a sizeable structure.
Sporophyte is well developed into foot, seta and capsule. *Frullania* seta is of numerous rows of cells. Foot of the sporophyte does not penetrate into the stem. Capsule is globose and the wall is 2-layered. Elaters attached to the capsule valves, arranged vertically inside the capsule, with 2-3-spirals. Spores large, multicellular, germination endosporic.

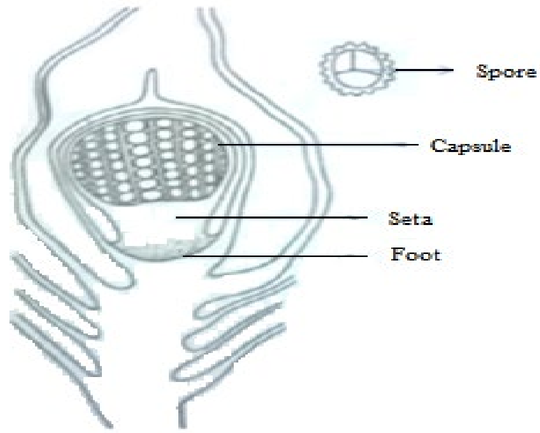


Fig.11.19.*Frullania* Sporophyte L.S.

Spore Dispersal: The wall of the spore capsule is two to several cell layers thick and the walls of the cells develop bands of thickening. The spores are produced by meiosis and so are haploid. As the ripe capsule dries out, these bands of thickenings, which are deposited in very specific patterns, create stresses in the shrinking tissues which cause the capsule to rupture and to split into four valves (above right). In most leafy liverworts, the spores are discharged by a water rupture mechanism. Interspersed with the spores are swollen, elongated cells called **elaters**. These clear, water-filled elaters have a double spiral band of wall-thickenings on the inside of the cell wall. The elaters may be free or anchored to the inside walls of the spore capsule (**sporangium**) in liverworts, but are anchored at their base in this mechanism.

In some leafy liverworts, such as *Frullania*, each elater spans the sporangium and is firmly attached to the sporangium floor at one end and to the roof at the other. As the four valves of the capsule bend back, as the capsule dries and opens, the elaters are momentarily stretched and each has a single spiral of thickening and is essentially a stretched spring in the wall of a water-filled tube. In less than a second the elaters are torn free at their lower ends, which moves in an arc (as when a stretched spring is bent backwards and then released from one end) flinging out the spores. In *Frullania fragifolia*, the large antical lobes of the bilobed leaves detach, leaving only the smaller postical lobes.

9.6.2-*Porella*

Division	–	Bryophyta
Class	–	Hepaticopsida
Order	–	Jungermanniales
Family	–	Porellaceae
Genus	–	*Porella*

External Structure of *Porella:* The gametophyte of *Porella* is flat, dorsiventral and foliose. The prostrate stem or axis is bi- or tripinnately branched. There are three rows of leaves arranged on the stem, two dorsal rows and one ventral row. The dorsal rows form the lateral leaves and the leaves of the ventral row are called amphigastria. Leaves are devoid of midribs.

The dorsal leaves are bilobed. The upper anterior lobe, called antical lobe, is larger, usually ovate with rounded apex; while the lower posterior lobe, called postical lobe or lobule, is much smaller and narrower with acute apex. The dorsal leaves are closely overlapping and show incubous arrangement i.e. the lower edge of each leaf is covered by the upper edge of the next leaf below. This arrangement can be seen when viewed from the dorsal side.

A large number of scattered rhizoids of smooth-walled type arise from the ventral surface of the stem. The main function of rhizoids is to attach the thallus to the substratum. The absorption of water and minerals is taking place primarily through the leaves and stem.

Internal Features of *Porella*:

Stem: The T.S. of the mature stem shows two distinct regions, the cortex and the medulla. The cortex is 2-3 layered zone, consists of thick-walled parenchymatous cells, while the medulla is composed of thin-walled, elongated cells.

Leaf: The leaves are very simple in configuration. Each leaf is composed of a single layer of isodiametric parenchymatous cells containing many chloroplasts. In a few species, leaves contain oil cells.

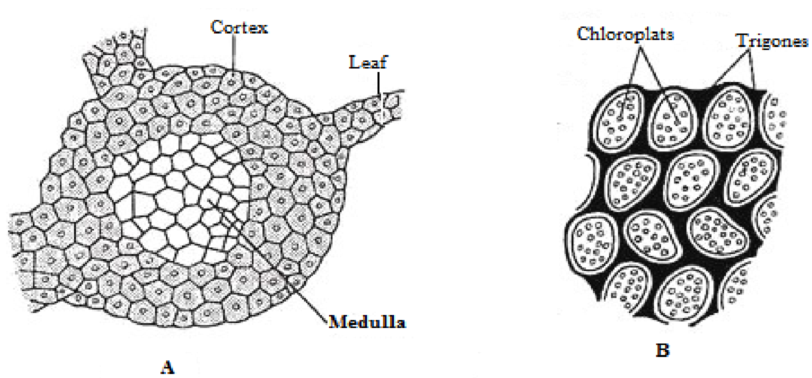


Fig.9.20. *Porella*: (A) Stem T.S. (B) Leaf T.S.

Reproduction:

1. Vegetative Reproduction in *Porella:* *Porella* reproduces vegetatively by the following two methods:

(a) By Progressive Death and Decay of the Gametophyte: The apical growth of the thallus is accompanied by the progressive death and decay of the older parts of the thallus and consequent separation of the younger parts at the point of dichotomy of the thallus. The separated branches develop to form new plants.

(b) By Gemmae: In some species (*P. rotundifolia*) discoid multicellular gemmae are produced on the lower surface of the leaves. Gemmae germinate to produce new plants.

2. Sexual Reproduction in *Porella:* *Porella* is dioecious. Male gametophytes are comparatively smaller than the female gametophyte.

Antheridium: Antheridia are borne on specialized lateral antheridial branches which project out at right angles to the main axis. The dorsal leaves, called bracts, are smaller than those on the main branch and are closely imbricated. The ventral leaves (amphigastria) of the antheridial branch are known as bracteoles. A single antheridium is borne in the axil of each leaf.

Development of Antheridium: An antheridial initial, situated at the base of the young bract, divides transversely to produce an outer cell and a basal cell. The basal cell does not divide further and forms the embedded part of the stalk. The outer cell functions as antheridial mother cell which, by transverse division, forms an upper primary antheridial cell and a lower primary stalk cell.

A two-celled thick long stalk is developed from the primary stalk cell, following repeated transverse and vertical divisions. The primary antheridial cell forms the main body of the antheridium. It forms two identical antheridial cells by a vertical division.

Each of these cells, by a periclinal division, forms two unequal cells, the outer smaller first jacket initial and the inner larger primary androgonial cell. The latter again divides to form a second jacket initial. Both the jacket initials form a single layered jacket of the antheridium following periclinal divisions.

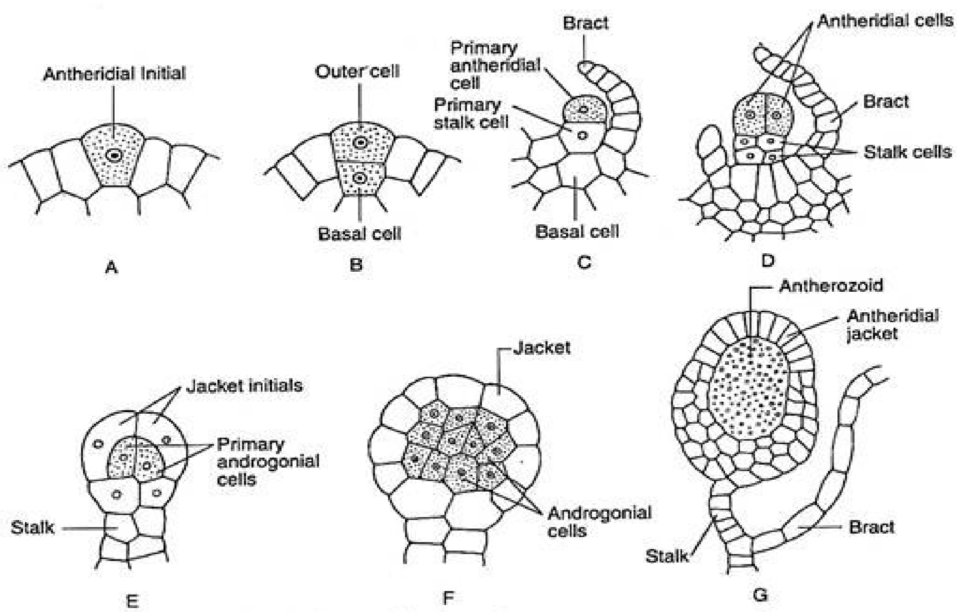


Fig.9.21. ***Porella:*** **Antheridia Developmental Stages**

The primary androgonial cell forms a large number of rectangular androgonial cells following several divisions in all possible planes. Androgonial cells further transformed to androcyte mother cell. Each androcyte mother cell following a diagonal division forms two androcytes, each of which metamorphoses into a biflagellate antherozoid.

Structure of Mature Antheridium: The mature antheridium is differentiated into a globose body and a long stalk. The jacket is single-layered at the upper part, while it becomes 2-3 layered at the lower region through periclinal divisions. The jacket contains inside a mass of androcytes which ultimately metamorphose into biflagellate antherozoids. The distal part of antheridial jacket is single- layered and thin. This part of the jacket breaks up into many irregular lobes. This allows the antherozoids to release into the water.

Archegonium: Archegonia are produced at the apex of archegonial branch on the female plant. The archegonial branch is much smaller than the vegetative branch, bearing a number of large perichaetial leaves (bracts). The lower bracts form involucre, while the two upper bracts coalesce to form a perianth. Ten to fifteen archegonia develop within the perianth.

Development of Archegonium: The archegonia develop in acropetal succession. Each archegonium develops from a single superficial cell, the archegonial initial which increases in size and appears as a papillate outgrowth.
The pattern of development of archegonia is identical with that of *Riccia* and *Marchantia*.

Structure of Mature Archegonium:
A mature archegonium differentiates into a neck and a venter. The neck is long, comprises of five vertical rows of neck cells enclosing 6-8 neck canal cells. The venter is 2-layered, consists of a small ventral canal cell and a large egg. A rosette of 4 cover cells is present at the top of the archegonial neck.

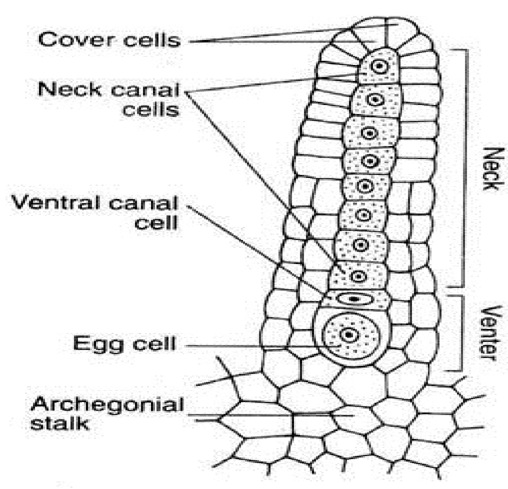


Fig.9.22.Mature Archegonium of *Porella*

Fertilization: Like other bryophytes, water is essential for release of sperms and eventual fertilization in *Porella.* The process of fertilization is found to be similar with that of other bryophytes.

Sporophyte: The zygote increases in size and secretes a wall around itself. Like other bryophytes; zygote divides transversely to form an epibasal cell and a hypobasal cell. The hypobasal cell does not divide further, it forms a suspensor. The epibasal cell divides transversely to form two daughter cells.

These daughter cells undergo repeated transverse as well as vertical divisions in regular sequence to form an irregular mass of cells. Later, the peripheral amphithecium and inner endothecium are differentiated by the periclinal divisions in the upper part of the embryo.

The amphithecium gives rise to the capsule wall, while the entire endothecium functions as archesporium. The archesporium forms the sporogenous tissue through the repeated divisions in all possible planes.

The sporogenous tissue differentiates into spore mother cells and elater mother cells. The elaters mother cells become elongated endowed with two spiral thickening and form the sterile elaters. The spore mother cells divide meiotically to produce haploid spores. The foot and seta develop from the lower part of the embryo.

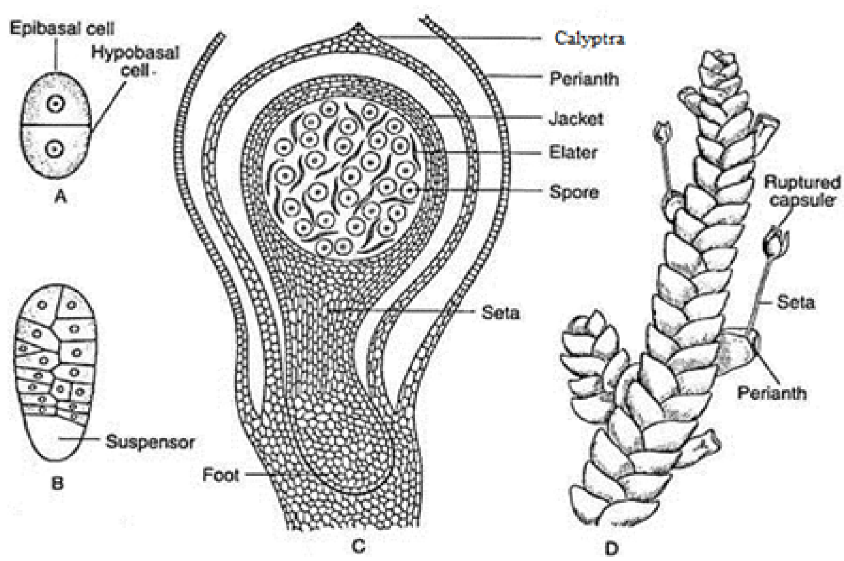


Fig.9.23. Sporophyte of *Porella* (A) Embryo (B) Young Embryo (C) L.S. Mature Sporophyte

Structure of Mature Sporophyte: The mature sporophyte of *Porella* differentiates into three parts, viz., foot, seta and capsule. The young sporophyte is enclosed by three protective coverings — calyptra, perianth and involucre.

(i) Foot: It is the expanded bulbous mass of cells at the base of the sporogonium.

(ii) Seta: It is an elongated structure which connects -the foot with the capsule, made up of parenchymatous cells.

(iii) Capsule: It is a globose structure containing numerous spores and elaters. The jacket is 3-4 cells thick, made up of thick-walled parenchymatous cells, except for four vertical rows of thin-walled cells that demarcate the vertical lines of dehiscence.

Dehiscence of Capsule: At maturity, the seta elongates suddenly, pushing the capsule out of the calyptra and perianth. As the capsule wall dries up, the capsule now splits into four valves along the line of dehiscence. The hygroscopic movement of elaters helps in discharging of spores.

Young Gametophyte: The spore is the first stage of gametophytic generation. A spore has two concentric walls: the outer ornamented exine and the inner thin- walled intine. Sometimes a third layer, called perinium, is found outside the exine. The spore germinates immediately after the fall on the suitable substratum. It differentiates into an apical cell. Then a multicellular thalloid structure is formed.

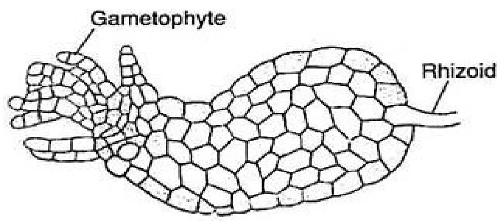


Fig.9.24.Gametophyte: Multicellular Thalloid Structure

The rhizoids develop from the lower side and leaves are produced on the upper side.The germination of spores may take place while the spores are still within the capsule.

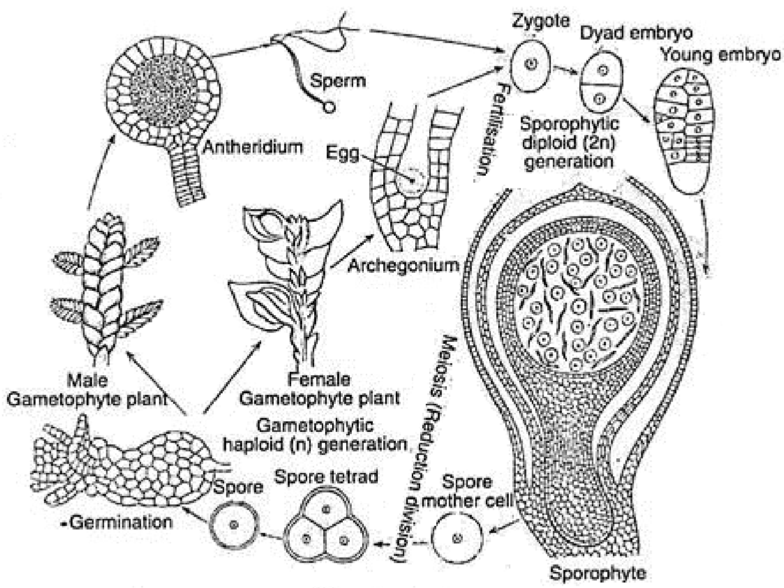


Fig.9.25. Life Cycle of *Porella*

9.7 MORPHOLOGY, ANATOMY AND REPRODUCTION OF METZGERIALES

Metzgeriales is an order of liverworts. The group is sometimes called the simple thalloid liverworts: "thalloid" because the members lack structures resembling stems or leaves, and "simple" because their tissues are thin and relatively undifferentiated. All species in the order have a small gametophyte stage and a smaller, relatively short-lived, spore-bearing stage. Although these plants are almost entirely restricted to regions with high humidity or readily available moisture, the group as a whole is widely distributed, and occurs on every continent except Antarctica.

Members of the Metzgeriales typically are small and thin enough to be translucent, with most of the tissues only a single cell layer in thickness. Because these plants are thin and relatively undifferentiated, with little evidence of distinct tissues, the Metzgeriales are sometimes called the "simple thalloid liverworts".

There is considerable diversity in vegetative structure of the Metzgeriales. As a rule, simple thalloid liverworts do not have structures resembling leaves. However, a few genera, such as *Fossombronia*, and *Symphyogyna*, are "semileafy" and have a thallus that is very deeply lobed, thus giving the appearance of leafiness. The several semileafy groups within the Metzgeriales are not closely related to each other, and the currently accepted view is that the leafy condition evolved separately and independently in each of the groups where it occurs.

Members of the Metzgeriales also differ from the related Jungermanniales in the location of their archegonia (female reproductive structures). Whereas archegonia in the Jungermanniales develop directly from the apical cell at the tip of a fertile branch, archegonia in the Metzgeriales develop from a cell that is behind the apical cell.As a result, the female reproductive organs, and the sporophytes that develop within them, are always located on the dorsal surface of the plant. Because these structures do not develop at the apex of the branch, their development in the Metzgeriales is described as *anacrogynous*.

The characteristic features of this order are as follows:

1. The gametophyte may be thalloid or differentiated into stem and lateral leaves.
2. In most cases the gametophytes are without internal differentiation of tissues but certain genera have a central strand of thick-walled cells.
3. The ventral surface of a gametophyte bears smooth-walled rhizoids.
4. The sex-organs are found to be scattered on dorsal surface of thallus.
5. The archegonia arise from the young segments cut off by the apical cell.
6. The mature sporophytes lie some distance back from the growing apex of a gametophyte.
7. The sex organs (antheridia and archegonia) are produced on any branch of the gametophyte or only on special branches.

9.7.1-*Pellia*

Division	:	Bryophyta
Class	:	Hepaticopsida

Order	:	Metzgeriales
Sub-order	:	Metzgerineae
Family	:	Pelliaceae
Genus	:	*Pellia*

Pellia is a small but widespread genus of liverworts in the cool and temperate regions of the Northern Hemisphere. It is classified in order Metzgeriales and is a member of the family Pelliaceae within that order. Pellia, a genus with only four species, is known to exist only in India. They are *P.calycina, P.epiphylla, P.endiviaefolia* and *P.neesiana*. It is found between 5000 to 8000 ft. in Western Himalaya, Uttarakhand, and Himanchal Pradesh etc.

Habit and Habitat

Pellia grows mainly in moist, shady places, especially by ditches and streams. They also grow on moist soil or rocks or in soil between rocks if it is shady. Sterile plant parts may be seen growing under frequently running shallow water while fertile plants tend to grow in exposed conditions. Plants growing on damp soil have robust thallus and elongated lobes. When grow submerged the thallus is delicate, long narrow and with distinct midrib.

Vegetative Structure: Plant body is thin, dorsiventral, prostrate, dichotomously branched, with somewhat wavy margin. Thallus is thin, flat, green and lobed. The dorsal surface is almost smooth and a median midrib is prominent. On the ventral surface numerous smooth, unicellular rhizoids are borne from under the midrib. Each lobe of the thallus has terminal notch in which growing point is present.

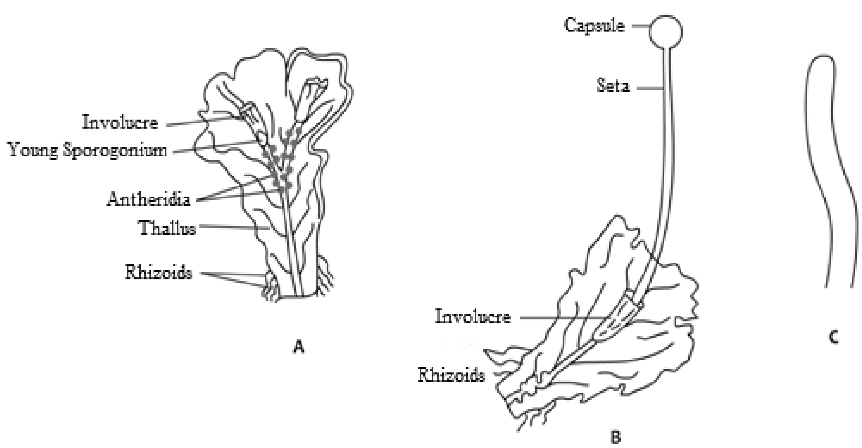


Fig.9.26. A. *Pellia* habit (dorsal surface); B. Thallus with sporophyte; C. Simple rhizoid

Internal features: Thallus anatomy is simple but several layer deep.In T.S. through the thallus, following layers can be noticed:

(a) Upper and lower epidermis are present lower epidermis is with numerous smooth rhizoids. Cells near the surface contain abundant chloroplast.

(b) In between the two epidermal layers there are compact parenchymatous, chloroplast containing cells with a few scattered fibrous cells. Usually the midrib portion is thicker (8 – 16 layers in depth) than margins (2-5 layers in depth).
(c) Thallus shows no differentiation and is composed of parenchymatous cells which serve the purpose of food storage. The cells are joined together like honey-comb.

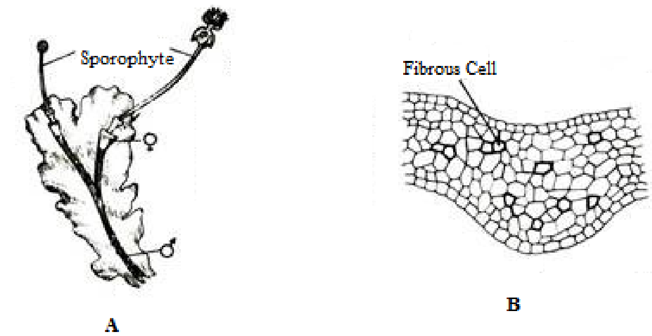


Fig.9.27. ***Pellia*****: (A) Gametophyte (B) T.S. Through Gametophyte**

(d) Apical growth is by single apical cell with four cutting faces.
(e) Unicellular rhizoids grow from undersurface in the mid rib region.
(f) Air pores and air chambers are absent which is found in *Marchantia*.

Reproductive Structure: *Pellia* reproduces by vegetative and sexual process.
Vegetative Reproduction: Vegetatively it reproduces by adventitious branches and fragmentation and in few species regeneration is also seen from bits of thallus in culture.

Sexual Reproduction: Plants are either monoecious or dioecious. In the dioecious forms, the male plant bears antheridia all along the dorsal surface of the midrib while the archegonia develop in a cluster just behind the growing tip on the dorsal side of the female plant. In monoecious forms, the antheridia are behind the archegonia.

1. **Antheridia:** Immersed inside the cavity on the dorsal surface of the thallus. The mature antheridium is globose with a jacket layer which is one cell in thickness and a multicellular short stalk generally one celled. It lies at the bottom of the antheridial chamber which is open on the dorsal surface by a pore. Outer wall surrounds a central mass of androcyte mother cell. These androcytes metamorphoses into a biflagellate sperms.
2. **Archegonium:** They are produced in cluster on the upper surface of the thallus. All the archegonia in the cluster stand on a slightly raised transverse ridge of tissue called receptacle. Archegonia of the cluster are surrounded by a complete flap like sheath called involucre. Archegonium is a flask shaped structure, seated on a short stout stalk. The mature archegonium shows a venter containing the egg, a ventral canal cell and 4 to 6 neck canal cells and four cap cells at the top of the neck. Venter is two layered.

Fertilization: Fertilization takes place in the presence of water. All the cells except egg disorganize in the archegonium and mucilage mass is formed. It fills the neck canal and absorbs water and swells up. In the same time the antheridia ruptures at its apex androcytes emerge through the opening. Sperms release and swim towards archegonial neck to reach the egg. The first sperm loses its flagella and fuse with egg cell forming zygote.

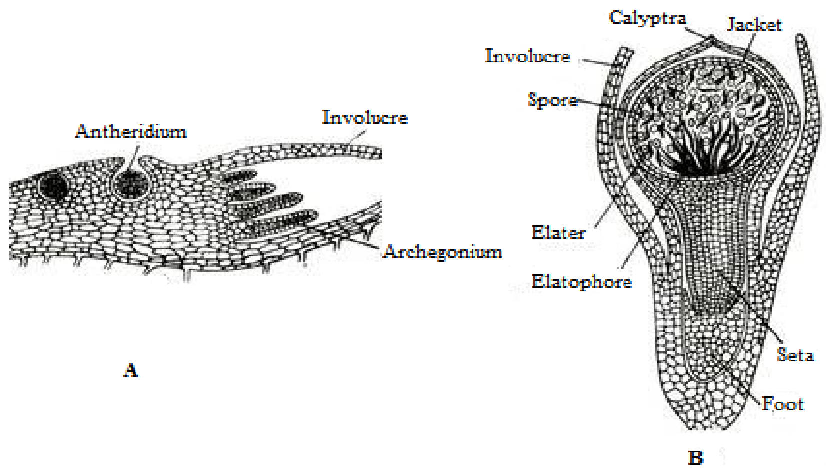


Fig.9.28. *Pellia:* (A) Section Through Gametophyte Growing Region (B) Section Through Sporophyte

Sporogonium: Sporophyte is covered by involucre and calyptra. Each sporophyte has a distinct foot, seta and globose capsule. Foot is conical, forming collar-like outgrowth and covering a part of the seta. Seta is present and is small. Capsule is globose in shape and has two-layered jacket cells of outer layer larger with radial walls thickened and cells of inner layer with inner tangential wall thickened and numerous spores and elaters. Amphithecium forms the jacket of the capsule and endothecium forms archesporium. Archesporium forms spore, elaters and elatophores. There is a distinct elaterophore (formed by a group of elaters) at the base of each capsule. Capsule wall dehisces and splits into four valves. Elaters help in the dispersal of spores.

9.7.2-*Sewardiella*

Division	:	Bryophyta
Class	:	Jungermanniosida
Order	:	Fossombroniales
Family	:	Petalophyllaceae
Genus	:	*Sewardiella*

Sewardiella is a genus of liverwort in the family Petalophyllaceae. It contains the single species, ***Sewardiella tuberifera***, which is endemic to India. Its natural habitat is rocky areas, and it is threatened by habitat loss.

Gametophyte: Plant is foliose grows in cluster on moist soil. Thallus is light green, dorsiventral and prostrate in habit. Thallus consists of well-defined central axis or midrib bearing leaf like structure in two lateral rows. From the ventral surface numerous simple, smooth walled, violet coloured, unicellular rhizoids occur, which anchor the plant. Leaves are thin, light green or pale and alternate. The leaf is one cell thick except basal portion which is 2 or 3 cells in thickness.

Reproduction: Reproduction takes place by vegetative and sexual type.

Vegetative Reproduction: It takes place by regeneration and tuber formation. At the end of growing season the stem apex of the plant bend downwards, grows more or less vertical into the soil forming tuber.

Sexual Reproduction: Most of the species are monoecious. The sex organs develop on the dorsal surface and occur scattered or in groups

Antheridia: Antheridia develop in acropetal succession scattered or in group of 2-5 on the upper surface of the thallus. Antheridial group mostly occur near the anterior end and each separated by its neighbor by a small scale. Mature antheridia are round, shortly stalked and orange in colour. The antheridial wall is one cell thick. Antheridium arises from a single superior cell. Antheridium is covered by a jacket layer and the inner cells are called androgonial cells. These cells divide diagonally to form androcytes. Each androcyte metamorphose into a biflagellate sperm.

Archegonia: They develop in small groups laterally on the midrib near the growing point protected by the young leaves. Archegonium has a twisted base, a broad venter and a long neck with 5-6 neck canal cells. After fertilization each archegonial cluster is invested by a bell shaped perianth.

Fertilization: Sex organs dehisce after imbibing moisture and sperms are released with a force. In female sex organs all the cells except egg cell disorganizes. Sperm reaches to egg cell by swimming in the water. The act of fertilization provides added stimulus to the thallus tissue, adjacent to the base of the fertilized archegonium to grow into a bell shaped organ called perianth.

Sporophyte: It is differentiated into foot, seta and capsule. Foot is haustorial and provides nourishment. Seta is fairly long in few species and short in others. Capsule is a globular structure and comprising two cell thick walls. Capsule contains elaters and spores but no elaterophore. Mature sporophyte is surrounded by a bell shaped sheathing organ called perianth. The perianth develops after fertilization.

When spore matures in the capsule, the seta elongates and this elongation ruptures the calyptra and elevates capsule above the perianth. Exposed capsule dries up and splits into four valves or dehisce irregularly. Spores are liberated from the capsule and dispersed by the hygroscopic movement of the elaters.
Spores remain in dormant phase for some duration and with the onset of rain, they start germination. On germination they form a green filamentous protonema and so the gametophyte.

9.8 MORPHOLOGY, ANATOMY AND REPRODUCTION OF CALOBRYALES

The characteristic features of this order are as follows:

1. They possess erect leafy gametophytes with leaves in three vertical rows. Leaves are either isophyllous or anisophyllous.
2. The leaves are dorsiventrally flattened and central strand of conducting tissue.
3. They have a pale, subterranean, sparingly branched rhizome from which arise erect leafy branches.
4. Erect branches bearing sex organs have the uppermost leaves close together and in more than three rows.
5. They are devoid of rhizoids.
6. The antheridia are ovoid, stalked, and borne at the apex of the stem.
7. The jacket of the neck of archegonium has only four vertical rows of cells.
8. The sporophyte bears an elongate capsule whose jacket layer is only one cell in thickness except at the apex.
9. The number of chromosomes is n=9.
10. Since there is single family Calobryaceae the characters are similar to that of the order. Two genera- *Calobryum* and *Haplomitrium*.

9.8.1-*Calobryum*

Calobryum plants are pale to bright green with a prostrate, leafless rhizome with descending, hyaline, leafless stolons and aerial leafy shoots.Growth takes place via tetrahedral apical cell; central strands of hydroids present. Leafy shoots 3-ranked, isophyllous or anisophyllous with the reduced row of leaves dorsal; oil bodies present; rhizoids absent. Stolons positively geotropic, unbranched (branched), hyaline. The main stem is at first prostrate, growing either interwoven in a felt of other liverworts or in the brown leaf-litter derived from these, or sometimes under the soil. This part of the stem is white in colour and on the outside has a colourless mucilaginous sheath as thick again as the stem itself. Neither leaves nor rhizoids are present.

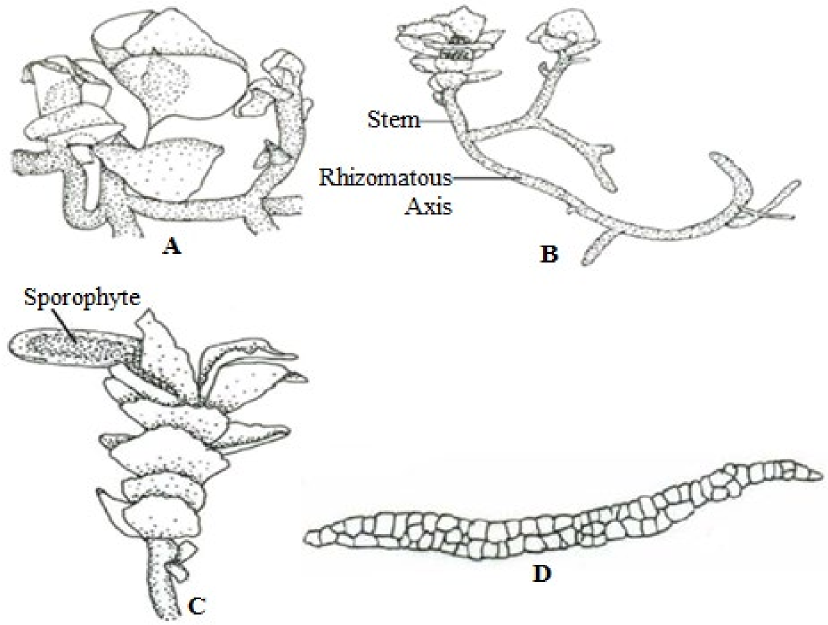


Fig.9.29. ***Calaobryum*****: (A) Heterotrichous Plant (B) Male Plant (C) Female Plant (D) Leaf Anatomy**

When the subterranean stem is 1 to 2 cm long the tip turns erect and gives rise to a translucent, pale green, leafy stern. Lateral shoots grow out from the base of the erect stem. But one or more grow out strongly and these after a period of horizontal growth turn erect as new leafy shoots.

Anatomy of the Erect Shoot

The erect stem shows a central colourless zone which may be up to 16 cells in diameter. Male shoots are more slender, with a central zone only 4 cells in diameter and an outer zone 5 to 7 cells wide.The surface cells are approximately isodiametric, have a very thin cuticle, and contain more plastids than deeper cells; some of them give rise to mucilage hairs consisting of a club-shaped terminal cell and a short stalk cell. The deeper cells gradually become more elongated until in the central zone.

At the tip of the stem is an apical cell with 3 cutting faces, all three faces being equal in size except immediately after cell division. From each segment cut off by the apical cell a leaf arises. These leaves are at first uniseriate, but as they enlarge the basal portion becomes multiseriate, usually 4 cells in thickness.

Reproduction: Sexual condition dioecious or monoecious; antheridia and archegonia with a common pattern of development at least in early ontogenetic stages. There are distinct antheridial and archegonial plants which grow either intertwined or in separate clumps. The antheridial plant is the more slender of the two, with erect stems and the leaves tend to be more widely spaced than on female plants. The male shoots continue to grow for some time, giving rise to successive series of leaves and antheridia. The appearance differs with the stage of development. In September (spring), when new growth begins, the young antheridia are present. They lie in a mucilage-filled cavity at the tips of the erect branches, completely overarched and surrounded by the three youngest leaves.

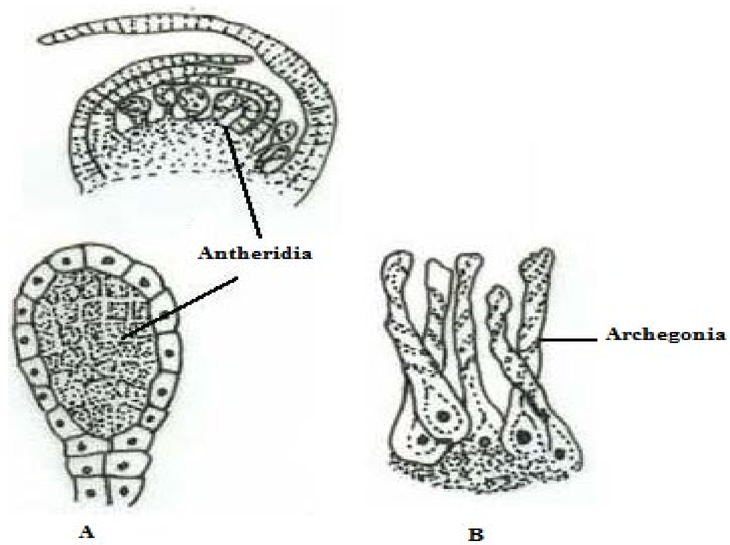


Fig.9.30 *Calobryum*: (A) Antheridia (B) Archegonia

Antheridium: The antheridia occur interspersed with mucilage hairs at the tip of the antheridiophore. Young antheridia develop close to the apical cell and also amongst the older antheridia.The antheridium arises from a superficial cell which projects from the surface and then divides transversely into an inner cell embedded in the receptacle tissue and an outer protruding cell. The outer cell divides transversely into the primary antheridial cell and the primary stalk cell. The latter divides by two intersecting vertical walls followed by transverse walls to produce the antheridial stalk.

In the primary antheridial cell the first wall is an obliquely vertical one, dividing the antheridial cell into 2 cells of unequal size. In the larger cell 2 further obliquely vertical walls are formed, which meet the first wall above. At this stage there is a densely-staining central cell, shaped like a three-sided pyramid, enclosed by 3 jacket cells. The first-formed jacket cell divides vertically, and when the resulting cells enlarge the central cell expands in this direction and forms a four-sided pyramid. Later the other jacket cells divide also. Transverse divisions follow, producing the uniseriate jacket of the fully developed antheridium. The central pyramidal cell divides transversely and then by repeated divisions in various planes gives rise to the spermatogenous cells. Either all the fertile cells divide simultaneously or else those belonging to the top half of the antheridium divide prior to those of the bottom half. The last division in the formation of the spermatogenous cells is not necessarily a diagonal one, such as frequently occurs in the hepaticae, but lies in any plane.

The mature antheridium is oval in shape and stands away from the surface of the receptacle on a stalk composed of 4 rows of cells 3 to 5 tiers in height. When water is present it opens at the top, the terminal cells separate from one another and bend outwards as the mass of sperm cells is slowly extruded.

Archegonium: The archegonium arises from a superficial cell alongside the apical cell and in position replaces a leaf rudiment. The superficial cell projects from the surface and divides transversely into an inner cell embedded in the receptacle tissue and an outer protruding cell. The latter divides transversely forming a stalk initial and a terminal cell. The stalk initial soon divides by vertical and by transverse walls giving rise to the base of the venter, and to the short stalk of the archegonium standing above the surface of the receptacle. Meanwhile in the terminal cell 3 inclined walls are laid down successively in such a way as to cut out a pyramidal central cell from 3 jacket cells. One of the jacket cells divides vertically so producing 4 jacket cells. In the venter region the jacket cells divide both vertically and transversely, and just before the archegonium is mature they divide once periclinally.

In the mature archegonium there is a short stalk projecting above the surface of the receptacle, a biseriate venter only, slightly broader than the base of the neck, and a spirally twisted, often curved neck. At a late stage of development vertical or obliquely vertical divisions take place amongst the uppermost neck canal cells.

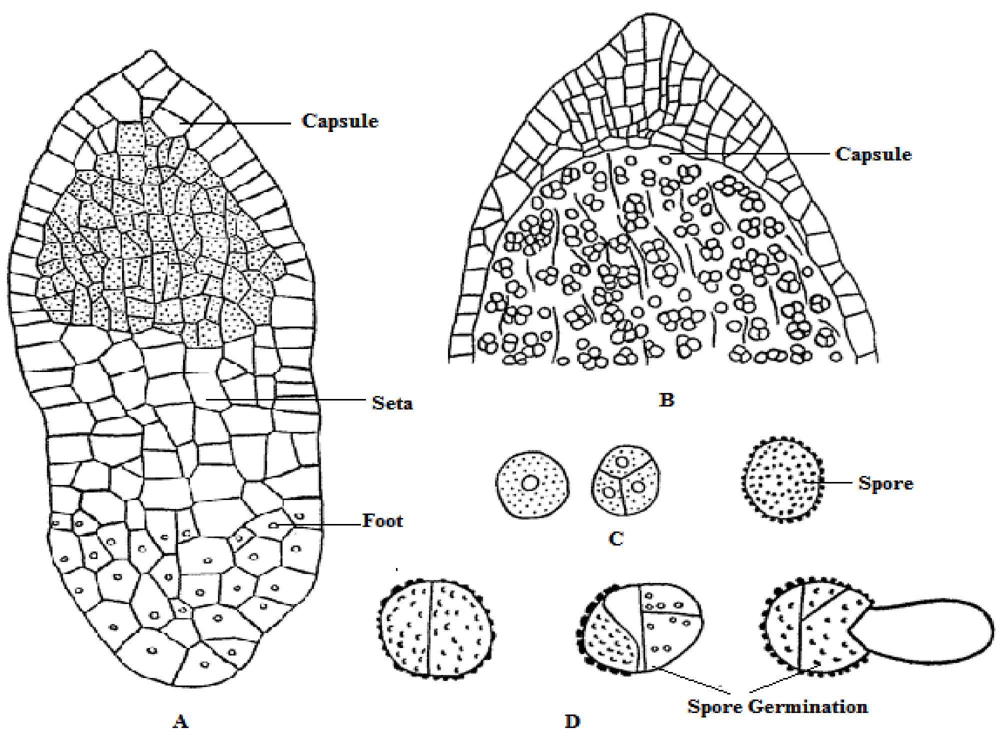


Fig.9.31*Calobryum*: (A) Sporophyte L.S. (B) Mature Capsule with Spores (C & D) Spore & Its Germination

Sporogonium: Young archegonia were forming in September. The tip of the stem forms a flat or dome-shaped disc on which up to 20 archegonia develop. At first these lie in a mucilage-filled cavity enclosed and overarched by the surrounding leaves, but later the leaves enlarge and flatten. These leaves are transversely inserted in 3 rows on the stem but are much larger than the vegetative leaves. If fertilization fails to take place, the archegoniophores remain in position for several months, the disc covered with old bronze-coloured archegonia and surrounded by the large dentate leaves. Ripe sporogonia are found in November at the tips of some of the archegoniophores.

Sporogonium has three parts i.e. foot, seta and capsule. The base of the sporogonium is surrounded by a colourless, fleshy foot or pengynium 5 to 8 mm long. The slender, colourless seta stands erect to a height of 22 mm and carries at its tip the dark brown capsule 3 to 4 mm long and 0.5 mm wide. Usually only one sporogonium develops on an archegoniophore.

The mature capsule has a uniseriate jacket except in the region of the projecting knob-shaped terminal cap, which at the top is up to 5 cells in thickness. Here the cells are colourless and lack thickenings on their walls. The cells forming the sides of the capsule are elongated lengthwise, being 3 to 12 times as long as they are broad; those on the shoulders are approximately isodiametric. The spores have a brown outer wall, rough with small rounded projections, and are oval in shape. Commonly they hold together in tetrads or in pairs.

The mature capsule is eventually pushed out through the calyptra at the top of the perigynium by the rapid elongation of the seta. Dehiscence is usually into 4 valves, occasionally into 2 or 3 or 5 valves, which remain united at the ends. The dehiscence begins at the base of the capsule and gradually extends upwards, the edges of the valves curling back as the twisting elaters free the spores.

9.9 SUMMARY

Liverworts are believed to represent the phylogenetically oldest phylum of bryophytes. Their principal characters include the short-lived sporophyte (persisting for at most a few weeks), stomata absent in generations, seta hyaline and elongating after maturation of the sporangium (capsule). The capsule lacks peristome teeth and sterile tissue of the columella and spores are released mostly following the split of the sporangial wall into four valves, aided by hygroscopic elaters with spiral wall thickenings, which are produced from sporogenous tissue together with spores. Gametophytic protonema in liverworts is extremely reduced and produces only a single bud that develops into a leafy or thallose gametophore.

The Jungermanniales or 'leafy Liverworts', is the largest order of liverworts and contrast with thalloid liverworts such as *Marchantia* and *Pellia* and with mosses and hornworts which collectively make up the bryophytes. Shoots may be vegetative, ending in a cluster of expanding leaves which protect the growing tip or they may be fertile shoots, ending in female or male reproductive organs. The female shoot shown here ends in a vase-like **perianth** which encloses and protects the female reproductive organs (**archegonia**).

Members of the Metzgeriales typically are small and thin enough to be translucent, with most of the tissues only a single cell layer in thickness. Because these plants are thin and relatively undifferentiated, with little evidence of distinct tissues, the Metzgeriales are sometimes called the "simple thalloid liverworts". Members of the Metzgeriales also differ from the related Jungermanniales in the location of their archegonia (female reproductive structures). Whereas archegonia in the Jungermanniales develop directly from the apical cell at the tip of a fertile branch, archegonia in the Metzgeriales develop from a cell that is behind the apical cell. As a result, the female reproductive organs, and the sporophytes that develop within them, are always located on the dorsal surface of the plant.

9.10 GLOSSARY

Abaxial: facing away from the axis of plant

Antheridium: The male sex organ of the cryptogam

Antherozoid: Small, motile male gamete with flagella

Apophysis: Swollen sterile tissue at the base of the capsule where it joins the seta

Archegonium: The female sex organ of bryophytes, pteridophytes and gymnosperms containing the egg inside a cellular jacket.

Archesporium: Group of cells from which the spores of a sporangium are derived.

Capsule: the terminal, spore-producing part of a moss sporophyte.

Calyptra: A covering developed from the venter of the archegonium in bryophytes and pteridophytes, which surrounds the young sporophyte.

Endohydric: having water transport essentially internal.

Elater: elongate sterile cells, usually hygroscopic, admixed among spores of most hepatics and hornworts

Foot: the basal organ of attachment and absorption for the bryophyte sporophyte, embedded in the gametophyte.

Gametophyte: the haploid, sexual generation; in bryophytes the free-living, dominant generation.

Gemma (pl. **gemmae**)**:** uni- or multi-cellular, globose, clavate, filiform, cylindrical or discoid structures, borne on the aerial part of the plant and functioning in vegetative reproduction.

Hepatic: a member of Class Hepaticopsida; also known as liverworts.

Heteroicous: having several forms of gametoecia on the same plant; also called polygamous.

Prostome: a rudimentary structure outside and usually adhering to the main peristome teeth.

Proximal: the end or part nearest to the base or place of origin.

Rhizoid: a hair-like structure that anchors a moss to the substratum; multicellular with oblique cross walls, often pigmented, and sometimes clothing the stem.
Sinus: a gap between two lobes of a leaf.
Struma: a cushion-like swelling at one side of the base of a capsule.
Tetrad: a group of four; e.g. the 4 spores derived from a single sporocyte by meiosis.
Tetrahedral: a four-faced cell or spore.

9.11 SELF ASSESSMENT QUESTION

9.11.1 Multiple Choice Questions:

1. The antheridia occur in the axil of the modified leaves are called?
(a) Perigynium (b) Perichaetium
(c) Perigonial Bract (d) Perianth

2. Rhizoids are single celled and smooth walled in
(a) *Sphaerocarpos* (b) *Riccia*
(c) *Marchantia* (d) *Funaria*

3. In bryophytes diploid chromosome number occurs in
(a) Spore mother cell (b) Gametes
(c) Spores (d) Meiospores

4. Gemmae are vegetative reproductive structures found in
(a) Angiosperms (b) Bryophytes
(c) Algae (d) Gymnosperms

5. In bryophytes, antherozoids are
(a) Biflagellate (b) Sometimes biflagellate and sometimes multi-flagellate
(c) Multi-flagellate (d) Biflagellate in a few species and multi-flagellate in the rest

6. In which plant a gemma cup-present?
(a) *Riccia* (b) *Marchantia*
(c) *Anthoceros* (d) *Funaria*

7. Which place in India is called "The Golden Mine of Liverworts"
(a) Eastern Himalayas (b) Western Himalayas
(c) Western Ghats (d) Eastern Ghats

8. Mid rib is absent in the leaves of?

(a) *Funaria* (b) *Porella*
(c) *Polytrichum* (d) *Pellia*

9. Which of the following is a leafy liverwort?
(a) *Pellia* (b) *Riccia*
(c) *Anthoceros* (d) *Frullania*

10. Rhizoids are absent in
(a) *Riccia* (b) *Marchantia*
(c) *Pellia* (d) *Calobryum*

9.11.1 Answer Key: 1. (c), 2. (a), 3. (a), 4. (b), 5. (a), 6. (b), 7. (b), 8.(b), 9. (d), 10. (d)

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9.14 TERMINAL QUESTIONS

9.14.1 Short Answer Questions:

1. What are Gemmae? Give their function.
2. What structure is produced by the division of endothelium and amphithecium?
3. List the distinctive features of class Hepaticopsida.
4. How do sporophytes of liverwort take their nourishment?
5. What are tubers? Give their function.
6. Define morphological and anatomical features of *Marchantia* gametophyte.
7. How is fertilization occurred in *PoreIla*?
8. Define structure and position of sex organs in *Sphaerocarpos*.
9. How *Pellia* sporogonium is advance then *Marchantia*?
10. Describe in brief the life cycle of *Pellia*.

9.14.2 Long Answer Questions

1. In what respect the sex organs of Jungermanniales differ from those of *Marchantia*les.
2. List the salient features in the life cycle of Jungermanniales.
3. Describe the life cycle of *Sphaerocarpos*, giving suitable diagram.
4. Compare the life cycle of *Marchantia*and *Plagiocasma*.
5. Describe the structure and development of sex organs in *Marchantia*.
6. Define the sex organs and reproduction of Calobryales.
7. Give a comparative account of sporophytes of *Pellia* and *Porella*.

UNIT-10 ANTHCEROTALES, SPHAGNALES, EUBRYALES, ANDREALES AND TAKAKIALES

10.1 OBJECTIVES

After reading this unit students will be able -

- to know Detail description of order Anthocerotales and species Anthoceros.
- to learn about the Characteristics of Sphangnales and description of Sphagnum.
- to understand the Important features of order Eubryales and Funaria.
- to understand about the Order Andreales and its important characteristics with description of Andreaea.
- to learn about Takakiales and its salient features of ecological importance.

10.2 INTRODUCTION

Bryophyta is the most ancient lineage of terrestrial plants. They show an alternation of generations between the independent gametophyte generation, which produces the sex organs and sperm and eggs, and the nutritionally dependent sporophyte generation, which produces the spores. In contrast to vascular plants, the bryophyte sporophyte usually lacks a complex vascular system and produces only one spore-containing organ (sporangium). The mature gametophyte of most bryophytes is leafy, but some liverworts and hornworts have a flattened gametophyte, called a thallus. The salient features and detailed description of the species of mosses and hornworts is given in this unit. This unit deals with general features of different species and their life cycle pattern.

10.3 SALIENT FEATURES OF IMPORTANT GROUPS WITH EMPHASIS ON THE GIVEN GENERA

Class 2. Anthocerotae or Anthocerotopsida: The members of this class possess following characteristics:

- Gametophytic plant body is simple, thalloid; thallus dorsiventral without air chambers shows no internal differentiation of tissues.
- Scales are absent in the thallus.
- Each cell of the thallus possesses a single large chloroplast with a pyrenoid.
- Sporophyte is cylindrical only partly dependent upon gametophyte for its nourishment. It is differentiated into bulbous foot and cylindrical capsule. Seta is meristematic.
- Endothecium forms the sterile central column (i.e., columella) in the capsule (i.e. columella is present).
- It has only one order-Anthocerotales.

10.4 MORPHOLOGY, ANATOMY AND REPRODUCTION OF ANTHOCEROTALES

The class Anthocerotopsida consists of a single order, the Anthocerotales and a single family, the Anthocerotaceae, 6 genera and 301 species. According to Proskauer (1951) the order Anthocerotales includes two families, (i) Anthocerotaceae and (ii) Notothylaceae. The latter includes a single genus, i.e., *Notothylas*.

However, according to top bryologists, there is only one family, i.e., Anthocerotaceae. About five or six genera are included in this family.These genera are—*Anthoceros, Phaeoceros*, *Aspiromitus, Notothylas, Dendroceros* and *Megaceros*. Four genera are universally recognised, they are—*Anthoceros, Megaceros, Dendroceros* and *Notothylas*. This group differs in many respects from the other bryophytes.

This group is placed intermediate between Hepaticopsida (Hepaticae) and Bryopsida (Musci). The group is considered to be very important from the point of view of its morphology, because of its intermediate position between the two important groups, the Hepaticopsida and Bryopsida.The most characteristic features of the group are as follows: The gametophytic plant body is thalloid and dorsiventral. The rhizoids are simple and smooth walled. Tuberculate rhizoids and ventral scales are altogether absent.

10.4.1 *Anthoceros*

Systematic Position of Anthoceros:

Division	-	Bryophyta
Class	-	Anthocerotopsida
Order	-	Anthocerotales
Family	-	Anthocerotaceae
Genus	-	*Anthoceros*

Distribution and Habitat of *Anthoceros*

Anthoceros is represented by about 200 species. All species are terrestrial and cosmopolitan in distribution. The species grow in very moist and shady places like slopes, rocks or sides of the ditches. Some species are found growing on decaying wood. Unlike other bryophytes *Anthoceros* is usually not well adapted to resist dry conditions.

In India *Anthoceros* is represented by about 25 species. Out of these three species of *Anthoceros* viz., *A. himalayensis, A. erectus and A. chambensis* are commonly found growing in the Western Himalayan region at an altitude of 5000-8000 feet (Kashyap, 1915). These species are also found growing in Mussoorie, Kulu, Manali, Kumaon, Chamba valley, Punjab, Madras and in plains of South India.

Gametophytic Phase of Anthoceros

The gametophytic plant body is thalloid, dorsiventral, prostrate, dark green in colour with a tendency towards dichotomous branching. Such branching results into an orbicular or semi orbicular rosette like appearance of the thallus. Anthoceros form small rosette like plant. Unicellular rhizoids are attached to the underside of the thallus. Small mucilaginous cavities are present on the ventral side. These cavities contain colonies of a blue green alga like Nostoc. Stomata like small slits are present on the dorsal side of the thallus. Mucilage oozes out through these slits.

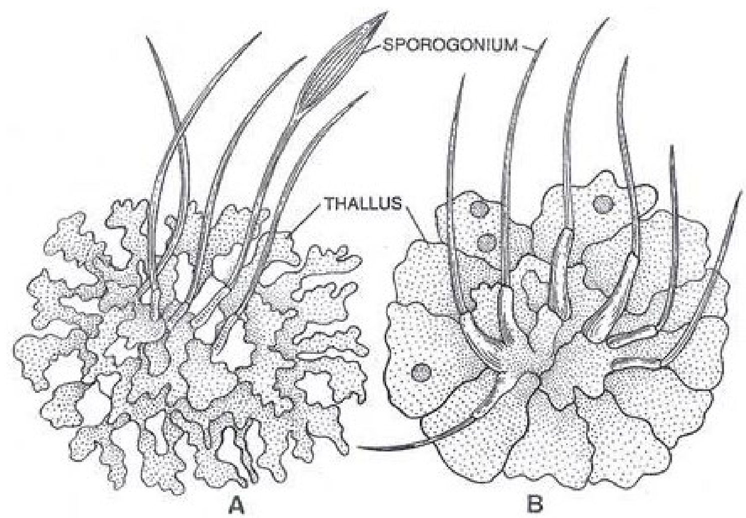

Fig.10.1. ***Anthoceros*** **Spp. (A & B) Thallus with sporogonium**

Dorsal Surface: The dorsal surface of the thallus may be smooth (*A. laevis*) or velvety because of the presence of several lobed lamellae (*A. crispulus*) or rough with spines and ridges (*A. fusiformis*). It is shining, thick in the middle and without a distinct mid rib.

Ventral Surface: The ventral surface bears many unicellular, smooth-walled rhizoids. Their main function is to anchor the thallus on the substratum and to absorb water and mineral nutrients from the soil. Tuberculated rhizoids, scales or mucilaginous hairs are absent. Many small, opaque, rounded, thickened dark bluish green spots can be seen on the ventral surface. These are the mucilage cavities filled with Nostoc colonies.

In the month of September and October the mature thalli have erect, elongated and cylindrical sporogonia. These are horn like and arise in clusters. Each sporogonium is surrounded by a sheath like structure on its base. It is called involucre.

Internal Structure: The vertical transverse section (V. T. S.) of the thallus shows a very simple structure. It lacks any zonation. It is uniformly composed of thin walled parenchymatous cells. The thallus is thickest in the middle. It gradually becomes thinner towards the margins. The thickness of the middle region varies in different species. It is 6-8 cells thick in *A. laevis*, 8-10 cells thick in *A. punctatus* and 30-40 cells thick in *A. crispulus*. The outer most layer is upper epidermis. The epidermal cells are regularly arranged, smaller in size and have large lens shaped chloroplasts.

Each cell of the thallus contains a single large discoid or oval shaped chloroplast. Each chloroplast encloses a single, large, conspicuous body called pyrenoid, a characteristic feature of class Anthocerotopsida. 25-300 disc to spindle shaped bodies aggregate to form pyrenoid.

The air chambers and air pores are absent in *Anthoceros*. However, in a few species intercellular cavities are present on the lower surface of the thallus. These cavities are formed due to break down of the cells (schizogenous). The cavities are filled with mucilage and are called mucilage cavities. These cavities open on the ventral surface through stoma like slits or pores called slime pores. Each slime pore has two guard cells with thin walls. The guard cells are non-functional and do not control the size of the pore.

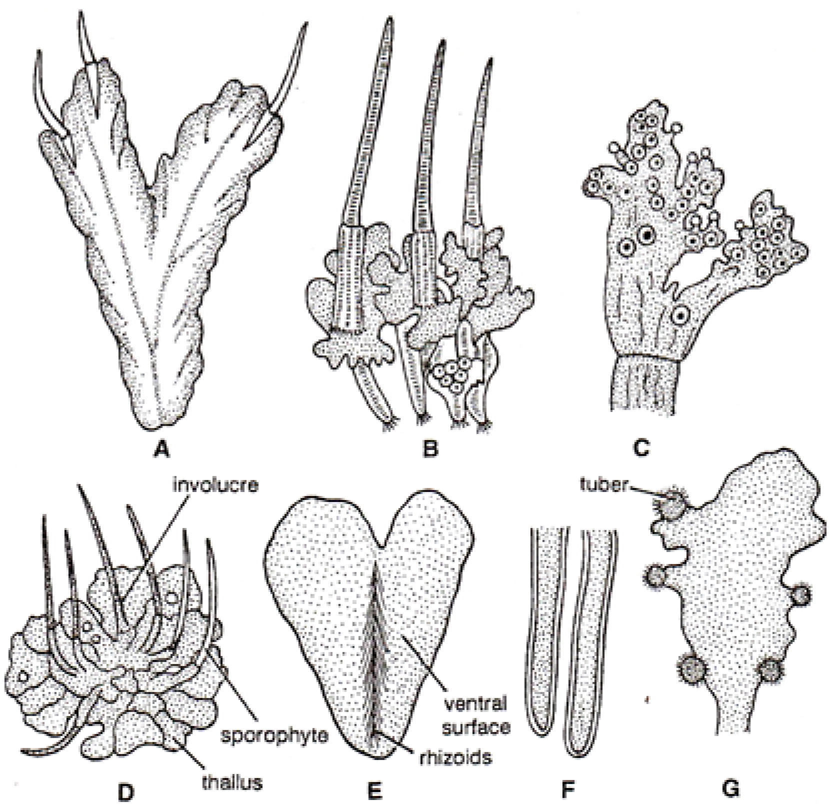

Fig.10.2. *Anthoceros* External Features of Different Species (A) *A. himalayansis* (B) *A. erectus*(C)*A. gemmulosus*(D)*A. crispulus*(E) Ventral Surface of Thallus (F) Smooth walled rhizoids (G)Thallus with tubers

With the maturity of the thallus the mucilage in the cavities dries out. It results in the formation of air filled cavities. The blue green algae *Nostoc* invades these air cavities through slime pores and forms a colony in these cavities. The presence of *Nostoc* colonies in the thallus of

Anthoceros is beneficial for the growth of gametophyte is not definitely known. However, according to Rodgers and Stewart (1977) it is a symbiotic association. The thallus supplies carbohydrates to the *Nostoc* and the latter, in turn, adds to nitrate nutrients by fixing atmospheric nitrogen. The lowermost cell layer is lower epidermis. Some cells of the lower epidermis extend to form the smooth-walled rhizoids.

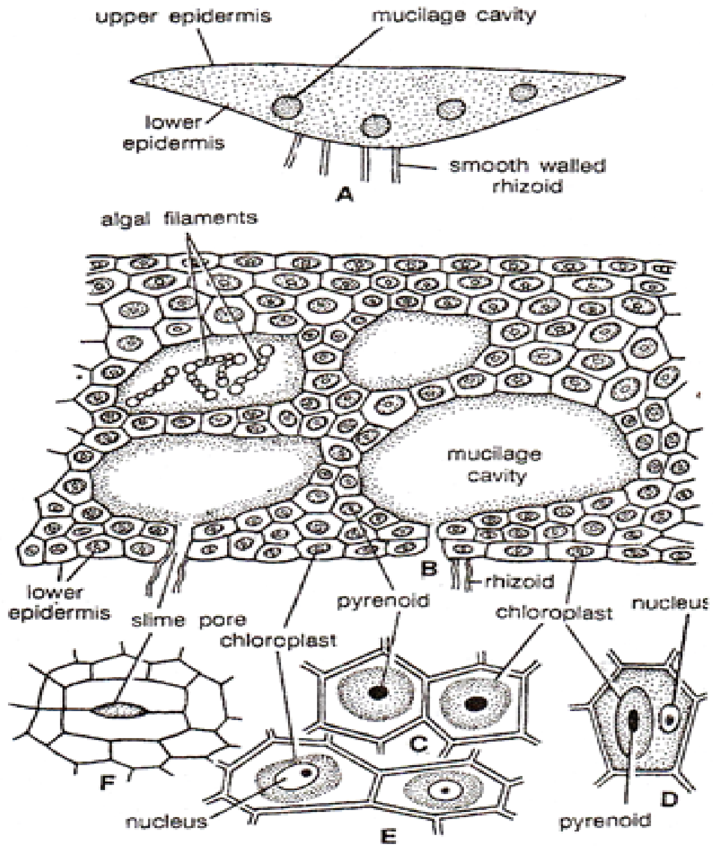

Fig.10.3. ***Anthoceros*** **Vertical Transverse Section (V.T.S.)**

Reproduction in *Anthoceros*:

Anthoceros reproduces by vegetative and sexual methods.

(A) Vegetative Reproduction: It takes place by the following methods:

1. By death and decay of the older portion of the thallus or fragmentation:

The older portion of the thallus starts rotting or disintegrates due to ageing or drought. As it reaches up to the place of dichotomy, the lobes of the thallus get separated. Thus, detached lobes develop into independent plants by apical growth. This method is not so common in *Anthoceros* as in liverworts.

2. By tubers: Under unfavorable conditions or prolonged drought, the marginal tissues of the thallus get thickened and form the perennating tubers. Their position varies in different species. They may develop behind the growing points (*A. laevis*) or along the margins of the thallus (*A.*

hallii, A. pearsoni). In *A. himalayensis* the tubers are stalked and develop along the margins on the ventral surface of the thallus.

The tubers have outer two to three layers of corky hyaline cells which enclose the tissue containing oil globules, starch grains and aleurone granules. They are capable to pass on the unfavorable conditions. On resumption of favourable conditions tubers produce new thalli.

3. By Gemmae: In some species of *Anthoceros* like *A. glandulosus*, *A. propaguliferus, A. formosae* many multicellular stalked structures develop along the margins of the dorsal surface of the thallus. These structures are called gemmae. When detached from the parent thallus, each gemma develops into new plant.

4. By persistent growing apices: Due to prolonged dry summer or towards the end of the growing season, the whole thallus in some species of *Anthoceros* (*A. pearsoni, A. fusiformis*) dries and gets destroyed except the growing point. Later it grows deep into the soil and becomes thick under unfavorable conditions. It develops into new thallus. It is more a method of perennation then multiplication.

5. By apospory: In *Anthoceros*, unspecialized cells of the many parts of the sporogonium (for e.g., intercalary meristematic zone, sub epidermal and sporogenous region of the capsule) form the gametophytic thallus. This phenomenon is called apospory (Schwarzenbach, 1926, Lang, 1901). The thalli are diploid but normal in appearance e.g., *A. laevis*.

(B) Sexual reproduction: Sexual reproduction is oogamous. Male reproductive bodies are known as antheridia and female as archegonia. Some species of *Anthoceros* like *A. longii, A. gollani, A. fusiformis, A. punctatus, A. crispulus*and *A. himalayensis* are monoecious while some species like *A. erectus, A. chambensis, A. hallii, A. pearsoni* and *A. laevis* are dioecious. The monoecious species are protandrous i.e., antheridia mature before archegonia.

Antheridium

Structure: A mature antheridium has a stalk and club or pouch like body. The stalk attaches the antheridium to the base of the antheridial chamber. Stalk may be slender and composed of four rows of cells (*A. punctatus, A. erectus*) or more massive (*A. laevis*). A single or a group of two to four or more antheridia are present in the same antheridial chamber. A single layered sterile jacket encloses the mass of androcytes which metamorphosis into antherozoids.

In some species for e.g., *A. punctatus* and *A. erectus* jacket layer is formed of four tiers of cells. Each tier appears to be composed of elongated rectangular cells. The cells of the upper most tiers are triangular with a narrow end towards the apex. Each cell of the jacket consists of plastids. At maturity these plastids change their colour from green to red to bright orange. Young antheridia are, therefore, green and mature one turn bright orange or reddish.A mature antherozoid is unicellular, uninucleate, bi-flagellated and has a linear body. The flagella are of almost the same length as the body.

Development of Antheridia

The development of the antheridium starts from a superficial dorsal cell. This cell never becomes papillate. It divides by periclinal division into an outer roof initial and inner antheridial initial. Unlike the class Hepaticopsida (e.g., *Marchantia*), the antheridium develops from the inner cell. Therefore, the antheridium is endogenous in origin. Soon after the division a mucilaginous filled space develop between the antheridial initial and roof initial.

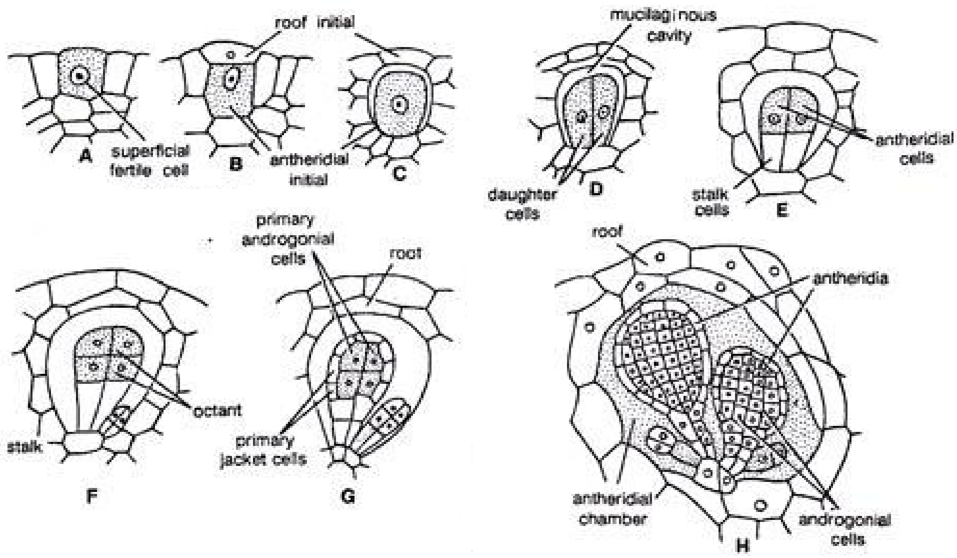

Fig.10.4. Successive Stages in the Development of Antheridium (A-H)

The roof initial divides by periclinal divisions followed by many anticlinal divisions to form two layered roof of the antheridial chamber. The antheridial initial either directly develops into a single antheridium (*A. pearsoni*) or it may divide vertically into two, four or sometimes more daughter cells (*A. erectus*).Each of the daughter cells functions as antheridial initial. The antheridial initial divides by two vertical divisions at right angle to each other to form four cells. At this stage the young antheridium consists of four cells.

All the four cells divide by transverse division to form eight cells, arranged in two tiers of four cells each. The cells of the lower tier are called stalk cells. These cells divide and re-divide by transverse divisions to form multicellular stalk of the antheridium.The four cells of the upper tier form the body of the antheridium. These cells divide by transverse division to form eight cells.Each cell of the octant divides by a curved periclinal division to form the eight outer primary jacket cells and eight inner primary androgonial cells. Primary androgonial cells divide by several repeated transverse and vertical division resulting in the formation of large number of small cubical androgonial cells.The last generation of androgonial cells is known as androcyte mother cells. Each androcyte mother cell divides by a diagonal mitotic division to form the two triangular cells called androcytes.

The protoplast of each androcyte metamorphoses into bi-flagellated antherozoid. In some species secondary antheridia develop later from the stalk of the older one. Therefore, in more advanced stages the antheridial group inside a single antheridial chamber consists of varying number of antheridia in different stages of development.

Dehiscence of Antheridium

Water helps in the dehiscence of the antheridium. As the antheridia mature the roof of the antheridial chamber breaks down irregular, exposing the antheridia in a cup like chamber. The antheridia absorb water and the uppermost tier of triangular cells fall apart releasing a mass of antherozoids.

After dehiscence the antheridium loses turgor and collapses. It is followed by other antheridia to converge towards the opening in the roof and in this way a continuous stream of antherozoids is possible. It explains the formation of large number of sporophytes in Hornworts.

Archegonium

Archegonia develop in the flesh of the thallus on dorsal surface. The place of an archegonium on a thallus can be identified by the presence of a mucilage mound.

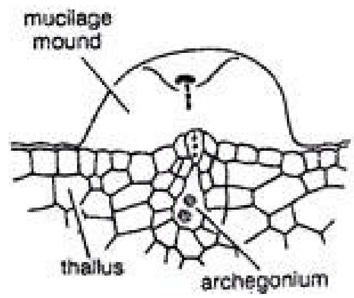

Fig.10.5. ***Anthoceros*****: Archegonium with Mucilage mound**

Structure

A mature archegonium consists of two to four cover cells, an axial row of four to six neck canal cells, a venter canal cell and an egg. The jacket layer is not distinct from the other vegetative cells like other bryophytes.

The development of the archegonium starts on the dorsal surface of the thallus from a single superficial cell which acts as an archegonial initial. It can be differentiated from other cells by its dense protoplasm. The archegonial initial may divide by transverse division to form an upper primary archegonial cell and lower primary stalk cell (*A. crispulus, A. gemmulosus*) or it may directly functions as primary archegonial cell (*A. erectus*).

The primary archegonial cell divides by three successive intersecting walls to form the three peripheral or jacket initials and a fourth median cell called the primary axial cell. Jacket initials divide by transverse divisions to form into two tiers of three cells each. The cells of the upper tier divide by anticlinal division to form six cells. These cells divide transversely to form a jacket of six rows of sterile neck cells. The three cells of the lower tier divide by transverse and vertical divisions to form venter wall. Since the archegonium is embedded in the thallus, it is difficult to trace the development of the cells and to distinguish them from the vegetative cells.

The primary axial cells divide by a transverse division to form an outer cell and inner (central) cell. The outer cell divides by a transverse division to form terminal cover initial and inner primary neck canal cell. The inner cell directly functions as primary venter cell and divide only once to form upper small venter canal cell and a lower large egg. Primary neck canal cell divides by series of transverse divisions to form four to six neck canal cells. Cover initial divided by one two vertical division to form two to four rosette like cover cell at the tip of the neck.

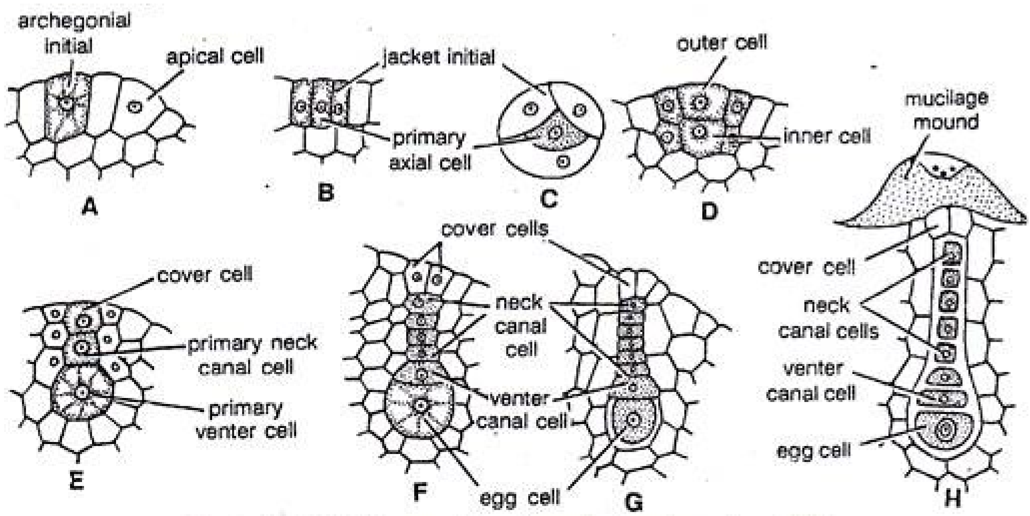

Fig.10.6. ***Anthoceros*****: Successive Stages of Development of Archegonia (A-H)**

Fertilization

Water is essential for fertilization. In the mature archegonium, the venter canal cell, neck canal cells disintegrate and form a mucilaginous mass. It absorbs water, swells up and becomes out of the archegonial neck by pushing the cover cells apart. This mucilaginous mass becomes continuous with the mucilage mound and in this way an open passage down to egg is formed.
The mucilaginous mass consists of chemical substances. Many antherozoids caught in the mucilage enter in the archegonial neck because of the chemotactic response, reach up to the egg, and fertilization is affected. Prior to fertilization, egg enlarges and fills the cavity of the venter. Fusion of both male and female nuclei results in the formation of diploid zygote or oospore. Fertilization ends the gametophytic phase.

Sporophytic Phase

After fertilization the diploid zygote or oospore still enlarges in size and fills the cavity of the venter of the archegonium. It secretes an outer cellulose wall. The first division of the zygote is vertical. In other bryophytes the first division of the zygote is transverse. This is the important difference in the development of sporophyte of hornworts and rest of the bryophytes. The second division is transverse and is so oriented that the upper two cells are usually longer than the lower two (quadrant stage). All the four cells divide by vertical walls to produce eight cells (octant stage). The eight cells are arranged in two tiers of four cells each.

Further development of the sporophyte varies in different species. In A. erectus the lower tier of four cells of octant stage form the foot while the seta and capsule are formed from the upper tier of four cells.In majority of the species like *A. fusiformis, A. pearsoni*and *A. himalayensis*upper tier of four cells divide by transverse division to form three tiers of four cells each. The lowermost tier forms the foot, the middle tier forms the meristematic zone or intermediate zone and uppermost tier develops into the capsule.

The four cells of the lower tier divide by irregular divisions to form broad, bulbous foot, made up of parenchymatous cells. In some species (*A. punctatus*) the superficial cells of the foot form a palisade layer of cells while in some species (*A. laevis, A. himalayensis*) the superficial layer grows into haustoria like projections.

The uppermost tier of four cells which forms the capsule divides by one to two transverse divisions to form two to three tiers of cells.It is followed by periclinal division to form an outer layer of amphithecium and the central mass of cells called endothecium. The entire endothecium develops into the sterile columella. In young sporophyte it is made of four cells but in mature sporophyte it is made of sixteen vertical rows of cells (4 x 4).

The amphithecium divides by a periclinal division to differentiate into an outer sterile layer of jacket initials and inner fertile layer.The cells of the jacket initials divide by anticlinal and periclinal divisions to form four to six layered capsule walls. The outermost layer of the capsule wall is called epidermis. It is characterized by the presence of stomata. The cells of the inner layers of capsule wall have chloroplast.

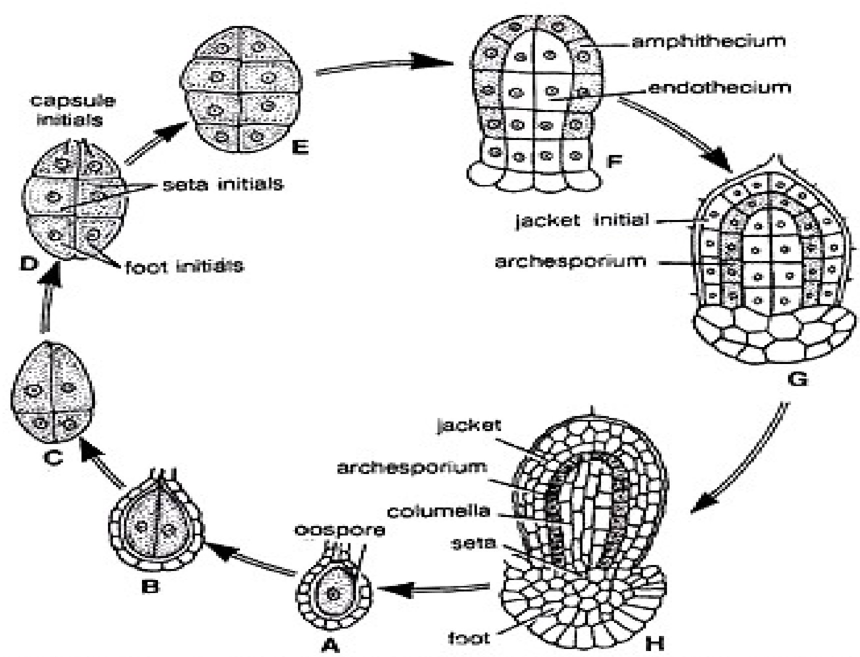

Fig.10.7. *Anthoceros*: Successive stages in the development of Sporophyte

On maturity the archesporium gives rise to two types of cells: spore mother cells and elater mother cells. Spore mother cells are spherical or oval with dense cytoplasm and large nuclei. These cells divide by meiotic divisions to form spore tetrads. Elater mother cells are elliptical with small nuclei. These cells divide mitotically to form four celled elaters.

The four cells of the elaters may remain attached to each other or may break into 1-celled, 2-celled or 3-celled units. The broken units are called pseudo elaters. (The elaters are without thickening bands and therefore, called pseudo elaters). By the activity of the meristematic zone various tissues of the capsule are continuously produced so that it becomes elongated. The young sporophyte of the *Anthoceros* is surrounded by a fleshy covering or sheath. It is called involucre. It is developed partly from the tissue of the archegonium and partly from the tissue of the gametophytic thallus. In young stages the sporophyte is completely surrounded by involucre.

Structure of Mature Sporogonium

The mature sporophyte consist a bulbous foot and a smooth, slender, erect, cylindrical, structure called capsule. Capsule varies in length from two to fifteen centimeter in different species. The sporogonium appears like a **'bristle'** or **'horn'**, hence the species are called 'hornworts'.

Internal structure

A mature sporogonium can be differentiated into three parts viz., the foe: seta and the capsule.

Foot: It is bulbous, multicellular and made up of a mass of parenchymatous cells. It acts as a haustorium and absorbs food and water from the adjoining gametophytic cells for the developing sporophyte.

Meristematic Zone or Seta: Seta is represented by meristematic zone. This is present at the base of the capsule and consists of meristematic cells. These cells constantly add new cells to the capsule at its base.The presence of meristem at the base enables the capsule to grow for a long period and form spores. It is a unique feature of *Anthoceros* and is not found in any other bryophyte.

Capsule: Its internal structure can be differentiated into following parts:

a. **Columella:** It is central sterile pan, extending nearly to its tip. It is endothecial in origin. In young sporophyte it consists of four vertical rows of cells but in mature sporophyte it is made up of 16 vertical rows of cells (4 x 4). In a transverse section these cells appear as a solid square. It provides mechanical support, functions as water conducting tissue and also helps in dispersal of spores.

b. **Archesporium:** It is present between the capsule wall and the columella. It extends from base to the top of the capsule. It originates from the inner layer of amphithecium. In a few species of *Anthoceros* for e.g., *A. crenatifrons, A. hawaiensis* and *A. erectus*, the archesporium may remain one cell in thickness throughout its further development. However, in *A. pearsoni* and *A. himalayensis* it may become two layered thick a little above the base. In *A. hallii* it may even become two to four cells in thickness. In upper part of the capsule it is differentiated into sporogenous tissue which produces spores and pseudo elaters. Pseudo elaters may be unicellular or multicellular, branched or un-branched and may consist of more or less elongated cells.

c. **Capsule wall:** It consists of four to six layers of cells, of which the outermost layer is epidermis. The cells of the epidermis are vertically elongated and have deposit of cutin on their walls. The continuity of epidermis is broken by the presence of stomata. The stomata are oriented vertically with the axis of the sporogonium and are widely separated from each other.

Each stoma consists of a pore surrounded by two guard cells. The cells of the inner layers have intercellular spaces and contain chloroplast. Thus, the sporogonium is partially self-sufficient to synthesize its own organic food but partially it depends on the gametophyte for the supply of water and mineral nutrients.

Dehiscence of the capsule

Capsule dehisces basipetally i.e., from apex to base. As the capsule matures, its tip becomes brownish or black. Vertical lines of dehiscence appear in the jacket layer. The dehiscence of the capsule is usually by two longitudinal lines, occasionally it is by single line or rarely by four lines. The capsule wall dries and shrinks at maturity.

The two valves thus separated, diverge and twist hygroscopically. The pseudo elaters also dry out, twist and help to loosen the spores. Thus, the twisting of the valves and the movement of the pseudo elaters in the exposed spore mass helps in the shedding of the spores. Air currents also help in the dispersal of spores.

Structure of Spore

The spores are haploid, uninucleate, semi-circular with a conspicuous triradiate mark. Each spore remains surrounded by two wall layers. The outermost layer is thick ornamented and is known as exospore. It varies in colour from dark brown to black (e.g., *A. punctatus*) or yellowish (e.g., *A. laevis*). The inner layer is thin and is known as endospore. Wall layers enclose colourless plastids, oil globules and food material.

Germination of spore and formation of young gametophyte

Under favourable conditions the spores germinate immediately in few species. However, in some the spores undergo a resting period of few weeks or months before germination. At the time of germination spore absorbs water and swells up. Exospore ruptures at the triradiate mark and endospore comes out in the form of a tube. It is called germ tube.

Contents migrate into the germinal tube where the colourless plastids turn green. Two successive transverse walls are laid down at the tip of a germinal tube resulting in the formation of three celled filament. The upper cell divides by a vertical division followed by similar vertical division in the lower cell (quadrant stage).These four cells again divide by a vertical division at right angle to first to form eight cells (octant stage). The total tier of four cells functions as apical cells and forms the new gametophyte. First rhizoid develops as an elongation of any cell of the young thallus. As the growth proceeds, the mucilage slits appear on the lower surface and these slits are infected by *Nostoc*.

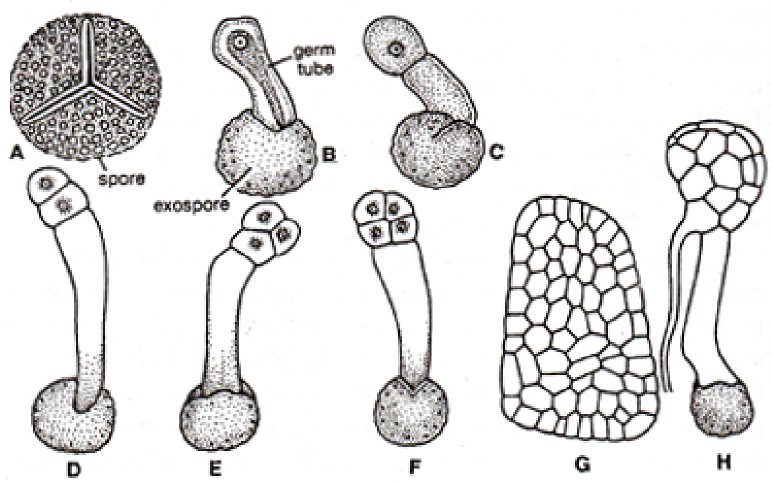

Fig.10.8. *Anthoceros*: Successive Stages in Spore Germination and Gametophyte Formation

Alternation of Generation

The life cycle of *Anthoceros* show regular alternation of two morphologically distinct phases. One of these generations is haplophase and the other is diplophase.

1-Haplophase or gametophytic phase

In *Anthoceros* this phase is dominant and produces the sex organs. Sex organs produce gametes to form a diploid zygote.

2- Diploid phase of sporophytic phase

Zygote develops into sporophyte. In *Anthoceros* sporophyte is represented by foot, meristematic zone and capsule. The sporophyte produces the spores in the capsule. The spores on germination produce the gametophyte.

So, in *Anthoceros*, two morphologically distinct phases (haplophase and diplophase) constitute the life cycle. The life cycle of this type which is characterised by alternation of generation and sporogenic meiosis is known as heteromorphic and diplohaplontic.

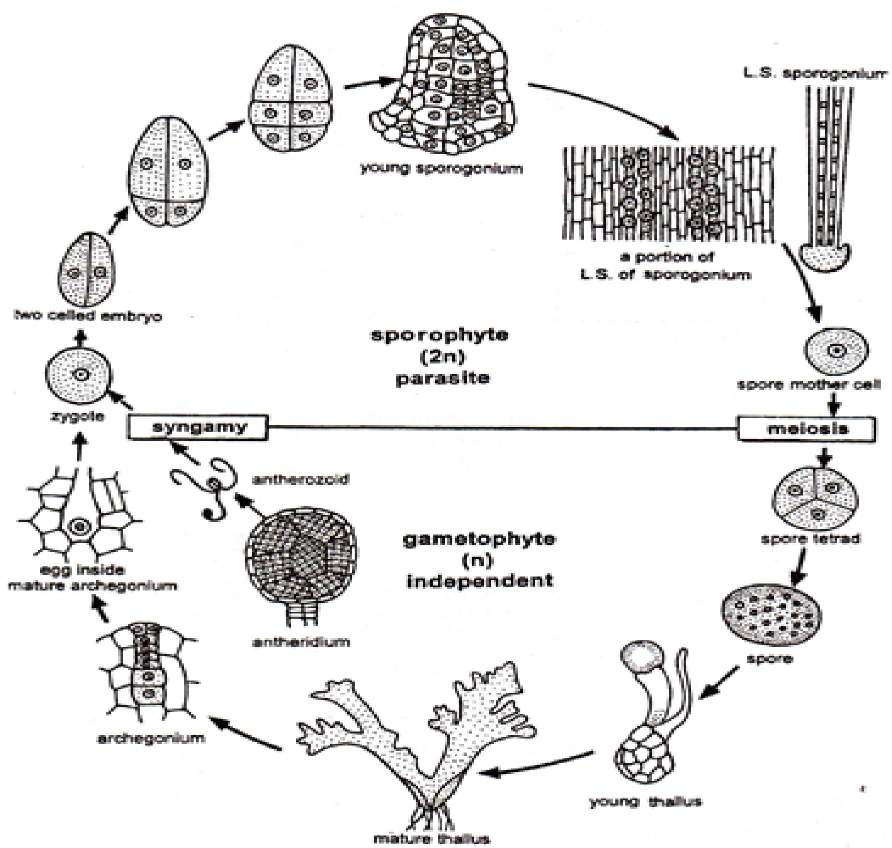

Fig.10.9. ***Anthoceros*****: Diagrammatic Life Cycle**

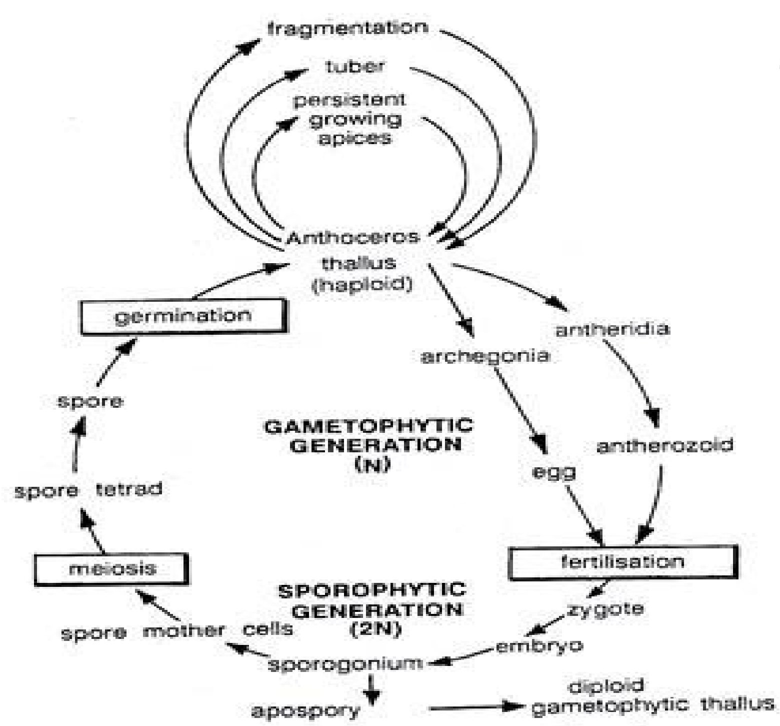

Fig.10.10. ***Anthoceros*****: Schematic Life Cycle**

10.5 MORPHOLOGY, ANATOMY AND REPRODUCTION OF SPHAGNALES

Order- Sphagnales have single genus *Sphagnum*, which occupies a very distinct and isolated position among mosses.

1. The plants occur in large patches of a pale green or reddish colour on moors, and, when filling up small lakes or pools, may attain a length of some feet.
2. Their growth has played a large part in the formation of peat.
3. The species are distributed in temperate and arctic climates, but in the tropics only occur at high levels.
4. The protonema forms a flat, lobed, thalloid structure attached to the soil by rhizoids, and the plants arise from marginal cells.
5. The main shoot bears numerous branches which appear to stand in whorls; some of them bend down and become applied to the surface of the main axis.
6. The structure of the stem and leaves is peculiar.
7. Outside this come one to five layers of large clear cells, which when mature are dead and empty; their walls are strengthened with a spiral thickening and perforated with round pores. They serve to absorb and conduct water by capillarity.
8. The leaves have no midrib and similar empty cells occur regularly among the narrow chlorophyll-containing cells, which thus appear as a green network.
9. The antheridia are globular and have long stalks. They stand by the side of leaves of special club-shaped branches.
10. The archegonial groups occupy the apices of short branches. The mature sporogonium consists of a wide foot separated by a constriction from the globular capsule.
11. The capsule, the wall of which bears rudimentary stomata, has a small operculum but no peristome. There is a short, wide columella, over which the dome-shaped spore-sac extends, and no air-space is present between the spore-sac and the wall.
12. In the embryo a number of tiers of cells are first formed. The lower tiers form the foot, while in the upper part the first divisions mark off the columella, around which the archesporium, derived from the amphithecium, extends.
13. The sporogonium when nearly mature bursts the calyptra irregularly. The capsule opens explosively in dry weather, the operculum and spores being thrown to a distance.

10.5.1-*Sphagnum*

Division	-	Bryophyte
Subdivision	-	Musci
Class	-	Sphagnopsida
Order	-	Sphagnales
Family	-	Sphagnaceae

Genus - *Sphagnum*

Introduction to *Sphagnum*

Sphagnum is popularly known as bog moss, peat moss or turf moss because of its ecological importance in the development of peat or bog. The plants are perennial and grow in swamps and moist habitat like rocky slopes where water accumulates or where water drips. They grow along the bank of lakes and gradually encroach more and more of the water as creeping bogs and in course of time they completely cover up the lake transforming it into a bog. Hence *Sphagnum* is known as bog moss. As a result the topography of the bog gets changed and water of bogs becomes very acidic. In this acidic soil the upper portion of the *Sphagnum* gametophores grows indefinitely, while the basal part dies progressively. The dead plant parts do not decompose easily in acidic soil. Consequently a large mass of dead remains accumulated year after year followed by compression from plants on top, thus a compact, dark coloured substance rich in carbon is formed which is known as peat. Since *Sphagnum* is the chief constituent of peat, it is often called peat moss.

Structure of *Sphagnum*:

A. External Features:

The gametophyte phase of *Sphagnum* is represented by two distinct stages namely, (a) juvenile protonema, and (b) mature leafy or gametophore stage. The mature plants grow in dense clumps and their shoots are of whitish or brownish green in colour.

All species of *Sphagnum* accumulates water and often grow with bright colour (deep red, rose pink, etc.) due to the presence of water-soluble pigments, anthocyanin. They are perennial showing unlimited growth by means of an apical cell with three cutting faces. Very young gametophytes bear multicellular rhizoids with oblique septa. Mature gametophytes, however, do not bear rhizoids. It is differentiated into an upright branched axis and leaves.

Main Axis and Branches: The main axis is soft and weak at young stage, but becomes erect and stout at maturity. However, the main axis is much longer in aquatic species, but is relatively short in terrestrial form due to the progressive death of the older basal part. The axis branches profusely on the lateral sides. Single branch or in tufts of 3 to 8 branches arise from the axils of every fourth leaf of the main axis. At the apex of the main stem, many small branches of limited growth are densely crowded forming a compact head called coma. The coma is formed near the apex due to the condensed growth of apical internodes. As the stem grows in length these short branches elongate and become normal branches.

The submerged species (*S. obesum, S. cuspidatum*) have all the branches similar in form and structure, but the terrestrial species produce two types of branches viz., (i) pendent branches, and (ii) upwardly divergent branches.

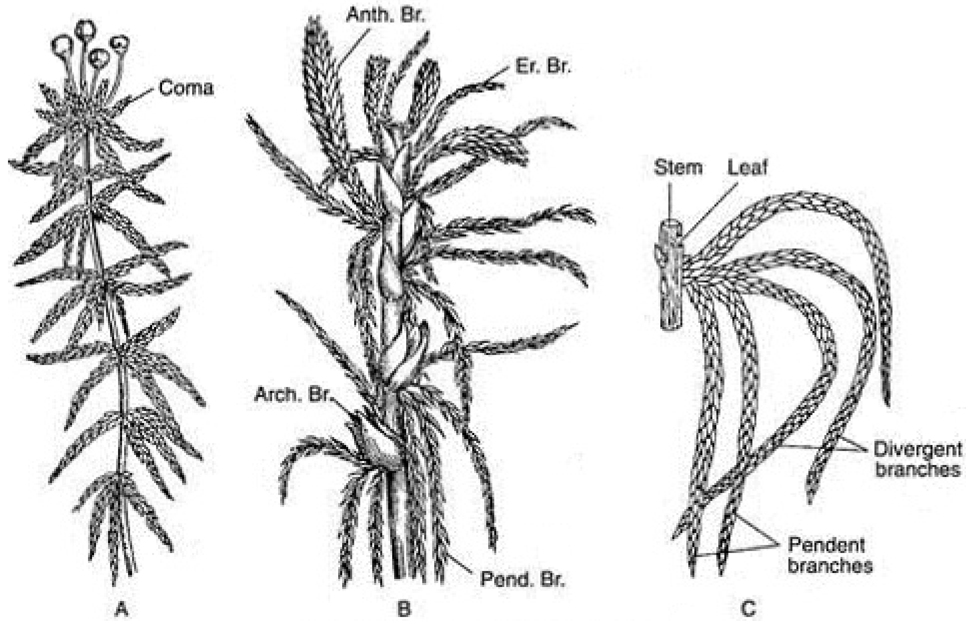

Fig.10.11. (A) *Sphagnum palustre* Gametophyte (B) Gametophyte with Antheridial Branches (C) Pendent and Divergent Branches on the Main Axis

Pendent Branches: These are long slender loosely arranged, turn downwards and then grow parallel to the main axis. They are also termed flagella form or de-current branches.

Divergent Branches: These are short and stout branches which grow outwards and upwards. They are also termed ex-current branches. Sometimes, one divergent branch in each node develops strongly than others and ultimately gives rise to a new plant when it becomes detached from the mother plant.

Leaves: The leaves occur both on the main axis as well as on the branches. On the branches, the leaves are closely set and, therefore, overlapping and are placed apart on the main axis. The leaves are arranged in spiral phyllotaxy. Moreover, the leaves on the main axis differ from those on the branches in size, shape and details of cell structure. In general, the leaves are small, sessile, entire, thin and scale-like with acute apex and without a midrib.

B. Internal Structure:

Stem: Internally, the stem shows distinct differentiation of tissues into three zones viz., outer cortex or the hyalodermis, the middle hadrom (prosenchymatous region) and the central cylinder or medulla.

(a) Outer Cortex: The cortex or the hyalodermis is the outermost region of the stem. This is bounded externally by a single- layered epidermis. It is composed of large hyaline cells. The genus, Sphagnum has often been divided into two sub-genera based on the nature of hyaline cells.

(b) Middle Hadrom: It lies next to the cortex and consists of 4-6 layers of small thick-walled, prosenchymatous cells. This part is called hadrom which gives mechanical support to the stem.

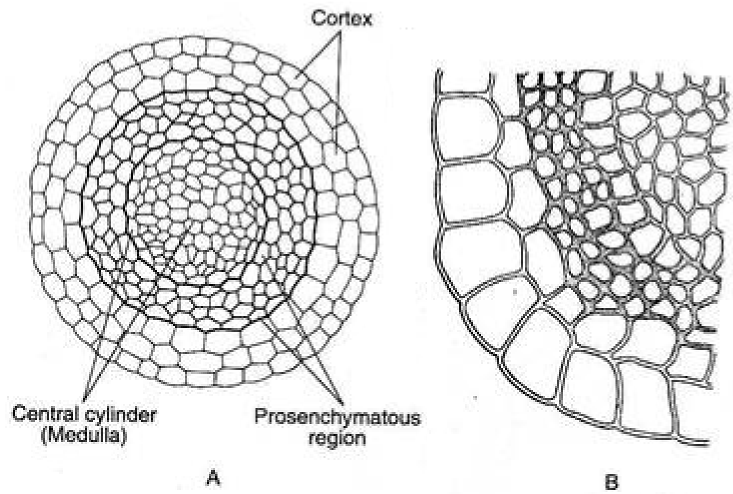

Fig.10.12. (A) Stem T.S. of *Sphagnum acutifolium* (B) T.S. *Sphagnum ovatum*

(c) Central Cylinder or Medulla: It is the innermost region of the stem, comprised of small, vertically elongated, thin-walled parenchymatous cells. It functions as storage region.

Leaf: In Sphagnum, the cross-section of leaf shows only one cell in thickness and composed of much elongated cells. A young leaf is comprised of square or rectangular cells of uniform size, while a mature leaf is characterised by two types of cells, the ordinary type hyaline cells and the green chlorophyllous cells or the assimilatory cells.

The hyaline cells are large polygonal and become colourless or hyaline by losing their protoplasts. Their walls are provided with pores and become spirally thickened. The hyaline cells have a remarkable capacity of absorption and retention of water (hence called capillary cells), thus rhizoids are not necessary in the mature plants.

The chlorophyllous cells are small triangular or biconvex living cells with many discoid chloroplasts and have their photosynthetic ability. The chlorophyllous and the hyaline cells are arranged in an alternate sequence to form a regular reticulate pattern and this leaf- feature alone can be used to identify the genus, *Sphagnum*.

Reproduction in Sphagnum

In *Sphagnum*, reproduction takes place both by vegetative and sexual methods; however, the vegetative propagation is more common:

1- Vegetative Reproduction:

Vegetatively, it reproduces by means of innovation. Sometime, one of the divergent branches grows upwards and becomes as strong as the main stem. Such an apical branch is called innovation. Due to the progressive death of the lower basal part of the main axis, the innovation gets detached from the mother plant and ultimately gives rise to a new plant. This phenomenon is responsible for the extensive growth of *Sphagnum* in nature.

2- Sexual Reproduction:

Sphagnum may be monoecious or dioecious, but the antheridia and archegonia are always borne on the special separate antheridial and archegonial branches of the same plant. These branches are much smaller than the vegetative branches. In monoecious plants, the antheridial branches develop first.

(a) Antheridial Branch: The antheridial branches first appear near the apex of the main shoot but eventually carried downwards due to the growth of the apical region. These branches are usually shorter but stouter than the vegetative branches. They are spindle-shaped and densely covered with yellow, red or dark green leaves generally smaller than the foliage leaves.

Antheridium

Development and Structure of Antheridium:

The antheridia develop singly and acropetally below the leaves. Each antheridium develops from a superficial antheridial initial of the stem. The antheridial initial develops a small filamentous structure. The terminal cell of this filament grows by two cutting faces to form an apical cell.

The latter is further differentiated into a 12-15 celled structure, of which 2-5 distal cells by periclinal division form the body of the antheridium and the rest cells form the stalk. Each distal cell gives rise to an outer jacket initial and an inner primary androgonial cell. The primary androgonial cell, by further divisions in all possible planes, forms the antheridium. A single-layered jacket is formed from jacket initials.

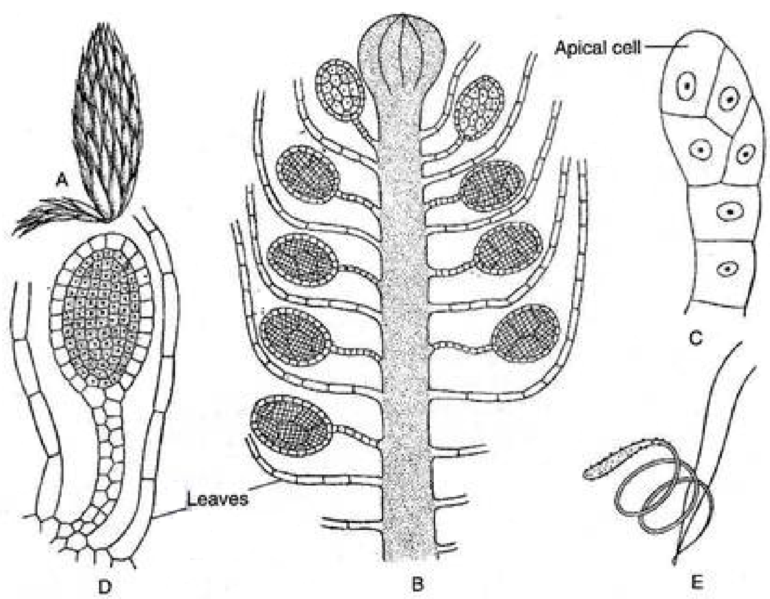

Fig.10.13.*Sphagnum* spp.(A) Antheridial Branch (B) Leaves and Antheridia (L.S. View) (C) Development of Antheridia (D) Mature Antheridium (E) Antherozoid

The Mature Antheridium: It has a long stalk of two to four rows of cells and a globose or ovoid body. The body has a jacket of one layer of cells enclosing a mass of androcytes formed from the sperm mother cells. Each androcyte cell metamorphoses into a spirally coiled biflagellate antherozoid or sperm.

Dehiscence of the Antheridium: The apical cells of the jacket of a mature antheridium swell through the absorption of water. As a result of turgor pressure thus generated, the wall of the swollen antheridium breaks into a number of irregular lobes at the apex that eventually turns backwards. The mass of androcytes comes out and the antherozoids are liberated immediately and swim freely in water.

(b) Archegonial Branches:

Archegonia are borne at the apices of the archegonial branches which develop at the apex, or laterally. The archegonial branches are very short and more or less ovoid in shape. The leaves on these branches are larger than those present on the foliage leaves. The upper leaves of these branches constitute the perichaetium enclosing the archegonia and thus protect archegonia from injury.

Archegonium:

Development and Structure of Archegonium:

The archegonia develop on the apex of the archegonial branches either singly or in groups. The apical cell of this branch forms the primary archegonium. Two to five secondary archegonia develop from derivatives of the apical cell.

Usually, there are three archegonia in a group i.e., one primary archegonium at the apex and two secondary archegonia emerge from the base of primary archegonium. The development of both the primary and secondary archegonia is similar. The archegonial initial divides transversely to form a four- to six-celled filament.Then the terminal cell, by three intersecting vertical walls, cuts off three periclinal jacket initial cells and a primary axial cell. The primary axial cell divides transversely to form an upper cover initial and lower central cell. The central cell divides transversely to form an upper primary neck canal cell and lower primary ventral cell.

The primary neck canal cell, by repeated transverse divisions, forms a row of 8-10 neck canal cells, while the primary venter cell, by a single transverse division, forms a ventral canal cell and an egg. The cover initial divides vertically to form a group of eight or more cover cells that form the upper portion of the archegonial jacket.The jacket initial, by anticlinal and periclinal divisions, subsequently forms the neck and the middle and basal portion of the archegonial jacket. The cover cells form the upper portion of the archegonial jacket.

Mature Archegonium: The mature archegonium is a relatively large structure. It has a long stalk, a long twisted neck with 8 to 9 neck canal cells, a massive multilayered venter containing a ventral canal cell, and an egg.

Fertilization of Archegonium: The process of fertilization takes place only in the presence of water. The antherozoids swim freely in water and reach the archegonia. At maturity, the neck canal cells and the ventral canal cell disorganize and form a passage for the antherozoids.
The antherozoids reach near the archegonia attracted chemotactically and pass into the passage to reach the egg. Ultimately, only one antherozoid fuses with the egg and forms a zygote.

The Sporophyte:
Development of the Sporophyte:
The diploid zygote is the first cell of the sporophytic generation. Among the few archegonia only one is developed to form embryo in an archegonial branch.

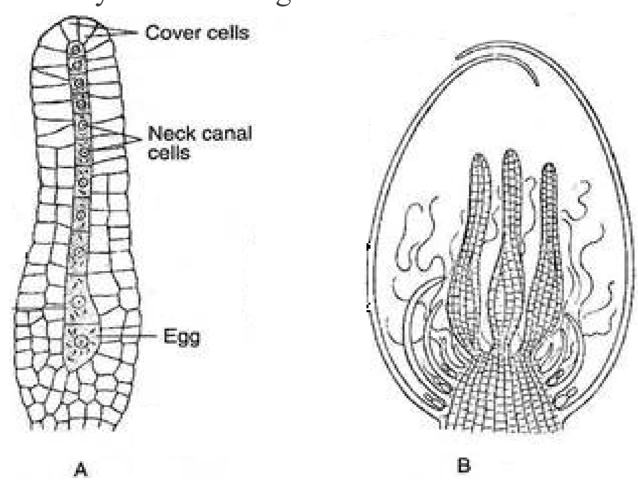

Fig.10.14. *Sphagnum* Spp. (A) Mature Archegonia (B) Three Archegonia on the tip of a branch

The zygote enlarges, invests itself with a cell wall and then divides transversely to form an upper epibasal cell and a lower hypobasal cell. Transverse divisions in both the cells continue until a 6- or 7-celled filament is formed. The lower half of the filament undergoes irregular divisions forming a parenchymatous bulbous foot. The foot acts as a haustorium.
The upper cells of the filament divide by two vertical divisions at right angle to each other — a quadrant is formed. The cells of the quadrant divide periclinally to form an inner endothecium and an outer amphithecium. The cells of the endothecium repeatedly divide and form a central sterile part, columella.
The amphithecium divides periclinally to differentiate an inner 2-4 layered archesporium and the outer 3-7 layered capsule wall. The archesporium forms a dome-shaped arch over the columella. The cells of the archesporium later develop into 2-4 layered sporogenous tissue.
All sporogenous cells function as spore mother cells that divide meiotically and form haploid spores. The spores are enclosed within a spore sac developed from the surrounding sterile tissue.
There is only a short neck like inconspicuous seta connecting the upper capsule and the lower bulbous foot.

Structure of the Mature Sporophyte: The mature sporophyte consists of a bulbous foot, a neck-like inconspicuous seta and an almost spherical black to dark-brown capsule. The whole sporophyte is covered by the calyptra. The lowest part of the calyptra that covers the foot is called the vaginula. The perichaetial leaves are present below the sporophyte.

The elongated archegonial branch at the base of the sporogonium is called pseudopodium. It increases in length and pushes out the capsule above the perichaetial leaves to facilitate the spreading of spores.

The capsule in longitudinal section shows an outer jacket and middle spore-sac with spores which overarches the dome-shaped inner columella.The capsule wall (jacket) is several layers thick. The outermost layer of the jacket is thick which bears several rudimentary non-functional stomata. The circular biconvex disc-shaped lid, called operculum, is present at the top of the jacket. The operculum is delimited from the rest of the jacket by a groove of thin-walled cells, called the annulus.

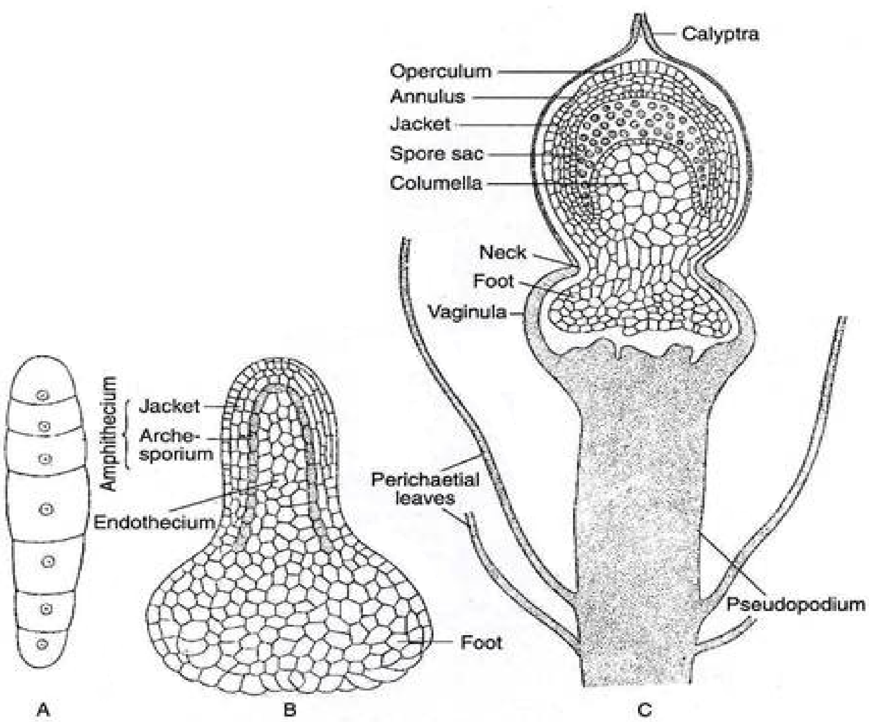

Fig.10.15. *Sphagnum*: Different Stages in Sporophyte Development

Dehiscence of the Capsule: The capsule dehisces on a bright sunny day by an explosive mechanism. The capsule wall and columella become dry and shrivel due to heat. This results in the formation of a large air space below the spore-sac.

The spherical capsule gradually becomes cylindrical and, therefore, an overpressure of 4-6 atmospheres builds up inside the capsule. Under this condition its operculum bursts open through the annulus with an audible sound. The spores are catapulted up to 20 cm and release in the air. The process is known as air-gun mechanism of spore dispersal.

The New Gametophyte

Like other bryophytes, the spore is the first cell of the gametophytic generation. Initially, the spores are arranged in tetrahedral tetrads. Each spore has a distinct triradiate ridge. The wall of the spore is differentiated into an outer smooth granular or papillate exine and an inner thin intine. Spores may germinate within 2-3 days or may remain viable for 4-6 months.

The spore on falling on a moist substratum germinates to develop a small thalloid primary protonema. Further development of the protonema produces a prostrate, green, irregularly lobed, one-celled thick thalloid structure which is attached to the substratum by multicellular rhizoids.

A single bud is developed from the marginal cell of the primary protonema or may give rise to secondary protonema with rhizoids and leafy buds. The bud eventually develops into a new leafy gametophyte.

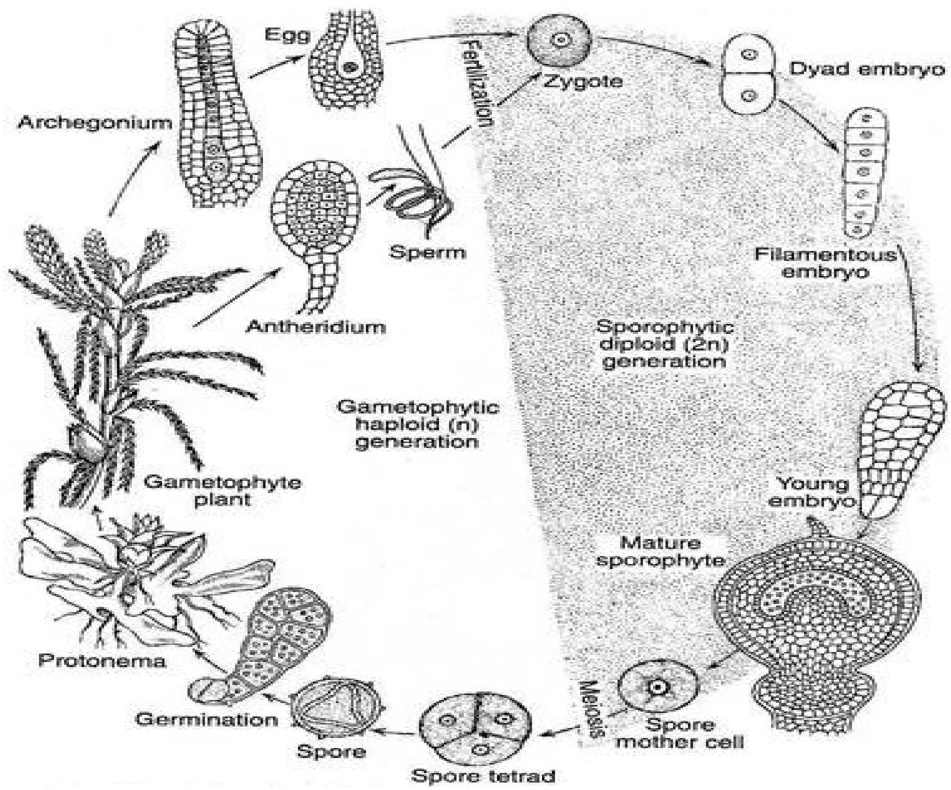

Fig.10.16. Alternation of Generation in *Sphagnum*

10.6 MORPHOLOGY, ANATOMY AND REPRODUCTION OF EUBRYALES

1. The main plant body is gametophytic and can be differentiated into two stages-juvenile stage and leafy stage or gametophore.
2. Gametophores are erect leafy branches which develop on the protonema. Branched or un-branched and can be differentiated into three parts-rhizoids, **'stem'** and **'leaves'**.
3. **'Leaves'** are with midrib, un-lobed and arranged spirally in three to eight rows on the axis or

4. Rhizoids are multicellular, filamentous, branched with oblique septa.
5. The axis is differentiated into central conducting strand enclosed by cortex.
6. Sex organs borne apically in the groups on main **'stem'** or a branch.
7. The sporophyte is green in early stages and can be differentiated into foot, seta and capsule.
8. The seta is usually elongated and rigid.
9. Columella is usually present and endothecial in origin.
10. Archesporiurn (spore forming tissue) is differentiated only in spores.
11. Elaters are absent.
12. Dehiscence of capsule takes place by separation of lid or operculum.
13. Peristome helps in the dispersal of spores.
14. Spores on germination produce the protonema.

10.6.1-*Funaria*

Division	-	Bryophyte
Subdivision	-	Musci
Class	-	Bryopsida
Order	-	Funariales
Family	-	Funariaceae
Genus	-	*Funaria*

Plant body is gametophytic and consists of two different stages namely:
(i) Juvenile stage represented by primary protonema and
(ii) The leafy gametophore which represents the adult form.
The adult gametophyte (gametophore) is differentiated into rhizoids, axis or **'stem'** and **'leaves'**. Rhizoids arise from the base of the axis. They are slender, branched, and multicellular and have oblique septa.
Axis is 1—3 cm. high, upright, slender and branched. Each branch is extra axillary i.e., arise below a leaf. Leaves are sessile, oblong-ovate with entire margin, pointed apex and are arranged spirally on the branches and 'stem'. Each 'leaf' is traversed by a single mid rib. 'Leaves' are borne in 1/3 phyllotaxy which becomes 3/8 at maturity.

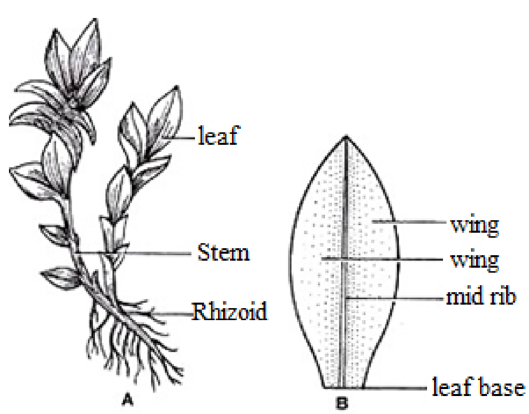

Fig.10.17. ***Funaria*** **Plant and Leaf**

(ii) Internal Structure:

1. Axis or 'stem'

The transverse section (T. S.) of axis can be differentiated into three distinct regions:

(i) Epidermis

(ii) Cortex

(iii) Central conducting strand or central cylinder.

(i) Epidermis: It is the outer most single layered protective covering consisting of small tangentially elongated chlorophyll bearing cells. Cuticle and stomata are absent.

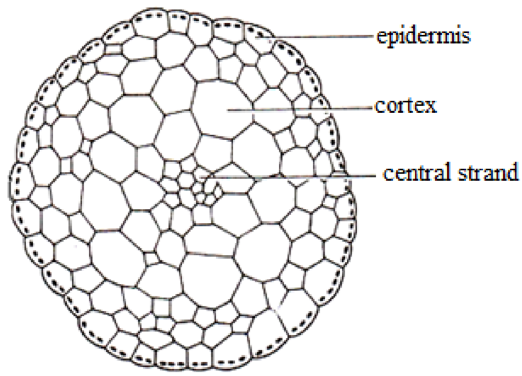

Fig.10.18. Transverse Section of Axis

(ii) Cortex: It is present between the epidermis and conducting tissue. It is made up to parenchymatous cells. Younger part of the cortex contains chloroplasts but in the older part they are lacking. At maturity few outer layers of cortex become thick walled and are reddish brown in colour but those of the inner layers become thin walled.

(iii) Central Conducting Strand: It is made up of long, narrow thin walled dead cells which lack protoplasm. These cells are now commonly called as hydroids. Conducting strand besides providing a certain amount of mechanical support, functions in the upward conduction of water and solutes.

2. Leaf: Transverse section (T. S.) of **'leaf'** shows a well-defined midrib with two lateral wings. Except the midrib region, the **'leaf'** is composed of single layer of parenchymatous polygonal cells. The cells contain many large and prominent chloroplasts. The central part of the mid rib has narrow conducting strand of thick walled cells which help in conduction.

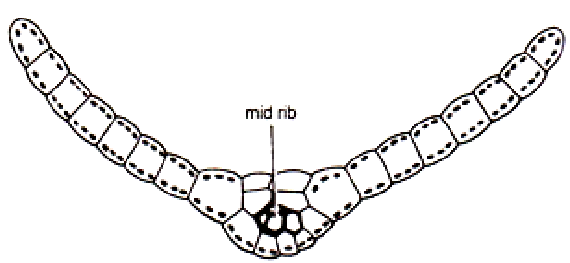

Fig.10.19. Transverse Section of *Funaria* leaf

Reproduction in *Funaria*:

Funaria reproduces by vegetative and sexual methods.

Vegetative Reproduction in Funaria: Vegetative propagation in Funaria is performed by the following methods:

(a) Fragmentation of Primary Protonema: The primary protonema is developed through the germination of the spore. Under certain circumstances, it breaks into several fragments. Each detached fragment bearing buds may grow into a new plant.

(b) Secondary Protonema: The protonema developing from any part of the plant other than spores is called secondary protonema. Generally, they are formed on injured rhizoids, stems, leaves or reproductive structures. They bear buds that are capable of growing into a new plant (Fig. 6.48B).

(c) Bulbil: The bulbils are multicellular, brown, bud-like structures that develop on the rhizoidal branches. The bulbils are useful for propagation during unfavourable environmental conditions by detaching them from the parent plants.

(d) Gemmae: Gemmae (Fig. 6.48B) are multicellular green bodies formed from the terminal cells of the protonema. They remain dormant throughout the unfavourable condition. However, on return of favourable condition, a gemma detaches from the parent plant body and later germinates into a new plant.

(e) Apospory: Apospory is the condition in which the haploid (n) gametophyte is developed from the diploid (2n) sporophyte without the formation of spores. In case of Funaria, gametophytic protonema may develop from any unspecialized cells of the sporophyte.

This protonema later, gives rise to gametophyte plant body. Though aposporously develop, gametophytes are normal in appearance, but are diploid (2n). Subsequently, the tetraploid sporophyte develops from the fusion of diploid gametes (2n) are sterile.

Sexual Reproduction in *Funaria*:

Funaria is autociously monoecious, because the male (antheridium) and female (archegonium) reproductive structures develop on separate shoots of the same plant. Antheridia are borne on the main shoot of the plant. The female branch develops as a side shoot, which grows more vigorously and becomes longer than the male branches.

Antheridium: The antheridia are borne in clusters at the apex of the main axis. A number of long multicellular hairs, called paraphyses are intermingled with the antheridia (Fig. 6.53). Both antheridia and paraphyses are surrounded by a number of bract-like leaves forming a rosette called the perichaetium.

The paraphyses have swollen tips (capitate) and contain chloroplasts. Besides their photosynthetic function, paraphyses protect the young antheridia against desiccation. The paraphyses assist in the liberation of antherozoids.

Development of the Antheridium: The antheridium develops from a superficial antheridial initial located at the tip of the male branch. It becomes papillose and projects above. It divides by a transverse wall to form an outer cell and a basal cell. The outer cell divides further by successive transverse divisions to form a linear filament of 2 to 4 cells.

The terminal cell of the filament divides by two vertical intersecting walls to form a wedge-shaped apical cell with two cutting faces. It forms segments in two rows in alternate sequence. Each young segment of the upper 3 to 4 cells now divides by a vertically diagonal wall to form two unequal cells.

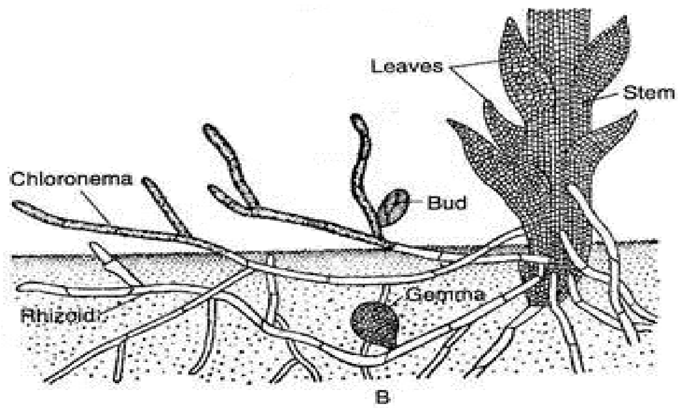

Fig.10.20. ***F. hygrometica*****: Gemma on Gametophyte Base**

The smaller peripheral cells are the first jacket initials. While, the larger sister cell, by a similar division, forms the outer second jacket initials and the inner primary androgonial cell.

The primary androgonial cell divides and re-divides to form androcyte mother cells. Each androcyte mother cell divides to form two androcytes. The androcytes transform into biflagellate antherozoids or sperms.

Antheridia in an antheridial head mature at the different times. Thus, antheridia of different developmental stages can be seen in a single antheridial head. The jacket initials only divide anticlinally to form a single- layered antheridial jacket.

Mature Antheridium: A mature antheridium has a multicellular long stalk and a red or orange coloured club- shaped body. The apical cell of the jacket forms a thick-walled, hyaline oper-culum or cap of the antheridium.

Dehiscence of the Antheridium: The dehiscence of the mature antheridium only takes place in presence of water. The opercular cell absorbs dew or rain water and swells up. The pressure thus created ruptures the inner wall and eventually a pore is formed at the distal end of the antheridium.

The androcytes spread out through the pore in the form of a viscous fluid due to the hygroscopic pressure developed within the antheridial cavity.

Archegonium: The archegonia are borne in clusters at the apex of the archegonial branch.

Development of the Archegonium: A cell at the tip of the female shoot differentiates into the archegonial initial. It divides transversely to form a upper cell and a lower cell. The upper cell becomes the archegonial mother cell which divides by two intersecting oblique walls forming an apical cell with two cutting faces.

The apical cell further divides by three intersecting oblique walls to form three peripheral cells surrounding a central axial cell. The peripheral cells divide anticlinally to form a single-layered jacket which, by further divisions, becomes double-layered.

The axial cell divides by a transverse wall to form an outer primary cover cell and an inner central cell. The central cell, by further transverse division gives rise to an outer primary neck canal cell and an inner primary ventral cell.

Primary neck canal cell, by further transverse divisions, forms a row of neck canal cells. The primary ventral cell, by further transverse divisions, forms a ventral canal cell and an egg.

The primary cover cell cuts off successively three lateral segments and a basal segment. The' lateral segments form the jacket of the neck, while the fourth basal segment forms neck canal cells.

Thus, the single-layered long neck of the archegonium of *Funaria* have double origin, one from primary cover cell and the other from central cell.

Mature Archegonium: The mature archegonium consists of a long stalk, a basal swollen venter and an elongated neck. The twisted and tubular neck encloses 4 to 10 or more neck canal cells. The archegonial jacket is single-layered thick in the neck region, but it is double-layered in the region of the venter. The venter contains a ventral canal cell and an egg.

Fertilization of Archegonium: During fertilization, the ventral canal cell and the neck canal cells of the archegonium disintegrate forming a mucilaginous substance. This mucilaginous substance absorbs water accumulated as rain or dew water, then swells up and the resultant pressure breaks apart the terminal cover cell. Now sugar containing mucilaginous substances ooze out through the opening of the archegonial neck.

The liberated antherozoids are now attracted chemotactically towards the archegonia. A large numbers of antherozoids enter the neck, but only one of them fuses with the egg nucleus to form the diploid zygote.

The Sporophyte: The fertilized egg or zygote is the first cell of the sporophytic generation. The zygote swells up, increases in size and forms a wall around it prior to further divisions.

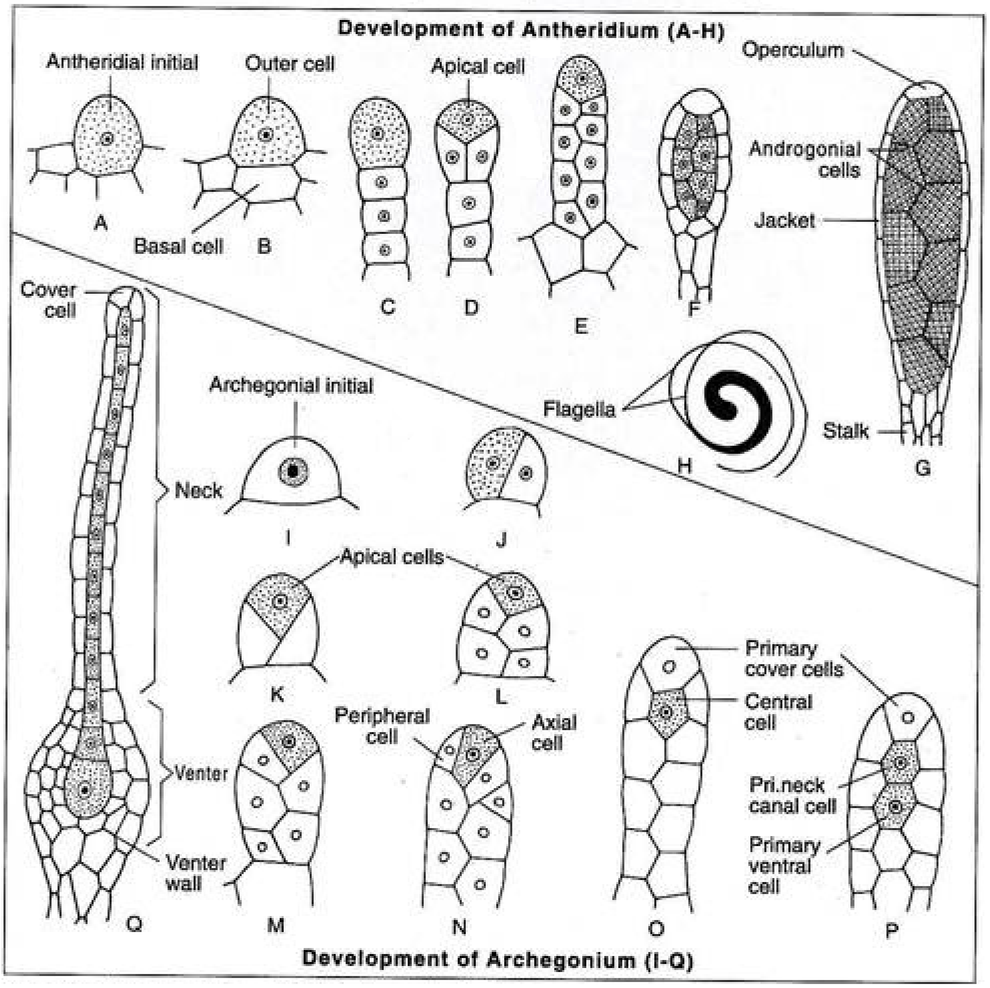

Fig.10.21.*Funaria hygromatica*: (A-G) Development of Antheridia (H) Sperm (I-P) Development of Archegonium

Development of the Sporophyte: The zygote divides transversely to form an upper epibasal cell and a lower hypobasal cell. Both the hypobasal and epibasal cells divide repeatedly to form an young embryo with two growing points at the two opposite ends, each representing an apical cell with two cutting faces.

The archegonial wall enlarges and forms calyptra which covers the capsule till maturity. A long slender sporophyte is then differentiated. The capsule differentiates at a later stage where the amphithecium surrounds the endothecium.

The multilayered jacket of the capsule is formed from the amphithecium, while the outer layers of endothecium forms the archesporium and axial layer produces the columella. The epibasal cell gives rise to the capsule and the upper part of the seta, while the hypobasal cell forms the lower part of the seta and the foot.

Structure of the Mature Sporophyte: The mature sporophyte of *Funaria* is differentiated into a foot, a long seta and a pear- shaped capsule at the tip.

1. Foot: It is a poorly developed conical structure, embedded in the apex of archegonial branch.

2. Seta: Seta is long, green in colour when young, but becomes reddish brown at maturity. T.S. of seta shows a single-layered epidermis, a central conducting strand of thin-walled cells surrounded by a cortex made up of comparatively thick-walled cells (Fig. 6.50A). Seta helps in conduction of nutrients and water from gametophyte to capsule.

3. Capsule: The mature capsule is pear shaped, asymmetrical. Internally, it is divided into three distinct parts viz., the sterile basal region, the apophysis, the central fertile region, the theca and the apical region.

Apophysis: The lowermost part of the capsule is the apophysis or the neck that connects it with the seta below. The axis of the apophysis shows in the lower part a central strand of thin-walled elongated cells connected with the similar tissue of the seta.

Loosely arranged chlorophyllous cells are bounded by a rather thick-walled epidermis which is interrupted by the stomata.

The presence of chlorophyllous tissue in the apophysis makes the sporophyte carry out photo-synthesis. Therefore, the sporophyte of Funaria is not fully dependent on the gametophyte for nutrition.

The Theca or Fertile Zone: The central zone of the capsule situated in between the apophysis and the operculum is called the theca.

It is a slightly bent cylindrical structure, fertile in nature and has four distinct regions:

(a) Capsule wall,

(b) Spore-sacs

(c) Air chamber and

(d) Columella.

(a) Capsule Wall: The capsule wall is many-layered. The single-layered outermost wall forms the epidermis which is followed by a 2-3 layered parenchymatous hypodermis. The inner 2-3 layers of parenchymatous cells are chlorophyllous, which constitute the photosynthetic tissue of the capsule.

(b) Spore Sacs: The columella is surrounded by two elongated spore-sacs. The spore-sac has a inner wall of one layer of small cells and an outer wall of 3 to 4 layers of such cells. The spore sacs are formed from the single layered archesporium. Archesporium first develops 6-8 layers of sporogenous cells. The sporogenous layer becomes a spore-sac by the production of spores from spore mother cells through meiotic divisions.

(c) Air Chamber: The outer wall of the spore-sac is followed by a big cylindrical air chamber. It is traversed by strings of filaments of elongated green cells, known as trabeculae which bridge the air space between the outer wall of the spore-sac and the innermost layer of the capsule wall.

(d) Columella: It is the central, axial part of the fertile zone, comprising of thin-walled, colourless, compact, parenchymatous cells, constricted at the base just above the apophysis. The distal part of the columella is cone-shaped which projects into the concavity of the operculum. The columella serves the purpose of conduction of water and nutrients to the growing sporophyte.

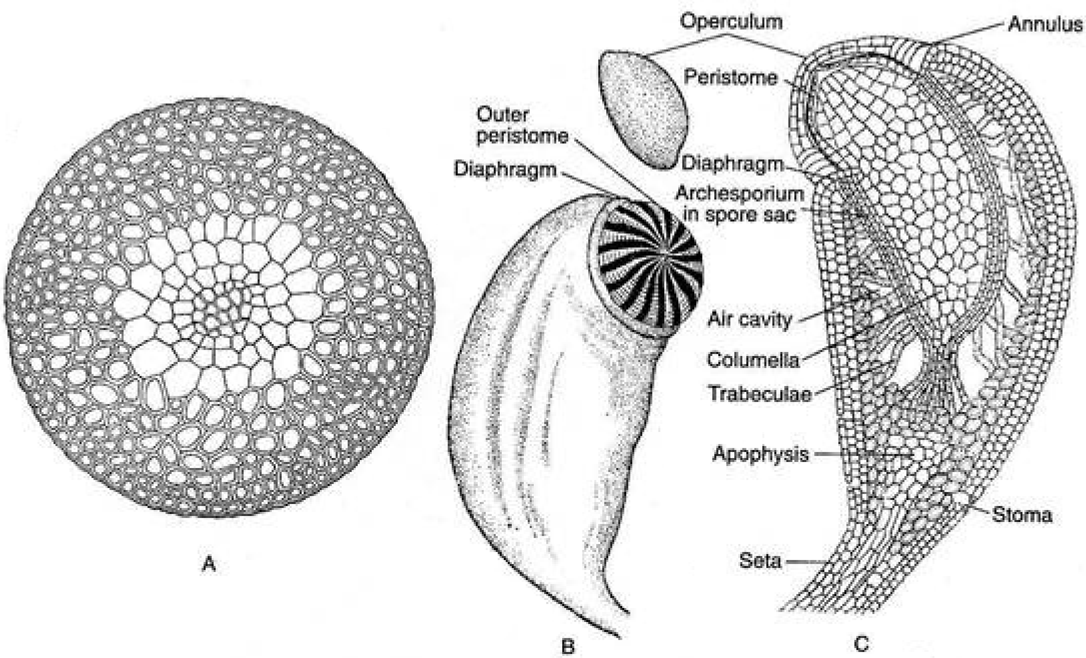

Fig.10.22. ***Funaria hygromatica*** **(A) T.S. of Seta (B) Mature Capsule with Operculum (C) L.S. of Capsule**

The Apical Region: The apical region of the capsule is a complicated structure. This joins the capsule proper through a notch. An annular rim (or diaphragm) of 2-3 layers of radially elongated small cells is present at this notch. The diaphragm demarcates the upper limit of the theca proper.

The operculum is an obliquely placed, dome-shaped lid that closes the mouth of the capsule. It is composed of 2 to 3 layers of thin-walled parenchymatous cells. The lower part of the operculum forms a ring of slightly large conspicuous cells, the annulus. The operculum keeps the peristome teeth covered, while the annulus helps in the dehiscence of the capsule.

The peristome teeth lies just below the operculum and are attached beneath the edge of the diaphragm. It consists of two rings of long triangular teeth, one within the other. The teeth are not cellular in nature and are made up of cuticle.

Each ring of peristome possesses 16 teeth. The outer teeth (exostome) are larger, thicker, and brown in colour and ornamented with transverse thickening bands. The inner peristome teeth (endostome) are small, delicate and of a pale colour.

The whole structure is called peristome which is epicranoid in nature, because the outer peristome teeth are superposed on the inner ring. The tapering distal ends of the outer peristome teeth are joined to a centrally placed disc of tissue.

Dehiscence of the Capsule and the Dispersal of Spores: At maturity, the operculum begins to dry up due to the non-availability of water supply to the capsule. Consequently, the thin-walled cells of the operculum, including the annulus which holdsthe operculum in place, shrink and shrivel. Ultimately, the annulus breaks and the loosened operculum are thrown away leaving the peristome teeth exposed.

The peristome teeth are twisted spirally appearing like an iris diaphragm. The outer peristome teeth are hygroscopic which show inward or outward movements according to the presence or absence of moisture in the environment. During dry atmosphere, the outer peristome teeth bend outwards with jerky movements. The slits between the inner peristome teeth widens due to the outward movements of the outer peristome teeth, thus allowing the spores to escape through these slits. In high humidity, the hygroscopic teeth of the outer peristome absorb water and bend inwards and close the slits. This prevents the escape of spores in wet weather. The young sporophyte is covered by calyptra that develops from the old archegonial venter wall. It protects the capsule from drying and sheds prior to its dehiscence.

The New Gametophyte: The haploid spore is the first cell of the gametophytic generation. It is small, spherical, measuring 12-20 pm in diameter. The spore wall is differentiated into an outer thick, brown coloured exine (exosporium) and an inner thin, colourless intine (endosporium).

Under favourable environmental conditions the spore germinates. The exine is ruptured and the intine protrudes out as a germ tube. The germ tube elongates, becomes septate and produces a filamentous protonema. The protonema branches freely and forms two types of branches viz., chloronemal branches and rhizoidal branches.

The chloronemal branches possess conspicuous chloroplasts in their cells and become green in colour which are either erect or very close to the substratum that form the partition walls at right angles to the lateral walls. The rhizoidal branches develop below the substratum, brown in colour and the partition walls are oblique to the lateral wall. The rhizoidal filaments are primarily meant for anchoring the protonema in the substratum. The chloronemal branches develop many minute buds and each bud grows into an erect leafy gametophore. They become independent shortly after the death of the protonema. Dense growths of the plants are observed because of this property. A young gametophyte comprises of leafy stem, rhizoids arid protonema.

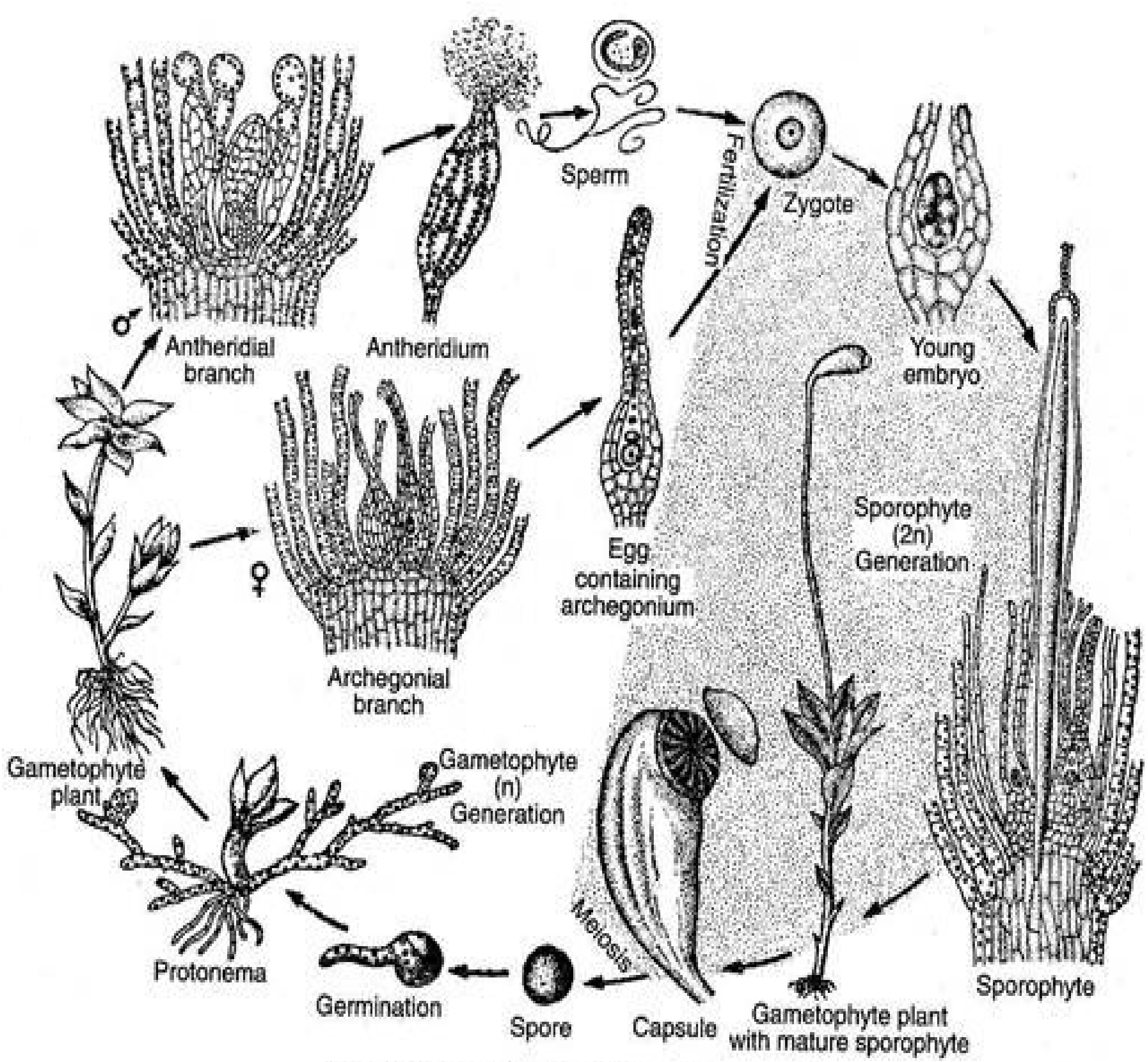

Fig.10.23. Life Cycle of *Funaria hygromatica* (Diagrammatic)

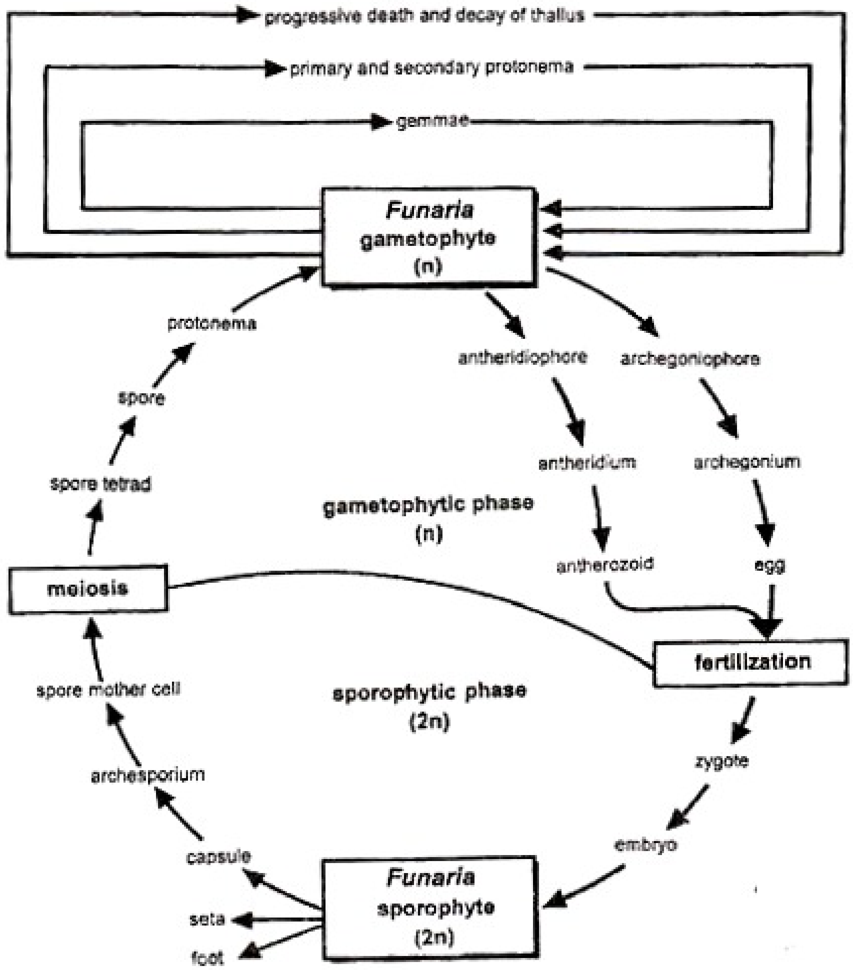

Fig.10.24. ***Funaria hygromatica*****: Graphic Presentation of Life Cycle**

10.6.2-*Polytrichum*

Division	-	Bryophyte
Subdivision	-	Musci
Class	-	Bryopsida
Order	-	Polytrichales
Family	-	Polytrichaceae
Genus	-	*Polytrichum*

Occurrence: *Polytrichum* have worldwide distribution. They are very common in cool temperature and tropical regions. Plants live in cool and shady places.

General structure: The main plant body is gametophyte. The adult plant consists of two parts: rhizome and upright leafy shoot.

1. **Rhizome:** It is horizontal portion and grows underground. It bears three rows of small brown or colourless leaves. It also bears rhizoids. The cells are rich in protoplasm and oil globules. The rhizoids may arise from base of the erect gametophores. They serve as mechanical function by providing support in species in which gametophores grows to considerable heights.

2. **Upright leafy shoot:** The leafy shoots are much longer. It is the most conspicuous part of the plant. It arises from rhizome. These branches consist of central axis. These branches bear large leaves arranged spirally.

3. **Leaves:** Leaves have broad bases. Leaves in the upper portion are green. But the lower ones are brown. Each leaf has a broad colourless sheathing leaf base and narrow distal limb. The mid-rib forms the major part of the leaf. These leaves possess extra photosynthetic tissue in the form of closely set vertical plates of green cells. These are known as lamellae. Green lamellae act as additional photosynthetic tissue. The leaves are of two types:

a) Scale leaves:- these are small brown or almost colourless leaves with a rudimentary blade. These occur in a spiral arrangement around the central axis.

b) Foliage leaves: - these are only present in upper portion of the branches. Each foliage leaf is 6-10mm long it is differentiated into the proximal sheath base and the distal diverging narrow limb or blade.

Anatomy

Leaf: *Polytrichum* have complex internal structure. The mid-rib region is thick. But the margins are only one cell thick. The lower surface is bounded by epidermis. One or two layers of sclerenchymatous tissues are present above the epidermis. The central tissue of leaf is composed of thin-walled parenchymatous tissues. Above this are again sclerenchymatous cells. The upper surface is formed of a layer of large cells from which arise numerous lamellae. This upper portion is the main photosynthetic region of the leaf.

Stem: The T.S. of stem shows three regions: medulla, cortex and epidermis. The medulla is again differentiated into two zones: central zone and peripheral zone. The cortex consists of thick-walled cells. The innermost layer of cortex around the conducting strands is known as a **mantle.** Its cells contain starch grain. Epidermis is present over the cortex.

Life cycle

Vegetative reproduction

Vegetative reproduction takes place by following methods:

I. Protonema: The spores germinate to form protonema. Several buds grow on the protonema. Each bud by of its apical cell develops into gametophyte.

2. These are also called vegetative buds. They are formed on the rhizoids.

3. **Fragmentation:** The rhizome gives rise to erect lea& shoots at intervals. Death or breaking of shoots separates the erect branches. These branches behave as independent plants.

Sexual reproduction

Polytrichum is dioecious. Antheridia archegonia occur on different plants.

Antheridial head: The antheridia are borne in the axillary clusters at the tips of leafy stems. They are surrounded by a rosette of leaves called **perigonial leaves.** These leaves are different from the ordinary vegetative leaves. The perigonial leaves are spirally arranged. The antheridia are produced in groups in the axils of these leaves. Thus the antheridial head have different antheridial groups. **Paraphyses** also occur among the antheridia. Mature antheridium is club-shaped. It is composed of a short stalk and a club-shaped body. Jacket is present around the capsule. Inside the jacket are present androcyte mother cells. They give rise to biflagellate sperms.

Development of Antheridium

1. The antheridia arise from the embryonic cells at the tip of male shoot. The embryonic superficial cell forming antheridium is called antheridial initial. It increases in size. It undergoes transverse division to form lower primary stalk cell and the upper antheridial mother cell.
2. The primary stalk cell forms a few stalk cells. The antheridial mother cell divides to form an apical cell with two cutting faces. The apical cell cut off 3-4 segments. Now this apical cell functions as the operculum cell.
3. The last segment divides by two vertical divisions. It forms peripheral jacket initials and central primary androgonial cells.
4. Die jacket initials further divide to form a single-layered jacket. The primary androgonial cells divide to form androgonial cells.
5. The last generation of primary androgonial cells is called the androcyte mother cells. Each androcyte mother cell gives rise to two coiled biflagellate sperms.
6. The antheridia always dehisce in the presence of water. The operculum cell is thrown out and pore is formed at the apex. Sperm mass contained in mucilage comes out.

Archegonial head

The flask-shaped archegonia are borne at the apices of leafy stems. Archegonium is surrounded by **perichaetial leaves.** These leaves overlap to form a closed bud-like structure. The archegonia occur in cluster of 3 to 6.Mature archegonium is flask-shaped. It has a thick multicellular stalk. The neck is long and twisted. It contains neck canal cells. The neck consists of 6-vertical rows of cells. Neck gradually merges into venter. Venter contains upper small venter canal cell and lower large egg cell. Paraphyses are absent.

Development of archegonium

1. Any apical cell in the apical region acts an archegonial initial. The archegonial initial enlarge. It divides by a transverse division to form lower primary stalk cells and upper archegonial mother cell.

2. The primary stalk cell forms a massive stalk. The archegonial mother cell forms the main body of archegonium. It undergoes three vertical division s to form three peripheral cells surrounding an axial cell.
3. Three peripheral cells divide to form 2-3-layered jacket around the venter. The axial cell divides transversely to form inner central cell and outer apical cell.
4. Central cell forms upper small venter canal cell and lover large egg cell. Apical cell divides to form long neck which consists of 6 vertical rows of cells. The cells cut off from the base to neck canal cells.

Fertilization: The sex organs dehisce in the presence of water. The venter canal cell and the neck canal cells dissolve to form mucilage. This mucilage exerts pressure and the neck opens out. The mucilage comes out of the neck. The sperms reached the archegonial heads by rain water. They are attracted towards the archegonia. One of the sperm swims down the open neck and reaches the base. It fuses with the egg to form oospore. Oospore is the first stage of sporophytic generation.

Sporophyte:

Development of Sporogonium

1. The oospore divides transversely to form upper (epibasal) andlower (hypobasal) cell.
2. The hypobasal region forms foot and lower part of seta. The foot region consists of thin-walled cells. It is embedded in the stalk of the archegonium. The cells of the seta are larger and poor in cytoplasmic contents.
3. The epibasal region forms upper portion of seta and the capsule. Epibasal cell divides to form young embryo. Young embryo is cylindrical and completely surrounded by calyptra. Cells of the embryo divide to form amphithecium and the endothecium regions. 8-amphithecium cells are surrounded by a group of 4- endothecium cells.
4. Endothecium forms central conducting strands of apophysis. It forms columella and spore sac of theca. It also forms membranous tissues of the operculum. The outermost layer of endothecium forms archesporium or spore mother cells. These cells divide meiotically to form haploid spores.
5. The amphithecium divides to form seven rings of cells. These cells give rise to spongy tissues and epidermis of apophysis. They also form outer wall of theca.

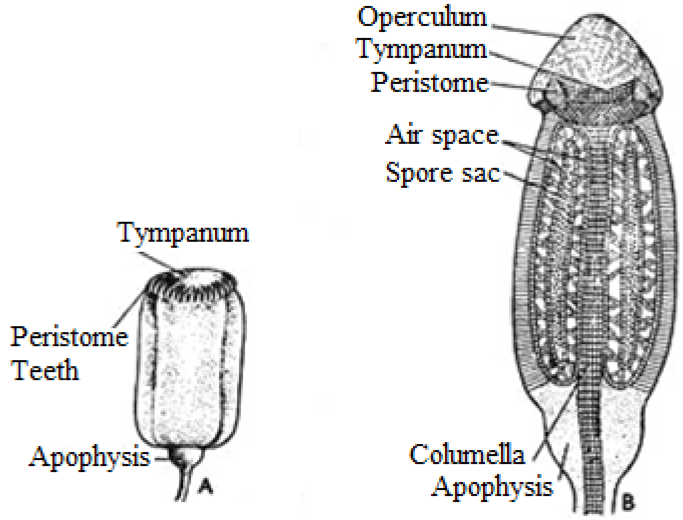

Fig.10.25.*Polytrichum commune*: (A) A Capsule (B) L.S. Capsule with Operculum

Structure of Mature Sporogonium (Sporophyte)

The mature sporogonium is differentiated into foot, seta and capsule.

Foot: The foot is buried deep in the tissue of gametophyte. It is absorptive in function. It consists of thin-walled narrow cells containing dense cytoplasm.

Seta: The seta is several inches long. It carries the capsule high into the air. It also conducts water and food. It consists of epidermis, cortex and central conducting strands.

Capsule: The upper part is capsule with quadrangular outline. It is differentiated into three regions: apophysis, theca and operculum.

1. Apophysis: It is the lower part of capsule. It is continuous with the seta. It is in the form of a swollen ring-like protuberance. Its cells are thin-walled, green and loosely arranged. The apophysis is the main photosynthetic region of the capsule.

2. Theca: It is the middle part of the capsule. It is four-lobed. Its wall is several layered. The outermost layer is epidermis. Trabecular air spaces are present inside the wall layers. These spaces have filaments of thin-walled elongated cells containing chloroplasts. Outer spore sac **wall** is present internal to outer trabecular spaces. This is followed by spore-sac proper. Then 2-layered inner spore-sac wall is present. Then inner trabecular air space is present. The centre is occupied by solid **columella.** All the sporogenous cells are fertile and form spores after reduction division.

3. Operculum: This is the uppermost part of the capsule. It is conical. The operculum is covered by calyptra. The calyptra forms a hairy structure. So *Polytrichum* is also known as ‘ hair cap’ moss. A constriction is present between operculum and theta. A rim or diaphragm is present at the base of this constriction. The columella of the theca is continuous into the operculum. It expands into a fan-shaped epiphragm.Peristome is present in the form of a thick rim. It bears a number of rigid teeth. The epiphragm fills the space inside the ring of peristome teeth and is attached to their tips. Peristome teeth arise from the rim or diaphragm.

Spores lie free in the centre of the capsule at maturity and come out through pores. They are dispersed by wind.

Structure and germination of spores

The spores are yellow. Each spore is uninucleate and has two wall layers. The outer layer is **exosporium** (exine). The inner layer is **endosporium.** The spore germinates under favourable conditions.Exosporium ruptures and endosporium comes out. It forms protonema. Protonema develops many buds. These buds produce new moss plants.

Alternation of generation

Polytrichum shows heteromorphic alternation of generation.

Gametophyte: The plant body is gametophytes. Gametophyte is haploid. It develops antheridia and archegonia. Antheridia produce antherozoids and archegonium produces egg. Antherozoids fuse with egg to produce diploid oospore.

Sporophyte: The oospore is the first stage of sporophyte generation. It is diploid generation. Sporophyte has three parts: foot, seta and capsule. Haploid spores are produced in the capsule by meiosis. Spore is the first stage of gametophyte. Spores germinate to produce protonema stage. It gives rise to mature gametophyte completing the life cycle.

10.7 MORPHOLOGY, ANATOMY AND REPRODUCTION OF ANDREALES

It is a small group of low growing, brittle dark brown rock inhabiting mosses. Nothing remarkable about the leafy shoot and the important features are:

1. Protonema is thalloid and the forerunner of the shoot is either a plate of cell or a cylindricalcell mass.
2. Stem lacks central conducting strand
3. Leaves are without midrib
4. Cells are notably thick walled
5. There is a tendency to replace initial rhizoids by cylindrical or plate like masses of cell
6. Perichaetial leaves are erect convoluted
7. Apical cell is involved in the formation of sex organs
8. Seta remain undeveloped and the ripe capsule is present on a post fertilization leafless gametophore
9. Spore sac extends like a dome over the central columella
10. Capsule wall is hygroscopic

10.7.1-*Andreaea*

Division - Bryophyte

Subdivision	-	Musci
Class	-	Andreaeopsida
Order	-	Andreaeales
Family	-	Andreaeaceae
Genus	-	*Andreaea*

Andreaea is one of two moss genera belonging to the class of mosses known as Andreaeidae and the family Andreaceae. Andreaeidae, referred to as the granite mosses, are commonly found on granite rock faces in mountainous and arctic regions. *Andreaea*, a genus comprised of about 125 species, is the single representative of Andreaeidae found in arctic, Antarctic and temperate zones of the world.

Gametophyte: The general appearance of the gametophyte is like that of a common moss (Bryidae). Macroscopically, the gametophyte of *Andreaea* is recognized by its unique dark-green to red-brown or black appearance which often forms cushions or tufts on exposed rocks, ledges, or cliffs. Majority of the species occur in alpine or subalpine habitat. The leafy gametophore is hardly 1 cm in height and is distinguished by its peculiar capsule. The stem is prostrate on the rock surface and branching is dichotomous sympodial with one branch growing more strongly than the other. There are many rhizoids on the lower part of the stem but these are different from those in other bryophytes.

Some of them are cylindrical while others are flattened, plate-like—the latter making the stems stick to the rock surface. Numerous rhizoids originate in tufts from the basal part of creeping stem. These are uniseriate multicellular with oblique cross walls as in the mosses.

The stem grows by an, apical cell with three cutting faces, leaves developing in three rows. Leaves are small; one layer of cells in thickness and without any midrib in some species, while in some other species the median longitudinal axis becomes more than one layer thick.Leaves are small, smooth, olive to brown in colour and brittle. They are very dense on the stem and are arranged specially in three rows. *A. rupestris* forms fiddle shaped leaves lacking a costa. *A. rothii* tends to taper into more narrow leaves divided by a costa. Leaves of both species are mostly concave and oblong-ovate standing erect at the base. Leaf margins are usually entire and the gametophyte's tissue is comprised of uniform, thickened, pappiliose cells containing oil globules.

The stem anatomy shows a uniform mass of parenchyma cells, there being no differentiation into a cortex and a central cylinder. But, the superficial cells are often somewhat thick-walled and darker in colour. Large oil drops are present in the cells.

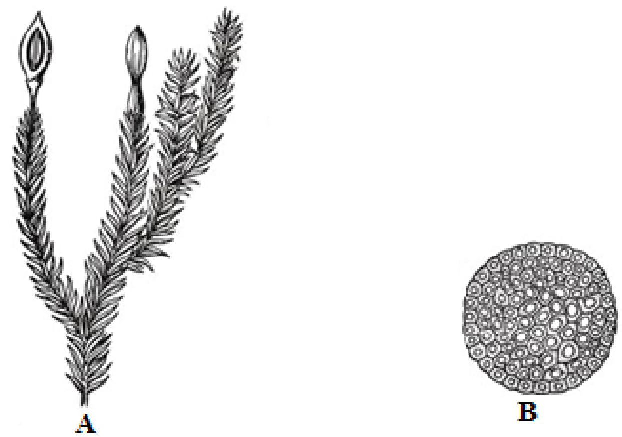

Fig.10.26. (A) *Andreaea rupestris* Gametophyte with Sporophyte (B) T.S. Stem

Sexual Reproduction: Andreaea is homothallic i.e. monoecious. Antheridia and archegonia are borne terminally in groups on the separate branches. A few species for instance *A. nivalis* and *A. blyttii* are heterothallic. Apical cell is involved in the formation of sex organs.

Antheridia

It occurs in the male branch in the terminal as cluster. The antheridium is surrounded by a number of male perigonial bracts. The mature antheridium has an ellipsoidal or nearly globular body raised on a long stalk composed of one or two longitudinal rows of cells. Body of the antheridium consists of a jacket layer of sterile cells enclosing a mass of sperm cells. The protoplast of each perm cell metamorphoses into a biflagellate sperm.

The apical cell of the male branch is directly involved in the development of first formed antheridium in the cluster. Antheridial initial projects above the thallus surface, a transverse wall appears in it separating an outer cell from the inner. Outer cell undergoes another transverse division and a short filament of three cells is formed. The terminal cell of the filament functions as primary antheridial cell. Middle cell constitute primary stalk cell, while the lower one play no role in the development of antheridium.

Primary antheridial cell divides by two inclined wall to differentiate a two sided apical cell. Obviously, owing to the absence of any pedicel, the stalk of the antheridium in the early stages of development cannot be distinguished definitely. All that can be said is that the lower segments (i.e., the first cut off by the apical cell) constitute the basal part of the stalk, while its upper limits are indefinite until periclinal walls appear in those segments destined to give rise to the body of the antheridium. Before these appear there is often a certain amount of subdivision of the lower segments cut off by the apical cell although the extent to which this occurs is variable and in general affects the lower portion of the stalk rather than the upper.The number of segments cut off by the apical cell varies, but is usually about eight. Before periclinal division sets in, a transverse section through a young antheridium shows two segments separated by their bounding wall. Further development is similar to other mosses and depends on the divisions of apical cell. Primary stalk cell undergoes repeated divisions to form the stalk.

Archegonia

Like the antheridia, the archegonia arise from surface cells at the apex of the female branches. A surface cell protrudes and becomes more or less papilliform. The first wall formed in it shows a little variation, but generally it is very oblique, so cutting off a two-sided apical cell, as in the antheridium. The variation is in the degree of slanting of this first wall, which may range from almost vertical to practically transverse. In the latter case a second wall meeting the first one has to form before one can speak of a "two-sided" apical cell.

The two-sided apical cell cuts off from three to six segments in the same manner as in the antheridium before the characteristic development of the archegonium from a so-called "three-sided" apical cell commences. The change from a two-sided to this "three-sided" apical cell takes place when a wall is formed in the former, which is more nearly vertical than the walls which proceed. This now divides by a transverse wall, so forming a terminal and an inner cell. This inner cell is the first of the axial row in both Liverworts and Mosses, while all the tissue below goes to form the pedicel.

The inner cell divides transversely, giving rise to a lower and an upper cell. The upper cell is the primary canal initial or mother cell of the canal row, while the lower is the primary ventral cell. The "three-sided" apical cell cuts off segments parallel to the three lateral faces. The former series divide by vertical walls, so forming six rows of cells which make up the wall of the archegonial neck, while the latter add to the axial row of neck canal cells. Both the cells of the neck and those of the axial row may undergo intercalary divisions so adding to the length of the archegonium.

In the vicinity of the egg the wall becomes two or three-layered, so forming the venter, which merges with the massive pedicel. This latter owes its origin first to the activity of the two-sided apical cell, and secondly to subsequent divisions in the original segments.

The mature archegonium consists of the usual long spirally-twisted neck, two-layered venter and massive pedicel. The axial row consists of from ten to fourteen neck canal cells, the ventral canal cell, and the egg—the latter in all cases observed being much larger than any other cell of the axial row. When mature, the archegonium opens at the apex, the terminal cells diverging fairly widely and being sometimes detached altogether. At a stage immediately before the neck opens the canal row has practically disintegrated. The walls between the cells disappear, so that finally, when the neck does open, there is a passage to the egg. This may be filled more or less with mucilage, derived from the disintegrated canal cells, a certain amount of which appears to be extruded when the archegonium opens.

The Sporophyte

The zygote divides by a transverse wall. The lower (hypobasal) cell divides irregularly and forms a haustorial tissue which later organizes into the foot. The upper (epibasal) cell is destined to form the capsule. It first functions as an apical cell with two cutting faces and soon, after periclinal divisions, develops an inner endothecium and an outer amphithecium. The amphithecium forms the jacket, 3 to 8 cells in thickness.

The inner layers of the endothecium become the sterile columella while its outer cells become the archesporium which develops a dome-like sporogenous tissue, two layers thick, and arches over the top of the columella. Large chloroplasts are present in the sterile cells showing that the sporophyte is not wholly parasitic.

The mature sporophyte shows a swollen foot which is haustorial in function and an elliptical capsule. The two are connected by a short neck which is the seta. The jacket of the capsule is 3 to 8 layers in thickness, the superficial cells of which are thick-walled except along four vertical lines. The club-shaped columella is in the centre and the dome-shaped spore-sac is arching over it.

The whole sporophyte is raised by a stalk which is the pseudopodium, a growth of gametophytic tissue as in *Sphagnum*. The pseudopodium pushes up the main sporophyte on its tip. Just below the tip, the pseudopodium becomes swollen (the foot of the sporophyte being embedded within it).Lower down, some of the lateral unfertilised archegonia may also be seen on the pseudopodium. The calyptra, remnant of the archegonial wall, is visible on the sporophyte as in other bryophytes.

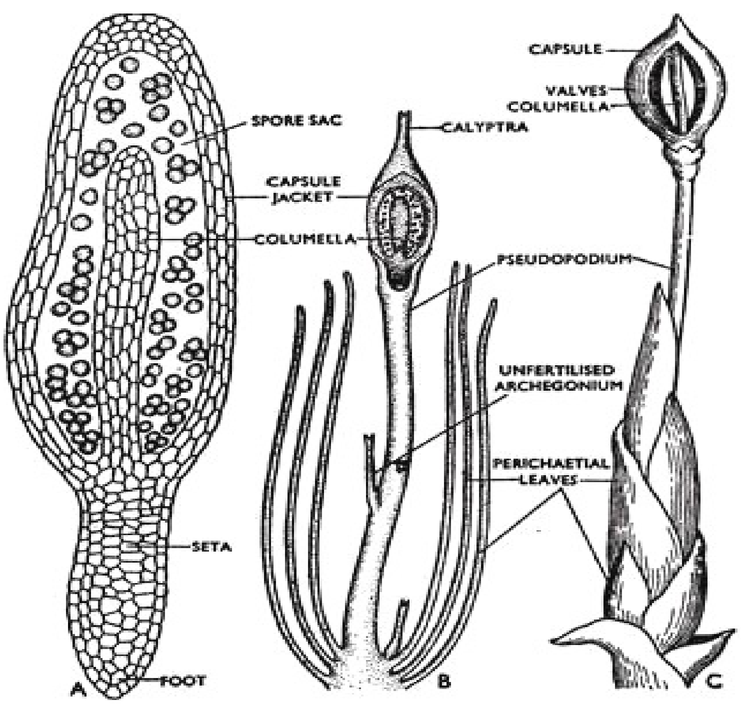

Fig.10.27-*Andreaea rupestris* (A) Sporophyte (B) Section of Sporogonial Shoot (C) Sporangial Shoot bearing Sporophyte

The capsule is easily recognized by its paper-lantern-like dehiscence. Lacking peristome teeth, the capsule splits along four longitudinal slits as a result cell weakness. The longitudinal valves are responsive to humidity, which allows the spores to be carried away when the air is dry and conditions are optimal, closing when the air becomes moist. This dehiscence type is a unique characteristic and occurs exclusively among the granite mosses. When present, the calyptra is small and mitrate. Spores within the capsule often undergo cell division before being emitted. Similar to spore discharge in liverworts, this adapted mechanism ensures survival in harsh conditions.

The New Gametophyte: The spore has two coats as usual and contains chloroplasts and oil globules. As soon as the spore is liberated, it begins to divide while still within the exospore and forms a globular mass of cells. The exospore, then, bursts and the cell mass begins to develop one or more filaments from different points.

The ultimate appearance of the gametophytic protonema varies. It may be a branched ribbon-like structure or it may be a thalloid leaf-like structure resembling that of *Sphagnum.* Unlike most other protonema, the *Andreaea* protonema may even lie in a dormant stage if the environment becomes too rigorous. Ultimately, buds develop on any part of the protonema and these develop into new leafy gametophytic plants.

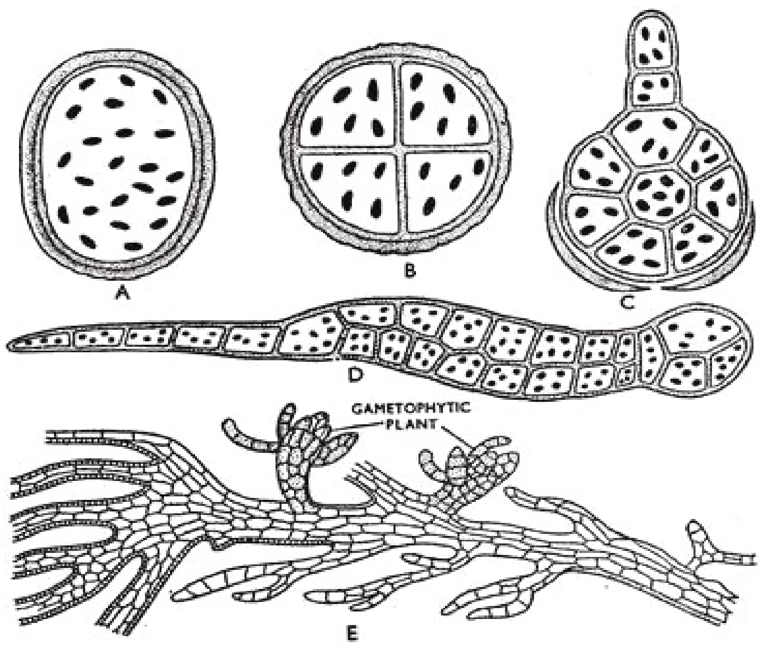

Fig.10.28. ***Andreaea*****: (A-E) Germination of Spore (E) Ribbon like Protonema**

10.8 MORPHOLOGY, ANATOMY AND REPRODUCTION OF TAKAKIALES

It is also a monotypic group having single family Takakiaceae and single genus Takakia. The genus is characterized by:

1. Heterotrichous nature of plants, which are differentiated into prostrate growing rhizomatous axis and erect growing aerial axis or shoot.
2. Both the shoots are densely covered with mucilage papillae.
3. The leaves are present in three rows, which are spirally arranged.These leaves (phyllids) are cylindrical, with 2-4 fingers like lobes.
4. Rhizoids are absent.
5. Antheridia are terminal and present in groups.
6. Archegonia are also present in group either terminal or on stem surface. They are stalked with long neck.
7. The sporophyte has distinct foot, elongated seta and ovate-elongated capsule, with multilayered capsule wall, dome shaped archesporium and central columella.
8. Operculum, annulus and peristome are absent.
9. The outermost layer of the capsule wall has characteristic thickening in the cell due to which cell lumen becomes more or less flask shaped.
10. Dehiscence of the capsule takes place through single longitudinal line (slit), which is dextrosely oriented and the cells are without thickening.
11. The spores are tetrahedral in shape with distinct triradiate mark
12. They have lowest chromosome number (i.e., n=4).
13. They are supposed to be most primitive and sometimes known as living fossil. There is one family- Takakiaceae and one genus *Takakia.*

10.8.1-*Takakia*

Division-	Bryophyte
Subdivision-	Musci
Class-	Takakiopsida
Order-	Takakiales
Family-	Takakiaceae
Genus-	*Takakia*

Takakia is a genus of two species of mosses known from western North America and central and eastern Asia. The genus is placed as a separate family, order and class among the mosses. It has had a history of uncertain placement, but the discovery of sporophytes clearly of the moss-type firmly supports placement with the mosses.

Takakia was discovered in the Himalayas and described by Mitten in 1861. It was originally described simply as a new liverwort species (*Lepidozia ceratophylla*) within an existing genus, and it was thus long overlooked. The discovery of similar odd plants in the mid-20th century by Dr. Takaki in Japan sparked more interest. The many unusual features of these plants led to the establishment in 1958 of the species *Takakia lepidozioides*, in a new genus *Takakia*, named to honor the man who rediscovered it and recognized its unique characteristics. The species originally described by Mitten was subsequently recognized by Grolle as belonging to this new genus, and accordingly renamed *Takakia ceratophylla*.

All of the plants originally collected lacked any reproductive structures; they were sterile gametophyte plants. Eventually, plants with archegonia were found, which resembled the archegonia found in mosses. Fertile plants bearing antheridia and sporophytes were first reported in 1993 from the Aleutian Islands, and both structures were clearly of the form found in primitive mosses. This discovery established *Takakia* as a genus of moss, albeit an unusual one.

Gametophyte

Takakia is not only unusual among mosses, but among all living plants. The plant's Japanese name (*nanjamonja-goke*) "impossible moss" reflects this. It was believed to have the lowest known chromosome count (*n*=4) per cell of any land plant, but some plants of the small Australian daisy *Brachyscomedichromo somatica* are now known to have a count of *n*=2.

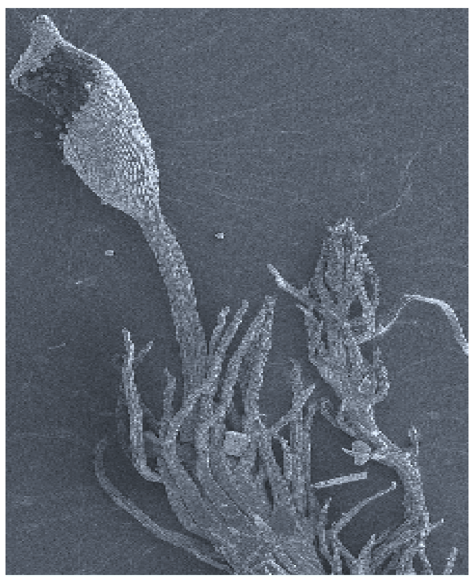

Fig.10.29. *Takakia* spp. Gametophyte with Sporophyte

From a distance, *Takakia* looks like a typical layer of moss or green algae on the rock where it grows. On closer inspection, tiny shoots of *Takakia* grow from a turf of slender, creeping rhizomes. The green shoots which grow up from the turf are seldom taller than 1 cm, and bear an irregular arrangement of short, finger-like leaves (1 mm long). These leaves are deeply divided into two or more filaments, a characteristic not found in any other moss. Both the green shoots and their leaves are very brittle.

Leaf Anatomy: Except at the tip the leaf is 3-5 cells thick in anatomy. Gradually taper towards the apex ending in a short, blunt, conical cell. Cells are parenchymatous and contain chloroplast.

The central strand of the medullary cells is always surrounded by a single layered cortex of cells smaller in size.

Stem Anatomy: Stem T.S. shows that it consists of two zones viz. outer cortical and inner medullary region. The cortical region is chlorophyllose. It is 1-2 stratose thick and consists of slightly strongly thick walled cortical cells with brownish wall. The medullary region shows differentiation into a small central core of small celled tissue constituting al ill-defined central strand surrounded by thick walled celled medulla. Cells of the central strand lost their protoplasmic contents and are empty. They are colourless, elongated and have delicate walls.

In some species of *Takakia* several minute spherical oil bodies are present in leaf and stem cortical cells. These oil bodies are smaller than chloroplast e.g. *T. lepidozioides* & *T. ceratophylla.*

Reproduction: Takes place by vegetative and sexual process.

1-Vegetative Reproduction: In *T. lepidozioides* the freely eadicpis leaves and shoot and in *T. ceratophylla* the upper portion of shoot helps in vegetative reproduction. These parts are taken away either by wind or water and there they propagate and produce new population.

2-Sexual Reproduction: It is dioecious or heterothallic. Morphologically there is no difference among between male and female plants.

Antheridia: They are present in the axil of leaves, bright orange and ellipsoidal in shape. Stalk is ill-demarked and is made up of 3-4 tiers of 4 cells each. Dehiscence of antheridium is via a cap or lid. Development of antheridium is in centrifugal pattern, where apical cell is not utilized or consumed in its formation, leading to further growth of male shoot.

Archegonia: Single archegonium is present in the female plant; sometime number varies 2-3 which are irregularly scattered. Archegonium is naked, large and green when young and stalked. Venter is fleshy and becomes stratose prior to fertilization. Sporophyte is unknown.

Fertilization: In antheridia the sterile jacket haploid flagellated sperms are formed. Water is required for transfer of the motile sperm to egg. Most antheridia are in terminal disk-shaped clusters to facilitate water capture for sperm transfer. Sperms are chemotactic and swim through free-water up a concentration gradient of the chemotactic agent to find the open archegonium. The first drop of water landing in the cup causes the cap cell of the antheridium to burst providing an opening for sperm into the drop of water. The next raindrop to land in the splash cup will splash out a solution containing sperm. These will swim through a film of rainwater to fuse with the egg.

All cells of the archegonium, including the egg cell, are produced by mitosis of haploid gametophyte cells. The disintegrating neck and ventral canal cells provide chemicals involved in sperm chemotaxis to fuse with the egg. After fusion of egg and sperm, zygote is formed which is diploid. After fertilization, the sporophyte grows out of the archegonium, and nutrients for the developing sporophyte are provided by the gametophyte.

Sporophyte: The sporophyte has distinct foot, elongated seta and ovate-elongated capsule, with multilayered capsule wall, dome shaped archesporium and central columella. Young sporophyte needs protection which is protected by two gametophytic covering that develops after fertilization. These covering are vaginula and calyptra.

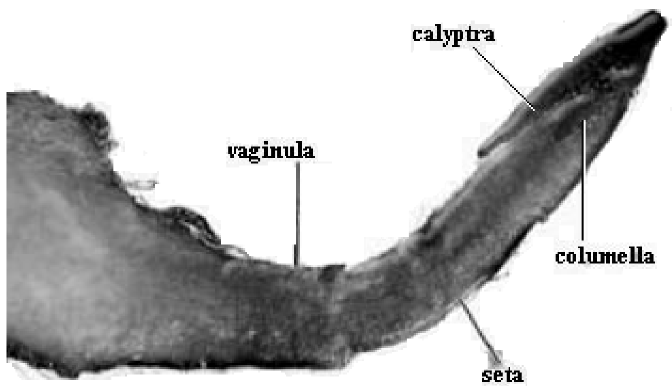

Fig.10.30.*Takakia* spp. Sporophyte

The lower part i.e. foot and seta, is protected by vaginula and the upper part of the capsule and some part of seta is protected by calyptra. Capsule is schizocarpous erect, elliptical, green in early stage of development. Thus sporophyte is autotrophic in nature. Capsule is thick in the middle region and symmetrically tapered at base and apex. Operculum, annulus and peristome are absent. The outermost layer of the capsule wall has characteristic thickening in the cell due to which cell lumen becomes more or less flask shaped. Dehiscence of the capsule takes place through single longitudinal line (slit), which is dextrosely oriented and the cells are without thickening.

Meiosis in the capsule produces haploid spores. The spores are tetrahedral in shape with distinct triradiate mark. When spores are mature, the lid of the capsule, called the operculum, opens. Due to changes of humidity a row or rows of hygroscopic teeth, the operculum, open and release spores.

The gametophyte plant is produced by the germination of a haploid spore. As a spore germinates, it produces a branched filament of photosynthetic cells called a protonema. This branching filament is similar to a green alga. The protonema produces a filament which can produce either a leafy moss gametophyte or a hard, dry bulbil for asexual reproduction.

10.9 SUMMARY

Mosses are members of the green plant lineage, showing alternation of generations, with an unbranched persistent sporophyte generation dependent on the dominant leafy gametophyte generation. The sexual generation is always a leafy plant, which is not developed directly from the spore but is borne on a well-marked and usually filamentous protonema. The general course of the life-history and the main features of form and structure will be best understood by a brief account of a particular example.

All of the features of the gametophyte (protonema, gametophore, gametangia) and sporophyte (seta, sporangium and peristome) described for the Bryophyta are applicable to the Bryopsida. Here, the basic pattern of variation in the peristome requires special examination, since it provides most of the characters for the classification at the ordinal level in the Bryopsida.

The majority of the mosses belong to the same great group as *Funaria,* the Bryales. The other two subdivisions of the Musci are each represented by a single genus. In the Andreaeales the columella does not extend to the upper end of the capsule, and the latter opens by a number of lateral slits. The Sphagnales also have a dome-shaped spore-sac continued over the columella, and, though their capsule opens by an operculum, they differ widely from other mosses in the development of the sporogonium as well as in the characters of the sexual generation. The three groups are described separately here, and general features of the mosses have been discussed in detail in this unit.

10.10 GLOSSARY

Apophysis – Swollen Sterile tissue at the base of the capsule where it joins the seta

Archegoniatae- Plants having archegonia applied to Bryophtes, Pteridophytes and Gymnosperms.

Calyptra (pl. **calyptrae**)**:** a membranous or hairy hood or covering that protects the maturing sporophyte; derived largely from the archegonial venter.

Capsule: the terminal, spore-producing part of a moss sporophyte.

Dehiscent: *of capsules*, splitting open by means of an annulus, operculum or valves (as opposed to indehiscent).

Emergent: partly exposed, as a capsule only partly protruding from among the perichaetial leaves. cf. exserted, immersed.

Epiphragm: a circular membrane, positioned horizontally over the capsule mouth of some mosses, attached to the tips of the peristome teeth and partially closing the mouth of an inoperculate capsule, e.g. *Funaria*, *Polytrichum*.

Fascicle: a group, bunch or tuft of branches, e.g. in *Sphagnum*.

Fimbriate: fringed, generally eroded with radiating cell walls of partly eroded marginal cells.

Gametangium (pl. **gametangia**)**:** an antheridium or archegonium; a structure forming gametes (**ovum**, spermatozoid).

Glabrous: smooth, not papillose, rough or hairy.

Heteromorphic – plants in which the gametophyte and sporophyte differ in structure as well as function

Homosporous – plants which produce similar spores in a sporangium

Perichaetial leaf: a modified leaf surrounding the archegonia.

Perichaetium: the female gametoecium, consisting of the sex organs and the perichaetial leaves surrounding them.

Polysety: having more than one sporophyte produced from a single gametoecium, each from a separate archegonium with its own calyptra, e.g. *Dicranolomadicarpum*.

Protandrous: maturation of the antheridia prior to the archegonia.

Protogynous: maturation of the archegonia prior to the antheridia.

Protonema (pl. **protonemata**)**:** a filamentous, globose or thallose structure resulting

Pseudopore: a pore-like structure with a thin membrane that is revealed by staining; e.g. in the hyalocysts of some Calymperaceae; in *Sphagnum* leaves consisting of fibril rings without an interior perforation.

Rhizoid: a hair-like structure that anchors a moss to the substratum; multicellular with oblique cross walls, often pigmented, and sometimes clothing the stem.

Sessile: without a stalk, e.g. of sporophytes with greatly reduced setae.

Seta (pl. **setae**)**:** the elongated portion of the sporophyte between the capsule and the foot.

Spermatozoid: a male gamete; bearing two flagella.

Sporocyte: a diploid cell that undergoes meiosis in the capsule to produce 4 haploid spores; sometimes called a **spore mother cell**.

Sporophyte: the spore-bearing generation; initiated by the fertilization of an ovum; consists of foot, seta and capsule; attached to and partially dependent on the gametophyte.

Sympodial: having a main stem of determinate growth, and further growth by innovations or lateral branches.

Synoicous: having antheridia and archegonia mixed in the same gametoecium.

Systylious: *of a capsule*, the operculum remains attached to the tip of the columella after the capsule has opened.

Theca (pl. **thecae**)**:** the spore-bearing part of a moss-capsule.

Trabecula (pl. **trabeculae**)**:** projecting cross-bars formed from the horizontal walls on either face of arthrodontousexostome teeth; also strands of cells bridging spaces within some capsules.

Triradiate ridge: a thickening on the proximal face of a spore caused by it being pressed against the three other spores of a tetrad.

10.11 SELF-ASSESSMENT QUESTION

10.11.1 Multiple choices Question:

1. The protonema of *Andreaea* consists of ______ of cells.
(a) a single row (b) two or more rows
(c) a two-layer-thick plate (d) a one-layer-thick plate

2. The granite mosses belong to the phylum ______, class ______.
(a) Bryophyta; Sphagnidae (b) Bryophyta; Andreaeidae
(c) Bryophyta; Bryidae (d) Hepatophyta; Sphagnidae

3. Hyaline cells are found in the _____ of ______.
(a) rhizoids; *Sphagnum* (b) leaves; *Andreaea*
(c) leaves; *Marchantia* (d) leaves; *Sphagnum*

4. The protonema of *Sphagnum* consists of ______ of cells.
(a) a single row (b) two or more rows
(c) a two-layer-thick plate (d) a one-layer-thick plate

5. Peat mosses belong to the phylum ______, class ______.
(a) Bryophyta; Sphagnidae (b) Bryophyta; Andreaeidae
(c) Bryophyta; Bryidae (d) Marchantophyta; Sphagnidae

6. ______ is a liverwort that carries its gametangia on gametophores.
(a) *Frullania* (b) *Marchantia*
(c) *Anthoceros* (d) *Riccia*

7. The ______ is embedded in the archegonium.
(a) foot (b) seta
(c) capsule (d) neck canal

8. When the cells of the ________ disintegrate, they form a tube through which sperm move to the egg.
(a) neck canal (b) capsule
(c) calyptra (d) venter

9. Largest gametophyte is found in ________.
(a) *Funaria* (b) *Selaginella*
(c) *Pinus* (d) *Cycas*

10. Stomata occur in:
(a) gametophyte of *Riccia* (b) gametophyte of *Marchantia*

(c) gametophyte of *Funaria* (d) sporogonium of *Funaria*

11. Apophysis in the capsule of Funaria is
(a) lower part (b) upper Part
(c) middle part (d) fertile part

12. Moss peristome takes part in
(a) spore dispersal (b) photosynthesis
(c) protection (d) absorption

13. A well-developed archegonium with neck consisting of 4-6 rows and neck canal cells, characterises
(a) gymnosperms and flowering plants (b) pteridophytes and gymnosperms
(c) gymnosperms only (d) bryophytes and pteridophytes

14. A perianth is characteristically found in the:
(a) thalloid liverworts (b) hornworts
(c) mosses (d) leafy liverworts.

15. In the liverworts, an androecium is a:
(a) structure producing sperm (b) group of water-conducting cells.
(c) short side branch bearing antheridia (d) tubular sheath surrounding the archegonium

16. After they germinate, bryophyte spores first give rise to:
(a) hyphae (b) archegonia
(c) rhizoids (d) protonema

17. At maturity, the sporophyte of most bryophytes consists of the:
(a) foot and seta only (b) seta and capsule only
(c) capsule and calyptra only (d) foot, seta, and capsule

18. Operculum is absent in:
(a) *Andreaea* (b) *Funaria*
(c) *Polytrichum* (d) *Pogonatum*

19. The spore mother cell in Sphagnum is:
(a) Haploid (b) Diploid
(c) Triploid (d) Tetrapoid

20. Peristome is absent in:

(a) *Funaria* (b) *Sphagnum*
(c) *Polytrichum* (d) *Pogonatum*

Answer Key:

10.11.1: 1- (b), 2- (a), 3- (d), 4- (d), 5- (a), 6- (b), 7- (a), 8- (a), 9- (a), 10- (d), 11- (a), 12- (a), 13- (d), 14- (d), 15- (c), 16- (d), 17- (d), 18- (a), 19-(a) . 20- (b).

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10.14 TERMINAL QUESTIONS

10.14.1 Short Answer Questions:

1. Explain the internal structure of aerial stem of *Funaria.*
2. Describe the capsule of *Andreaea.*
3. Draw well labeled diagram of *Andreaea rupestris* sporogonial shoot.
4. Define sporophyte of *Sphagnum.*
5. Explain the development of antheridium in *Anthoceros*.
6. Define the structure of *Anthoceros* archegonium.
7. Define the T.S. of *Funaria* stem.
8. Explain structure of capsule in *Polytrichum.*
9. Explain development of archegonia in *Funaria.*
10. Discuss structure of sporophyte in *Sphagnum.*

10.14.2 Essay Type Question:

1. Define the life cycle of *Funaria* with labeled diagram.
2. Describe the structure and development of sporophyte of Andreaea.
3. Give an illustrated account of *Takakia.*
4. List the distinctive features of class Bryopsida or Musci.
5. Give detailed account of alternation of generation in *Anthoceros.*
6. Define life cycle of *Polytrichum.*

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