# CYANOBACTERIA

## Cyanobacteria Definition and Introduction:

Cyanobacteria are prokaryotic oxygenic phototrophs that contain a green pigment called chlorophyll and a blue photosynthetic pigment called phycobilins. Prokaryotic means they don't have a membrane-bound nucleus, mitochondria or other type of membrane-bound organelle (like true algae do). A phototroph is an organism that uses energy from the sun to synthesize organic compounds for food.

They have the distinction of being the oldest known fossils, more than 3.5 billion years old and are still around; they are one of the largest and most important groups of bacteria on earth.

These are the only organisms able to perform oxygenic photosynthesis that can also fix nitrogen.

Many Proterozoic oil deposits are attributed to the activity of cyanobacteria. They are also important providers of nitrogen fertilizer in the cultivation of rice and beans. The cyanobacteria have also been tremendously important in shaping the course of evolution and ecological change throughout earth's history. The oxygen atmosphere that we depend on was generated by numerous cyanobacteria during the Archaean and Proterozoic Eras. Before that time, the atmosphere had a very different chemistry, unsuitable for life as we know it today.

The other great contribution of the cyanobacteria is the origin of plants. The chloroplast with which plants make food for themselves is actually a cyanobacterium living within the plant's cells. Sometime in the late Proterozoic, or in the early Cambrian, cyanobacteria began to take up residence within certain eukaryote cells, making food for the eukaryote host in return for a home. This event is known as **endosymbiosis**, and is also the origin of the eukaryotic mitochondrion.

Because they are photosynthetic and aquatic, cyanobacteria are often called "blue-green algae".

It is a primitive group of algae, consists of 150 genera and about 2,500 species. In India, the division is represented by 98 genera and about 833 species. Members of the class Myxophyceae (Cyanophyceae) are commonly known as blue green algae. The name blue green algae is given because of the presence of a dominant pigment c-phycocyanin, the blue green pigment.

## Characteristic Features of Cyanobacteria:

1. Cyanobacteria or blue green algae are the one of most successful autotrophic organisms on earth which have mastered all types of environments— fresh water, sea water, salt marshes, moist rocks, tree trunks, moist soils, hot springs (50-60°C and up to 85°C), frozen waters. Their abundance can be gauged from the fact that red sea is named after the colouration provided by red coloured planktonic cyanobacteria known as *Trichodesmium erythraeum*. Along with other organisms, they are found as saprophyte and parasites.
2. They show great diversity in form and shape. Some are spherical; some are rod-shaped, while few of them are unicellular or multicellular. Cyanobacteria may be unicellular, colonial or filamentous. Each filament consists of a sheath of mucilage and one or more cellular strands called trichomes. Single trichome filaments may further be of two types, homocystous (= undifferentiated, e.g., *Oscillatoria*) and heterocystous (= differentiated, having heterocysts, e.g., *Nostoc*). *Spirulina* has a spirally coiled filament. Colonies develop in some cases, e.g., *Nostoc*. Some forms are covered with sheath.
3. The individual cells are prokaryotic in nature. The nucleus is incipient type and they lack membrane bound organelles. Cell wall is made up of microfibrils and is differentiated into four (4) layers. The cell wall composed of mucopeptide, along with carbohydrates, amino acids and fatty acids.
4. The principal pigments are chlorophylls a (green), c-phycocyanin (blue) and c-phyco- erythrin (red pigment which absorb light of short wave length 470 to 600 /mm). In addition, other pigments like β-carotene and different xanthophylls like myxoxanthin and myxoxanthophyll are also present. Membrane bound chromatophore are absent. Pigments are found embedded in thylakoids.
5. Both vegetative and reproductive cells are non-flagellate. Locomotion is generally absent, but when occurs, it is of gliding or jerky type.

6. In trichomes of Cyanobacteria heterocysts are also present which help in fixation of free nitrogen. Cell wall is much thicker in comparison with the other cells of the trichome.
7. In some forms thick-walled akinetes are also found which help them to survive in unfavorable conditions.
8. The reserve foods are cyanophycean starch and cyanophycean granules (protein).
9. Reproduction takes place by vegetative and asexual methods. Vegetative reproduction takes place by cell division, fragmentation etc. Asexual reproduction takes place by endospores, exospores, akinetes, nannospores etc.
10. Sexual reproduction is completely absent. Genetic recombination is reported in 2 cases.

### OUTLINES OF CLASSIFICATION

There is only one class Cyanophyceae. According to first system it can be divided into two orders 1. Chamaesiphonales and 2. Hormogonales

Smith has added 1 more order Chroococcales. Finally F E Fritsch divided the class Cyanophyceae into 2 tribes, 7 orders, and 10 families.

**Tribe A.** Coccogoneae
1. **Order** Chroococcales- **Family 1.** Chroococcaceae Ex:- *Chroococcus*.
   **Family 2.** Entophysalidaceae Ex:- *Entophysalis*
2. **Order** Chamaesiphonales- **Family 1.** Pleurocapsaceae Ex:- *Pleurocapsa*
   **Family 2.** Dermaocarpaceae Ex:- *Dermocarpa*
   **Family 3.** Chamaesiphonaceae Ex:- *Chamaesiphon*

**Tribe B.** Hormogoneae
1. **Order** Oscillatoriales **Family 1.** Oscillatoriaceae Ex:- *Oscillatoria*
2. **Order** Nostocales **Family 1.** Nostocaceae Ex:- *Nostoc*
3. **Order** Scytonematales **Family 1.** Scytonemataceae Ex:- *Scytonema*
4. **Order** Stigonematales **Family 1.** Stigonemataceae Ex:- *Stigonema*
5. **Order** Rivulariales **Family 1.** Rivulariaceae Ex:- *Rivularia*

### OCCURRENCE OF CYANOPHYCEAE:

Members of Cyanophyceae are available in different habitats. They may grow in such conditions in which other plants cannot grow. They may grow in acidic or plain waters, extreme cold and hot streams (50-60°C and up to 85°C), moist soil, salt-water lakes etc. They are found in large numbers in damp places where moisture is more, e.g., slopes of the mountains, on rocks, on bark of trees etc. Mostly, they are found in rivers, lakes, ponds etc. Most of the species are fresh water (e.g., *Oscillatoria*, *Rivularia*), a few are marine (e.g., *Trichodesmium*, *Dermocarpa*), and some species of *Oscillatoria* and *Nostoc* are grown on terrestrial habitat.

Species of some members like *Anabaena* grow as endophytes in thallus of *Anthoceros* (Bryophyta) and in leaves of *Azolla* (Pteridophyta) and *Nostoc* in the root of *Cycas* (Gymnosperm).

Species of *Nostoc*, *Scytonema*, *Gloeocapsa*, and *Chroococcus* grow symbiotically with different fungi and form lichen. Some members like *Nostoc*, *Anabaena* etc. can fix atmospheric nitrogen and increase soil fertility.

Along with other organisms, they are found as saprophyte and parasites.

## THALLUS ORGANIZATION IN CYANOPHYCEAE:

Plants of this group show much variation in their thallus organization.

**The thallus may be of unicellular or colonial forms:**

**1. Unicellular Form:**

In unicellular form, the cells may be oval or spherical. Common members are *Gloeocapsa* (Fig. 3.23A), *Chroococcus* and *Synechococcus*.

**2. Colonial Form:**

In most of the members the cells after division remain attached by their cell wall or remain together in a common gelatinous matrix, called a colony.

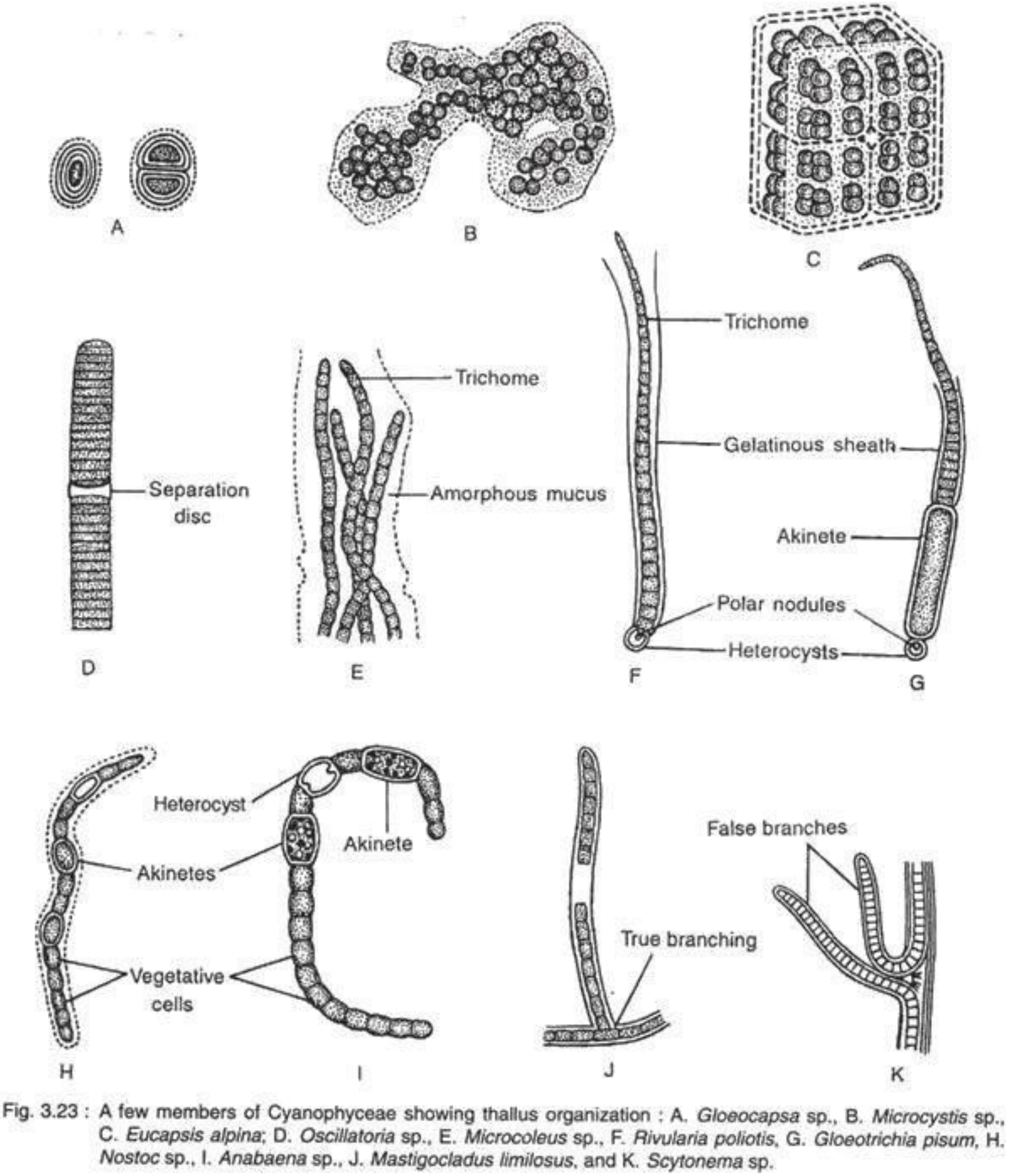


Fig. 3.23 : A few members of Cyanophyceae showing thallus organization : A. *Gloeocapsa* sp., B. *Microcystis* sp., C. *Eucapsis alpina*; D. *Oscillatoria* sp., E. *Microcoleus* sp., F. *Rivularia poliotis*, G. *Gloeotrichia pisum*, H. *Nostoc* sp., I. *Anabaena* sp., J. *Mastigocladus limilosus*, and K. *Scytonema* sp.

**The colonies may be of two types:**

a. Non- filamentous, and

b. Filamentous.

**a. Non-Filamentous Type:**

The cells of this type divide either alternately or in three planes, thereby they form spherical (*Gomphosphaera*, *Coelosphaerum*), cubical (*Eucapsis alpine*, Fig. 3.23C), squarish (*Merismopedia*) or irregular (*Microcystis*, Fig. 3.23B) colony.

**b. Filamentous Type:**

By the repeated cell division in one plane, single row of cells are formed, known as trichome. e.g., *Oscillatoria* (Fig. 3.23D), *Spirulina*, *Arthospira* etc. The trichome when covered by mucilaginous sheath is called a filament. The filament may contain single trichome (Oscillatoria, *Lyngbya*) or several trichomes (*Hydrocoleus*, *Microcoleus*, Fig. 3.23E).

The trichomes may be unbranched (*Oscillatoria*, *Lyngbya*), branched (*Mastigocladus limilosus*, Fig. 3.23J) and falsely branched (*Scytonema*, Fig. 3.23K and *Tolypothrix*).

## CELL STRUCTURE OF CYANOBACTERIA

Like bacteria, the cell of cyanobacteria also consists of a mucilaginous layer called sheath, the cell wall, plasma membrane and cytoplasm.

**1. Sheath:**

Usually the cell of cyanobacteria are covered by a hygroscopic mucilaginous sheath which provides protection to cell from unfavourable conditions and keeps the cells moist (Fig. 4.32). It protects the cell from the injurious factors of the environment. Thickness, consistency and nature of sheath are influenced by the environmental conditions. Sheath consists of pectic substances. It is undulating, electron dense and fibrillar in appearance.

**2. Cell Wall:**

After observing the cyanobacterial cell under electron microscope, it appears multilayered present between the sheath and plasma membrane. The cell wall consists of four layers designated as LI, LII, LIII and LIV (Fig.4.33). The layers LI and LIII are electron transparent, and LII and LIV electron dense.

(i) LI is the innermost layer of the cell wall present next to the plasma membrane. It is of about 3-10 nm thickness and enclosed by LII.

(ii) LII is a thin, electron dense layer. It is made up of mucopeptide and muramic acid, glucosamine, alanine, glutamic acid and di-amino-pamelic acid. The layer LII provides shape and mechanical strength to the cell wall. Thickness of this layer varies from 10 to 1000 nm.

(iii) LIII is again electron transparent layer of about 3-10 nm thickness,

(iv) The outermost layer is LIV which is a thin and electron dense layer. It appears wrinkled and is undulating or convoluted. All the layers are interconnected by plasmodesmata. Numerous pores are present on the cell which act as passage for secretion of mucilage by the cell. Chemically the cell wall of eubacteria and cyanobacteria are much similar.

**3. Plasma Membrane:**

The cell wall is followed by a bilayer membrane called plasma membrane or plasma lemma. It is 70A° thick, selectively permeable and maintain physiological integrity of the cell. Plasma membrane sometimes invaginates locally and fuses with the photosynthetic lamellae (thylakoids) to form a structure called lamellosomes (Fig.4.32). The plasma membrane encloses cytoplasm and the other inclusions.

**4. Cytoplasm:**

Cytoplasm is distinguished into the two regions, the outer peripheral region which is called the chromoplasm and the central colourless region called centroplasm.

**(i) Chromoplasm:**

The chromoplasm contains the flattened vesicular structures called photosynthetic lamellae or thylakoids (Fig.4.32). Thylakoids may be peripheral, parallel or central. Besides photosynthesis, thylakoids have the capacity of photophosphorylation, Hill reaction and respiration. Depending upon physiological conditions they are arranged accordingly.

Several photosynthetic pigments such as chlorophyll a, chlorophyll c, xanthophyll's, and carotenoids are present inside the lamellae. On its upper surface phycobilisomes (biliproteins) of about 40 nm diameter are anchored by a protein.

Phycobilisomes comprises of three pigments: Phycocyanin-C, allophycocyanin and Phycoerythrin-C. These three pigments harness light in the sequence: Phycoerythrin—Phycocyanin—Allophycocyanin—Chlorophylls.

**(ii) Centroplasm:**

The centroplasm is colourless and regarded as primitive nucleus devoid of bilayered nuclear membrane and nucleolus. Several grains that can take stain are dispersed in centroplasm. Some people are of the opinion that the centroplasm is the store house of food and according to the others it is an incipient nucleus (Fig.4.32).

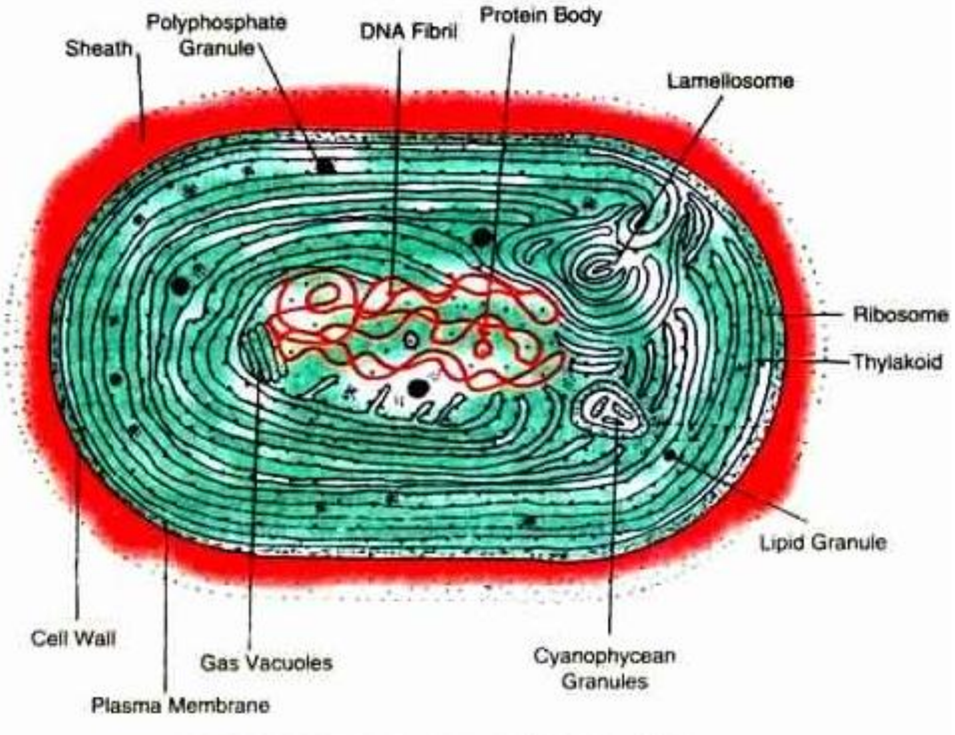


Fig. 4.32 : A typical cell of a cyanobacterium.

**5. Cytoplasmic Inclusions:**

Several glycogen granules, oil droplets and other inclusions are dispersed in chromoplasm as well as in centroplasm regions:

**(i) Cyanophycin:**

The cyanobacteria accumulate nitrogenous reserve material called cyanophycin or Cyanophycean granules when grown at conditions of surplus nitrogen. These are built with equal molecules of arginine and aspartic acid.

**(ii) Gas Vacuoles:**

In many cyanobacteria e.g. *Anabaena*, *Gloeotrichia*, *Microcystis*, *Oscillatoria*, etc. the gas vesicles of viscous pseudo vacuoles of different dimensions are found.

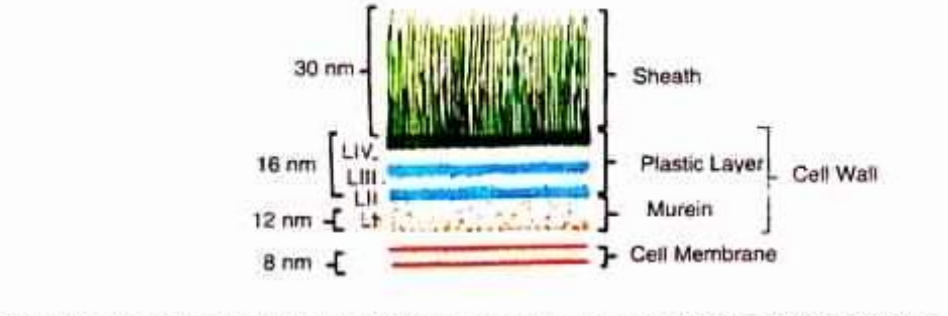


Fig. 4.33 : An enlarged view of different components of wall layer of the cell of a cyanobacterium (diagrammatic).

The cytoplasm lacks vacuoles. The vesicles are hollow, rigid and elongated cylinders (75 nm diameter, 200-1000 nm long) covered by a 2 nm thick protein boundary. The ends of vacuoles are conical (Fig. 4.32). The protein boundary is impermeable to water and freely permeable to gases. Under pressure they get collapsed, and therefore, lose refractivity.

The function of gas vesicles is to maintain buoyancy so that the cell can remain at certain depth of water where they can get sufficient light, oxygen and nutrients. Floating and sinking phenomenon is a key feature found in free floating cyanobacteria. Through this mechanism they can escape from harmful effect of bright light.

**(iii) Carboxysomes:**

Carboxysomes are the polyhedral bodies containing 1, 5-ribulose bi-phosphate carboxylase (Rubisco).

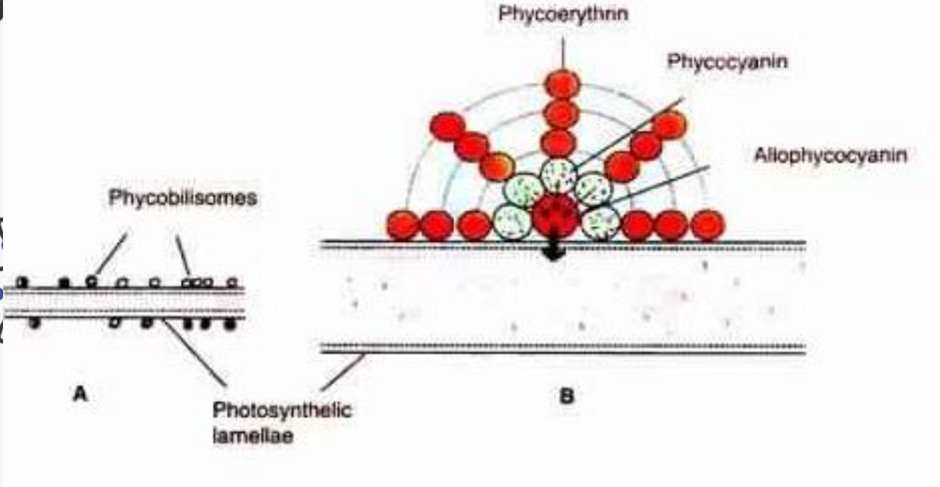
**(iv) Phosphate Bodies:**

These are the spherical structures formed as a result of the aggregation of high molecular weight linear polyphosphates. These subcellular inclusions are also called metachromatin granules or volutin granules and serve as phosphate stores and are consumed during periods of phosphate starvation. These structures develop mostly in those cyanobacteria that grow in a phosphate-rich environment.

**(v) Phycobilisomes:**

Some phototrophic organisms (i.e. cyanobacteria and red algae) contain two accessory pigments such as carotenoids and phycobilins (also called phycobiliproteins), in addition to chlorophyll or bacteriochlorophyll pigments. The carotenoids play a photo-protective role, whereas phycobilins serve as light harvesting pigments.

Phycobilins are the main light-harvesting pigments of these organisms. Phycobiliproteins are red or blue in colour. Phycobiliproteins are aggregated to form a high molecular weight darkly stained ball-like structure called Phycobilisomes. The phycobilisomes are attached to the outer surface of lamellar membrane (Fig. 4.34 A).



4.34 : Phycobilisomes attached to the lamellar membrane (A); arrangement of phycobiliproteins in a phycobilisome attached to lamellar membrane (B); arrows show the direction of transfer of energy (diagrammatic)

**Phycobiliproteins includes three different pigments:**

(a) A red pigment Phycoerythrin which strongly absorbs light at 550 nm,
(b) A blue pigment Phycocyanin which absorbs light strongly at 620 nm, and
(c) Allophycocyanin which absorbs light at 650 nm.

The pigments in phycobilisomes are arranged in such a way that Allophycocyanin is attached to photosynthetic lamellar membrane. Allophycocyanin is surrounded by the molecules of Phycocyanin and the latter by Phycoerythrin.

Phycoerythrin and phycocyanin absorb shorter (high energy) wavelength of light and transfer energy to allophycocyanin. Allophycocyanin is closely linked to the reaction centre chlorophyll. Thus energy is transferred from allophycocyanin to chlorophyll a. Presence of phycobilisomes makes the cyanobacterial growth possible at the region of lowest light intensities.

**(vi) DNA Matrix:**

Like other prokaryotes the cyanobacteria also contain naked DNA fibrils dispersed in the centroplasm. DNA material lacks nucleoplasm, and like E. coli contains a histone like protein that binds with DNA. The total number of genomes is yet not known but in *Agmenellum* 2 to 3 genomes have been reported.

However, base composition of DNA in different cyanobacteria varies, for example in chroococcales (35-71 moles percent G + C), Oscillatoriales (40- 67 moles percent G + C), Pleurocapsales (39-47 moles percent G + C) and heterocystous forms (38- 47 moles percent G + C). The molecular weight ranges from 2.2 x $10^9$ to 7.4 x $10^9$ Daltons.

**(vii) Ribosomes:**

These are the sites of protein synthesis. Cyanobacterian ribosomes occur freely in the cytoplasm and are identical to those of bacteria in being 70S ribosomes.

**(viii) Glycogen or α-granules:**

Glycogen or α-granules are the sites for storage of excess photosynthetic products. The latter is used as energy source in darkness or when $CO_2$ supply is limiting.

**(ix) Plasmids:**

All the naturally occurring plasmids in cyanobacteria are phenotypically cryptic. They are covalently closed circular DNAs and their genetic compositions and complete function is not yet known. However, plasmid-mediated transfer of genetic material has been reported in certain cyanobacteria.

## PHOTOSYNTHESIS IN CYANOBACTERIA

The process of photosynthesis goes on in blue green algae, in the same manner as in other plants. The Cyanophyceae contain chlorophyll-a, in addition to phycocyanin and other pigments. With the help of these pigments the blue-greens are able to synthesize their own carbohydrate food from carbon dioxide and water in the presence of sunlight. Thus the Cyanophyceae in general are obligate photoautotrophs. Phycocyanin may facilitate the synthesis of food in these algae under the limited, light conditions in which they usually live. Its presence, however, enables the blue greens to absorb and use more of green, red or orange and yellow wave-lengths of light than the green algae. Wolk (1973) reported that the light absorbed by phycocyanin appears to be about as active photosynthetically as chlorophyll. Duysens (1951) demonstrated energy transfer directly. Light energy absorbed by phycocyanin is transferred to chlorophyll situated nearby. Like other algae photosynthesis in blue green algae involves both photosystem “II” and photosystem “I”. The first evident products of photosynthesis are starch like sugars (Cyanophycean starch) and glycogen. They are converted into glycoproteins. An amino acid known as diaminopimelic acid is found in the proteins of blue green algae and bacteria but never found in higher plants or animals. Nitrogenous materials are also present in various forms such as nucleoproteins and albumins. Minute droplets of oil are often present which indicate the synthesis of fats.

As mentioned above the blue-greens in general are obligate photoautotrophs. They cannot grow in darkness even in the presence of organic nutrients in the substrate. However, experiments conducted by Moare, Hoare and Smith (1970) have shown that some blue-greens can assimilate organic compounds and incorporate them into specific cell contents. The capacity of blue-greens can assimilate organic compounds and incorporate them into specific cell contents. The capacity of blue-greens to assimilate and metabolize exogenous organic compounds is very limited and they cannot use organic compounds as a source of energy.

## REPRODUCTION IN CYANOPHYCEAE:

The blue green algae (Cyanophyceae) reproduce by both vegetative and asexual means. Sexual reproduction is absent.

The vegetative reproduction performs through fission (*Synechococcus*), fragmentation (*Oscillatoria*, *Cylindrospermum muscicola*), hormogonia formation (*Oscillatoria*, *Nostoc*), hormospores (*Westiella lanosa*), planococci and Palmelloid stage.

During asexual reproduction various types of asexual spores are formed. These are akinetes (*Anabaena sphaerica*, *Gloeotrichia natans*, *Calothrix fusca*), endospores (*Dermocarpa*), exospores (*Chamaesiphon*) and nannocyte (*Microcystis*) (Fig. 3.27).

Specialized structures such as akinetes, hormogonia, hormocysts and spores, are partly involved in the process of reproduction.

So far as the sexual reproduction in its true sense is concerned, it is absent in them and the requirements of sexuality are considered to be met by some alternative pathways referred to as parasexual-pathways.

**1. Akinetes:**

The members of Stigonemataceae, Rivulariaceae and Nostocaceae are capable to develop the vegetative cells into spherical perennating structures called akinetes (dormant structures) in adverse condition or spores such as *Nostoc*, *Rivularia*, *Gloeotrichia*, etc. (Fig. 4.35A).

During unfavourable conditions, the vegetative cells accumulate much food, enlarge and become thick walled. These are formed singly or in chains. Akinetes possess cyanophycean granules hence these appear brown in colour. Under favourable conditions the akinetes germinate into vegetative filaments.

**2. Hormogonia:**

Hormogones are the short segments of trichomes produced in all filamentous cyanobacteria. Hormogones are produced by several methods such as fragmentation of trichomes into pieces (e.g. *Oscillatoria*) (Fig. 4.35C), delimination of cells into intercalary groups (*Gloeotrichia*) (Fig. 4.35A), fragmentation and round off the end cells (*Nostoc*) (B), formation of separating disc or necridia and their subsequent degradation (*Oscillatoria*, *Phormidium*). The hormogones show gliding movement. Each hormogone may develop into a new individual.

**3. Hormocysts:**

Some other cyanobacteria produce hormocysts or hormospores which function similar to hormogones, which are multicellular, highly granulated, structures having a thick and massive sheath with a large quality of food. They may be intercalary or terminal in position and may germinate from either end or both the ends to give rise to the new filaments.

**4. Spores: Endospores, Exospores and Nanocysts**

Non-filamentous cyanobacteria generally produce spores such as endospores, exospores and nanocysts which contribute by germinating and giving rise to new vegetative cells when the unfavourable condition is over. For example *Chamaesiphon*, *Dermocapsa* and *Stichosiphon*. The endospores are produced inside the cell. During endospore formation, cytoplasm of the cell is cleaved into several bits which are converted into endospores.

After liberation each endospore germinates into a new plant, for example *Dermocapsa*. When the size of endospores is smaller but larger in number, they are called Nano spores or nanocysts. Some of the cyanobacteria (e.g. *Chamaesiphon*) reproduce by budding exogenously. The spores produced through this method are called exospores.

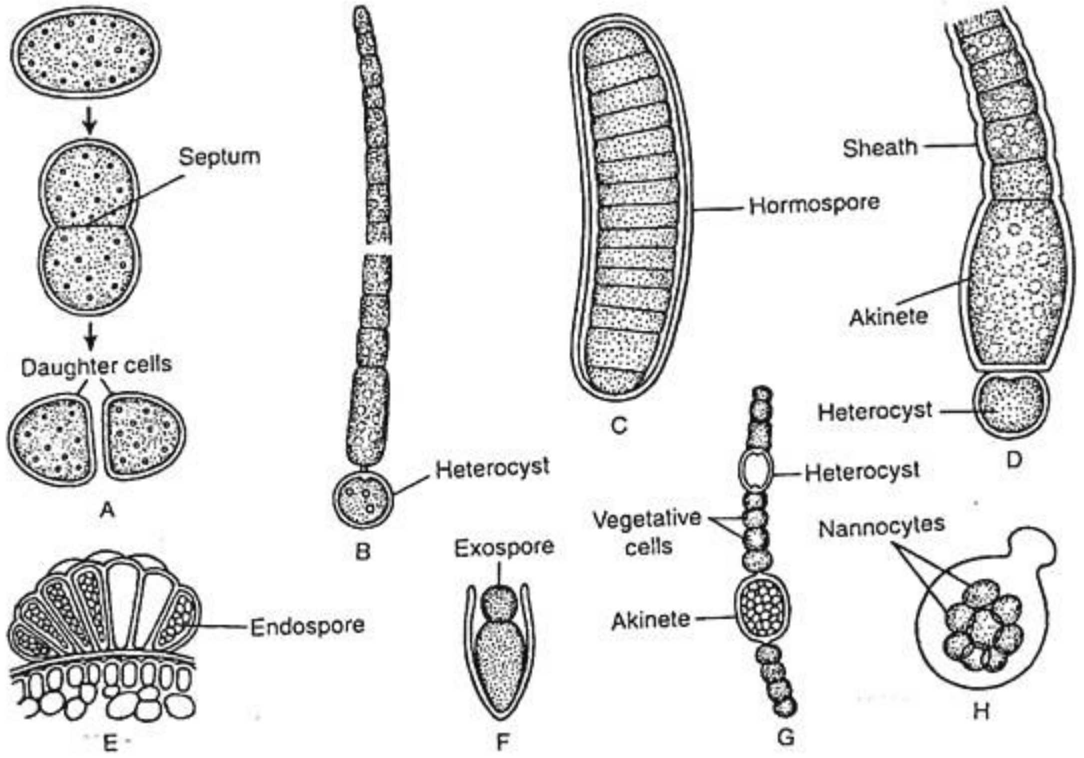


Fig. 3.27 : Vegetative and asexual reproduction in Cyanophyceae : A. Cell division (*Synechococcus* sp.), B. Fragmentation of filament (*Cylindrospermum muscicola*), C. Hormospore (*Westiella lanosa*), D. Akinete (*Gloeotrichia natans*). E Endospore (*Dermocarpa prasina*), F. Exospore (*Chamaesiphon incrustans*), G. Akinete (*Anabaena* sp.) and H. Nannocytes (*Aphanothece*)

The difference between an endospore and a nanocyst is that in endospore formation the parent cell concomittantly enlarges in size, whereas in nanocyst formation there is no such enlargement of the cell.

**Parasexuality in Cyanobacteria:**

The knowledge of cyanobacterial genetics is relatively new and was pioneered by Kumar in 1962 who obtained penicillin and streptomycin resistant strains of *Anacystis nidulans*, crossed them, and successfully demonstrated the appearance of a third type of recombinant strain resistant to both the antibiotics.

However, the mechanisms of genetic recombination in cyanobacteria are thought to be the same as those in bacteria.

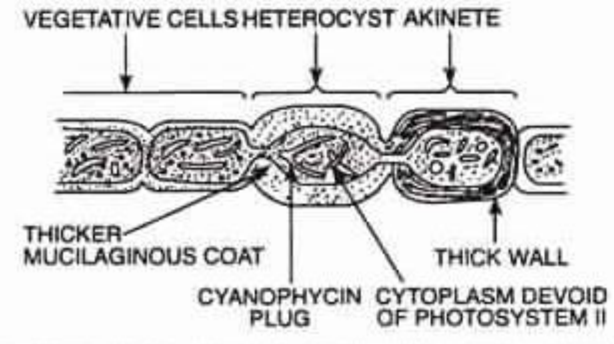


FIG. 6.12. Trichome of *Anabaena* possessing heterocyst and akinete.

**Heterocysts:**

Heterocysts are the modified vegetative cells (Fig.4.35A-B). Depending on nitrogen concentration in the environment, hetero- cyst formation occurs. During differentiation several morphological, physiological, biochemical and genetical modifications take place in heterocyst.

They are slightly enlarged cells, pale yellow in colour containing an additional outer investment. They are produced singly or in chains and remain intercalary or terminal in positions. These are found most frequently in Oscillatoriaceae, Rivulariaceae, Nostocaceae and Scytonemataceae.

In heterocysts, total amount of thylakoids gets reduced or absent. The photosystem II that generates oxygen becomes non-functional. The amount of surface proteins that combine with oxygen and create oxygen tense environment is increased.

Rearrangement in nif gene (nitrogen fixing gene) cluster takes place and expression of nitrogenase and nitrogen fixation are accomplished. In addition, these take part in perennation and reproduction as well.

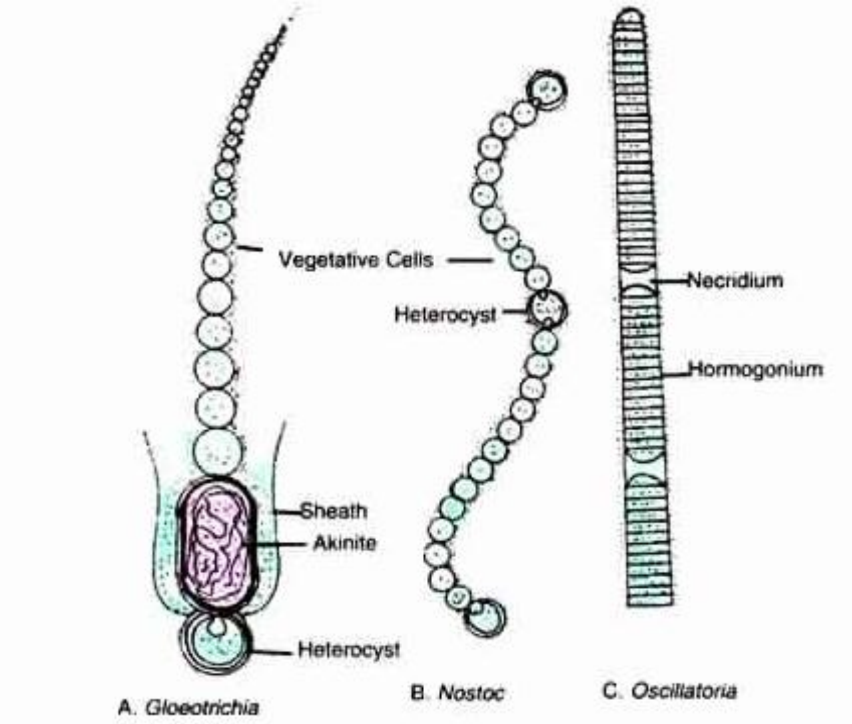


Fig. 4.35 : Diagrams of a *Gloeotrichia* (A), *Nostoc* (B) and *Oscillatoria* (C).

## ECONOMIC IMPORTANCE OF CYANOBACTERIA:

The Cyanophycean members show both beneficial and harmful activities.

**Beneficial Activities:**

1. Cyanobacteria are one of the early colonizers of bare and barren areas and generate such conditions that favour the growth of other organisms even in the most hostile environment.
2. They are good food source for several aquatic animals. Moreover, the cyanobacteria are now-the-days exploited as food for animals including humans. *Spirulina*, a filamentous cyanobacterium, is

now incorporated in food supplement as well as animal feed through 'single cell protein' manufacture because of its high protein content (upto 70%).

3. Some Indian dishes, for instance, like 'puri' 'idli' and 'sandwich' prepared by supplementing 5-10% *S. fusiformis* have been found to be palatable. In parts of Rajasthan Anabaena and Spirulina are collected from Sambar lake and used as fodder and manure. *Nostoc commune* is boiled and used as soup in China.
4. About twenty two (22) filamentous members of Cyanophyceae like *Nostoc*, *Anabaena*, *Aulosira*, *Anabinopsis*, *Calothrix*, *Scytonema* etc. can fix atmospheric nitrogen and form nitrogenous compounds. These compounds are further absorbed by the plant for their metabolic activity and increase yield.
5. All the above members have heterocyst. But certain non-heterocystous members like *Plectonema boryanum* are able to fix atmospheric nitrogen in anaerobic condition.
6. *Aulosira*, *Nostoc*, *Anabaena*, etc. are some such cyanobacteria that are now regularly inoculated in the rice fields for nitrogen supply. This saves consumption of nitrogen fertilizers.
7. $N_2$-fixing cyanobacteria (e.g., *Nostoc*, *Anabaena*) form a thick substratum over the soil resulting a reclamation of land. They produce acidic chemicals for counteracting alkalinity of the soil and they supply nitrogen compounds which are generally deficient in these soils.
8. Species of *Anabaena* and *Aulosira* do not allow mosquito larvae to grow nearby. Such cyanobacteria can be inoculated in village ponds to prevent the growth of mosquitoes.
9. Extracts of *Lyngbya* are used to manufacture antibiotic-like compounds.

**Harmful Activities:**

1. Some members of Cyanophyceae cause damage of building plasters, stones etc. It can be avoided by spraying $CuSO_4$ and sodium arsinate.
2. Some members like *Microcystis*, *Anabaena*, form water blooms and can grow well in $O_2$ deficient water. Continuous respiration by submerged plants and animals during night time (when photosynthesis does not take place) causes the depletion of $O_2$ to almost zero level. At that condition mortality of both animals and other submerged plants takes place due to suffocation.
3. Blue green algae contaminate the water of reservoirs. They develop a foul odour in water and make it unhygienic for human being and cause several diseases.
4. Different diseases like gastric troubles may appear by drinking the water contaminated with *Microcystis* and *Anabaena*.
5. Certain cyanobacteria such as *Microcystis aeruginosa* (= Anacystis cyanea), *Anabaena flos-aquae* and *Aphanizomenon flos-aquae* produce toxins harmful to most aquatic animals. These toxins may prove equally harmful to humans drinking or bathing in such water.
6. Cyanobacteria generally grow on walls and roofs of buildings during the rainy seasons and cause discolouration, corrosion, and leakage.

## *Anabaena*

### CLASSIFICATION

Kingdom: Bacteria
Division: Cyanobacteria
Class: Cyanophyceae
Order: Nostocales
Family: Nostocaceae
Genus: *Anabaena*

Total 110 species around the world. About 25 species from India of which important species are *Anabaena Aphanizomenoides, A. spiroides, A. sphaerica* etc.

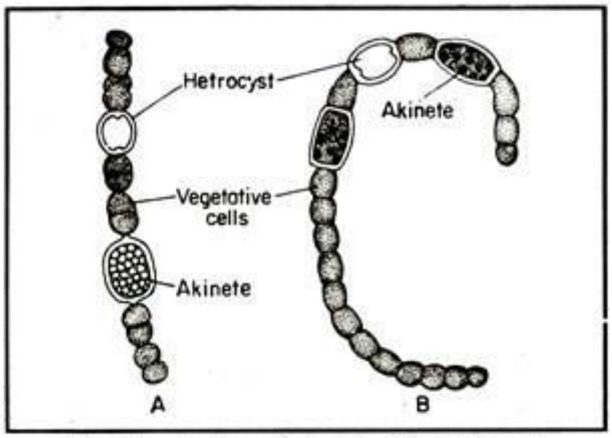


Fig 2.5. Anabaena Sp. A & B – Single filament.

### OCCURRENCE

Anabaena is a blue green algae grows in moist rice fields or temporary puddles with shallow water. It found as plankton in lakes, ponds and impart blue green colouration to the water. Some are terrestrial. Some species of *Anabaena* are endophytes. They live as symbionts in the roots of *Cycas* (*A. cycadae*), thalli of *Anthoceros* and leaves of mosquito fern- *Azolla* (*A. azollae*).

*Anabaena* is found in all types of water. 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.

### STRUCTURE

It has filamentous or trichome structure which aggregate to form floccose colony. 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*. Trichomes are unbranched, uniformly broad throughout or only the apices are attenuated. 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. Sheaths are always hyaline and watery gelatinous. Colonies of *Anabaena* are smaller than those of *Nostoc*.

**Structure of cells:** The cells are spherical or barrel or subcylindrical shaped. They are rarely cylindrical and never discoid. Cells have typical cyanophycean structure. The majority of the cells of a colony are similar in size. A number of gas vacuoles are found more particularly in planktonic species Its cells have following components:

I. Each cell has outer cell wall. This wall consists of three layers. The inner layer is thin cellular layer, median is pectic layer and outer is mucilage layer.

2. The cytoplasm is homogenous or granulated. The peripheral part is called chromoplasm. It contains pigment. Hence it is colored. The central colourless part of protoplasm contains nucleus like material called central body or chromatin granules.

3.Heterocysts are of same shape as of vegetative cell.

4. Golgi bodies, endoplasmic reticulum and mitochondria are absent in their cells.

## REPRODUCTION

*Anabaena* reproduces only asexually by means of Hormogones, Akinetes and Heterocysts. Heterocysts and Akinetes are present in mature filaments.

**Hormogonia (Hormogones):-** Common method of reproduction. Heterocysts are the point at which the filament breaks into hormogones. Hormogones may also formed by the breaking of filament or decay of filament at some other points. The hormogones remain motile (gliding movement) and at a later stage they escape from the colony to develop into new long filaments.

**Akinetes (Arthrospores) formation:-** Akinetes (resting spores) are formed during unfavorable conditions. Akinetes are long, thick walled cells or spores with a large amount of reserved food material that help in reproduction. Their wall is two to three layers thick. They have granular protoplasm. Akinetes are capable of forming new filaments. The Akinetes can survive dry conditions. They are present away from the heterocyst or on one side or on both side of the heterocyst in different species. The Akinetes get separated from the filament and germinate to form a new celled filament (Hormogonium).

**Heterocysts:-** They are also thick walled cells but not long and are generally intercalary and rarely terminal. These are slightly larger than vegetative cells. Heterocysts have a thick two layered envelop with the inner wall forming a knob like projection (Polar nodules) into the cell cavity. There is single polar nodule in the terminal heterocyst while there are two polar nodules in an intercalary heterocyst. Heterocysts are mainly involved in nitrogen fixation, there are occasional reports of heterocyst germinating and developing into a new filament. During germination its contents divide into two and then four celled germling which comes out either by ruptures of the outer wall or by gradual dissolution and widening of pore and develops into a new trichome.

**Endospore formation:** Endospores formation is rare in *Anabaena*.

### Nitrogen fixation by Anabaena

During times of low environmental nitrogen, about one cell out of every ten will differentiate into a heterocyst. Heterocysts then supply neighboring cells with fixed nitrogen in return for the products of photosynthesis. Such nitrogen fixing cell now cannot perform photosynthesis. 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 entry of oxygen into the cell. It gives heterocyst its *Chara*cteristic 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 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.

## *Scytonema*

**CLASSIFICATION**

| | |
|---|---|
| Kingdom: | Bacteria |
| Division: | Cyanobacteria |
| Class: | Cyanophyceae |
| Order: | Nostocales |
| Family: | Nostocaceae |
| Genus: | *Scytonema* |

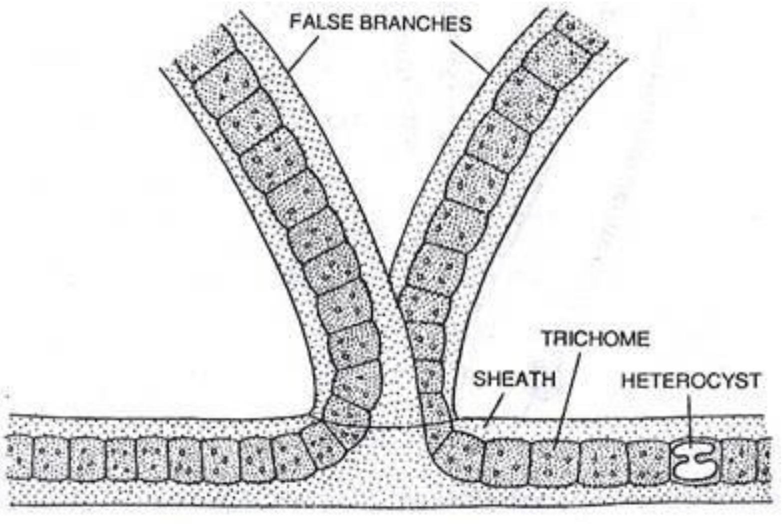


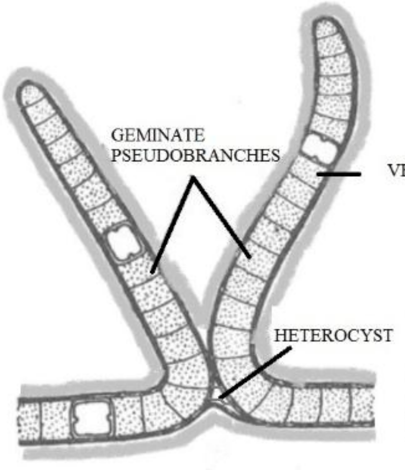
Fig. 2.54. Cyanobacteria. Scytonemataceae. *Scytenema* sp.

***Scytonema*** **(Scyto, Leather; Nema, Thread):**

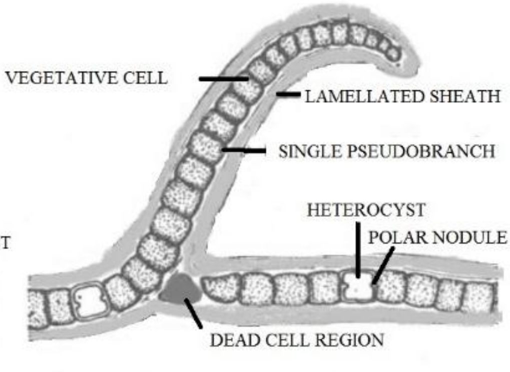
The genus is usually found in subaerial habitats. Some species grow best on damp soil, others on rocky cliffs. The filaments that consist of trichome and sheath possess distinct basal and apical regions forming little erect tufts. The genus contains false type of branching. The branches arise either between two heterocysts or else adjoining one as a result of the degeneration of an intercalary cell.

The intercalary growth results in strong pressure being applied to the sheath, which finally ruptures and the trichome forms a loop outside. Further growth results in the breaking of this loop and twin branches are produced. One or both of these branches may subsequently proceed to additional growth, the branch sheaths extending back into the parent sheath, sometimes the false branching is initiated by degeneration of a heterocyst or a vegetative cell and subsequent growth of two filaments on either side.

The trichomes are usually of the same diameter throughout and with cylindrical cells. The sheaths which surround the trichomes are always firm, hyaline or coloured. The sheaths are homogeneous or lamellated. The heterocysts are intercalary and are borne singly or in twos or threes. The heterocysts are the same size as vegetative cells. Akinetes are rare.



**A filament showing geminate branch**



**A filament showing false banch**

**CLASSIFICATION**

Kingdom: Bacteria
Division: Cyanobacteria
Class: Cyanophyceae
Order: Nostocales
Family: Oscillatoriaceae
Genus: *Spirulina*

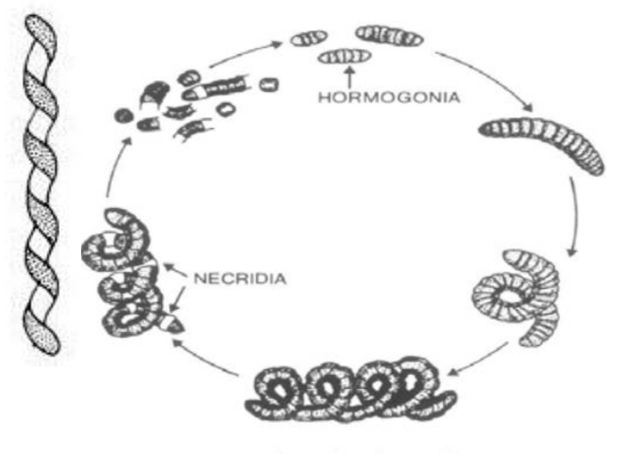


**Fig. 3: Life cycle of *Spirulina*.**

**Occurrence:**

**Introduction:**

Only 8 species of *Spirulina* have been discovered and some well-known species are *Spirulina major*, *S. subsalsa*, *S. subtilisima*, *S. platensis*, *S. princeps*, *S. fenneri*, *S. versicolor*. They are free floating (planktonic) found in fresh water ponds, pools, ditches and may also grow in brackish water rich in salts.

**General characters:**

1. It is filamentous blue green algae. Its trichomes are multicellular and coiled into a more or less regular fashion.
2. The cells of the trichome are cylindrical elongated structure, except the terminal cell which is round in shape. The cells have a typical cyanobacterial structure and it is not surrounded by mucilage sheath.
3. Occasionally cross walls may be found making the multicellular like appearance. Sometimes the cross walls are incomplete.
4. Cell wall is multilayered made up of mucopolymer and pectic compounds.
5. The protoplast of the cell is differentiated into peripheral pigmented chromoplasm, central colorless incipient nucleus or centroplasm. It contains pseudo vacuoles or gas vacuoles (buoyancy).

**Reproduction:**

No sexual reproduction, vegetative reproduction takes place through fragmentation and hormogonia formation.

i. Fragmentation: Due to mechanical injury, the trichome divides into 2 or more small pieces, each developing into a new trichome.
ii. Hormogonia (Hormogones): it is the most common method of reproduction during which hormogones are formed due to the fragmentation of trichomes. The hormogones develop into new trichomes.

# Algae: Definition, Characteristics and Structure

## Introduction to Algae:

The term algae (Latin — seaweeds) was first introduced by Linnaeus in 1753, meaning the Hepaticeae. The algae comprise of a large heterogeneous assemblage of plants which are diverse in habitat, size, organisation, physiology, biochemistry, and reproduction.

It is an important group of Thallophyta (Gr. Thallos — a sprout; phyton — a plant), the primitive and simplest division of the plant kingdom. The orderly systematic study of algae is called Phycology (Gr.phycos — seaweeds; logos — study or discourse).

The algae are chlorophyll-containing primitive plants, both prokaryotic and eukaryotic, with wide range of thalli starting from unicellular to multicellular organizations. Autophytic (which can manufacture their own food)

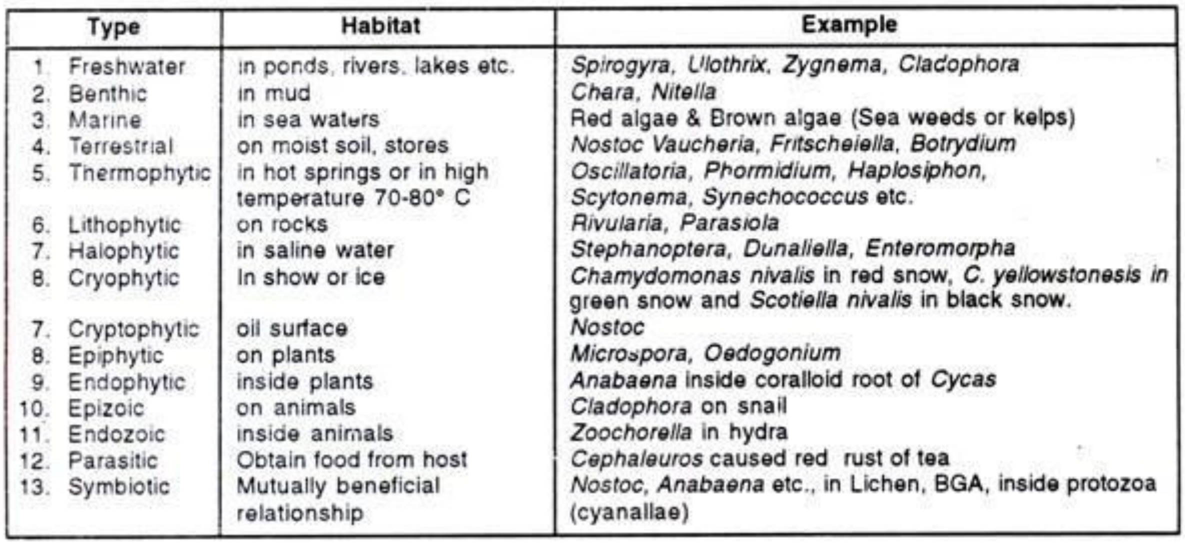
## Characters of Algae

### 1. Occurrence:

They are largely aquatic, either free floating (plankton) or attached (benthos). They occur in other habitats like moist stones, soil, wood etc.

Some of them occur in association with fungi (e.g. lichen) & animals (e.g. on the fur of sloth bear).

**On the basis of habitat, algae are of flowing types:**



| Type | Habitat | Example |
|---|---|---|
| 1. Freshwater | in ponds, rivers, lakes etc. | *Spirogyra, Ulothrix, Zygnema, Cladophora* |
| 2. Benthic | in mud | *Chara, Nitella* |
| 3. Marine | in sea waters | Red algae & Brown algae (Sea weeds or kelps) |
| 4. Terrestrial | on moist soil, stores | *Nostoc Vaucheria, Fritscheiella, Botrydium* |
| 5. Thermophytic | in hot springs or in high temperature 70-80° C | *Oscillatoria, Phormidium, Haplosiphon, Scytonema, Synechococcus* etc. |
| 6. Lithophytic | on rocks | *Rivularia, Parasiola* |
| 7. Halophytic | in saline water | *Stephanoptera, Dunaliella, Enteromorpha* |
| 8. Cryophytic | In show or ice | *Chamydomonas nivalis* in red snow, *C. yellowstonesis in* green snow and *Scotiella nivalis* in black snow. |
| 7. Cryptophytic | oil surface | *Nostoc* |
| 8. Epiphytic | on plants | *Microspora, Oedogonium* |
| 9. Endophytic | inside plants | *Anabaena* inside coralloid root of *Cycas* |
| 10. Epizoic | on animals | *Cladophora* on snail |
| 11. Endozoic | inside animals | *Zoochorella* in hydra |
| 12. Parasitic | Obtain food from host | *Cephaleuros* caused red rust of tea |
| 13. Symbiotic | Mutually beneficial relationship | *Nostoc, Anabaena* etc., in Lichen, BGA, inside protozoa (cyanallae) |

### 2. Thallus organization:

The algal plant body is a thallus i.e. not differentiated into root, stem & leaves. They vary in form & size. The size ranges from the microscopic unicellular forms, like *Chlamydomonas*, to multi-cellular forms like *Volvox* colony, *Spirogyra* filament. A few brown algae form massive plant bodies (40-60 mt) called kelps or seaweeds. In filamentous & sheet like forms, thallus has 3 parts: holdfast (root-like), stipe (stem-like) and lamina or blade (leaf-like).

### 3. Mucilage:

The whole algae body is covered by mucilage which protects from desiccation & epiphytic growth.

### 4. Mechanical Tissue:

Algal lack mechanical tissue as buoyancy holds them erect & their flexibility resist the tides without being torn.

### 5. Vascular Tissue:

As they live in aquatic medium, no vascular tissues required for water conduction. In some large brown algae (Kelps) trumpet hyphae (food conducting tubes) similar to sieve tubes of phloem found that carry food from lamina to the hold fast.

### 6. Algal plastids:

In algae, plastids are without grana & called as rhodoplasts in red algae, phaeoplasts in brown algae & chloroplasts in green algae.

**7. Algal pigments:**

In algae three classes of photosynthetic pigments found i.e. chlorophylls (5 types), carotenoids (6 types of Carotenes & 20 types of Xanthophylls) & phycobilins (3 types). Chlorophyll-a and β-carotene in all the algal groups.

**8. Food reserves:**

Food reserves vary from group to group, e.g., starch (green algae), laminarin (brown algae), Floridean starch (red algae), Cyanophycin (BGA), paramylon (in Euglenoids) etc.

**9. Vegetative reproduction:**

It occurs through fragmentation, fission (e.g. diatoms, desmids), tubers (e.g. *Chara*), hormogonia (e.g. *Nostoc*) etc.

**10. Asexual reproduction:**

It occurs by zoospores, aplanospores, hypnospores, autospores, tetraspores, carpospores, exospores, endospores, akinetes etc.

**11. Sexual Reproduction:**

It is the most advanced form of reproduction which involves the fusion of two specialized haploid cells called gametes to form a diploid zygote or zygospore (2n). Meiosis takes place during germination of zygote and the developing new plant is a haploid gametophyte.

The haploid gametes are produced in a sac-like structure called gametangia. The flagellated gametes, as produced by most algae, are called planogametes & their fusion is called planogamy. Some algae (*Spirogyra*, diatoms etc.) produced non-flagellate gametes called aplanogametes & their fusion process in called aplanogamy or conjugation.

In algae, sexual reproductions occur during or end of the growing season. When the same algal thallus produces two types of fusing gametes then it is called monoecious or homothallic. But in dioecious or heterothallic species fusing gametes produced by separate thalli.

**Based on the size and movement of gametes, following types of sexual reproduction is recognized in algae:**

**(a) Isogamy:**

It involves the fusion of gametes which are morphologically similar but physiologically distinct. Such gametes are called isogametes and produced in vegetative cells called gametangia. Isogametes may be planogametes (e.g. *Ulothrix*, *Chlamydomonas*) or aplanogametes (e.g. *Spirogyra*).

**(b) Anisogamy:**

It involves the fusion of anisogametes i.e. morphologically & physiologically distinct gametes. The smaller male gamete is more active than the larger female gamete, e.g., *Chlamydomonas braunii*, *Aphanochaete*, *Phyllobium dimorphum*, *Enteromorpha intestinalis* etc. *Pandorina* shows incipient anisogamy where fusion takes place between a small and a large gamete.

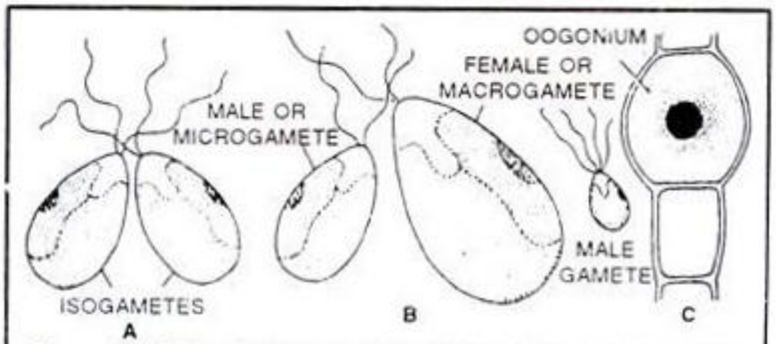


Figure 5.1 Different types or sexual reproduction A, isogamy, B. Anisogamy and C. Oogamy.

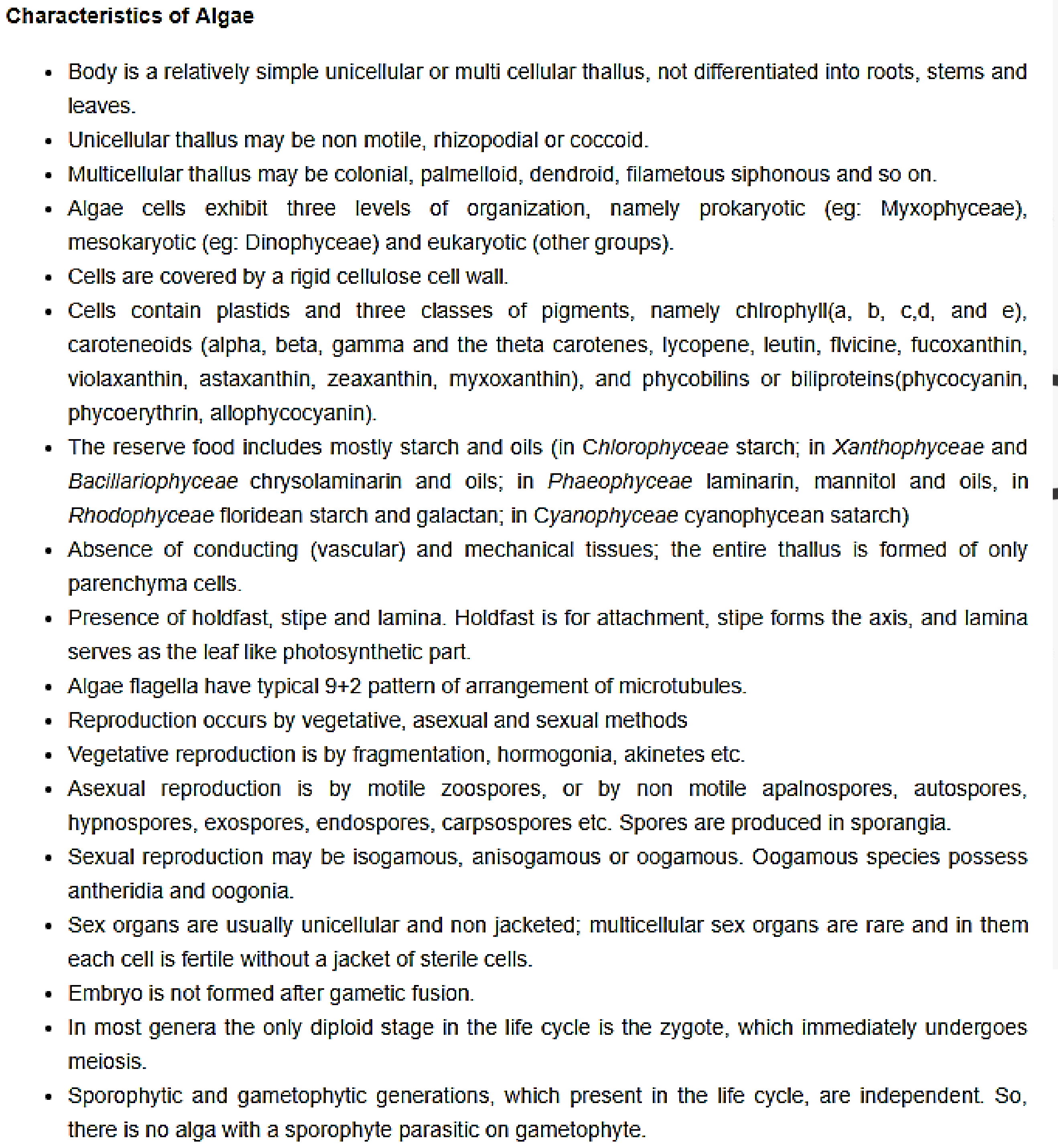
**(c) Oogamy:**

It is the highest evolved type of sexual reproduction. Oogamy involves the fusion between a smaller motile male gamete and a larger non-motile female gamete. The antheridum (male sex organ) produces motile male gametes called antherozoid or spermatozoid while oogonium (female sex organ) produces non motile female gamete called egg or oospheree. Eg. *Oedogonium*,*Vaucheria*, *Chlamydomonas coccifera* etc.

**12. Life cycle:**

Among the sexually reproducing algae, at least 5 main types of life cycle can be seen. These are—haplontic, diplontic, haplo-haplontic (diphasic haplontic), haplo-haplo-haplontic (triphasic haplontic) and diplodiplontic (triphasic diplontic).

**OR**



**Characteristics of Algae**

- Body is a relatively simple unicellular or multi cellular thallus, not differentiated into roots, stems and leaves.
- Unicellular thallus may be non motile, rhizopodial or coccoid.
- Multicellular thallus may be colonial, palmelloid, dendroid, filametous siphonous and so on.
- Algae cells exhibit three levels of organization, namely prokaryotic (eg: Myxophyceae), mesokaryotic (eg: Dinophyceae) and eukaryotic (other groups).
- Cells are covered by a rigid cellulose cell wall.
- Cells contain plastids and three classes of pigments, namely chlrophyll(a, b, c,d, and e), caroteneoids (alpha, beta, gamma and the theta carotenes, lycopene, leutin, flvicine, fucoxanthin, violaxanthin, astaxanthin, zeaxanthin, myxoxanthin), and phycobilins or biliproteins(phycocyanin, phycoerythrin, allophycocyanin).
- The reserve food includes mostly starch and oils (in *Chlorophyceae* starch; in *Xanthophyceae* and *Bacillariophyceae* chrysolaminarin and oils; in *Phaeophyceae* laminarin, mannitol and oils, in *Rhodophyceae* floridean starch and galactan; in *Cyanophyceae* cyanophycean satarch)
- Absence of conducting (vascular) and mechanical tissues; the entire thallus is formed of only parenchyma cells.
- Presence of holdfast, stipe and lamina. Holdfast is for attachment, stipe forms the axis, and lamina serves as the leaf like photosynthetic part.
- Algae flagella have typical 9+2 pattern of arrangement of microtubules.
- Reproduction occurs by vegetative, asexual and sexual methods
- Vegetative reproduction is by fragmentation, hormogonia, akinetes etc.
- Asexual reproduction is by motile zoospores, or by non motile apalnospores, autospores, hypnospores, exospores, endospores, carpsospores etc. Spores are produced in sporangia.
- Sexual reproduction may be isogamous, anisogamous or oogamous. Oogamous species possess antheridia and oogonia.
- Sex organs are usually unicellular and non jacketed; multicellular sex organs are rare and in them each cell is fertile without a jacket of sterile cells.
- Embryo is not formed after gametic fusion.
- In most genera the only diploid stage in the life cycle is the zygote, which immediately undergoes meiosis.
- Sporophytic and gametophytic generations, which present in the life cycle, are independent. So, there is no alga with a sporophyte parasitic on gametophyte.

# OUTLINES OF CLASSIFICATION (FRITSCH- 1945)

Algae possess diverse characters in their pigments, nature of reserve food, nature of cilia etc. According to these morphological and physiological differences they are classified by many people. Fritsch (1935,1945) classified the whole of the algae into eleven classes on the basis of type of pigments, nature of reserve food material, number and point of insertion of flagella of motile cells, presence or absence of organized nucleus in the cell, mode of reproduction etc. They are Chlorophyceae, Xanthophyceae, Chrysophyceae, Bacillariophyceae, Cryptophyceae, Dinophyceae, Chloromonadineae, Euglenophyceae, Phaeophyceae, Rhodophyceae and Myxophyceae (Cyanophyceae). The classification is published in his book titled “The Structure and Reproduction of Algae”.

**1. Class: Chlorophyceae (Grass Green Algae)**

- Occurrence: Most forms are fresh water and a few are marine.
- Pigments: Chief pigments are chlorophyll a and b and carotenoids (yellow pigments)
- Reserve food: Starch
- Structure: Unicellular motile to heterotrichous filaments. Cell wall consists of Cellulose. Pyrenoids are commonly surrounded by starch sheath. Motile cells have equal flagella.
- Reproduction: Sexual reproduction ranges from isogamous to advanced oogamous type.
- Example: *Chlamydomonas, Volvox, Chlorella, oedogonium, spirogyra, Hydrodictyon etc.,*

**2. Class: Xanthophyceae (Yellow green algae)**

- Occurrence: Most forms are fresh water but a few are marine.
- Pigments: Yellow xanthophyll is found abundantly.
- Reserve food: oil
- Structure: Unicellular motile to simple filamentous. Cell wall rich in pectic compounds and composed of two equal pieces overlapping at their edges. Motile cells have two very unequal flagella. Pyrenoids absent.
- Reproduction: Sexual reproduction is rare and always isogamous.
- Example: *Botrydium, Vaucheria, Heterochloris, Chloroglea, Chlorothecium* etc.,

**3. Class: Chrysophyceae (Golden Brown Algae)**

- Occurrence: Most forms occur in cold fresh water but a few are marine.
- Pigments: Chromatophores are brown or orange colored. Phycochrysin serves as chief accessory pigments.
- Reserve food: Fat and leucosin.
- Structure: Plants are unicellular motile to branched filamentous. Flagella are unequal attached at front end. Cells commonly contain one or two parietal chrmoatophores.
- Reproduction: Sexual reproduction seldom occurs but is of isogamous type.
- Example: *Chromulina, Coccolithus, Monas, Chrysocapsa, Chrysosphaera* etc.,

**4. Class: Bacillariophyceae (Diatoms-yellow or golden brown Algae)**

- Occurrence: In all kind of fresh water, sea, soil and terrestrial habitats.
- Pigments: Chromatophores are yellow or golden brown. Nature of accessory pigments is not very definite.
- Reserve food: Fat and volutin.
- Structure: All the members are unicellular or colonial. Cell wall is partly composed of silica and partly of pectic substances. It consists of two halves and each has two or more pieces. Cell wall is richly ornamental.
- Reproduction: Forms are diploid. Sexual reproduction is special type, occurs by fusion of protoplasts of the ordinary individuals.
- Example: *Pinnularia, Cyclotella, Isthmia, Eunotia, Navicula* etc.,

**5. Class: Cryptophyceae (Cyclomonads-nearly Brown)**

- Occurrence: Both in marine and fresh water
- Pigments: Chromatophores show diverse pigmentation. It may be some shades of brown. Chromatophores are usually parietal.
- Reserve food: Solid carbohydrates or in some cases starch.
- Structure: Represented by motile cells and most advanced forms are coccoid, flagella are slightly unequal.
- Reproduction: Isogamous in the reported cases.
- Example: *Cryptomonas, Chroomonas, Hillea, sennia, Phaeoplax, Tetragonidium* etc.,

**6. Class: Dinophyceae (Fire Algae)**

- Occurrence: Plants occur widely as sea water planktons. A few may be fresh water forms.
- Pigments: Starch and oil.
- Reserve food: Chromaophores are dark yellow, brown , etc., and contain a number of special pigments.
- Structure: plants are unicellular motile to branched filamentous.
- Reproduction: Sexual reproduction is of isogamous type. it is rare and not very definite.
- Example: *Dinoflagellate , Ceratium, Desmocapsa, Amphilothus, Protoceratium* etc.,

**7. Class: Chloromonadineae (Bright Green Algae)**

- Occurrence: All plants are fresh water forms.
- Pigments: Chromatophores are bright green in colour and contain an excess of xanthophyll.
- Reserve food: Oil.
- Structure: The plants are motile, flagellate with two almost equal flagella.
- Example: *Chattonella, Fibrocapsa, Trentonia, Vacuolaria* etc.,

**8. Class: Euglenineae (Pure Green Algae)**

- Occurrence: Only fresh water forms are known.
- Pigments: Chromatophores are pure green. Each cell has several chromatophores.
- Reserve food: Polysaccharide and Paramylon.
- Structure: Motile flagellates, flagella may be one or two arising from the base of canal like invagination at the front end. Complex vacuolar system and a large and prominent nucleus.
- Reproduction: Sexual reproduction is not substantially known.It is isogamous type.
- Example: *Euglena, Klebsiella, Astasia, Peranema* etc.,

**9. Class: Phaeophyceae (Brown algae)**

- Occurrence: Mostly marine.
- Pigments: chl a, c, carotenes, xanthophylls, not chl b.
- Reserve food: Mannitol as well as laminarin and fats.
- Structure: The plants may be simple filamentous to bulky parenchymatous forms. Several plants attain giant size, external and internal differentiation.
- Reproduction: Sexual reproduction ranges isogamous to oogamous. Motile gametes have two laterally attached flagella. Varied types of alternation of generation.
- Example: *Ectocarpus, Sargassum, Dictyota, Laminaria, Fucus* etc.,

**10. Class: Rhodophyceae (Red algae)**

- Occurrence: Few forms are fresh water and others are marine.
- Pigments: Chromatophores are res blue containing pigments like red phycoerythrin and blue phycocyanin, Chla,d, carotenes.
- Reserve food: Floridean starch.
- Structure: Simple filamentous to attaining considerable complexity of structure. Motile structures are not known.

- Reproduction: Sexual reproduction is advanced oogamous type. The male organ produces non motile gametes and the female organ has a long receptive neck. After sexual reproduction special spores (carpospores) are produced.
- Example: *Batrachospermum*, *Polysiphonia*, *Porphyra*, *Gelidium*, *Gracillaria* etc.,

### 11. Class: Myxophyceae (Cyanophyceae or Blue green algae)

- Occurrence: Found in sea and fresh water.
- Pigments: Chlorophyll, carotenes, xanthophylls, and phycocyain and phycoerythrin. The ratio of last two pigments exhibits colour variation, commonly blue green.
- Reserve food: Sugars and Glycogen
- Structure: Simple type of cell to filamentous, some of the filamentous forms show false or true branching, very rudimentary nucleus, no proper chromatophores, the photosynthetic pigments being diffused throughout the peripheral position. No motile stages.
- Reproduction: There is no sexual reproduction.
- Example: *Oscillatoria*, *Nostoc*, *Scytonema*, *Rivularia*, *Chroococcus* etc.,

### 12. Class: Nematophyceae.

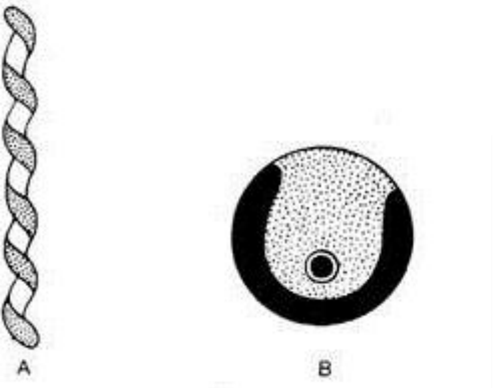
- A fossil group with two genera. Whose true affinities are still doubtful; internal morphology akin to higher Chlorophyceae, while spore tetrads akin to Rhodophyceae.

# RANGE OF THALLUS STRUCTURE IN ALGAE

Algae are chlorophyll bearing autotrophic thallophytes, bounded by a cell wall. Algae represent the most diverse kingdom in form and structure with both prokaryotic and eukaryotic members.

Following is the summary chart showing the diversity in algal thallus organization.

Algal thallus organization can be broadly classified into Unicellular and multicellular thallus.



: Unicellular non-motile algae. A. *Spirulina*, and B. *Chlorella*

**1. Unicellular**

**a) Non motile unicellular:** A single non motile cell carrying out all essential functions of life. Flagella is absent. Example – *Chlorella, Synechococcus.*

**b) Motile unicellular:** A single cell with flagella for locomotion. This group varies greatly in size and shape. The unicellular forms may be spherical, oblong, pear - shaped or sometimes elongated bearing flagella. Example – *Chlamydomonas.*

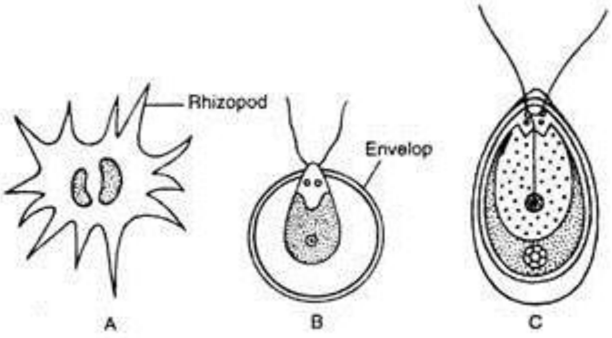


Fig. 3.1 : Unicellular motile algae : A. *Chrysamoeba*, B. *Phacotus*, and C. *Chlamydomonas*

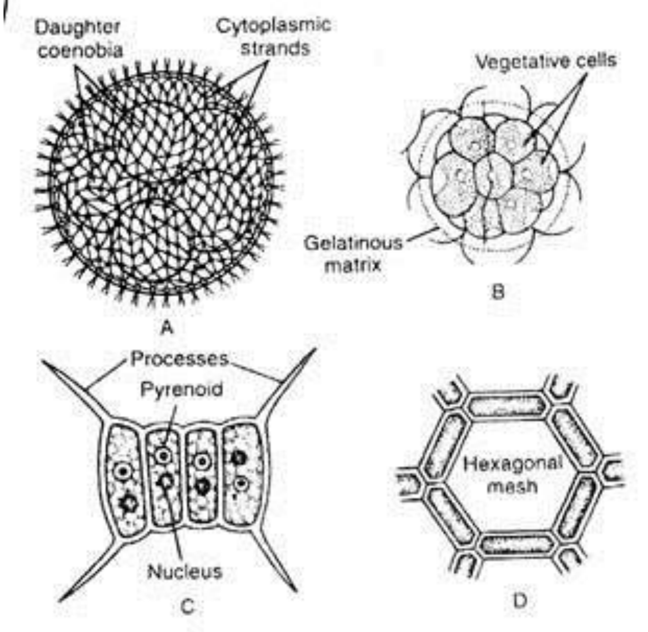


Fig. 3.3 : Colonial algae : A. *Volvox*, B. *Pandorina*, C. *Scenedesmus*, and D. *Hydrodictyon*

**2. Multicellular:** Colony is formed by aggregation of individual cells.

**a) Non motile colony:** Individual cells in the colony lacks flagella. often a coenobium. Coenobium: A colony with definite number of cells and having a constant shape and size. Example – *Pediastrum, Scenedesmus.*

**b) Motile colony:** Individual cells in the colony possess flagella for locomotion. Often a coenobium *Volvox* (50050000 cells) are interconnected with each other with division of labour. Example – *Volvox, Gonium.*

**c) Palmelloid or amorphous colony:** Here numerous non motile cells are embedded in a common mucilaginous matrix Number, size or shape of cell is not constant unlike coenobium. All cells are independent and fulfils all function of an individual. Example – *Tetraspora, Chlorosaccus, Palmella.*

**d) Dendroid forms:** treelike The plant body appears as 'tree like' under microscope. Mucilage often seen at the base. Example – *Ecballocyctis, Dinobryon, Chrysodendron.*

**e) Filamentous:** Cells arranged one upon the other in a definite sequence or uniseriate row forming filament. Filaments may be branched or unbranched.

**e 1. Unbranched filaments:** Cells arranged one above the other without any branching points. Example – *Spirogyra, Zygnema* (free floating), *Nostoc, Anabaena, Spirulina, Ulothrix, Oedogonium* (attached to the substratum by a basal specialized cell).

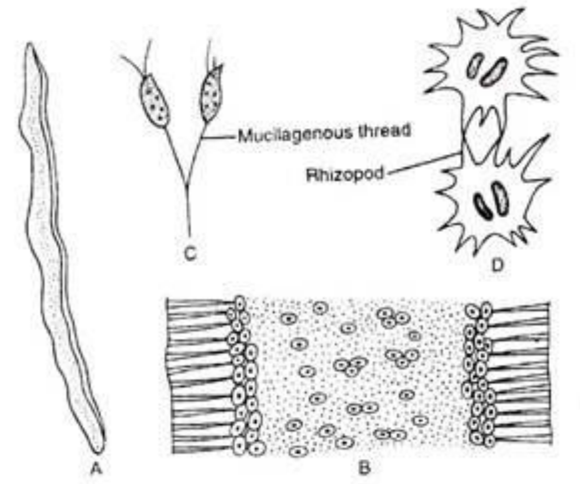


Fig. 3.4 : Aggregated form : A. *Tetraspora*, B. *Tetraspora*, (portion of a colony in T.S.), C. *Chrysodendron* and D. *Chrysidiastrum*

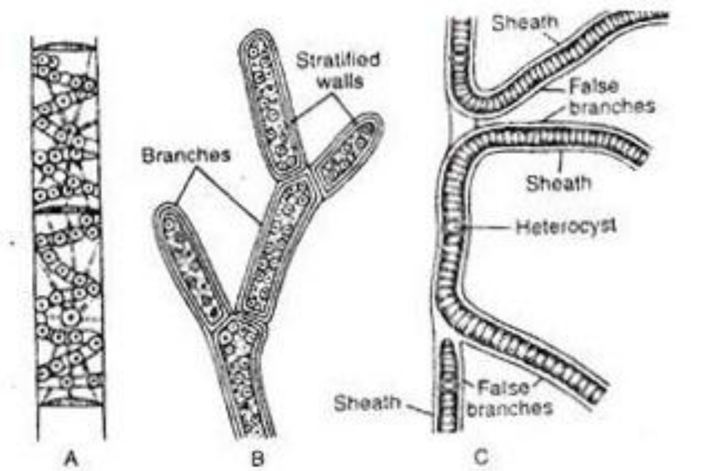


Fig. 3.5 : Filamentous type : A. *Spirogyra*, B. *Cladophora* and C. *Scytonema*

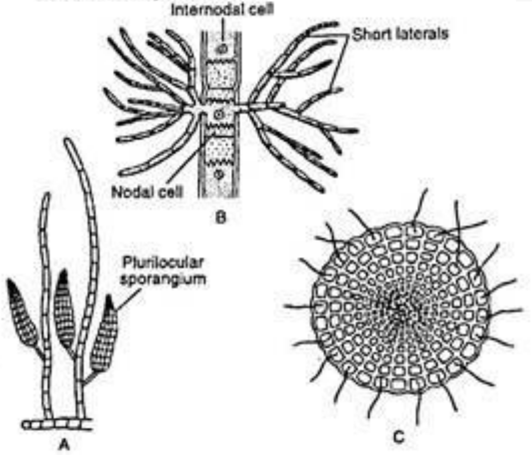


Fig. 3.6 : Branched filament showing heterotrichous habit : A. *Ectocarpus*, B. *Draparnaldiopsis*, and C. *Coleochaete*

**e 2. Branched filaments:** Filaments with branching often dichotomous branching. Example– *Cladophora, Pithophora, Bulbochaete.*

**e 3. Pseudobranched:** Appear like branched under microscope. Actually, branching is due to the close association of unbranched individual filaments. Example –*Scytonema.*

**f) Heterotrichous form (hetero: different, trichous: trichome or filament):** Presence of more than one type of filament. Plant body consists of a prostrate system from which an erect system develops (also called as primary projecting system). Branches may give rise to primary projecting system, secondary projecting system sometimes even tertiary projecting system. Example – Chlorophyceae: *Drapanaldia, Stigeoclonium, Draparnaldiopsis, Fritschiella Phaeophyceae, Ectocarpus.*

**g) Siphonous forms:** Elongated plant body without septation. Many nuclei present in a common protoplasm called as coenocytic condition Multicellular plants lacking usual septation (Fritsch,1935) Example *Vaucheria, Botrydium, Codium, Bryopsis.*

**h) Pseudoparenchymatous**

Two types: Uniaxial and multiaxial forms

**a) Uniaxial** "Close juxtaposition of the branch systems of a single main axial thread which form the thallus "(Fritsch,1935) Plant body consist of a one main pseudoparenchymatous axis and all others are side branches Example: *Batrachospermum, Dumontia.*

**b) Multiaxial forms:** Main axis made up of association of many pseudoparenchymatous threads, appearing as more than one axes. Example: *Polysiphonia, Chondrus.*

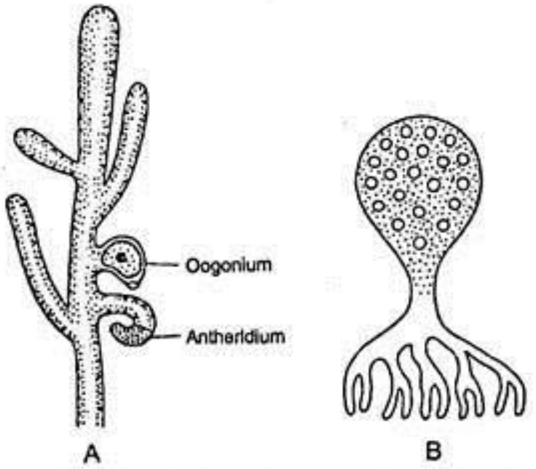


Fig. 3.8 : Siphonaceous algae : A. *Vaucheria*, and B. *Botrydium*

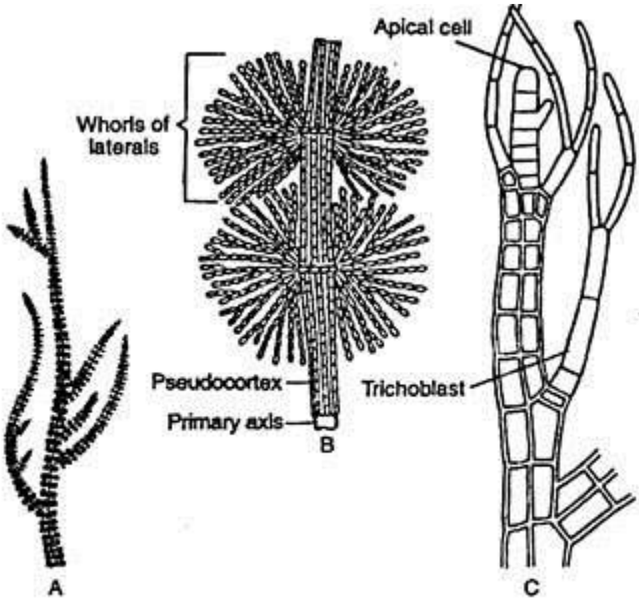


Fig. 3.7 : Pseudoparenchymatous habit : A. *Batrachospermum*, B. *Batrachospermum* (portion of the plant body), and C. *Polysiphonia*

**i) Parenchymatous forms:** In some algae, cell division and associated septation in all planes lead to the formation of a parenchymatous body. Such algae are foliose and flat Example: *Chara*, *Dictyota*, *Laminaris*, *Fucus*, *Macrocysytis* Some algae like *Microcystis* even possess sieve tube like structures similar to higher plants.

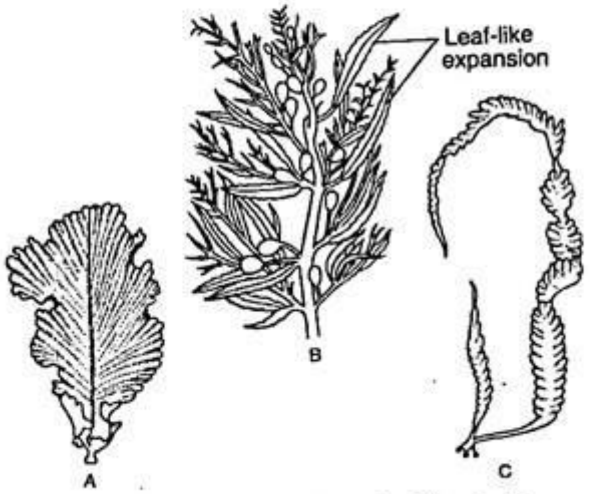
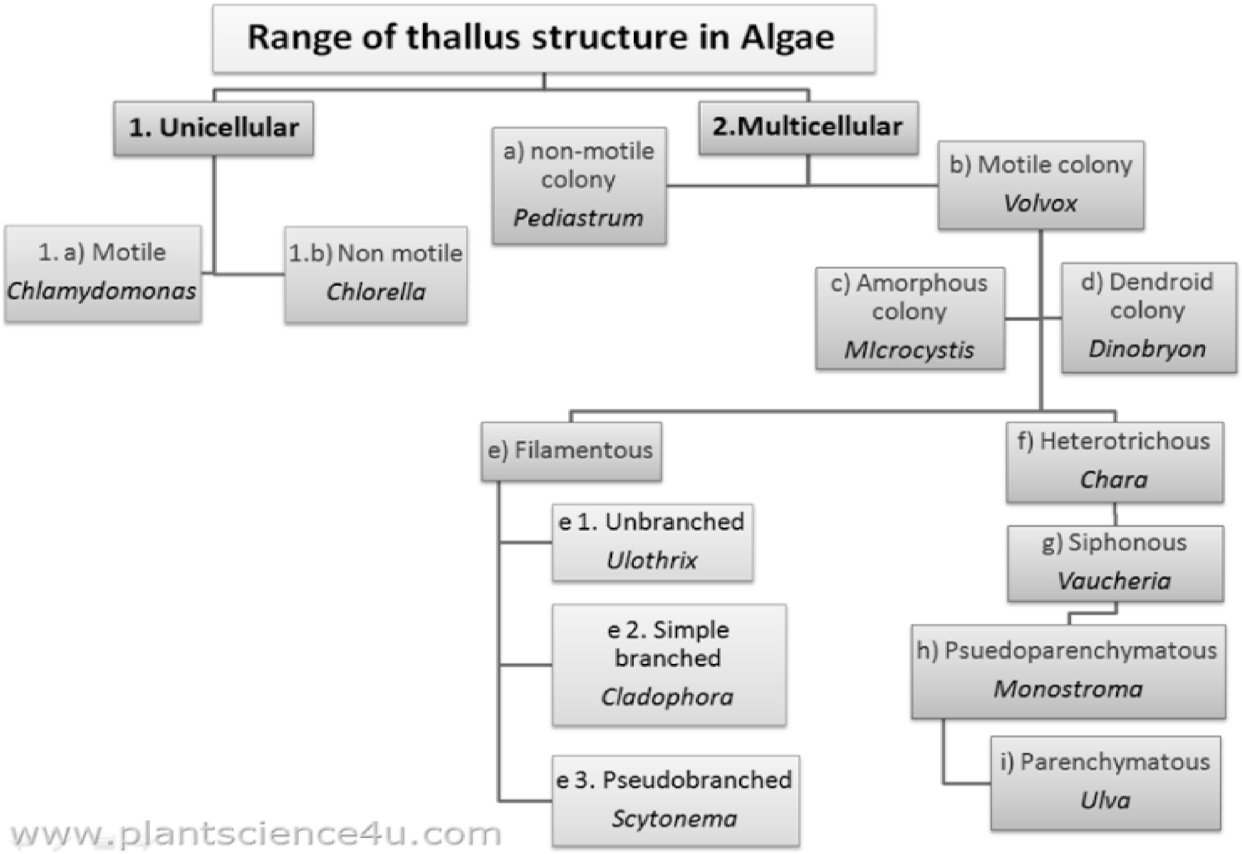
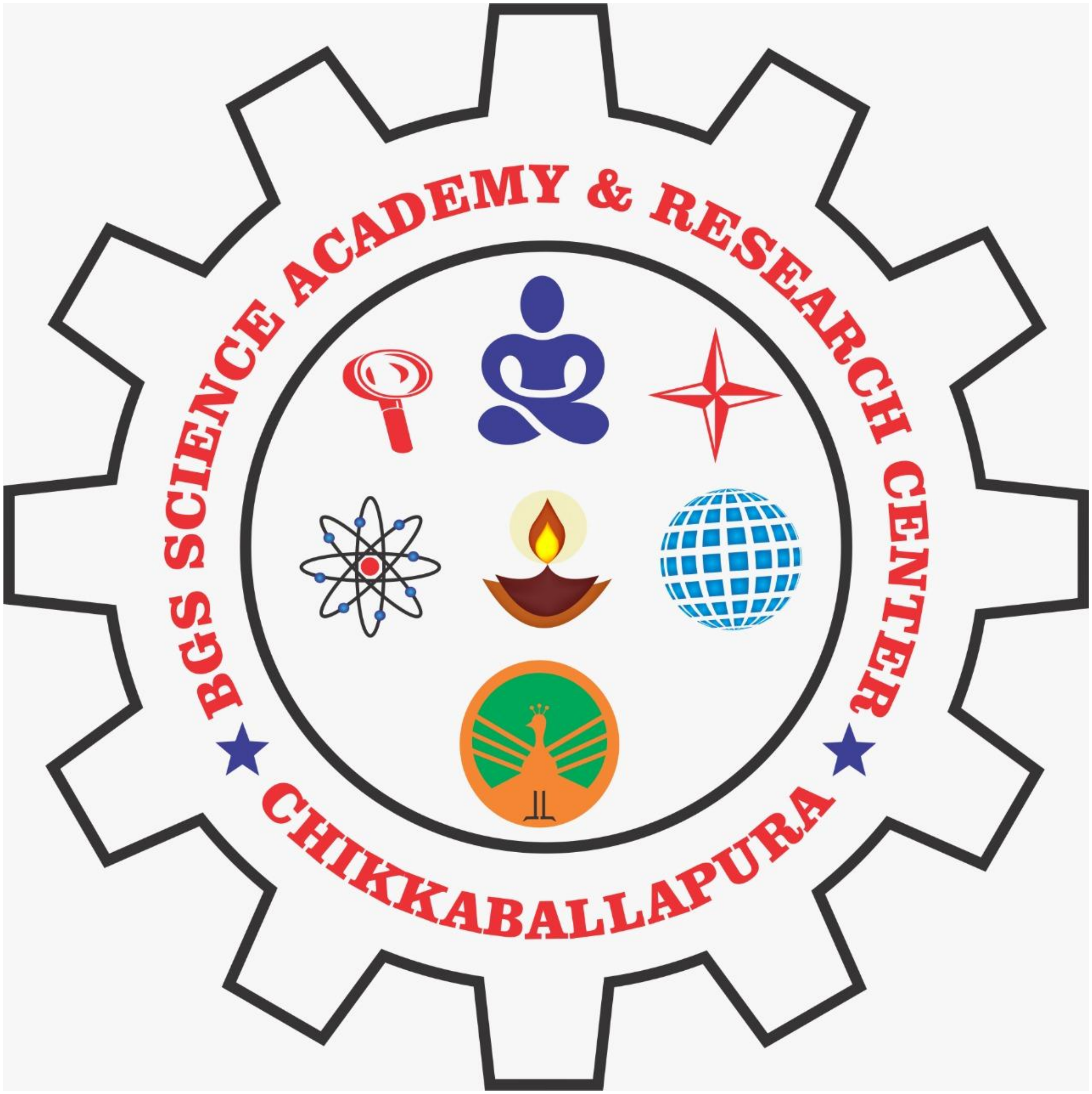


Fig. 3.9 : Parenchymatous algae : A. *Ulva*, B. *Sargassum*, and C. *Laminaria*

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CHIKKABALLAPURA

# PIGMENTATION IN ALGAE

Algae show great diversity in pigmentation. Green, red, yellow & blue are found in marine and freshwater algae. Different groups of algae have different and specific pigment composition. Pigments found in specialized plastids called chromophores. Distribution pattern of pigments has great taxonomic significance. Classification proposed by Fritsch is primarily based on algal pigmentation. All major algal groups have at least one characteristic pigment in their cells.

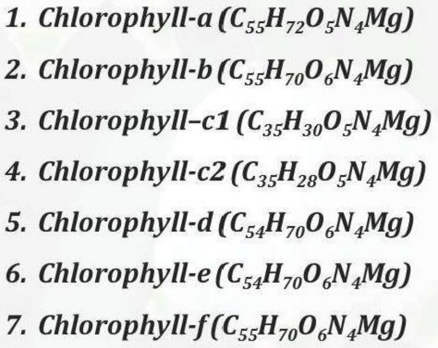
Pigments in algae belong to 3 major categories based on their physical and chemical properties:

1. Chlorophylls 2. Carotenoids 3. Phycobilins

1. **Chlorophylls:**

   Chlorophylls are fat soluble green pigments. They are chlorines which absorb blue region and reflect green light. Chlorophylls are responsible for the green colour of algae and other higher plants.

   Seven different types of chlorophylls are reported in algae. They are:



1. Chlorophyll-a ($C_{55}H_{72}O_5N_4Mg$)
2. Chlorophyll-b ($C_{55}H_{70}O_6N_4Mg$)
3. Chlorophyll–c1 ($C_{35}H_{30}O_5N_4Mg$)
4. Chlorophyll-c2 ($C_{35}H_{28}O_5N_4Mg$)
5. Chlorophyll-d ($C_{54}H_{70}O_6N_4Mg$)
6. Chlorophyll-e ($C_{54}H_{70}O_6N_4Mg$)
7. Chlorophyll-f ($C_{55}H_{70}O_6N_4Mg$)

**Distribution of different chlorophylls in different algal groups**

Chlorophyll-a : Present in all groups of algae.
Chlorophyll-b : Present in Chlorophyta (green algae).
Chlorophyll-c : Present in Bacillariophyceae (diatoms).
Chlorophyll-d : Present in the members of Rhodophyceae (red algae).
Chlorophyll-e : Present in Xanthophyceae.
Chlorophyll-f : Recently discovered chlorophyll from Stromatolites.

2. **Carotenoids:**

   Carotenoids are fat soluble yellow pigments. Found in close association with chlorophylls. They protect chlorophylls from photo damage. Chemically carotenoids are tetraterpenoids. Carotenoids are present in almost all algal groups. Carotenoids with beta ionone ring have vitamin A like activity. All carotenoids are strong antioxidants.

   Two types of carotenoids are found in algae. A. Carotenes B. Xanthophylls.

   A. **Carotenes:**

      Carotenes are yellow coloured pigments. They are unsaturated fat soluble hydrocarbons. They do not contain oxygen. They absorb blue and green light and transmit yellow and red light. Examples: α-carotene, β- carotene and lycopene.

   B. **Xanthophylls:**

      Xanthophylls are also called as carotelos. They are oxygen derivatives of carotenes. Example: lutein and zeaxanthin (both are responsible for the colour of egg yolk).

3. **Phycobilins:**

   Phycobilins are water soluble pigments. Phycobilins are always bonded with some water soluble proteins called Phycobiliproteins. They are blue and red in colour. They are present in Cyanophyceae and Red algae. Phycobilins are usually found in organisms living in deep water for the efficient absorption of light. All phycobilins are strongly fluorescent. They emit orange or red light after fluorescence.

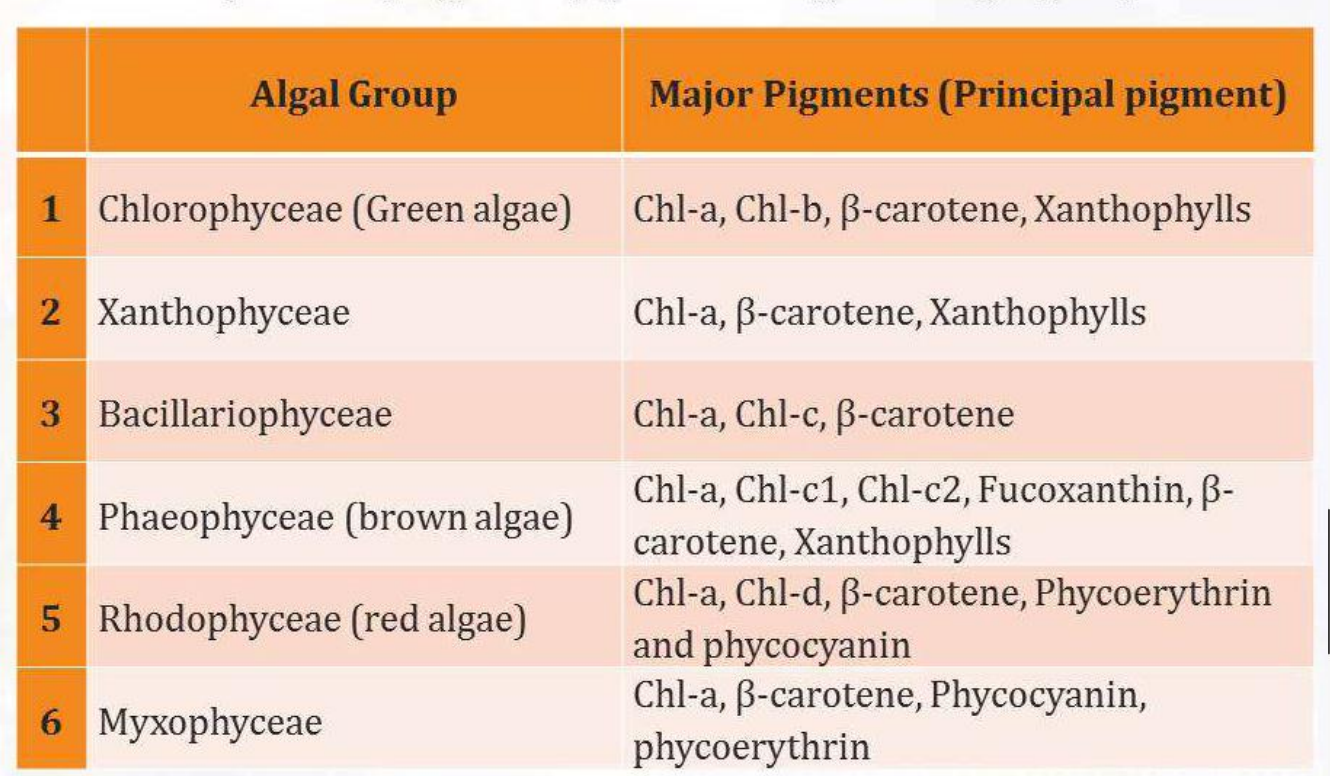
Two classes of phycobilins are present in algae. A. Phycocyanins B. Phycoerythrins.

**A. Phycocyanin:**

Phycocyanin are blue coloured pigments. They absorb green, yellow and red light and transmit blue colour. Phycocyanins are the principal pigment of blue green algae.

**B. Phycoerythrin:**

Phycoerythrin are red coloured pigments. They absorb blue green, green and yellow light and transmit red light. Phycoerythrin present abundantly in members of Rhodophyceae (Red algae).



**Distribution pattern of different pigments in different algal groups**

| | Algal Group | Major Pigments (Principal pigment) |
|---|---|---|
| 1 | Chlorophyceae (Green algae) | Chl-a, Chl-b, β-carotene, Xanthophylls |
| 2 | Xanthophyceae | Chl-a, β-carotene, Xanthophylls |
| 3 | Bacillariophyceae | Chl-a, Chl-c, β-carotene |
| 4 | Phaeophyceae (brown algae) | Chl-a, Chl-c1, Chl-c2, Fucoxanthin, β-carotene, Xanthophylls |
| 5 | Rhodophyceae (red algae) | Chl-a, Chl-d, β-carotene, Phycoerythrin and phycocyanin |
| 6 | Myxophyceae | Chl-a, β-carotene, Phycocyanin, phycoerythrin |

### Pigments

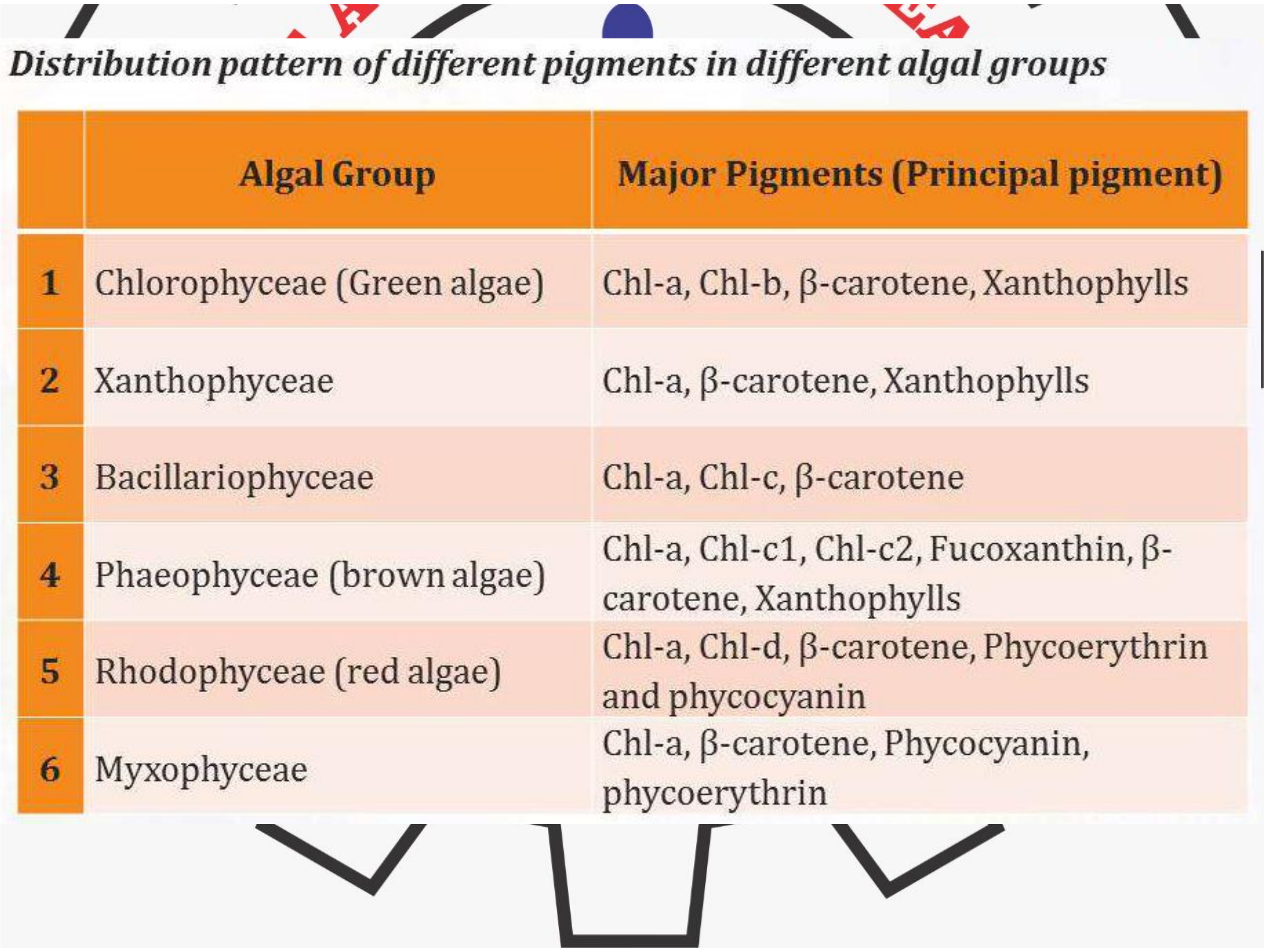
Algae from various phyla show striking differences of colour, which often affords a quick guide to preliminary classification of an alga. As the colour frequently varies with change in environmental conditions, an accurate classification depends on the chemical analyses of photosynthetic pigments. No other group of plants exhibits such remarkable variations and intricate organization of photosynthetic pigments as algae. In algae, there are three kinds of photosynthetic pigments: **Chlorophylls**, **carotenoids** and **phycobilins**, of which chlorophylls and carotenoids are lipid derivatives and fat soluble, whereas phycobilins (biloproteins) are tetraphyrrolic compounds joined to globulin proteins and are water soluble. According to Prescott (1969), in all, there occur five kinds of chlorophylls, twenty kinds of xanthophylls, five kinds of carotenes and seven kinds of phycobilins in algae. Phycobilins may be blue or red. The prefix 'phyco' in phycobili denotes the presence of these pigments in algae only. The classified presence of various kinds of pigments in algae is shown in Table 1.2. Carotenoids impart various colours, such as red, orange, yellow, green, brown etc.

**Chlorophylls:** Chlorophylls extracted from different algae exhibit different spectral properties. On this basis, five different chlorophylls have been recognized. They have been termed chlorophylls *a*, *b*, *c*, *d* and *e*. Chlorophyll *a* is present in all algae. It is the primary photosynthetic pigment directly involved in the Photosystem I (light reaction). It is also found in all photosynthetic organisms except bacteria. Chlorophyll *b*, the other chlorophyll of higher plants, is found in Euglenophyta and Chlorophyta and in no other algal phyla. Chlorophyll *c*, the most widespread of other chlorophylls, occurs largely in algae of native habitats, e.g., members of Bacillariophyceae, Pyrrophyta, Cryptophyta, Phaeophyceae and Chrysophyta. Chlorophyll *d* appears to be present only in Rhodophyta. Chlorophyll *e* has been reported in only two genera, namely, *Tribonema bombycinum* and *Vaucheria hamata* (in zoospores) of Xanthophyceae.

**Carotenoids** Carotenoids are of two kinds: **Carotenes** and **Xanthophylls**. Carotenes are linear (alicyclic), unsaturated (oxygen-free) hydrocarbons (isoprene units), whereas xanthophylls are oxygenated derivatives of carotenes. β-carotene, present in most algae (except cryptophyceae), is replaced by carotene in caulerpales of chlorophyta, in the cryptophyta and to a lesser extent in Rhodophyta. In the charophyta, β-carotene is replaced by two carotenes: lycopene and y-carotene, characteristic of photosynthetic bacteria. C-carotene occurs in chlorophyta. Another carotene, e-carotene, characteristic of Bacillariophyceae, has also been reported in some members of Cryptophyta, Bacillariophyceae, Phaeophyceae and Cyanophyta. Among more than 20 types of different xanthophylls known, many are unique to various algal groups. Thus, they serve important diagnostic features to particular algal phyla, e.g., (i) peridinin is found only in Pyrrophyta, (ii) myxoxanthin, myoxanthophyll, oscilloxanthin and flaracene are found only in Cyanophyta, (iii) taraxanthin in Rhodophyta and (iv) antheraxanthin in Euglenophyta. Many xanthophylls (lutein, violaxanthin and neoxanthin) common in higher plants, are found in chlorophyta. Fucoxanthin is the main xanthophyll pigment of Phaeophyceae and diatoms. Carotenes are the accessory pigments involved in harvesting light in photosynthesis.

**Phycobilins (Bioloproteins).** These water soluble complexes of protein and bile pigments are of two kinds: **phycocyanin** and **phycoerythrin**. They are found (i) in Cyanophyta in which they are of the C-type (phycocyanin) and are blue, and (ii) in Rhodophyta of R-type (phycoerythrin) and are red. In Cyptophyta, they are of the third type. These accessory pigments function for harvesting light in photosynthesis. The light absorbed by them is transferred to chlorophyll *a*.

There occurs variation in the proportion of one kind of pigment to the other, e.g., cells of Chlorophyta and Euglenophyta appear green because of an excess of chlorophylls over carotenoids but yellow-brown colour of groups, such as Bacillariophyceae, Chrysophyta, Pyrophyta, Cryptophyta and Phaeophyceae and the yellow-green colour of Xanthophyceae reflect an excess of carotenoids compared with chlorophylls and the colour of Cyanophyta (blue-green) and Rhodophyta (red) are due to an excess of appropriate phycobilins. Since the proportion of one type of pigment to the other also varies considerably with change in the environmental conditions, it is difficult to justify its use as a taxonomic feature.



***Distribution pattern of different pigments in different algal groups***

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| 6 | Myxophyceae | Chl-a, β-carotene, Phycocyanin, phycoerythrin |

## REPRODUCTION IN ALGAE

In algae, reproduction takes place by all the three means, i.e., the *vegetative*, *asexual* and *sexual*.

### Vegetative Reproduction

This, the most common method of reproduction in algae, involves all those processes of propagation in which without any obvious changes in the protoplast, i.e., without involving rejuvenation of the protoplast, portions of the plant body may separate to give rise to full individuals.

Various methods of vegetative reproduction are:

1. **Fragmentation:** In fragmentation, common in many filamentous algae belonging to Cyanophyta and Chlorophyta (e.g., *Ulothrix*, *Oedogonium*, *Spirogyra*, and *Zygnema*), the parent plant breaks up into small segments (fragments) which are capable to develop into new individuals. The fragmentation may be due to mechanical pressure, dissolution of transverse walls or differences in turgor pressure between adjoining cells of the filament.

2. **Hormogonia:** It is a characteristic method of reproduction in filamentous forms of Cyanophyta. Under unfavourable conditions, the trichome breaks into short motile segments, the hormogonia (e.g., *Nostoc*, *Ocillatoria* and *Cylindrospermum*) due to the formation of intercalary heterocysts, specialized separation discs or due to death and decay of intercalary cells.

3. **Fission, or Cell Division:** In fission (the simplest method of propagation common in unicellular algae), the plant divides by the formation of a deep constriction on the sides of the cell, divides mitotically and forms two daughter cells, each growing independently. e.g., in diatoms, desmids, *Chlamydomonas*, and *Euglena*. Longitudinal fission usually begins at the anterior end and progresses downwards.

4. **Formation of Adventitious Branches:** Some large thalloid forms of algae develop adventitious branches which when detach from the parent thallus, develop into new plants (e.g. *Dictyota*). On the internodes of *Chara* or stolon of *Cladophora glomerata*, adventitious branches like *protonema* are formed.

5. **Tubers:** Due to the storage of food materials, some tuber-like structures are formed on the rhizoids and lower nodes of *Chara*. When detached from the parent plant, they produce independent plants. Similar structures also occur in *Cladophora*.

6. **Budding:** In some algae (e.g., *Protosiphon*) bud-like structures are formed due to the proliferation of vesicles which eventually get separated from the parent plant by the formation of septum. These buds have the capacity to develop into new plants.

7. **Secondary Protonema:** Some thread-like vegetative structures develop in *Chara*, which help in reproduction.

8. **Amylum Stars:** Some special star-shaped starch-filled bodies are reported in *Chara*, which give rise to a new plant.

**9. Bulbils:** Usually, some bud-like structures develop on the rhizoids of *Chara*, which are called bulbils. Each bulbil is capable of developing into a new plant.

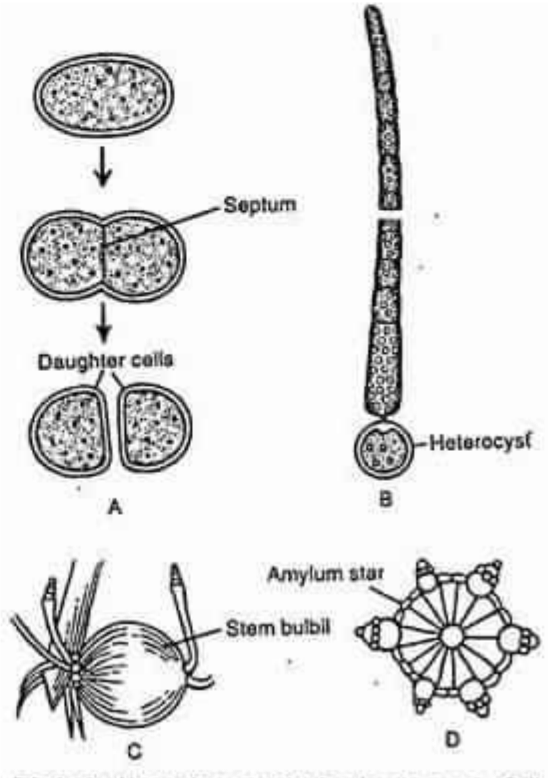


Fig. 3.16 : Vegetative reproduction in algae : A. Cell division (*Synechococcus* sp.) B. Fragmentation of filament (*Cylindrospermum* sp.) C. Stem bulbil (*Chara* sp.) and D. Amylum star (*Chara* sp.)

## Asexual Reproduction

Asexual reproduction involves rejuvenation of the protoplasts. Asexually formed higher specialized reproductive bodies (the spores and other similar structures), are either naked or are provided with a newly formed wall of their own. These are capable of multiplying directly, without fusing with other cells. In general, asexual reproduction is a process by which the protoplast undergoes obvious changes to form various kinds of motile and non-motile spores that are released from the algal cell. These spores germinate without fusing and form new individuals. Asexual reproduction is uniparental and takes place in a variety of ways.

**1. Zoospores:** Most groups (except Cyanophyta and Rhodophyta) produce motile unicells, the **zoospores**. They are commonly found in most of the forms belonging to Chlorophyta (*Chlamydomonas*, *Ulothrix*, *Oedogonium*, *Pediastrium*, *Vaucheria*) and a few of Phaeophyceae (*Ectocarpus*). In *Ectocarpus*, the zoopore bears two laterally placed unequal flagella of which one is whip-lash and the other is tinsel. In *Ulothrix*, the zoopores are quadriflagellated in macrozoopores and biflagellated in microzoopores and in *Oedogonium* and *Vaucheria* they are multiflagellates. Multiflagellated zoospores may again be of two kinds: (1) flagella distributed throughout the entire body and (2) flagella arranged in a ring surrounding a beak-like projection. **Synzoospore** (compound zoospore) is a multinucleate multiflagellated zoospore found in *Vaucheria*. Zoospore is equipped with one or more **flagella** (uni-bi-quadri- or multiflagellate) and commonly contains a chromatophore, a nucleus and an eyespot. **Zoospores** are formed during favourable condition and resemble the adult form except for size. They are formed either in specialized structures, the zoosporangia or directly within the vegetative cell and are liberated by the breaking of the cell wall. After swimming around in water, resting, settling and shedding, the flagella (zoospore) gives rise to an adult plant.

**2. Aplanospores:** Aplanospores are non-flagellated, non-motile and thin-walled spores in semiaquatic algae and some aquatic algae (e.g., *Ulothrix*, *Microspora*). They are formed during unfavourable conditions by the failure of the development of flagella during the formation of zoospores. Each cell may form a single aplanospore or its protoplast divides within a cell and forms many aplanospores.

**3. Hypnospores:** During prolonged period of dessication, aplanospores of some green algae (*pediastrum* and *Sphaerella*) store abundant food reserve, secrete thick walls around them and develop into hypnospores. Under favourable conditions, they germinate and grow into new individuals or their protoplast may form zoospores. In *Chlamydomonas nivales* the walls of hypnospores become red due to the pigments *heamatochrome*, causing to call it red snow. In *Vaucheria*, the hypnospores divide into many small **cysts**.

**4. Akinetes** In some filamentous algae (*Cladophora* and *Pithophora*) the entire protoplast of the vegetative cell stores abundant food reserve, rounds off, grows in size due to deposition of thick cell wall and develops into akinete. Unlike aplanospore, akinetes always acquire additional wall layers around their protoplast which are fused with the parent wall. Akinetes are highly resistant against unfavourable conditions. Among other factors, availability of carbohydrate

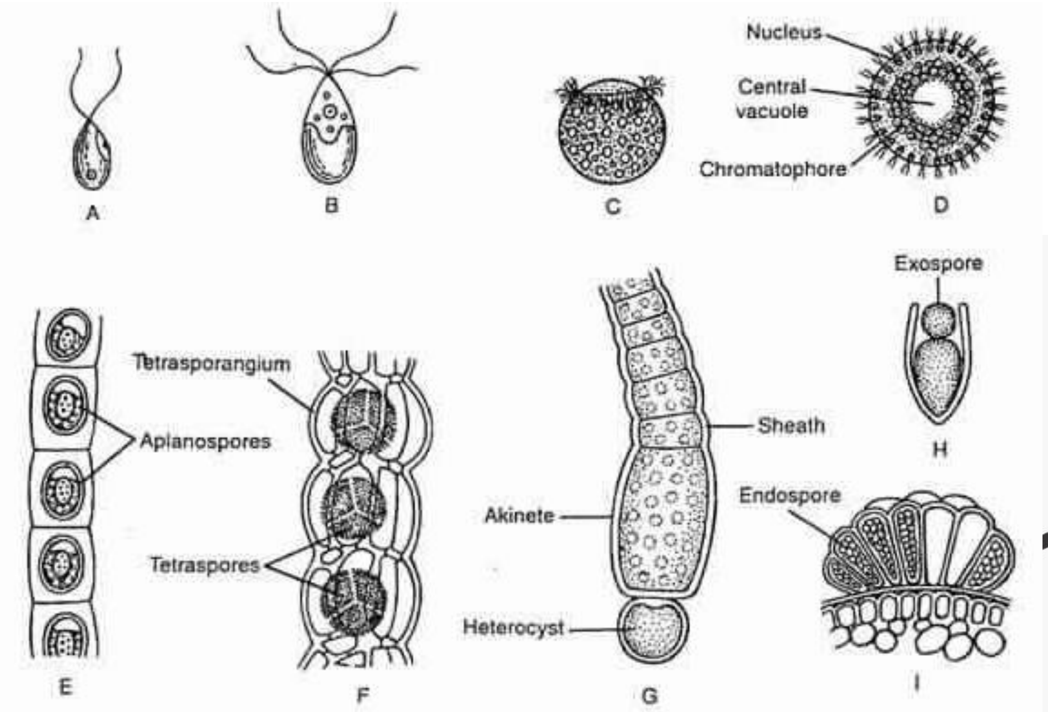


Fig. 3.17 : Asexual spores in algae : A. Biflagellate microzoospore, and B. Quadriflagellate microzoospore of *Ulothrix* sp., C. Multiflagellate zoospore of *Oedogonium* sp., D. Synzoospore of *Vaucheria* sp., E. Aplanospores of *Ulothrix* sp., F. Tetraspores of *Polysiphonia* sp., G. Akinete of *Gloeotrichia* sp., H. Exos-

and light are mainly responsible for their formation. In blue green algae, they are formed next to a heterocyst or at the end of a trichome, rarely they are intercalary in position. On the return of favourable conditions, the akinete develops into a new filament.

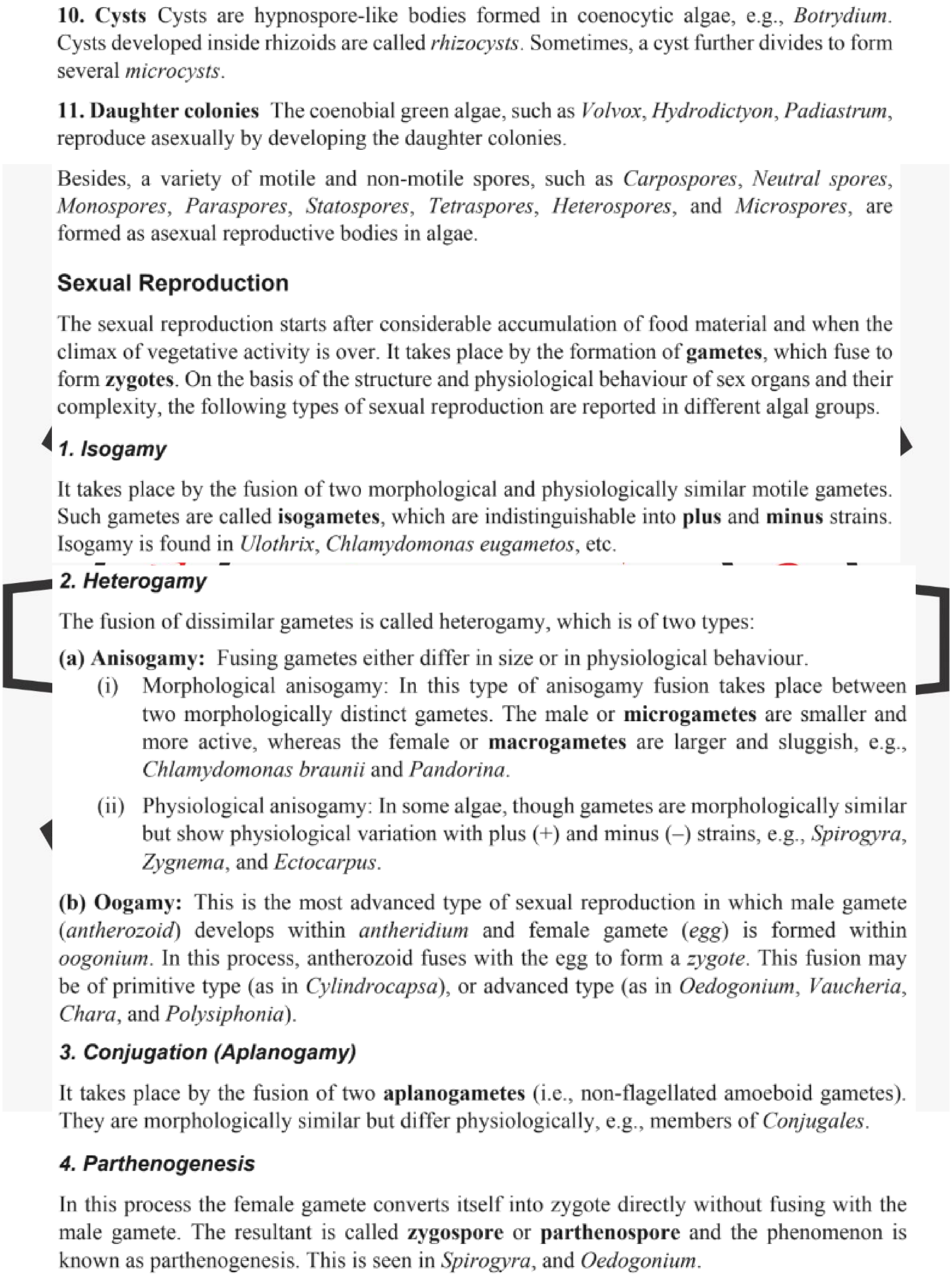
**5. Endospores** In some unicellular blue green algae (e.g., *Dermocarpa pacifica*) the cell becomes somewhat enlarged and its protoplast divides successively in three planes to form four to many more or less spherical, non-flagellate, thin-wall and internally produced endospores which develop into new individuals.

**6. Exospore** In some unicellular blue green algae the cell wall ruptures apically and the protoplast thus exposed (e.g., *Chamaesiphon*) cuts thin-walled non-flagellate spherical spores, the exospores, which on liberation germinates into a new individual.

**7. Nannospores (Nannocytes)** In *Gloeocapsa* and *Microcystis*, due to a very fast rate of cell division, the miniature of parent cells are formed. They remain smaller to vegetative cells and germinate *in situ* to develop a new colony.

**8. Palmella Stage** This phase is attained in comparatively drier conditions. The individuals divide and redivide into innumerable daughter cells and remain embedded in the gelatinous matrix. On return of favourable conditions this matrix dissolves, and the cells develop into new individuals, e.g., *Chlamydomonas*, and *Ulothrix*.

**9. Autospores** Autospores are structurally similar to the parent but smaller in size. They are non-motile spores which develop within a cell by successive divisions of protoplasts followed by wall formation. They are liberated by the dissolution of parental cell wall and give rise to new individuals, e.g., *Chlorella*.



**10. Cysts** Cysts are hypnospore-like bodies formed in coenocytic algae, e.g., *Botrydium*. Cysts developed inside rhizoids are called *rhizocysts*. Sometimes, a cyst further divides to form several *microcysts*.

**11. Daughter colonies** The coenobial green algae, such as *Volvox*, *Hydrodictyon*, *Padiastrum*, reproduce asexually by developing the daughter colonies.

Besides, a variety of motile and non-motile spores, such as *Carpospores*, *Neutral spores*, *Monospores*, *Paraspores*, *Statospores*, *Tetraspores*, *Heterospores*, and *Microspores*, are formed as asexual reproductive bodies in algae.

## Sexual Reproduction

The sexual reproduction starts after considerable accumulation of food material and when the climax of vegetative activity is over. It takes place by the formation of **gametes**, which fuse to form **zygotes**. On the basis of the structure and physiological behaviour of sex organs and their complexity, the following types of sexual reproduction are reported in different algal groups.

### *1. Isogamy*

It takes place by the fusion of two morphological and physiologically similar motile gametes. Such gametes are called **isogametes**, which are indistinguishable into **plus** and **minus** strains. Isogamy is found in *Ulothrix*, *Chlamydomonas eugametos*, etc.

### *2. Heterogamy*

The fusion of dissimilar gametes is called heterogamy, which is of two types:

**(a) Anisogamy:** Fusing gametes either differ in size or in physiological behaviour.

(i) Morphological anisogamy: In this type of anisogamy fusion takes place between two morphologically distinct gametes. The male or **microgametes** are smaller and more active, whereas the female or **macrogametes** are larger and sluggish, e.g., *Chlamydomonas braunii* and *Pandorina*.

(ii) Physiological anisogamy: In some algae, though gametes are morphologically similar but show physiological variation with plus (+) and minus (–) strains, e.g., *Spirogyra*, *Zygnema*, and *Ectocarpus*.

**(b) Oogamy:** This is the most advanced type of sexual reproduction in which male gamete (*antherozoid*) develops within *antheridium* and female gamete (*egg*) is formed within *oogonium*. In this process, antherozoid fuses with the egg to form a *zygote*. This fusion may be of primitive type (as in *Cylindrocapsa*), or advanced type (as in *Oedogonium*, *Vaucheria*, *Chara*, and *Polysiphonia*).

### *3. Conjugation (Aplanogamy)*

It takes place by the fusion of two **aplanogametes** (i.e., non-flagellated amoeboid gametes). They are morphologically similar but differ physiologically, e.g., members of *Conjugales*.

### *4. Parthenogenesis*

In this process the female gamete converts itself into zygote directly without fusing with the male gamete. The resultant is called **zygospore** or **parthenospore** and the phenomenon is known as parthenogenesis. This is seen in *Spirogyra*, and *Oedogonium*.

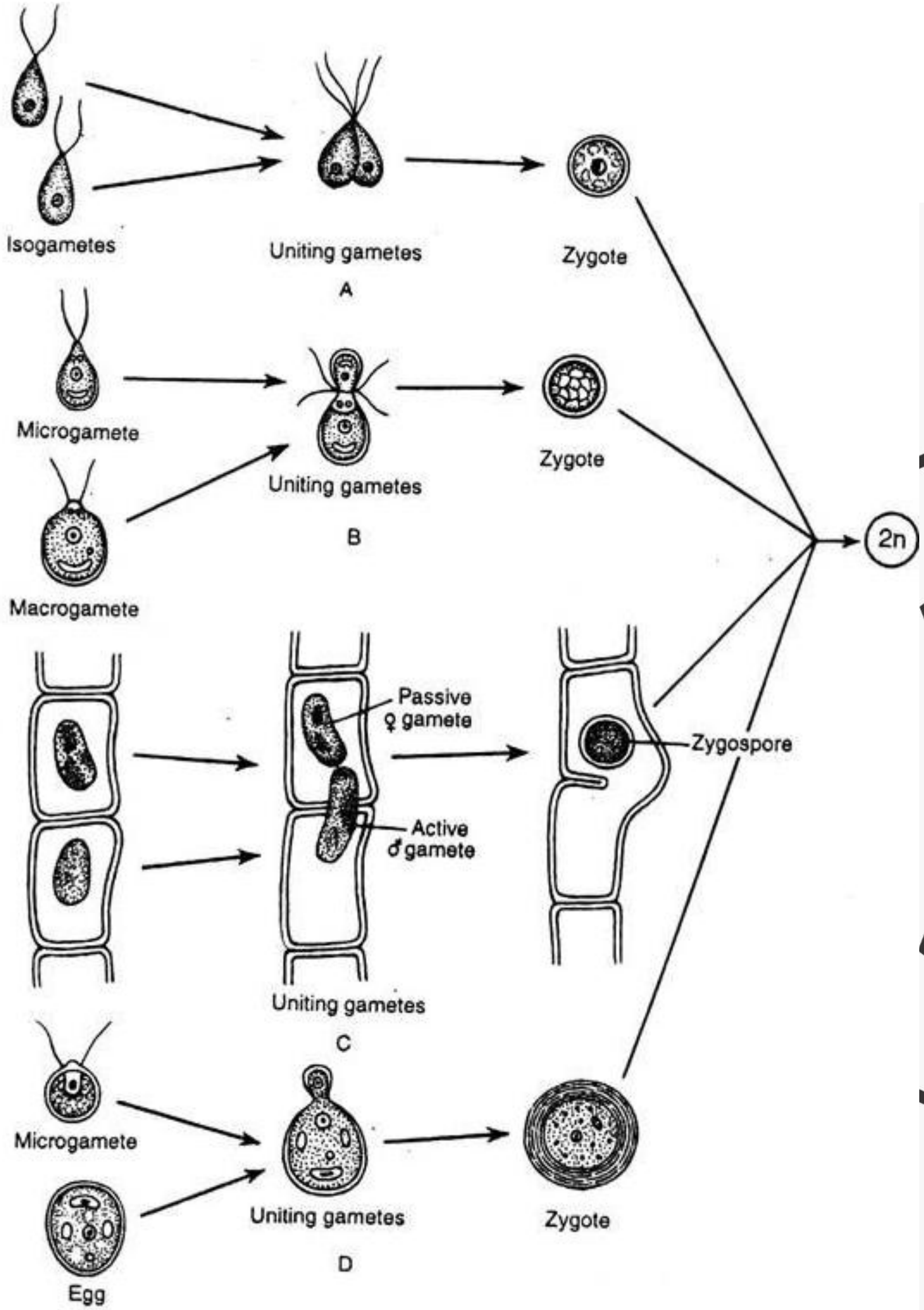


Fig. 3.18 : Types of sexual reproduction in algae : A. Isogamy in *Chlamydomonas* sp., B. Anisogamy in *Ectocar* sp. C. Physiological anisogamy in *Spirogyra* sp., and D. Oogamy in *Chlamydomonas* sp.

### 4. Parthenogenesis

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### 5. Autogamy

In this phenomenon, the two gametes of the same mother cell fuse to form a diploid nucleus. This process is known in many **diatoms** and in colourless **dinoflagellate**.

### 6. Hologamy

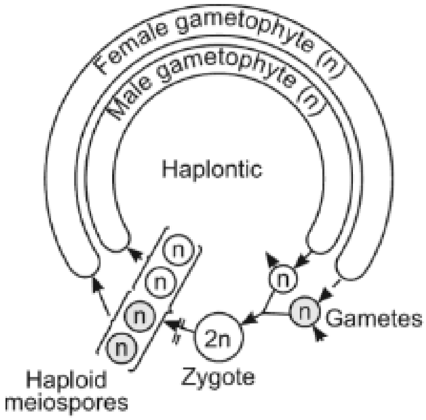
In some unicellular forms the vegetative cells of different strains (+) and (–) behave as male and female gametes, respectively, and fuse to form zygote, e.g., in *Chlamydomonas*, *Dunaliella*.

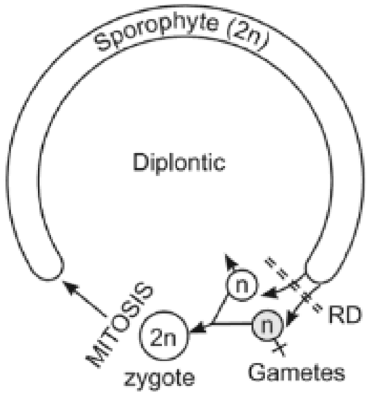
Sexual reproduction in algae accomplishes when the conditions are unfavourable. Thus, this is also a means of *perennation* because it is followed by the formation of thick walled **zygote** or **zygospore**.

## LIFE CYCLE PATTERNS IN ALGAE

Cytologically, the following **five** different types of life cycle patterns are observed among algae.

1. **Haplontic:** This is the most primitive type of life cycle pattern in which an alternation takes place between dominant gametophytic generation (i.e., the haploid vegetative plant body) with an insignificant sporophytic generation (i.e., the diploid zygote), e.g., in *Chlamydomonas*, *Ulothrix*, and *Chara*.
2. **Diplontic:** This type of life cycle pattern is just the opposite of haplontic type in which the main body is a sporophyte and meiosis occurs at the time of gamete formation. The zygote either directly or through diploid zoospores germinates to develop the sporophyte, e.g., in *Ficus*, *Codium*, and *Bryopsis*.





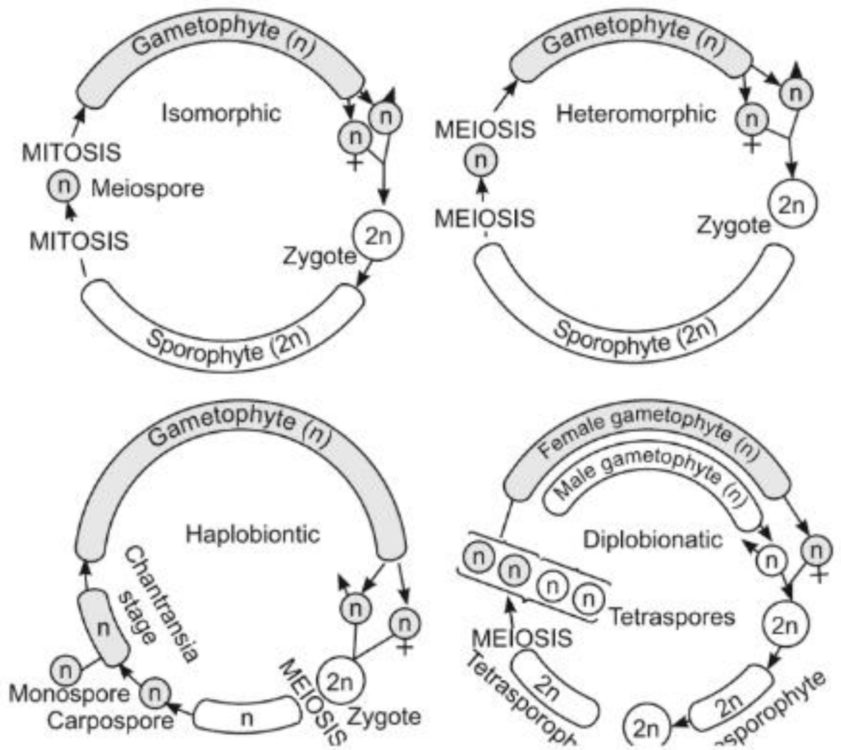


**Figure 1.22** Life cycle patterns in algae

3. **Haplodiplontic:** In this pattern both gametophytic as well as sporophytic generations are free living, which alternate with each other at regular intervals. Thus, haplodiplontic life cycle is dimorphic, which can be of the following two types:
   (a) **Isomorphic:** The gametophytic and sporophytic plants are morphologically identical, e.g., *Ulvales*, *Cladophorales*, and *Ectocarpales*.
4. **Haplobiontic**: This type of life cycle is characterized by an alternation of two or more successive haploid generations with diploid zygote. It is found in primitive red algae, e.g., *Nemalion*.
5. **Diplobiontic:** This is also known as **diplohaplontic**, or **diplo-diplo-haplontic**, life cycle which is found in higher red algae, e.g., *Polysiphonia*. It is **triphasic** and involves an alternative of two diploid (2*n*), or sporophytic generations (carposporophyte and tetrasporophyte) with one haploid (*n*), or gametophytic generation.

# Economic Importance Of Algae

## Industrial Utilization of Algae:

Many commercial products are extracted from different alga and used as basic raw material in certain commercial industries. These include:

Source of alginates: Certain algae like *Macrocystic*, *Laminaria*, *Ascophyllum*, *Lessonia* are used for alginates extraction wherein the seasonal content variation has been reported.

Agar-agar: Many red algae are used as the basic raw material for extraction of gel-like non-nitrogenous extract. This material is mainly used in preparation of microbial culture media. Some of the important Agar sources are - *Gelidium*, *Gracilaria*, *Pterocladia*, *Gigartina*, *Ceramium*, *Chondrus*, etc.

Agar is used extensively in medicine, chiefly as laxative, since it is not digested and increases greatly in bulk with the absorption of water.

Agar serves widely as a substitute for gelatin, as an anti-drying agent in breads and pastry, in improving the slicing quality of cheese, in the preparation of rapid-setting jellies and desserts, and in the manufacture of frozen dairy products. The use of agar in meat and fish canning has greatly expanded, and hundreds of tons are utilized annually.

Agar has proved effective as a temporary preventive for meat and fish in tropical regions, due to the inability of most purifying bacteria to attack it.

Early industrial uses of agar in the Orient included sizing fabric, water-proofing paper and cloth, and making rice paper more durable. Modern industry has refined and expanded these uses to meet new needs in the manufacturing of such items as photographic film, shoe polish, dental impression molds, shaving soaps, and hand lotions.

In the tanning industry agar imparts a gloss and stiffness to finished leather. In the manufacture of electric lamps, a lubricant of graphite and agar is used in drawing the hot tungsten wire.

Carrageenan: A mucilage extracted from *Chondrus crispus* and *Gigartina* is a combination of a few polysaccharides which are used in food preparation, textile manufacture, leather manufacture, in pharmaceutical manufacture and brewing industries.

Algae as source of iodine: Iodine industry is mainly depended upon algae. Algae belonging to Phaeophyceae, like *Laminaria digitata*, *Fucus* spp., *Ecklonia*, *Eisenia*, etc. are used in the industry to prepare iodine. *Phyllophora* is used to prepare iodine in Russia.

Algae as source of funori and funorin: *Gloeopeltis furcata*, *Chondrus*, *Iridaea*, and *Gratilaupia* have been identified as important sources of sizing agents funori and funorin.

Algae as source of diatomite: *Diatom* walls are constantly being deposited in fresh water and marine sediments. This in turn deposits a high content of silicon dioxide which ultimately facilitates formation of diatomite. This diatomite is used industrially for filtration processes, refining industries, brewing industries and manufacture of dynamite. Because diatomaceous earth is inert chemically and has unusual physical properties, it has become an important and valuable material in industry. It makes an excellent filtering agent, which is widely used to remove colouring matters from products as diverse as petrol and sugar.

As a poor conductor of heat it is used in soundproofing. It is used in the manufacture of paints and varnishes, of phonograph records, and as a filler for battery boxes. Because of its hardness, it is used as an abrasive in scouring and polishing powders.

Industrial utilization of seaweeds in Europe had its principal early development in the production of ‘kelp’, a name that originally referred to the ash, rich in soda and potash, derived from burning marine plants. Kelp production was begun sometimes in the seventeenth century by French peasants and spread to other parts of North-West Europe.

Drift-weeds were first used, but cutting was later resorted to *Laminaria* and *Saccorhiza* in North Britain as of major importance.

But *Fucus* and *Ascophyllum* were also widely used, and in some areas Himanthalia and Chorda. The kelp ash from these plants was widely bought by early industrialists for use in manufacture of soap, glass and alum. During the eighteenth and early nineteenth centuries the demands became considerable, and enormous quantities of seaweeds were handled in areas of rich algal growth.

Kelp extract contains a number of chemical elements, notably potassium and iodine. About 25 per cent, of the dry weight of kelp is potassium chloride. Many species of kelp are used as food for man, especially in the Orient. In Northern Europe they also serve as food for domestic animals, such as sheep and cattle.

## Algae in Agriculture:

## Used as Fodder:

Some kinds of algae, such as *Rhodymenia palmata* and *Alaria esculenta*, are favourable food of goats, cows, and sheep, and in Scotland and Ireland the stock actively hunt the shores at low tide for particular algae, especially the former. *Laminaria saccharina, Pelvitia, Ascophyllum,* etc. species are used as food for cattle.

The milk does not have any taste of algae, nor is the meat inferior because of the seaweed diet. Such animals, that have for several generations been nourished on algae, show better ability to digest it than those not so habituated.

The shortage of grain in many parts of Europe during World War I led to considerable experimentation with the use of seaweeds as food for cows and horses. Stock- feed factories were established in France, Norway, Denmark and Germany, and various methods of treating and reducing seaweeds to meal or powder were developed.

The favourable results in animal husbandry in Europe led to the industrial processing of the great Pacific-Coast kelp (*Macrocystis*) for animal rations. Seaweed-meal factories have been operating in the United States for several decades, providing supplementary feeds for poultry, cattle and hogs.

The high mineral and vitamin G content of kelp meal has made possible its use in various poultry and other animal rations.

## Algae is Used as Fertilizers:

Blue-green algae are treated as bio-fertilizers from olden days. *Nostoc, Oscillatoria, Scytonema, Spirulina*, etc. are used as fertilizers to rice fields. All these algae fix the atmospheric nitrogen.

Cultivation of *Spirulina* is gaining importance as feed for fish, poultry and cattle.

In India, *Turbinaria* is used around palm tree while as sea weeds are used as compost.

The water-holding capacity of fragments of the algae in the soil proved effective. These provided valuable small reservoirs of water in close contact with the roots of the cultivated plants.
Furthermore, the bulky organic substances decay slowly in the soil and form humus. Again yield of paddy is increased substancially when paddy field is inoculated with nitrogen fixing blue-green algae. Some of them are: *Tolypothrix tenius*, *Aulosira fertilissima*, *Anabaena oryzae*, *Anabaenopsis arnoldii*, *Calothrix confervicola*, *Nostoc commune*, and *Cylindrospermum bengalense*.

Our country has more number of alkaline soils or sterile soils. Blue-green algae like *Nostoc, Oscillatoria, Scytonema, Spirulina* are used to modify these soils in to fertile soils. Because they fixed nitrogen in to soil. Nearly they fixed 400kg of nitrogen per year.

Due to their mucilaginous sheath, they are able to prevent soil erosion by binding the soil particles firmly.

## Algae is Used as Medicine:

Brown algae mainly used in manufacture of various goitre medicines due to their high iodine content. The main alga used for this purpose include *Sargassum* and members of Laminariales.

The extract of *Corallina*, *Digenia*, *Codium*, *Alsidium* and *Durvilla* are used for treatment of veromious diseases.

Some algae, like *Gelidium* are used for treatment of kidney, bladder and lung diseases while *Laminaria* is used as surgical tool in the opening of wound due to its gentle swelling property.

Antibiotic chlorellin is extracted from *Chlorella vulgaris*, which inhibits the growth of certain bacteria and a few algae. *Rhodomela larix*, *Ascophyllum nodosum*, *Pelvetia* etc. have also shown antibiotic properties.

*Acetabularia* major is used in treatment of kidney and bladder problems.

*Ulva* is used in treatmAlgae are also used as growth promoting substances. Many algae such as *Phormidium tenue* have been reported to induce greater height and yield in rice. It has also been seen to increase protein content of rice grains.ent of glandular troubles.

In Japan *Spirogyra* is used in manufacture of lens paper, suitable for cleaning of optical instruments.

*Gelidium* very early became employed for stomach disorders arid for heat-induced illness.
The gentle swelling of dried *Laminaria* stipes upon exposure to moisture make them surgical tool in the opening of wounds. Similarly, the orientals have employed the same technique in child-birth for expansion of the cervix.
Agar early became useful for stomach disorders and as a laxative, and was once employed as a dietetic.

# TOXIC ALGAE

## Algal bloom:

- An algal bloom or marine bloom or water bloom is a rapid increase in the population of algae in an aquatic system.
- Algal blooms may occur in freshwater as well as marine environments.
- Typically only one or a few phytoplankton species are involved and some blooms may be recognized by discoloration of the water resulting from the high density of pigmented cells.
- Although there is no officially recognized threshold level, algae can be considered to be blooming at concentrations of hundreds to thousands of cells per milliliter, depending on the causative species.
- Algal bloom concentrations may reach millions of cells per milliliter.
- Colors observed are green, yellowish-brown, or red.
- Bright green blooms may also occur.
- These are a result of blue-green algae, which are actually bacteria (cyanobacteria).
- Some algal blooms are the result of an excess of nutrients (particularly phosphorus and nitrogen) into waters and higher concentrations of these nutrients in water cause increased growth of algae and green plants.
- As more algae and plants grow, others die.
- This dead organic matter becomes food for bacteria that decompose it.
- With more food available, the bacteria increase in number and use up the dissolved oxygen in the water.
- When the dissolved oxygen content decreases, many fish and aquatic insects cannot survive.
- This results in a dead area.
- Algal blooms may also be of concern as some species of algae produce neurotoxins.
- At the high cell concentrations reached during some blooms, these toxins may have severe biological impacts on wildlife.
- Algal blooms composed of phytoplankters known to naturally produce biotoxins are often called Harmful Algal Blooms, or HABs.

## Fish poisoning – Toxicity

- Some algae can be harmful to humans. A few species produce toxins that may be concentrated in shellfish and finfish, which are thereby rendered unsafe or poisonous for human consumption. The dinoflagellates (class Dinophyceae) are the most notorious producers of toxins. Paralytic shellfish poisoning is caused by the neurotoxin saxitoxin or any of at least 12 related compounds, often produced by the dinoflagellates *Alexandrium tamarense* and *Gymnodinium catenatum*. Diarrheic shellfish poisoning is caused by okadaic acids that are produced by several kinds of algae, especially species of *Dinophysis*. Neurotoxic shellfish poisoning, caused by toxins produced in *Gymnodinium breve*, is notorious for fish kills and shellfish poisoning along the coast of Florida in the United States. When the red tide blooms are blown to shore, wind-sprayed toxic cells can cause health problems for humans and other animals that breathe the air.

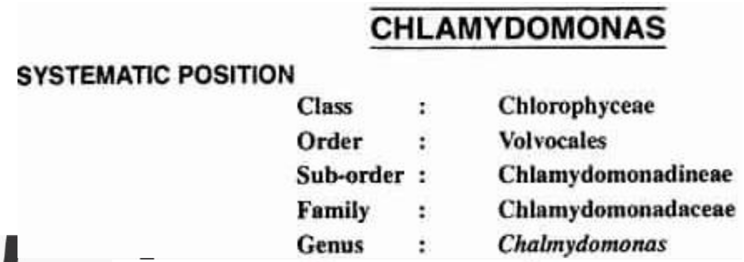
- Not all shellfish poisons are produced by dinoflagellates. Amnesic shellfish poisoning is caused by domoic acid produced by diatoms (class Bacillariophyceae), such as *Nitzschia pungens* and *N. pseudodelicatissima*. Symptoms of this poisoning in humans progress from abdominal cramps to vomiting to memory loss to disorientation and finally to death.

- Ciguatera is a disease of humans caused by consumption of tropical fish that have fed on the alga *Gambierdiscus* or *Ostreopsis*. Unlike many other algal toxins, ciguatoxin and maitotoxin are concentrated in finfish rather than shellfish. Levels as low as one part per billion in fish can be sufficient to cause human intoxication.

- Several algae produce toxins lethal to fish. *Prymnesium parvum* (class Prymnesiophyceae) has caused massive die-offs in ponds where fish are cultured, and *Chrysochromulina polylepis* (class Prymnesiophyceae) has caused major fish kills along the coasts of the Scandinavian countries. Other algae, such as *Heterosigma* (class Raphidophyceae) and *Dictyocha* (class Dictyochophyceae), are suspected fish killers as well.

- Algae can cause human diseases by directly attacking human tissues, although the frequency is rare. Protothecosis, caused by the chloroplast-lacking green alga, *Prototheca*, can result in waterlogged skin lesions, in which the pathogen grows. *Prototheca* organisms may eventually spread to the lymph glands from these subcutaneous lesions. *Prototheca* is also believed to be responsible for ulcerative dermatitis in the platypus. Very rarely, similar infections in humans and cattle can be caused by chloroplast-bearing species of *Chlorella*.

- Some seaweeds contain high concentrations of arsenic and when eaten may cause arsenic poisoning. The brown alga *Hizikia*, for example, contains sufficient arsenic to be used as a rat poison.



CHLAMYDOMONAS

SYSTEMATIC POSITION

| | | |
|---|---|---|
| Class | : | Chlorophyceae |
| Order | : | Volvocales |
| Sub-order | : | Chlamydomonadineae |
| Family | : | Chlamydomonadaceae |
| Genus | : | *Chalmydomonas* |

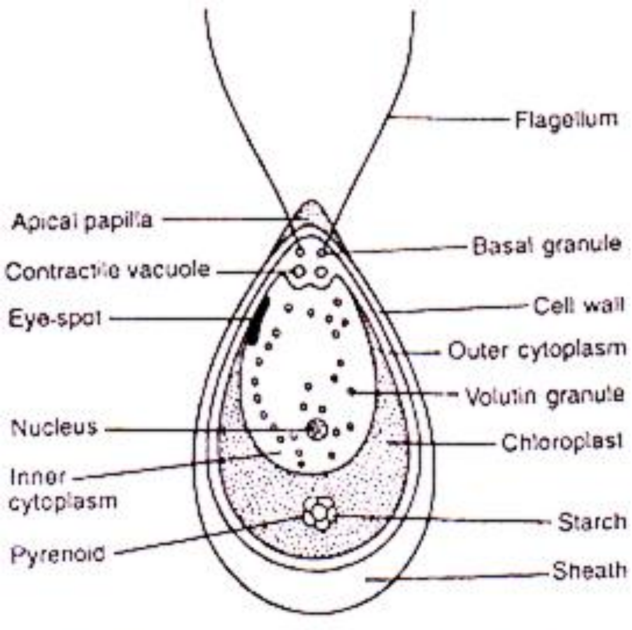


Fig. 3.41 : *Chlamydomonas* : A vegetative cell

**Occurrence:** The genus *Chlamydomonas* (Gr. Chlamys, mantle; monas, single organism) includes about 400 species, found almost everywhere (i.e., ubiquitous). Commonly they are found in fresh water of lakes, ponds, tanks etc., but they are also available in brackish water (*C. halophila*), saline water (*C. ehrenbergii*), snow (*C. nivalis*) and some are also air borne.

The snow of arctic and alpine zones becomes red due to the presence of *C. nivalis* which accumulates the red pigment haematochrome. But the snow covered mountain range of yellow stone national park (USA) becomes yellowish green due to the well- developed population of *C. yellowstonensis*.

**Indian Species:** *Chlamydomonas eugametos*, *C. grandistigma*, *C. ehrenbergii*.

**Plant Body:** It is unicellular and motile (Fig. 3.41). The cells are usually spherical, oval or oblong in shape but other forms like ellipsoidal, pyriform etc. are also available. Most of the species are broader towards the posterior side and pointed towards the anterior side, which gradually ends in apical papilla.

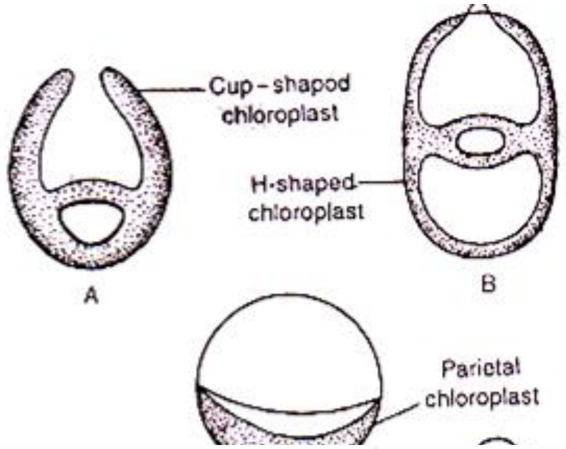
The length of the cell varies from 20 to 30µm but rarely exceeds 30µm in major diameter.

The cell wall is thin, smooth and firm. It is made up of cellulose. The major structural component of cell wall is glycoprotein. In some species (*C. gleocystiformis*), the cell wall is surrounded by mucilaginous pectin layer formed by the dissolution of pectose layer to pectin.

Inner to the cell wall, semipermeable cell membrane or plasma membrane is present which surrounds the protoplast.

**The protoplast contains the following:**

**a. Chloroplasts:** It occupies the lower broader part. It is generally of cup-shaped and parietal (Fig. 3.40). (However, the chloroplast is variable in shape, such as H-shaped in *C. biciliata*; parietal in *C. mucicola*; reticulate in *C. reticulata* and stellate in *C. arachne*).



Chloroplast has single pyrenoid with a starch sheath. The number is also variable and it may be two (*C. debaryana*) to many (*C. gigantae*). Sometimes they may be numerous and distributed irregularly inside the chloroplast (*C. sphgnicola*).

**b. Eye-Spot:** Towards the anterior end of the chloroplast at one side a circular to oval, photoreceptive organ, the stigma or eye spot is present. The spot consists of a curved pigmented plate, the pigmentosa and a biconvex lens.

**c. Nucleus:** The nucleus remains suspended inside the cups and is of prokaryotic in nature.

**d. Other Inclusion:** It includes mitochondria, E.R. vesicles, contractile vacuoles etc.

**e. Flagella:** Two whiplash-types of flagella are present towards the anterior region of the cell. They are equal in length. The flagella may be very small, same size of the cell or bigger than the cell in most species.

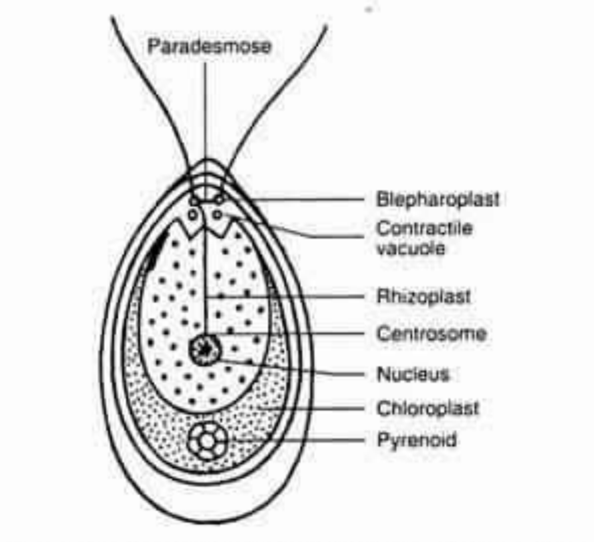


Fig. 3.42 : *Chlamydomonas* showing neuromotor apparatus

The flagellum originates from the blepharoplast, situated towards the anterior side (Fig. 3.42). The flagella come out through very fine canals, on the outer wall.

In some species like *C. nasuta* neuromotor apparatus (Fig. 3.42) is said to be present. The neuromotor apparatus consists of two basal granules, the blepharoplasts. Both are connected by a fibre, called paradesmose. One of the blepharoplast is connected to the centrosome of the nucleus by a thread, the rhizoplast. Many fine fibrils connect the centrosome with the nucleolus.

**The E.M. studies have not confirmed about the neuromotor apparatus:**

**f. Contractile Vacuoles:** Two contractile vacuoles are present just below the blepharoplast. Possibly they regulate the water content of the cell, by discharging more water at times.

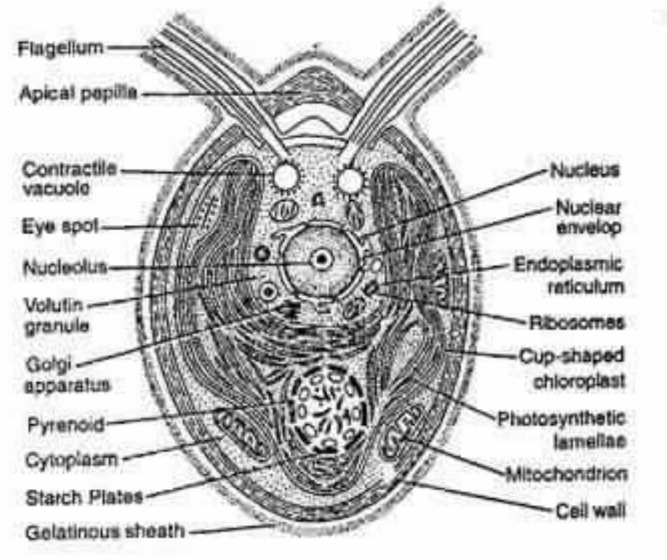


Fig. 3.43 : *Chlamydomonas*. Cell structure as observed under electron microscope

**Structure as observed under E.M.:** Roberts et al (1972), Hills (1973) and Hills et al. (1973) have studied in detail the structure of *Chlamydomonas* under Electron Microscope (E.M.) (Fig. 3.43).

The cell wall is multilayered (7 layered) and it consists of proteins. Cellulose is absent. Cell membrane like normal eukaryotic cell is lipoprotein in nature. The flagellum remains attached to the basal granule, the blepharoplast and shows typical 9 + 2 fibrillar arrangement. The chloroplast is cup-shaped (*C. eugametos*) and surrounded by double-layered unit membrane.

It bears a number of band-shaped photosynthetic lamellae, the thylakoids; are lipoprotein in nature and remain dispersed in the granular matrix, the stroma. The grana-like bodies are formed by the aggregation of about 3-7 thylakoids. The chloroplast matrix contains ribosomes, microtubules, crystal-like bodies etc.

The cytoplasm contain nucleus, mitochondria, Golgi apparatus, E.R, ribosomes etc. The nucleus always lies in the cytoplasm, present in the cavity of chloroplast.

The eye-spot consist of 2-3 parallel rows of lipid droplets (i.e., granules) and each one measures about 75nm in diameter. It remains embedded at one side of the chloroplast.

**Reproduction : It reproduces both asexually and sexually.**

**Asexual Reproduction:** It takes place commonly by the zoospore formation. But some also reproduce by aplanospores, hypnospores, palmella stage & rarely by synzoospores.

**1. Zoospores:** During night with favourable environmental conditions zoospores are formed (Fig. 3.44). At the starting of zoospore formation, the parent cell withdraws its flagella and takes rest. The contractile vacuoles disappear and the protoplast slightly withdraws from the cell wall. The protoplast then undergoes repeated longitudinal division at right angles to one another and forms generally 8 but rarely up to 64 units.

Each unit of protoplast secretes a wall around and develops contractile vacuoles. They are released by rupturing or gelatinisation of the mother wall. At the time of liberations they develop their flagella. These flagellated daughter units are called zoospores. After liberation they behave as new individuals and capable of developing new crop of zoospores after 24 hours.

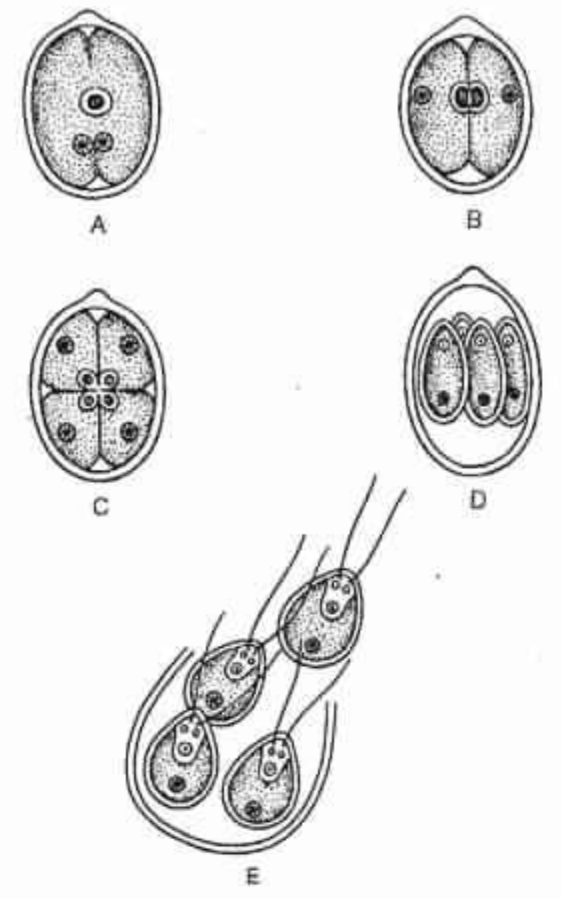


Fig. 3.44 : *Chlamydomonas* : (A-E) Sequential stages of zoospore formation

**2. Aplanospores:** These are formed during unfavourable conditions. Following the same procedure like zoospore-formation, they develop 2-16 daughter protoplasts. Each one secretes, thin wall around, itself. These thin walled non-motile spores are called aplanospores. During favourable conditions aplanospore comes out of the mother cell and develops a new cell directly or its protoplast divides to form more zoospores.

**3. Hypnospores:** These are formed during severe drought. The hypnospores are developed like aplanospores, but the wall becomes much thicker than aplanospores. During favourable condition they germinate like aplanospores i.e., either directly or by the formation of zoospores through more divisions of protoplasts.

**4. Palmella Stage:** During zoospore formation, suddenly if the environmental condition becomes unfavourable, the parent wall gets gelatinised. Consequently the daughter protoplasts also get gelatinised and undergo divisions. The entire structure becomes enlarged much more. This stage looks like another green alga Palmella of Tetrasporales and called this stage as Palmella stage (Fig. 3.45).

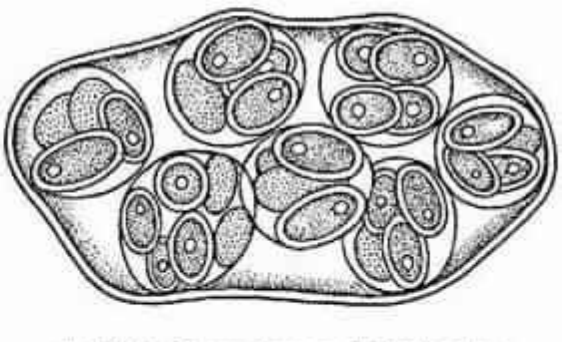


Fig. 3.45 : *Chlamydomonas* : Palmella-stage

During favourable conditions, the unit bodies develop into individual zoospore. Palmella stage is very common in *C. kleinii* and *C. braunii*.

**5. Synzoospore:** The multinucleate and multi- flagellate zoospores are called synzoospores. They are reported to be formed in artificial culture. The mother nucleus divides into 4 nuclei, those develop a pair of flagella and finally to synzoospores.

**Sexual Reproduction:** It takes place during desiccation or deficiency of nitrogenous compound in the growing medium. It takes place very commonly through isogamy and less frequently through anisogamy and oogamy.

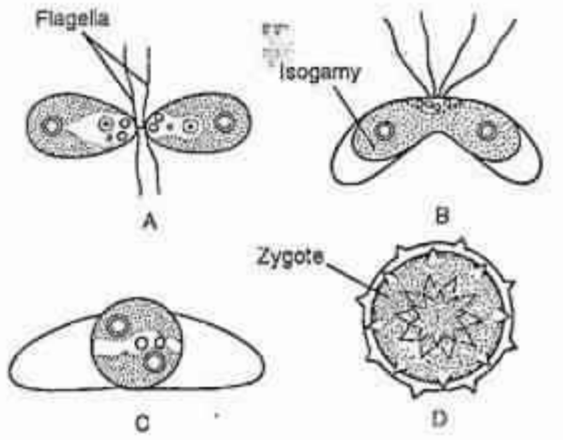


Fig. 3.46 : *Chlamydomonas moewusii* : (A-D) Stages showing isogamous sexual reproduction

**1. Isogamy:** Majority of the species are isogamous. In this type sexual union takes place between the morphologically identical gametes (Fig. 3.46).

In some species the vegetative cell directly develops into gametes (hologamy) or generally it divides into 8 to 64 gametes. The uniting gametes may develop from the same plant (e.g., *C. debaryanum*) i.e., homothallic or from different plants i.e., heterothallic (e.g., *C. reinhardii* and *C. moewusii*).

During union the flagella are found to be covered by agglutin (not found on the flagella of vegetative cell), a chemical substance (protein) which helps in the recognition of gametes of opposite mating type.

In most, the gametes are unicellular, uninucleate, very small and biflagellate structures (Fig. 3.46A).

During sexual union isogametes (+ and -) come very close to each other. The wall at the point of contact dissolves resulting in the formation of diploid quadriflagellate zygote through plasmogamy followed by karyogamy (Fig. 3.46B-D).

**2. Anisogamy:** It is the union between two gametes (male and female) of different sizes (Fig. 3.47A, B). The larger one is called macrogamete (female) produced only 2 or 4 in the female gametangium. The smaller one is called microgamete (male) produced 8 or 16 in the male gametangium.

The microgametes are more active than macrogametes. The microgamete comes very close to the macrogamete. Both the gametes undergo fusion and form zygote (Fig. 3.47C-E). This type of sexual union is found in *C. braunii*, *C. suboogama* etc.

**3. Oogamy:** It is the union between morphologically dissimilar gametes (Fig. 3.48A, B). The microgamete (male) is biflagellate and smaller in size than the macrogamete (female) which is non-motile and larger in size. The male cell divides repeatedly and forms 16 units, each of which is converted into male gamete.

On the other hand, the female cell leaves the flagella and directly functions as female gamete. The active male gamete comes very close to non-motile female gamete and attaches itself at the anterior end. Both the gametes undergo fusion and form zygote (Fig. 3.48C-D). This type of union is found in *C. coccifera*.

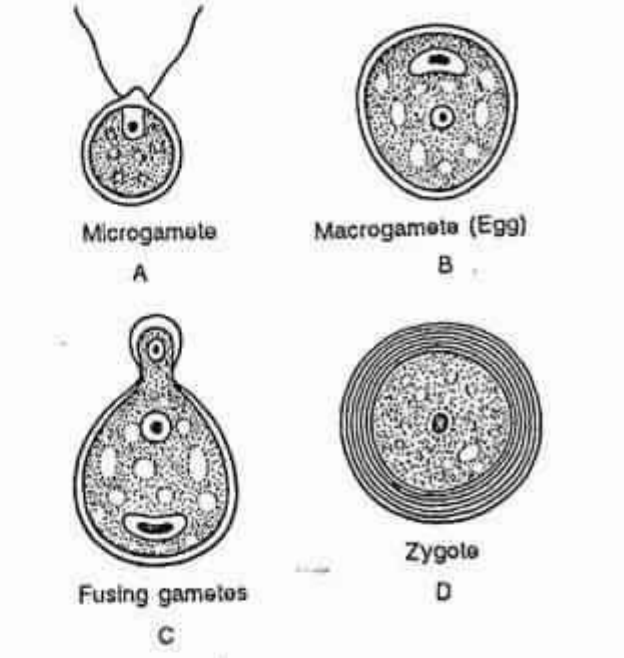


Fig. 3.48 : *Chlamydomonas coccifera* : A-D. Stages of oogamous sexual reproduction

**Zygote:** Initially the quadriflagellate zygote remains motile for several hours (*C. paradoxa*) to about 15 days (*C. pertusa*). After leaving flagella it settles down on the substratum and takes rest. Primary wall is formed by the zygote, followed by thick ornamented secondary wall (Fig. 3.49A, B). With maturity the zygote accumulates large amount of starch and oil.

**Germination of Zygote:** During germination (Fig. 3.49C) the diploid nucleus (2n) of the zygote undergoes meiosis to form 4 (*C. chlamy-dogama*) or with additional mitosis forms 16 to 32 (*C. intermedia*) nuclei (n). The segregation of + and – strains takes place during meiosis. The inner wall dissolves and by breaking the outer wall the haploid cells are liberated. During liberation they develop flagella and behave like new individuals.

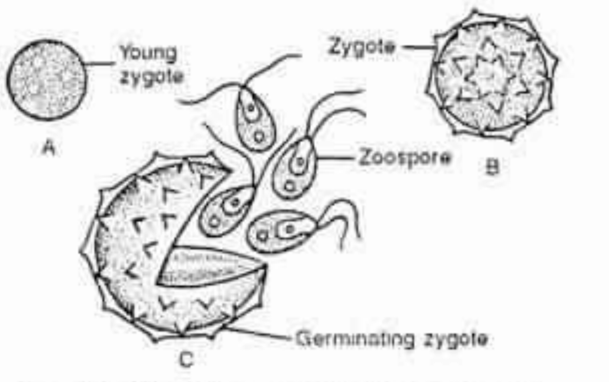


Fig. 3.49 : *Chlamydomonas* : A-C. Stages of germination of zygote

**Life history of Chlamydomonas is given in Fig. 3.50 and 3.51:**

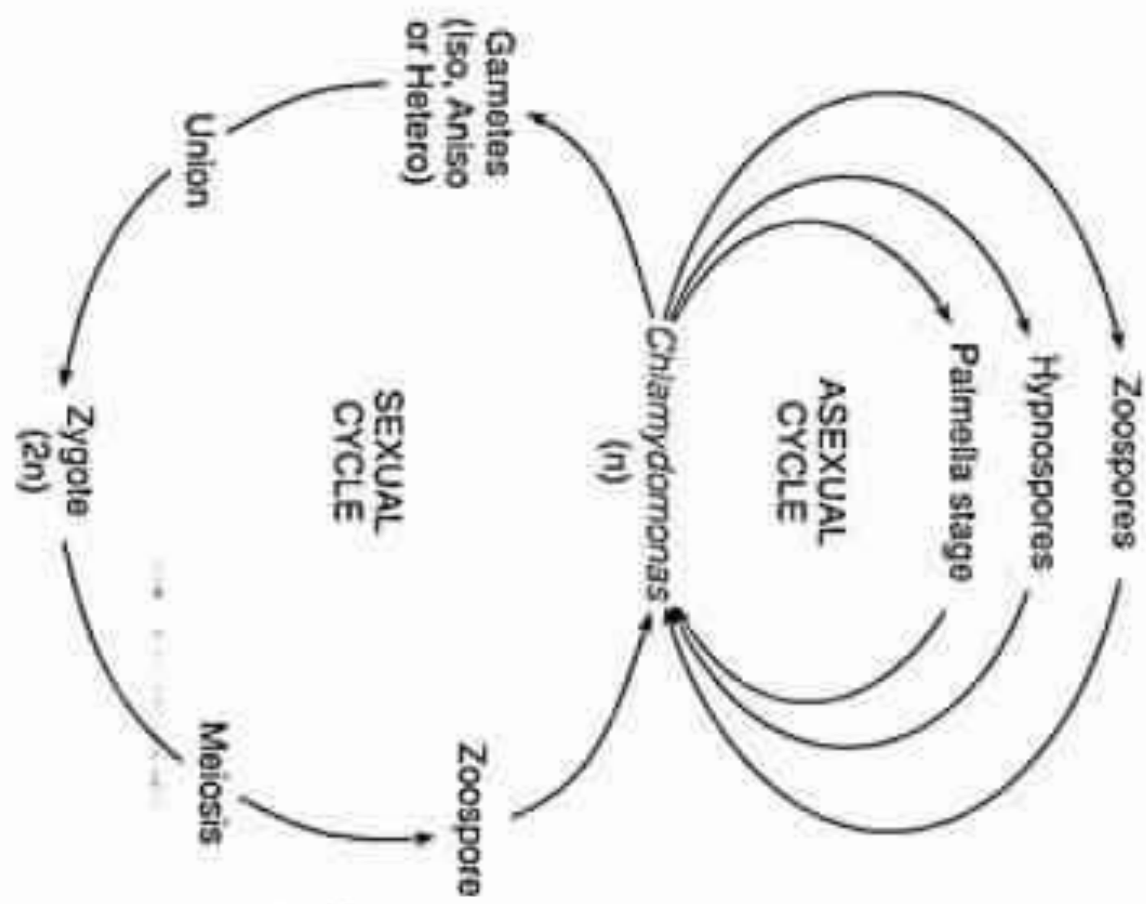


Fig. 3.50 : Graphic life-cycle of *Chlamydomonas*

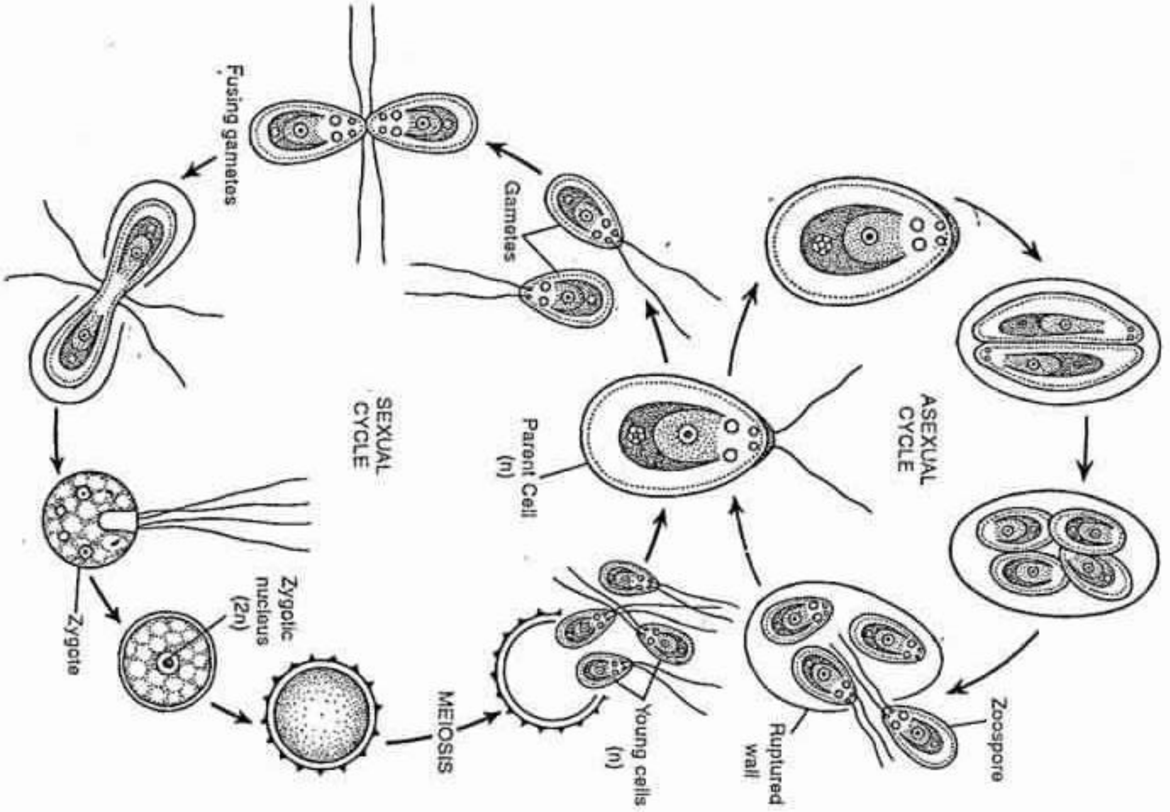
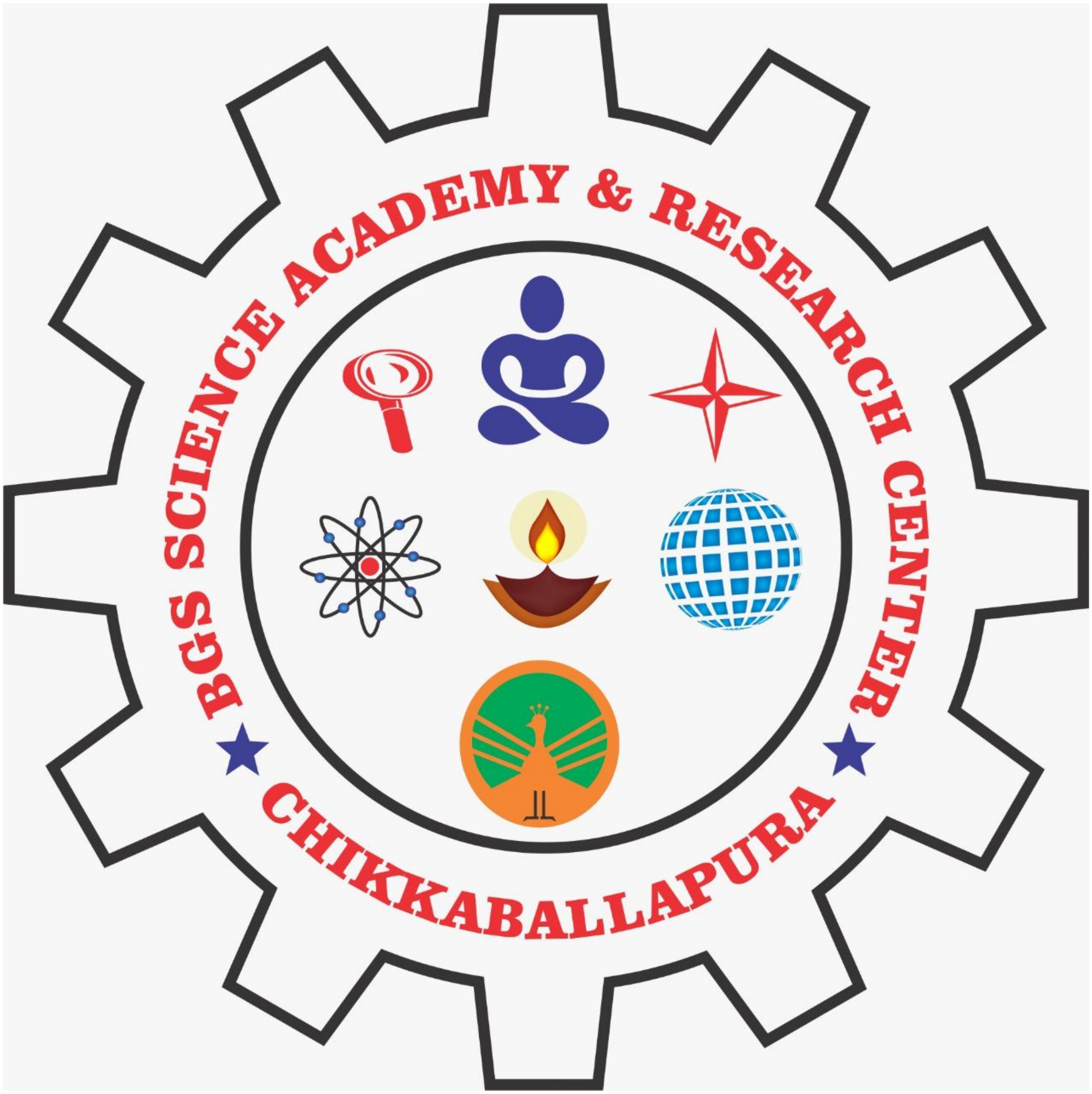


Fig. 3.51 : Diagrammatic life cycle of *Chlamydomonas*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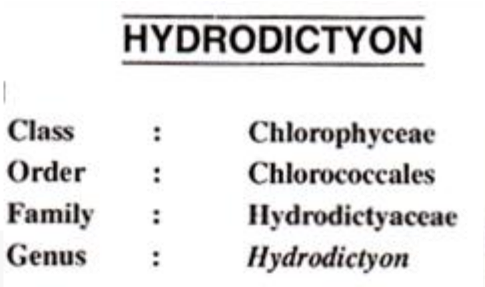


HYDRODICTYON

| | | |
|---|---|---|
| Class | : | Chlorophyceae |
| Order | : | Chlorococcales |
| Family | : | Hydrodictyaceae |
| Genus | : | *Hydrodictyon* |

**Occurrence:**
*Hydrodictyon*, a non-motile coenobium is macroscopic. Due to its net like plant body, it is known as **'water net'**. It has 5 species. Only 2 species are reported from India i.e., *H. reticulatum* and *H. indicum*. *H. reticulatum* is cosmopolitan.

These are found between spring and rainy season in slow running water or still water of ponds, pools and lakes. It generally floats on the surface of the water but may also lie on the bottom. Very often due to profuse growth, the nets assume big size and cover the entire pond.

**Thallus Structure:**
A mature coenobium consists of a hollow cylindrical network which is closed at both the ends (Fig. 1). It is flat and saucer shaped and its maximum size is generally 20-30 cm. Rarely it may reach up to a length of 60 cm. The mature net of coenobium is made up of a few hundred to several thousand cells.

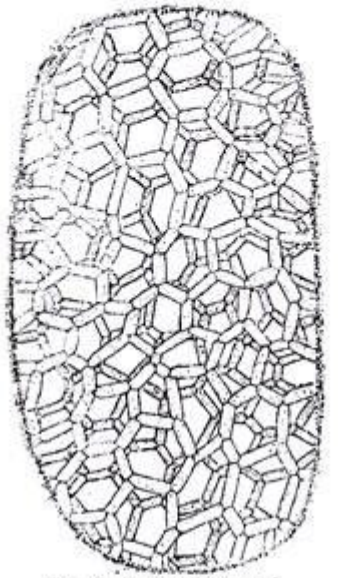


Fig. 1. *Hydrodictyon*. A coenobium.

These cells are joined at the end and form pentagonal or hexagonal structures. These structures are called meshes. Each mesh interspace is generally bounded by 5-6 or rarely three cells. At each angle of the net or mesh meet three cells (Fig. 2 A, B).

**Cell Structure:**
Each cell is long, cylindrical or ovoid in shape. Its internal structure can be differentiated into two parts: cell wall and protoplasm. Cell wall is two layered and is made up of cellulose. It encloses protoplasm. When young, the cells are uninucleate, but at maturity they become multinucleate (coenocytic).

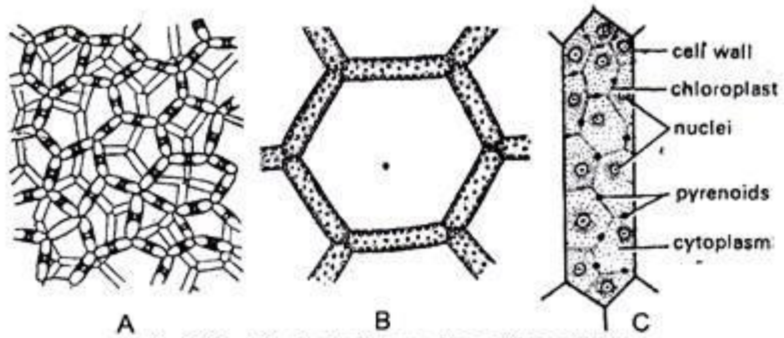


Fig. 2 (A—C). *Hydrodictyon*. Vegetative structure. A. A part of the net; B. Hexagonal mesh; C. A cell.

Cells contain reticulate chloroplast with many pyrenoids (Fig. 2C). All the typical structures of green algae like ribosomes, mitochondria, dictyosomes are also present. As the cell matures, a central vacuole appears and the protoplasm becomes peripheral.

**Reproduction:**
**It is of 3 types:** Vegetative, asexual and sexual.

**Vegetative Reproduction:**
It takes place by fragmentation. Coenobium breaks up into small pieces called fragments. Which have capability to grow into new colonies. It may be due to water currents and movement of aquatic animals.

**Asexual Reproduction:**
It takes place by the formation of auto colonies or daughter colonies (Fig. 3 A-G). These colonies are formed by the biflagellate, uninucleate zoospores. Under favourable conditions each coenocytic cell behaves as zoosporangium. Its nuclei undergo mitotic divisions to form a large number of nuclei (7000-20000).

Protoplasm gets segmented into as many segments as there are nuclei. Each segment gets surrounded by small amount of cytoplasm, a limiting membrane and develops two whiplash type equal flagella and represents biflagellate zoospore (Fig. 3 A-C). In *Hydrodictyon* a peculiar phenomenon is observed. The zoospores thus formed are never liberated outside the parent cell.

They remain motile within the restricted region i.e., within the cell. After swimming inside the cell, they ultimately withdraw their flagella and get themselves arranged into characteristic hexagonal or pentagonal fashion to form a new net (Fig. 3 D, E). This new net is called auto colony or daughter colony (Fig. 3 F, G).

The auto colonies are liberated by disintegration of the parent cell wall. The number of the cells in the daughter colony is fixed. Further growth of the coenobium is entirely due to increase in the cell size and not the number of the cells.

**Sexual Reproduction:**

It is isogamous. Any vegetative cell of the coenobium can function as gametangium. The biflagellate gametes are produced by the cleavage of the protoplasm of the gametangia like that of zoospores (Fig. 4A, B). They are produced in large number and are smaller in size than the zoospores. They are liberated individually through a hole in the parent cell wall and swim freely in water.

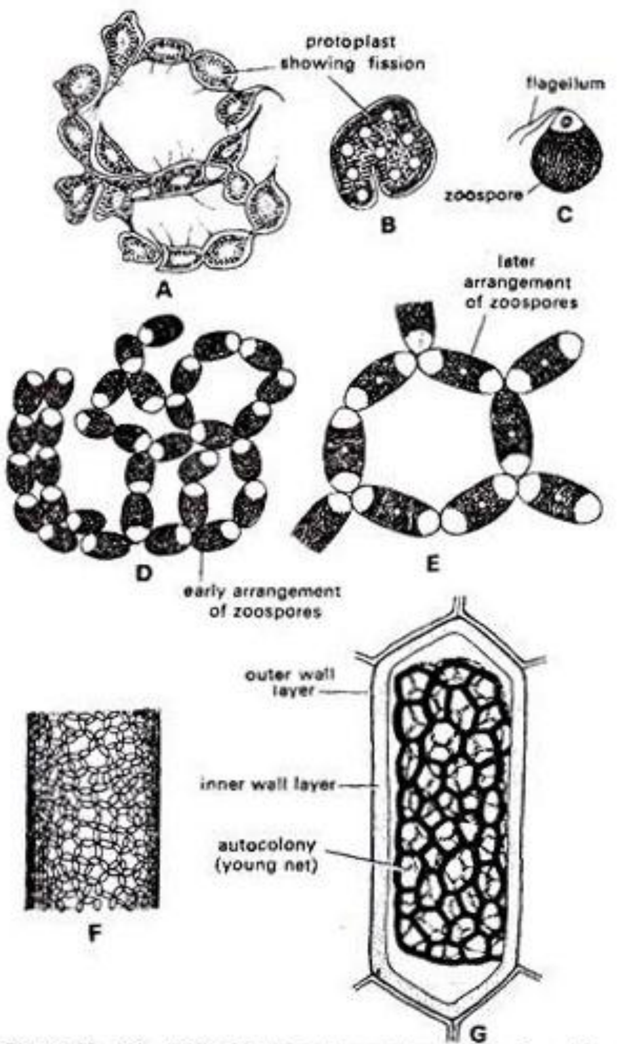


Fig. 3 (A—G). *Hydrodictyon*. Asexual reproduction. (A, B). Zoospores formation. C. A zoospore; (D, E). Arrangement of biflagellated zoospores into a net; F. Formation of new net (autocolony) within parent cell. G. A autocolony in the parent cell.

The gametes are uninucleate and biflagellate. *Hydrodictyon* is monoecious. The gametes from the same or different coenobia after liberation fuse to form quadriflagellate zygotes (Fig. 4C). Soon they lose their flagella and settle down. The immobilised zygote enlarges in size, becomes spherical and develops thick wall to form zygospore. First it is green but it becomes red because of the development of a red pigment haematochrome.

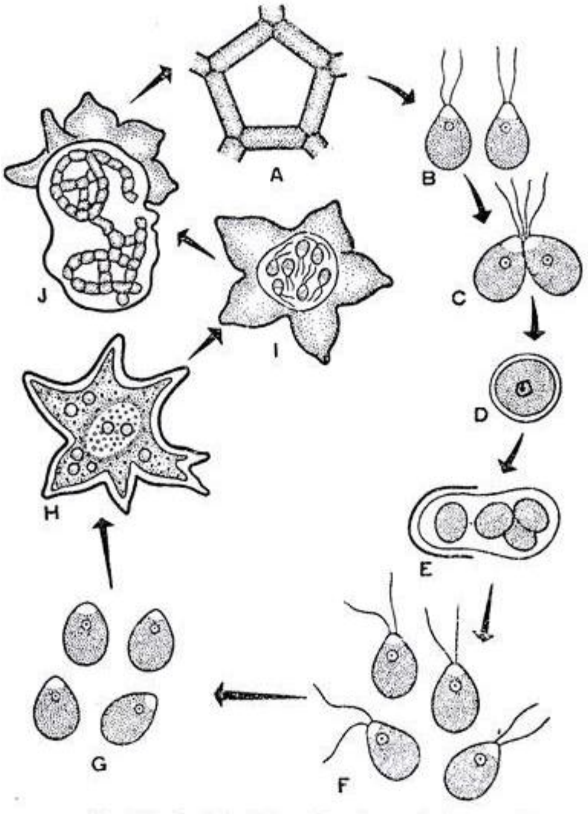


Fig. 4 (A—J). *Hydrodictyon*. Sexual reproduction.

**Germination of zygospore:**

Zygospore is capable to tide over the low winter temperature. At the onset of the spring season, its diploid nucleus undergoes zygotic meiosis to form four, haploid uninucleate, biflagellate gonozoospores or meiospores (Fig. 4 D-F). The zygospore wall bursts and the meiospores are liberated in the surrounding water. After swimming for some time these meiospores come to rest. They retract their flagella, enlarge and form the thick walled angular cells called polyhedrons or polyeders (Fig. 4 G, H). This stage is known as polyhedron stage. The single nucleus of the polyhedron divides and re-divides several times and ultimately forms the second generation of zoospores (Fig. 4 I). These zoospores are also uninucleate and are anteriorly biflagellate.

The wall of the polyhedron cracks down and the zoospores emerge into a thin vesicle (Fig. 4 J). These zoospores do not escape outside in the water but actively swim within the vesicle for some time.

They withdraw their flagella and arrange themselves in the form of a net of Hydrodictyon. It is a daughter or juvenile colony. It is released in water by the dissolution of the vesicle. Its cells grow in size and produce new coenobium where the cell number typical of the species is stored.

If a gamete fails to fuse, it develops into a zygospore parthenogenetically. It gives rise to zoospores which, in turn, produce polyhedrons.

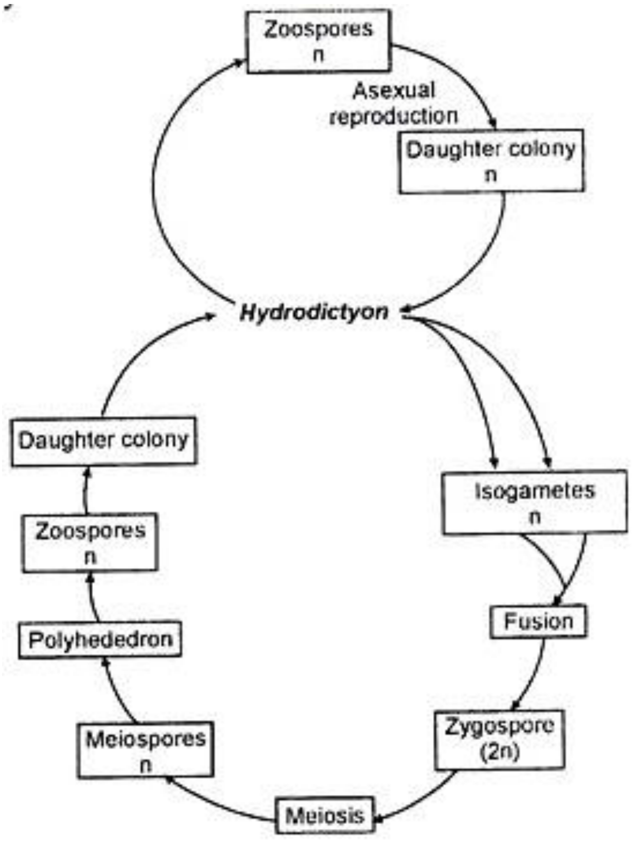


Fig. 5. *Hydrodictyon*. Graphic life cycle.

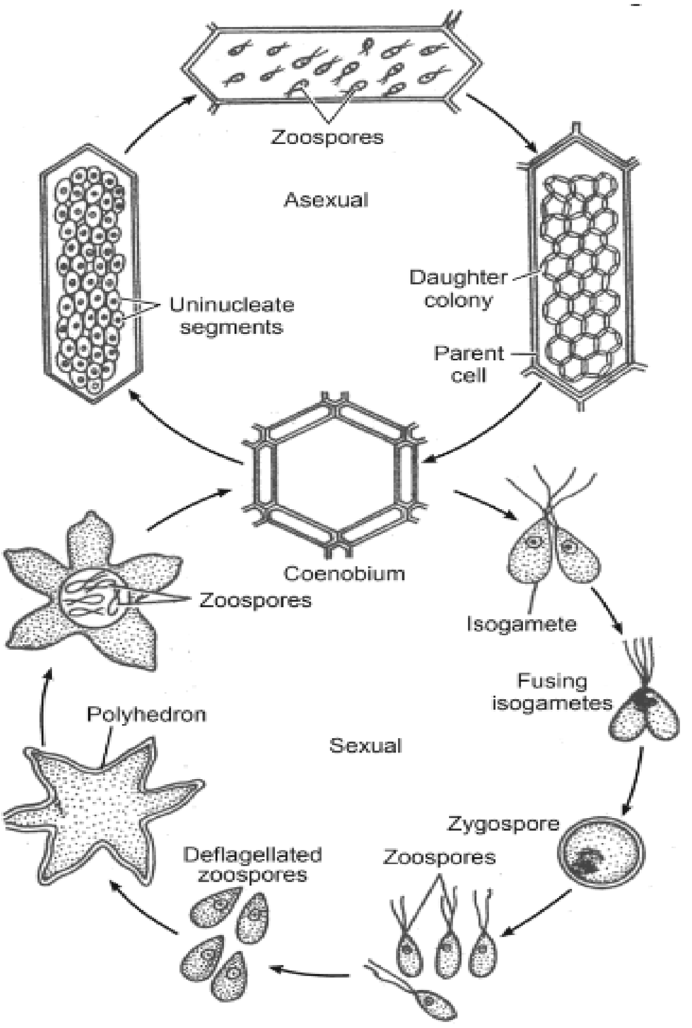


Figure 4.38 *Hydrodictyon*: Diagrammatic Life cycle

## *Oedogonium*-

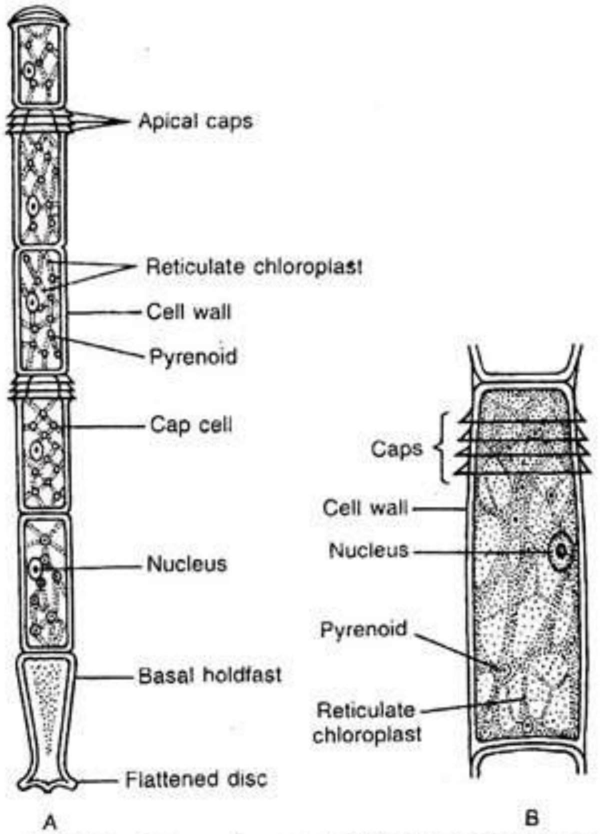


Fig. 3.72 : *Oedogonium* sp. : A. Single vegetative filament with holdfast and apical cell, B. Single vegetative cell

**Systematic position**

| | |
|---|---|
| **Kingdom -** | **Plantae** |
| **Division-** | **Chlorophyta** |
| **Class-** | **Chlorophyceae** |
| **Order -** | **Oedogoniales** |
| **Family -** | **Oedogoniaceae** |
| **Genus -** | ***Oedogonium*** |

**Occurrence:** *Oedogonium* (Gr. oedos, swelling; gonos, reproductive bodies) is an exclusively fresh water alga. Out of about 400 species more than 200 have been reported from India. They are very common in pools, ponds, lakes etc. The filamentous plant body may get attached with the stone, wood, leaves of aquatic plants, small branches of dead plant remain in water etc. by their basal cell the holdfast. Some species like *O. terrestris* are terrestrial. **Indian Species:** *Oedogonium cardiacum, O. aster, O. elegans, O. aerolatum* and *O. armigerum.*

**Plant Body:** The thalloid plant body is green, multicellular and filamentous. The filaments are unbranched and cells of each filament are attached end to end and form uniseriate row (Fig. 3.72A). The filament is differentiated into 3 types of cells: 1. Basal cell, 2. Apical cell and 3. Middle cells.

**1. Basal Cell:** It is the lowermost cell of the filament. The cell is long, gradually narrowed and towards the basal end it expands to form simple, disc-like, multilobed or finger-shaped structure. The cell is generally colourless, which performs the function of fixation to the substratum and called holdfast.

**2. Apical Cell:** It is the topmost cell of the filament. The cell is usually rounded towards apical side and green in colour.

**3. Middle Cells:** All the cells in between basal and apical cells are alike. The cells are longer than their breadth i.e., rectangular in shape.

Towards the upper end of some cells a ring-like structure is present known as cap or apical cap (Fig. 3.72A). The cell with cap is called cap cell. The number of caps on a cell indicates the number of cell divisions in that cell.

**Cell Structure:** The intercalary cells are longer than their breadth and are cylindrical in outline. The cells are surrounded by thick and rigid cell wall (Fig. 3.72B). The cell wall is differentiated into 3 layers an outer chitin, middle pectin and innermost cellulosic. Just interior to the wall, cell membrane is present, which encloses the protoplast. The protoplast consists of cytoplasm, chloroplast and nucleus. The cells contain many small or single large vacuoles situated in the centre and remain filled with cell sap. The cytoplasm lies between the cell membrane and vacuole. The Chloroplast is single, large and reticulate, which remains embedded in the cytoplasm. It extends from one end of the cell to the other end. Many pyrenoids are present. Cells are uninucleate and nucleus is generally present in the centre of the cell within the cytoplasm or it may be eccentric.

**Reproduction:**

**This reproduces by all the three means: vegetative, asexual and sexual.**

**Vegetative Reproduction takes place by fragmentation and akinete formation:**

**1. Fragmentation:** It takes place by accidental breakage of the filament, dying off of intercalary cells or by the formation of intercalary sporangia. The fragments are capable of developing into new filaments.

**2. Akinete:** During unfavourable condition the entire protoplast of a cell becomes a thick-walled, reddish-brown, round or oval structure, the akinete. The akinete germinates during favourable condition and develops a new filament. They generally form in chain.

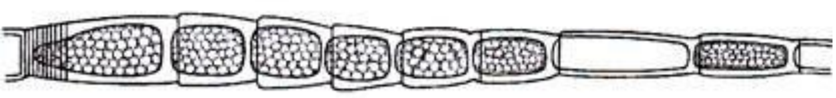


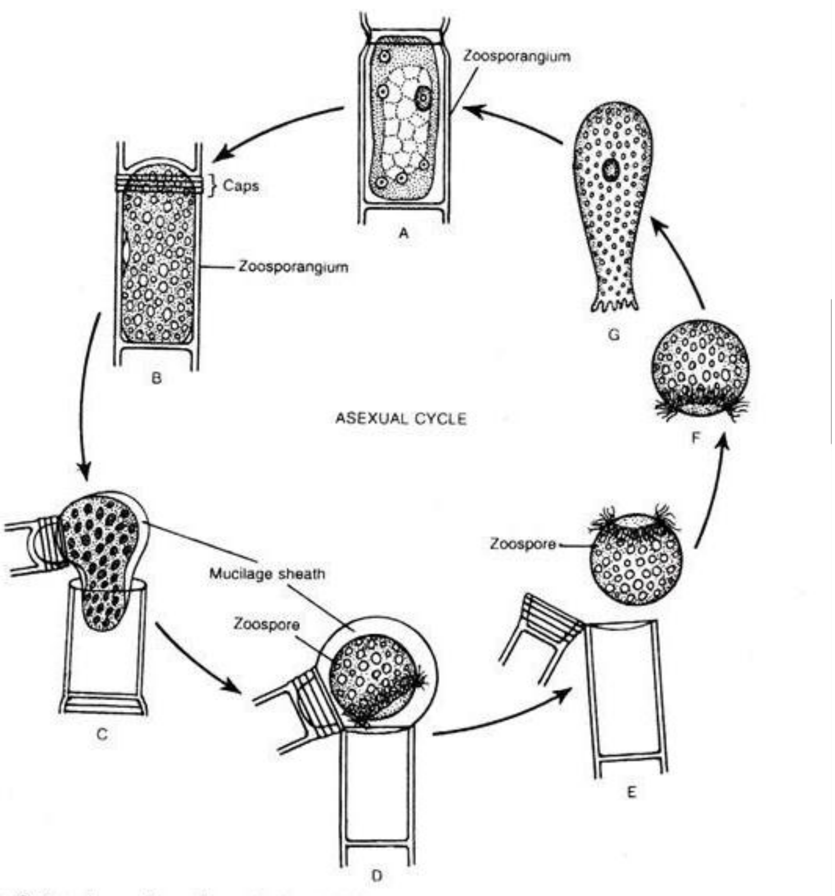
**Fig. 4.** ***Oedogonium.*** **Chain of akinetes**

**Asexual Reproduction:**

1. Zoospores are formed in the cap cells singly, when the cell starts to function as zoosporangium.
2. In each zoosporangium develops a single, spherical to ovoid, uninucleate and multi-flagellate zoospore.
3. Zoospore comes out in the membranous vesicle formed by rupturing of the outer cell wall.
4. On coming out of vesicle, zoospore settles on some substratum through its flagellar end. Its flagella withdraw and it germinates into new plant.

**Sexual Reproduction:**

The sexual reproduction in *Oedogonium* is an advanced oogamous type. The male gametes or antherozoides are produced in antheridium (Fig. 3.75) and the female gamete or egg is produced in oogonium (Fig. 3.76). Male and female gametes differ both morphologically and physiologically.



: *Oedogonium* sp. Asexual reproduction : A-E. Successive stages of zoospore formation, F. Single zoospore, and G. Germination of Zoospore

Only one egg is produced in each oogonium and two antherozoides in each antheridium. Another motile structure, the androspore, is produced singly in each androsporangium.

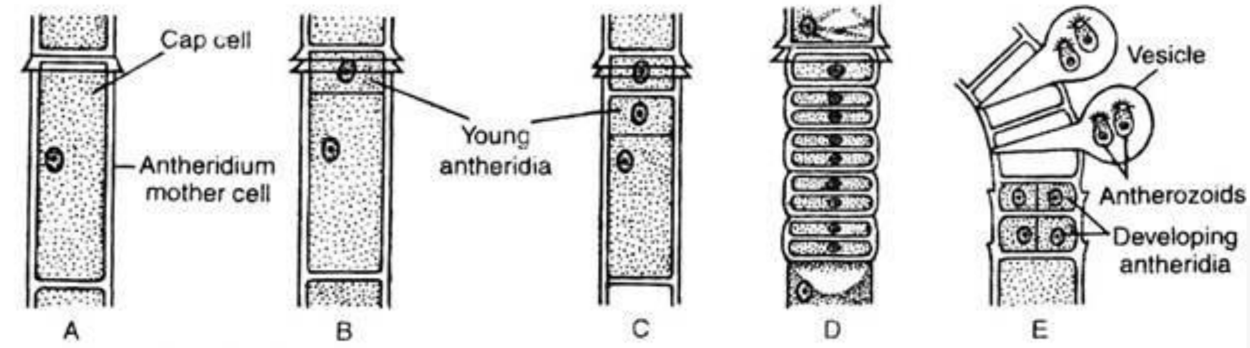


Fig. 3.75 : *Oedogonium* sp. : A-E. Successive stages of development of antherozoids

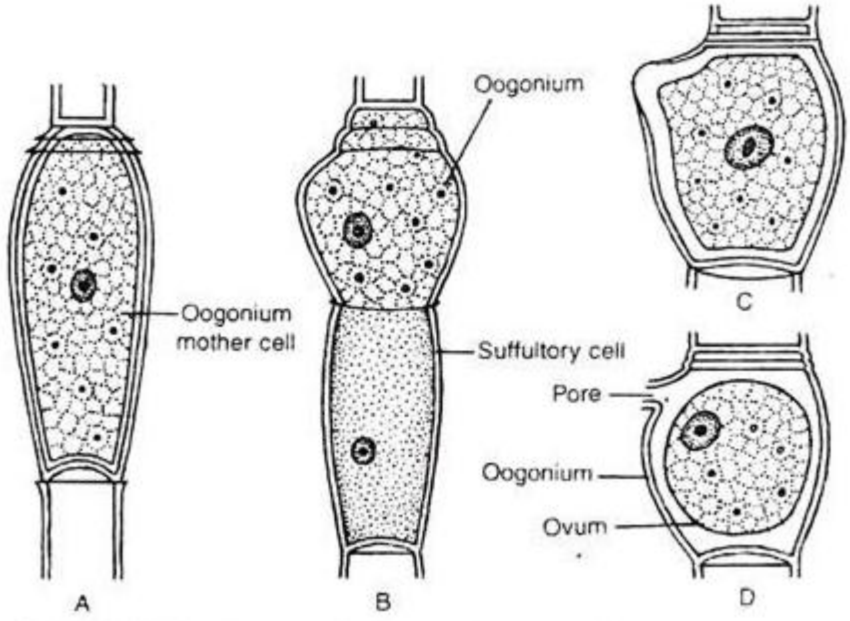


Fig. 3.76 : *Oedogonium* sp. : A-D. Successive stages of development of ovum

### Distribution of Sex Organ:

Based on the size of the male (antheridial) filament the species of *Oedogonium* are divided into two groups macrandrous and nannandrous type:

### 1. Macrandrous Type:

In macrandrous type the antheridium develops in the filament of normal size.

It is of two Types:

i. Monoecious type (homothallic or bisexual). In this type (e.g., *O. fragile*, *O. nodulosum* and *O. hirnii*) antheridia and oogonia are borne on the same filament (Fig. 3.79).

ii. Dioecious type (heterothallic or unisexual). In this type (e.g., *O. gracilius*, *O. cardiacum* and *O. aquaticum*) the antheridia and oogonia are borne on the different filaments (Fig. 3.80).

### 2. Nannandrous Type:

The nannandrous species are always dioecious (heterothallic) i.e., antheridia and oogonia are borne on different filaments. In this type the antheridia develop on a very small filament termed as dwarf male or nannandrium. In nannandrous type initially androsporangia are developed in series on normal sized filament. The androspore form singly within androsporangium.

Liberating from androsporangium, the androspores swim freely in water. The androspore germinates on the oogonial wall (*O. ciliatum*) or on supporting cell (*O. concatenatum*) and forms dwarf male filament. Towards the apical region, the dwarf male filament cuts off small cells as the antheridial mother cells.

Each antheridium produces two antherozoides. The androspores, antherozoids and zoospores are morphologically alike but differ in their sizes (Table 3.1). The androspores are smaller than zoospores (produced asexually) but larger than antherozoides.

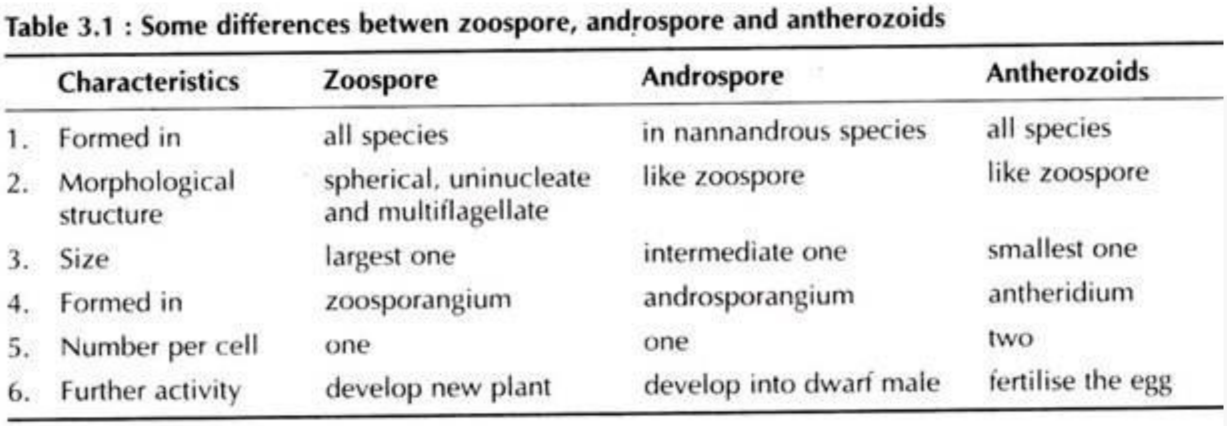


Table 3.1 : Some differences betwen zoospore, androspore and antherozoids

| | Characteristics | Zoospore | Androspore | Antherozoids |
|---|---|---|---|---|
| 1. | Formed in | all species | in nannandrous species | all species |
| 2. | Morphological structure | spherical, uninucleate and multiflagellate | like zoospore | like zoospore |
| 3. | Size | largest one | intermediate one | smallest one |
| 4. | Formed in | zoosporangium | androsporangium | antheridium |
| 5. | Number per cell | one | one | two |
| 6. | Further activity | develop new plant | develop into dwarf male | fertilise the egg |

**They are of two types:**

**i. Gynandrosporous Type:** In this type (*e.g., O. concatenatum*) the androsporangia and oogonia are borne on the same filament (Fig. 3.81).

**ii. Idioandrosporous Type:** In this type (e.g., *O. setigerum, O. confertum* and *O. iyengarii*) the androsporangia and oogonia are borne on different filaments (Fig. 3.82).

**Sexual Reproduction in Macrandrous Species:**

The structure and development of antheridium and oogonium are similar in all the species belonging to either monoecious or dioecious type. They differ only in the position of sex organs.

**a. Antheridium:** Any cap cell of the vegetative filament may function as antheridial mother cell (Fig. 3.75). It divides transversely into an upper smaller antheridium and a lower larger sister cell. The sister cell then undergoes repeated transverse division and form an uniseriate row of about 2-40 rectangular uninucleate antheridia.

The nucleus of the antheridium undergoes mitotic division and forms 2 nuclei. Each nucleus becomes surrounded by some cytoplasm and metamorphoses into an antherozoid. Thus two antherozoids are developed from each antheridium.

The antherozoids are unicellular, uninucleate, multiflagellate and yellowish in colour. The liberation of antherozoid is similar to zoospore formed during asexual process.

**b. Oogonium:** Any cap cell of the vegetative filament may function as oogonial mother cell (Fig. 3.76). It divides transversely into an upper oogonium and a lower supporting cell or suffultory. The lower cell may again undergoes similar divisions in repeated sequence to form two or more oogonia with a lower supporting cell.

With maturity the oogonium becomes globose, which contains single egg. A receptive spot is present at one side of the egg. Before fertilisation a transverse slit or pore develops on the oogonial wall through which the antherozoids take the entry.

**Sexual Reproduction in Nannandrous Species:**

The structure and development of androsporangium, antheridium and oogonium are similar in all the species either belonging to Gynandrosporous or Idioandrosporous type. They differ only in the position of androsporangium.

**a. Androsporangium:** The mode of development of androsporangia is alike with the antheridial development in macrandrous species. The androsporangia are larger than the antheridia of macrandrous type. The nucleus of androsporangium does not divide and the entire protoplast metamorphoses into a single androspore.

The androspores are unicellular, uninucleate and multiflagellate. The androspores are larger than the antherozoids. The androspores are liberated by breaking the wall of androsporangium. During liberation each androspore remains in a mucilage envelop for few minutes and then becomes free to swim in water (Fig. 3.77A, B).

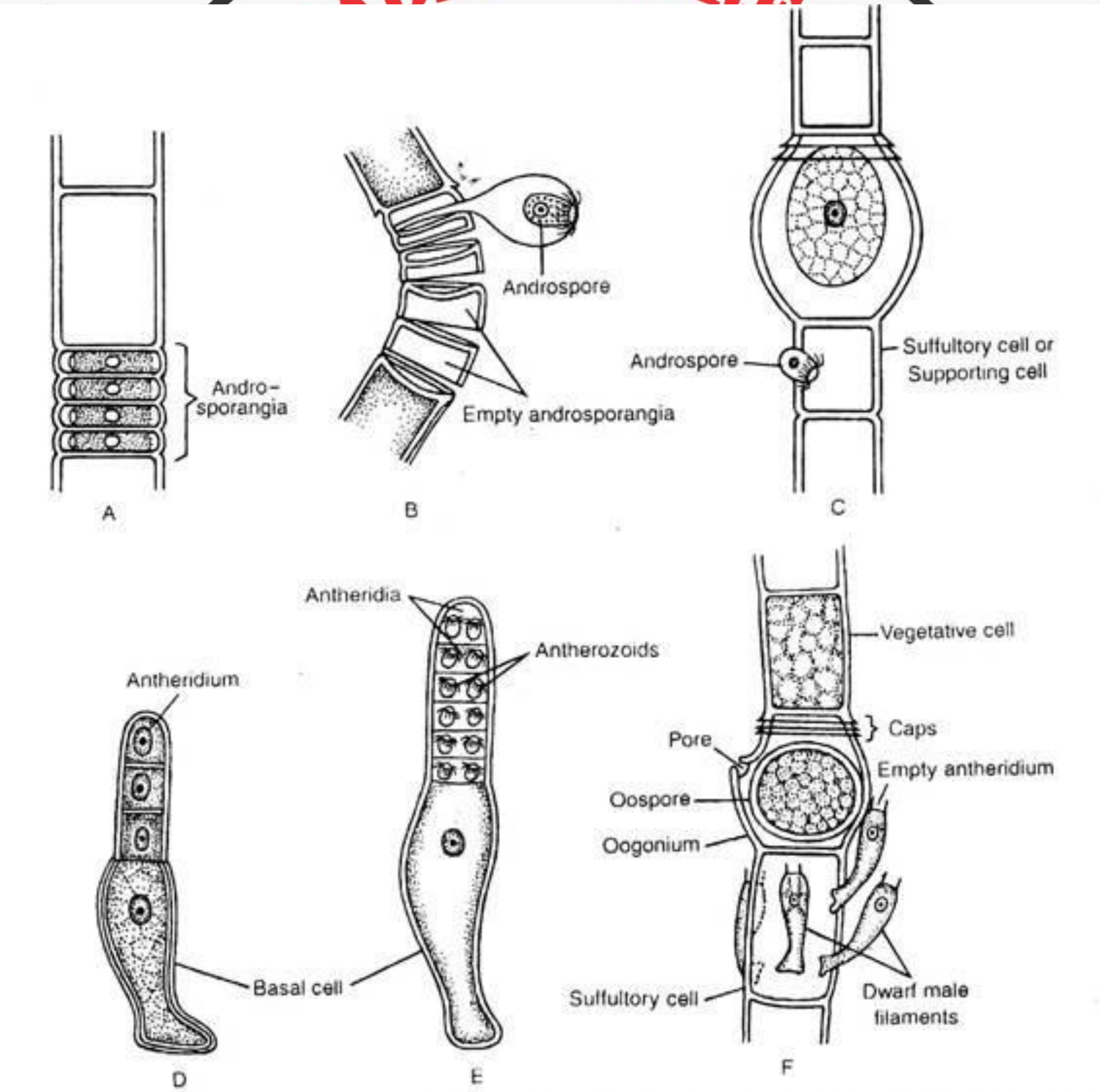


Fig. 3.77 : *Oedogonium* sp. Development of dwarf male : A-B. Development of androspore, C. Attachment of androspore on suffultory cell, D-E. Development of dwarf male and formation of antherozoid, and F. Formation of oospore after fertilisation

**b. Germination of Androspore and Formation of Antherozoids:** After swimming for some time, it gets attached either on oogonial wall or on supporting cell (Fig. 3.77C). Then a wall develops around the androspore. The androspore elongates and cuts off a few flat cells at its apex to form the antheridia (Fig. 3.77D). The nucleus of each antheridium divides mitotically to form two nuclei.

Each nucleus with some cytoplasm metamorphoses into single antherozoid. Thus two antherozoids are formed in each antheridium (Fig. 3.77E). The antherozoids are liberated in a similar way as found in macrandrous species. The antherozoids swim in water for some time and in contact with receptive pore or slit, antherozoid enters inside the oogonium and fertilizes the egg.

**c. Oogonium:** The structure and development of oogonium are same as macrandrous species.

**Fertilisation:** Antherozoids are attracted by the mature oogonium through chemical stimulus. Normally only one antherozoid enters through the opening on the oogonial wall and fertilises the egg, resulting in the formation of a diploid zygote or oospore (Fig. 3.78A, B; 3.77F).

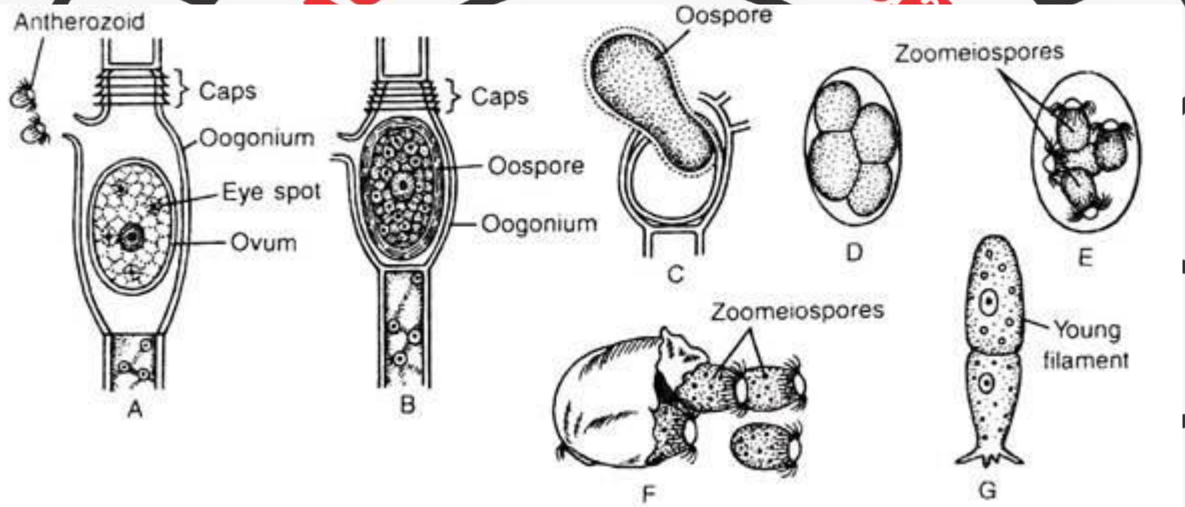


Fig. 3.78 : *Oedogonium* sp. : A. A stage before fertilization, B. Oospore in oogonium, C. Liberation of oospore from oogonium, D-E. Stages of zoospore formation, F. Liberation of zoospore, and G. Young filament develops after germination of zoomeiospore.

**Oospore:** The zygote during further development retracts itself from the oogonial wall and secretes 2-3 layered outer wall (Fig. 3.78B). Later on the outermost one becomes ornamented. The zygote generally undergoes a long period of rest and becomes brown in colour.

**Germination of Oospore:** The oospore germinates during favourable condition (Fig. 3.78C-G). The nucleus undergoes meiosis and forms 4 haploid daughter nuclei. The nuclei accumulate some cytoplasm and form 4 daughter protoplasts. They liberate by rupturing the oospore wall. During liberation they develop flagella and are called meiospores or zoomeiospores.

Initially they remain inside a delicate vesicle, which soon disintegrates and the zoospores get free into the environment. After swimming for some time in water they withdraw their flagella and germinate into new haploid *Oedogonium* filament like zoospore in asexual reproduction. The nature of zoomeiospore development varies in monoecious and dioecious species.

In monoecious species all the zoomeiospores develop into similar *Oedogonium* filament.

In dioecious species out of 4 zoomeiospores, 2 develop into male and other 2 develop into female *Oedogonium* filaments.

**Life Cycle of Oedogonium:** Fig. 3.79-3.82 depict life cycle of Oedogonium.

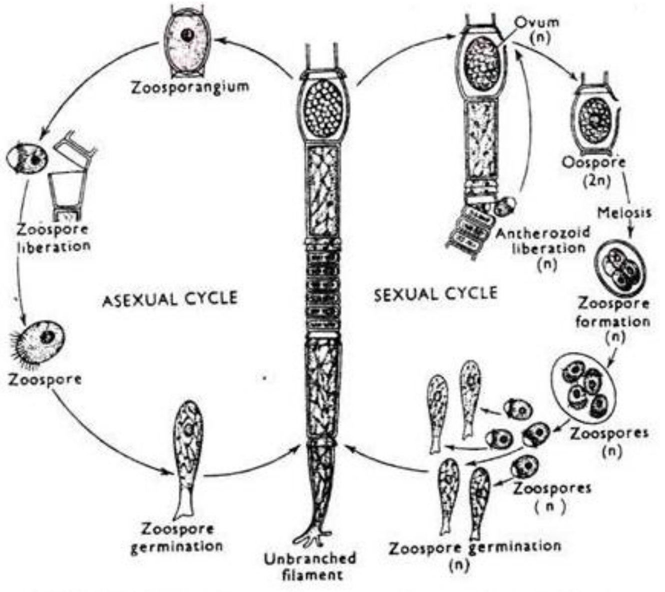


Fig. 3.79 : Life cycle of macrandrous monoecious species of *Oedogonium*

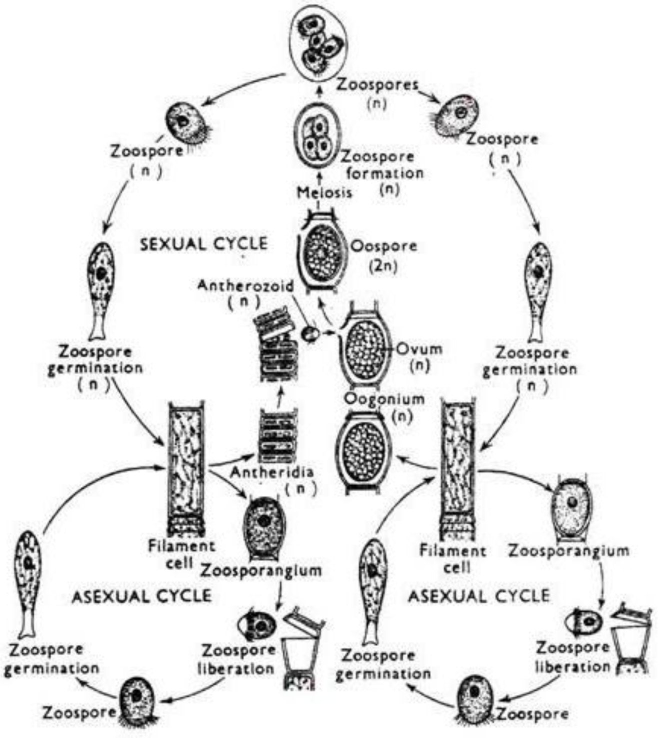


Fig. 3.80 : Life cycle of macrandrous dioecious species of *Oedogonium*

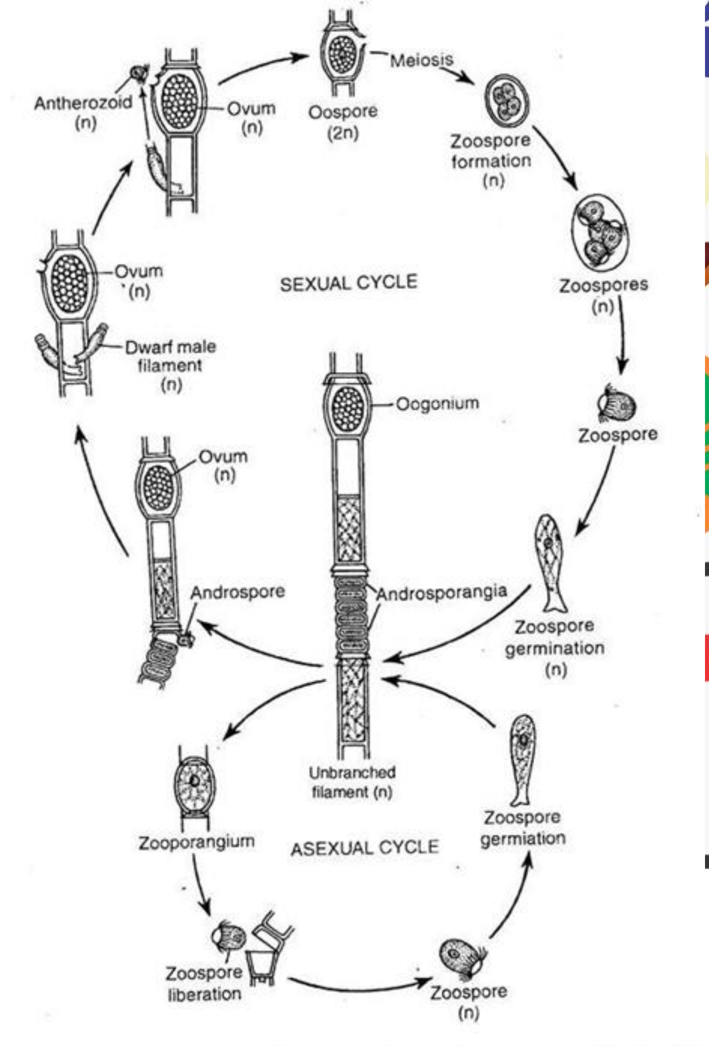
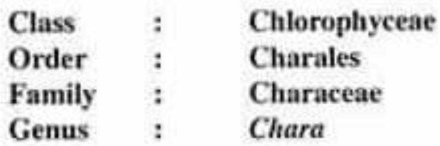


Fig. 3.81 : Life cycle of nannandrous (all are dioecious) – gynandrasporus species of *Oedogonium*



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

## Occurrence of Chara:

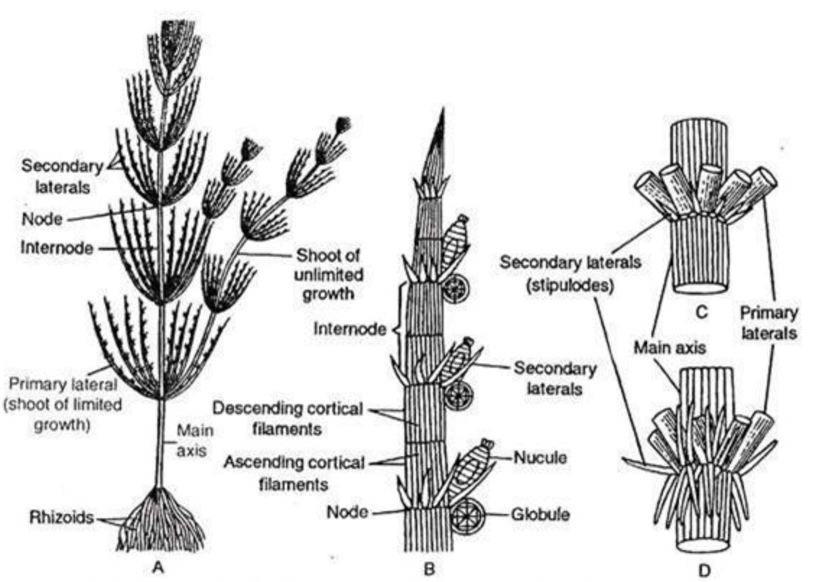


Fig. 3.91 : *Chara* sp. : A. External morphology, B. Shoot (branch) of limited growth or primary lateral, C-D. Appendages on node (C. Haplostephanous and D. Diplostephanous type)

*Chara* is represented by about 188 species, out of which 30 species are found in India. It is commonly known as “stonewort”. The plant body of *Chara* is encrusted with calcium and magnesium carbonate especially on the plants growing in heavy water.

Thus the plants become strengthened and called stoneworts. Generally they grow in fresh water of ponds, lakes, tanks etc. in submerged condition. Some species like *C. tragilis* grows in hot spring, whereas *C. baltica* grows in brackish water.

**Plant Body of Chara:** Chara is a macroscopic, multicellular, profusely branched thalloid plant body, generally attains a height of about 20-30 cm (rarely about 1 meter). It is differentiated into rhizoid and main axis (Fig. 3.91 A).

**A. Rhizoid:** The rhizoids are thread-like, white, multicellular, uniseriate and branched. It is an elongated branched structure having oblique septa. They are developed either from the base of the plant body or from peripheral cells of lower nodes of the main axis.

**B. Main Axis:** It is an erect, long, branched epigeal portion of the plant body, which is differentiated into internodes and nodes.

**(i) Internodes:** Generally it consists of two types of cells: i. axial cell or internodal cell, and ii. cortical cells.

**i. Axial Cell:** It consists of an elongated central cylindrical cell (Fig. 3.94)

**ii. Cortical Cells:** These are elongated but much smaller in diameter than axial cell and ensheathed or corticated as a layer on the outer surface of axial cell (Fig. 3.94). They originate from the node. After originating from the node, 50% of the cortical cells grow upward as the ascending filaments and the rest 50% grow downward as the descending filaments (Fig. 3.91 B).

The ascending filaments cover the lower half and descending filaments cover the upper half of the axial cell. Cortication is not common in all the species.

Depending on the presence or absence of cortex, the species of Chara are divided into two types: Corticate (e.g., *C. fragilis, C, zeylanica, C. hatei* etc) and Ecorticate (e.g., *C. corallina, C. suc- cinata, C. wallichii, C. braunii* etc.).

**(ii) Node:** The node consists of two cells surrounded by 6-20 peripheral cells (Fig. 3.91 C, D). Three types of appendages are developed from each node.

**These are:**

1. Branches of unlimited growth,

2. Branches of limited growth, and

3. Stipulodes.

**1. Branches (Shoots) of Unlimited Growth:** They are also called axillary branches or long laterals (Fig. 3.91 A) and are developed from the older nodes. These branches are also differentiated into nodes and internodes like the main axis. Each node bears branchlets like the main axis.

**2. Branches (Shoots) of Limited Growth:** They are also called primary laterals, branchlets or leaves (Fig. 3.91 B). About 6-16 branchlets develop in whorls around the node of main axis or branch of unlimited growth. It is also divided into 5-15 nodes and internodes. Each node develops some unicellular, hair-like secondary laterals. Sex organs are developed on lower nodes of each branchlet.

**3. Stipulodes:** These are unicellular outgrowths developed from lower nodes of branchlets i.e., branches of limited growth. The number of stipufode at each node may be equal to the number of branchlets which is called unistipulate (*C. nuda, C. brouni, C. coralline*) or if double it is called bistipulate (*C. contraria, C. tomentosa, C. baltica*):

Depending on the arrangement of stipulodes species of *Chara* are divided into haplostephanous (i.e., stipules are arranged in single row) e.g., *C. braunii*, and diplostephanous (i.e., stipules are arranged in two rows) e.g., *C. delicatula* (Fig. 3.91 C, D).

**Cell Structure of *Chara*:** The nodal cells are short, uninucleate, with dense and granular cytoplasm and many discoid chloroplasts without pyrenoids. Small vacuoles may be present in the cytoplasm.

The internodal cells are long, with a large central vacuole, many nuclei and many discoid chloroplasts in the cytoplasm. The cytoplasm is differentiated into outer ectoplasm and inner endoplasm. The endoplasm shows streaming movement.

**Growth:** Growth of *Chara* takes place by a dome-shaped apical cell. The cell undergoes repeated transverse divisions and form a row of three cells (Fig. 3.92A-B). 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 divisions 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 internode (Fig. 3.92).

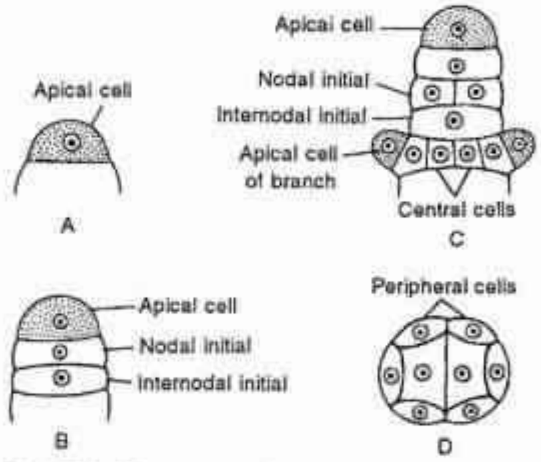


Fig. 3.92 : *Chara* sp. : A-C. Stages of growth, and D. T.S. of node

**Reproduction in *Chara*:** It reproduces by both vegetative and sexual means. Asexual reproduction is absent.

**Vegetative Reproduction:**

**The vegetative reproduction takes place by the formation of following structures:**

**1. Bulbils:** These are small oval or spherical bodies developed on stem or root nodes. Bulbils are formed on root of *C. aspera* and stem of *C. baltica*. After detachment, they germinate and develop new plants (Fig. 3.93A, B).

**2. Amorphous Bulbils:** These are small cells developed and aggregated at the node, called amorphous bulbils. They are found in *C. fragilis*, *C. baltica* etc. On being detached from the mother plant, they germinate and develop into new plants (Fig. 3.93C).

**3. Amylum Stars:** These are multicellular aggregations of cells, looking like stars and the cells are densely filled with amylum starch; thus they are called amylum stars. The amylum stars are developed at the nodal cells of the basal region e.g., *C. stelligera* (Fig. 3.93D).

**4. Secondary Protonema:** These are thread like structures developed from primary protonema or from the basal cell of the rhizoid. New plants are also developed from the secondary protonema.

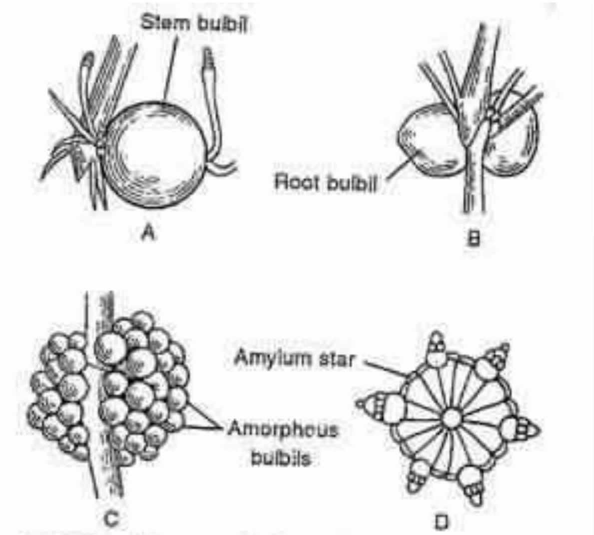


Fig. 3.93 : *Chara* sp. : A. Stem bulbil, B. Root bulbil, C. Amorphous bulbil, and D. Amylum star

**Sexual Reproduction:** It is an advanced oogamous type. The sex organs are macroscopic and large. The male sex organ is spherical and yellow to red in colour, called globule. The female sex organ is more or less oval and green in colour, called the nucule or oogonium.

They develop on the nodes of the branch of limited growth (i.e., primary lateral), intermingled with secondary laterals. Nucule is always situated singly above the globule (Fig. 3.91 B, 3.94).

Most of the species are homothallic or monoecious (i.e., male and female sex organs develop on the same plant), but some are heterothallic or dioecious (e.g., *C. wallichii*).

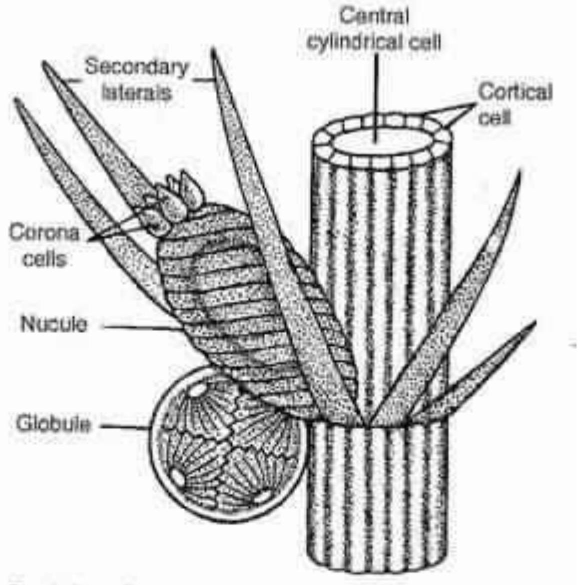


Fig. 3.94 : *Chara* sp. : A portion of the branch of limited growth showing attachment of nucule, globule and secondary laterals at the node

**Structure of Mature Globule:** Mature globules are spherical in shape and yellow to red in colour (Fig. 3.95C). Each globule consists of eight curved plates, situated towards the outer side, which are the shield cells.

From the inner side of the each shield cell, a centrally placed rod shaped structure is developed, called the manubrium. At the distal end of each manubrium one or more globose cells developed are called primary capitula. Each primary capitulum develops two or more secondary capitula.

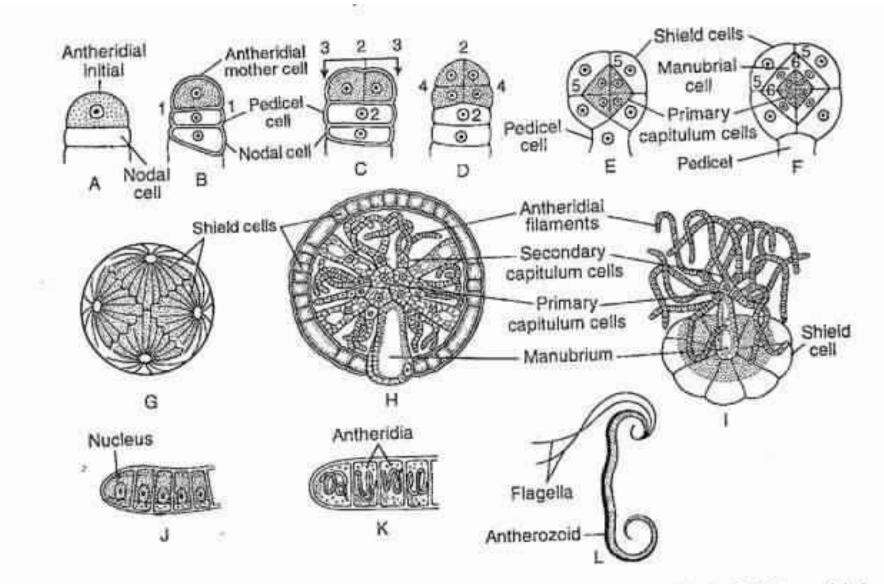


Fig. 3.95 : *Chara* sp. Development of globule. A-F. Stages in the development of globule, G. Mature globule, H. Globule in longitudinal section, I. A shield cells with manubrium, primary and secondary capitulum cells and spermatogenous filaments

Finally each secondary capitulum develops 2-4 long antheridial-filaments (Fig. 3.95H, I). Each antheridial filament has 25-250 cells and each cell i.e., antheridium (Fig. 3.95J, K) forms a biflagellate, coiled and uninucleate antherozoid (Fig. 3.95L). Thus a globule can develop as much as 20,000 to 50,000 antherozoids.

**Structure of Mature Nucule or Oogonium:**

The nucule of Chara is oval with a short stalk. Like globule it is also developed at the node of primary laterals just above the globule in homothallic species. It consists of centrally placed one central cell, one stalk and one large egg at the top (Fig. 3.96H). The entire structure is covered from the base by five spirally twisted tube cells except at the apex, where they form a crown made up of five corona cells (Fig. 3.94, 3.96H).

The jacket of nucule shows similarity with the neck cells of archegonium of Bryophyte.

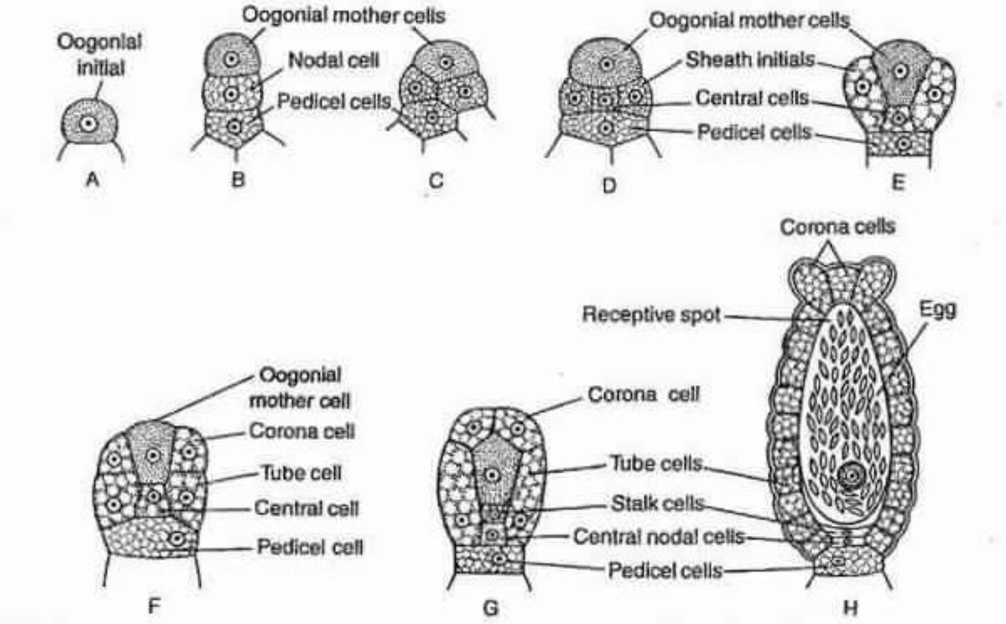


Fig. 3.96 : *Chara* sp. Development of nucule : A-G. Stages in the development of nucule, and H. L.S. of Mature nucule

**Development of Sex Organ in Chara:**

Development of globule (Fig. 3.95). The globule develops at the node of branches of limited growth. Single peripheral cell of each node functions as the antheridial initial (Fig. 3.95A). The antheridial initial first undergoes transverse division (1-1) to form 2 cells, of which the lower one is the pedicel cell, which forms the stalk.

The upper one is the antheridial mother cell. The antheridial mother cell, then undergoes two vertical divisions right angle to each other (2-2, 3-3) followed by one transverse division (4-4), thus an octant (8 celled stage) is formed.

Each cell of the octant stage then undergoes periclinal division (5-5) to form outer 8 and inner 8 cells. Either the outer or the inner cells then undergo another periclinal division (6-6), thus forming 3 layers of 8 cells each (Fig. 3.95B-F).

The outer 8 cells form the 8 shield cells, the middle 8 cells form the manubrium and the inner 8 cells form primary capitula. The primary capitula further divide and form two or more secondary capitula (Fig. 3.95H, I).

Each secondary capitulum further divides and forms 2-4 antheridial filaments consisting of 25 to 250 anthridial cells or antheridia, formed by repeated mitotic divisions. The protoplast of each antheridium metamorphoses into single biflagellate and coiled antherozoid (Fig. 3.95J, K, L).

Development of nucule (Fig. 3.96). The oogonial initial is developed from the peripheral nodal cell of the primary laterals (Fig. 3.96A). The oogonial initial cell undergoes two transverse divisions thus forming a 3 celled stage. The lowermost is the pedicel cell, middle one is nodal cell and uppermost one represents the oogonial mother cell (Fig. 3.96B). The pedicel cell remains undivided and forms stalk of the nucule.

The middle one undergoes several vertical divisions thus 5 sheath initials are formed which surround a central cell (Fig. 3.96C, D). The oogonial mother cell divides transversely and forms lower stalk cell and upper egg (Fig. 3.96G). The egg elongates further and forms an oval structure. The apical region of the egg develops the receptive spot. Large amount of oil and starch are deposited in the ovum.

The sheath initial elongates further and divides transversely into upper small cells, the corona cells which form a crown-like structure at the top of the oogonium and the lower five cells form the tube cells (Fig. 3.96F, G). The tube cells elongate and become spirally twisted in a clockwise direction outside the oogonium, giving protection to the egg (Fig. 3.94).

**Fertilisation:**

During fertilisation the tube cells just below the corona get separated slightly and form five narrow slits or openings. The antherozoids get entry through these slits (Fig. 3.96H). Out of many aggregated antherozoids towards the slits, only one comes near the receptive spot of the egg. On contact with the egg, it fuses and forms an oospore (2n).

**Oospore:**

It is hard, spherical to ellipsoidal in shape and of various colours like light yellow, brown, red or black. It is surrounded by four layered walls, of which the outer two are coloured and inner two are colourless.

**Germination:**

During germination the nucleus of oospore migrates towards the upper region (Fig. 3.97B). The nucleus then undergoes meiotic division to form 4 haploid nuclei (Fig. 3.97C). The oospore then divides into two unequal cells of which the upper lenticular cell contains one nucleus and lower large basal cell contains three nuclei (Fig. 3.97D). The nuclei of the basal cell gradually degenerate.

The lenticular cell projects out by rupturing the oospore wall and divides mitotically by an oblique longitudinal septum to form a larger protonemal initial and a small rhizoidal initial (Fig. 3.97E). Both the initials grow in opposite direction.

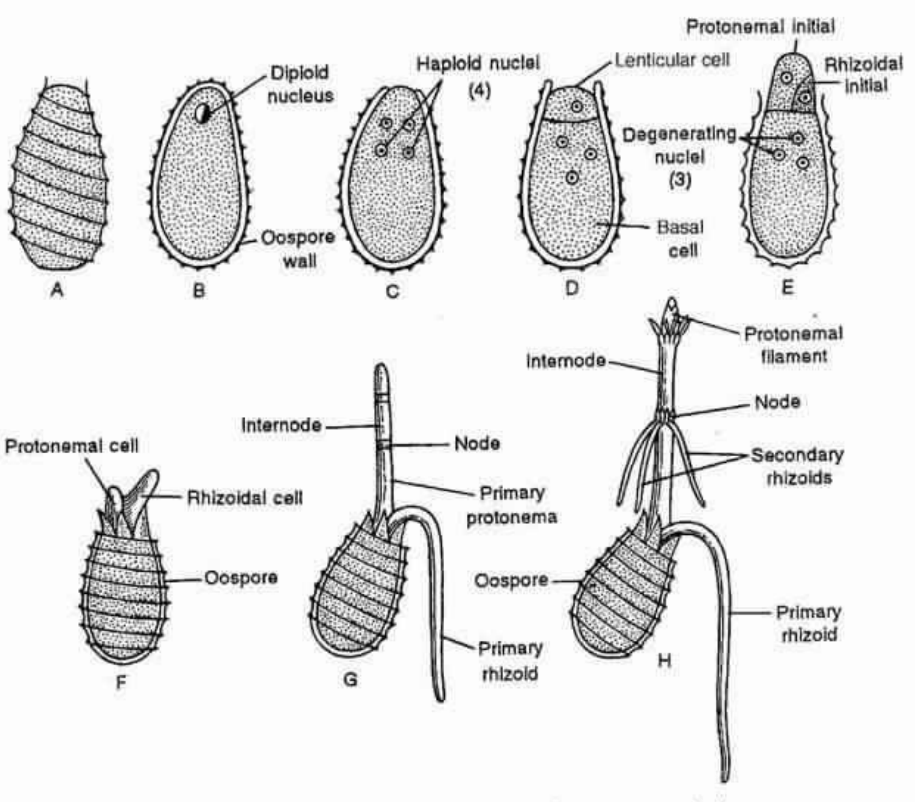


Fig. 3.97 : *Chara* sp. : A-H. Succesive stages in oospore germination

The protonemal initial is differentiated into nodes and internodes and form the upper part of the plant body, whereas the rhizoidal initial forms rhizoids (Fig. 3.97F, G, H). Secondary rhizoids may develop from the lower node of protonemal filament (Fig 3.97G)

**Life Cycle of Chara: Fig. 3.98 depicts the life cycle of Chara.**

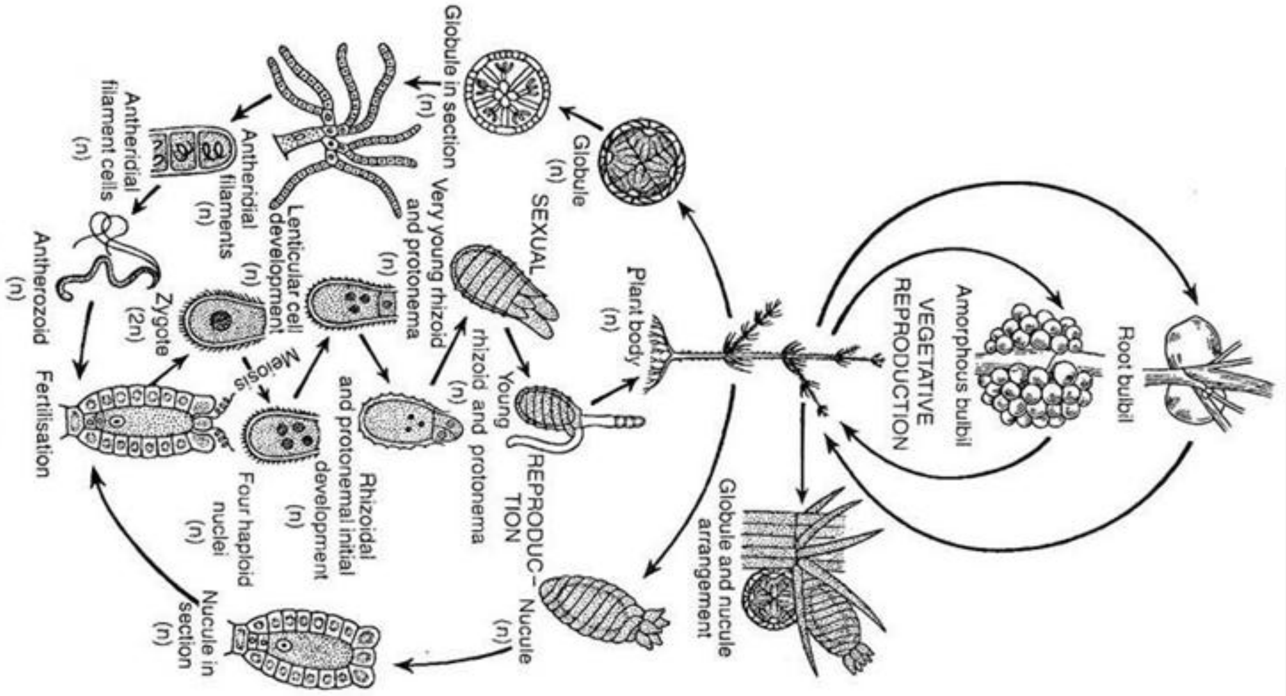


Fig. 3.98 : Life cycle of *Chara* sp.

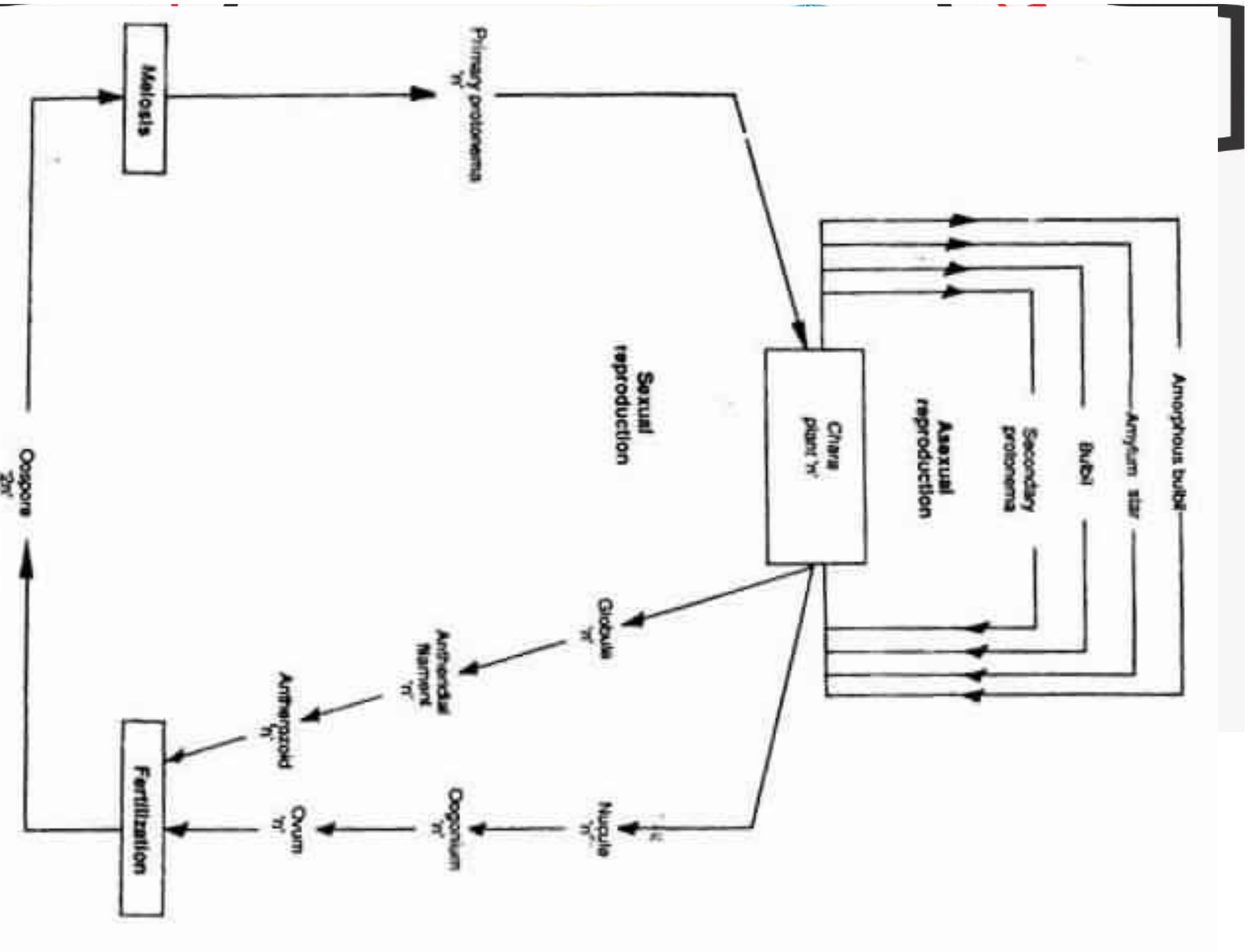
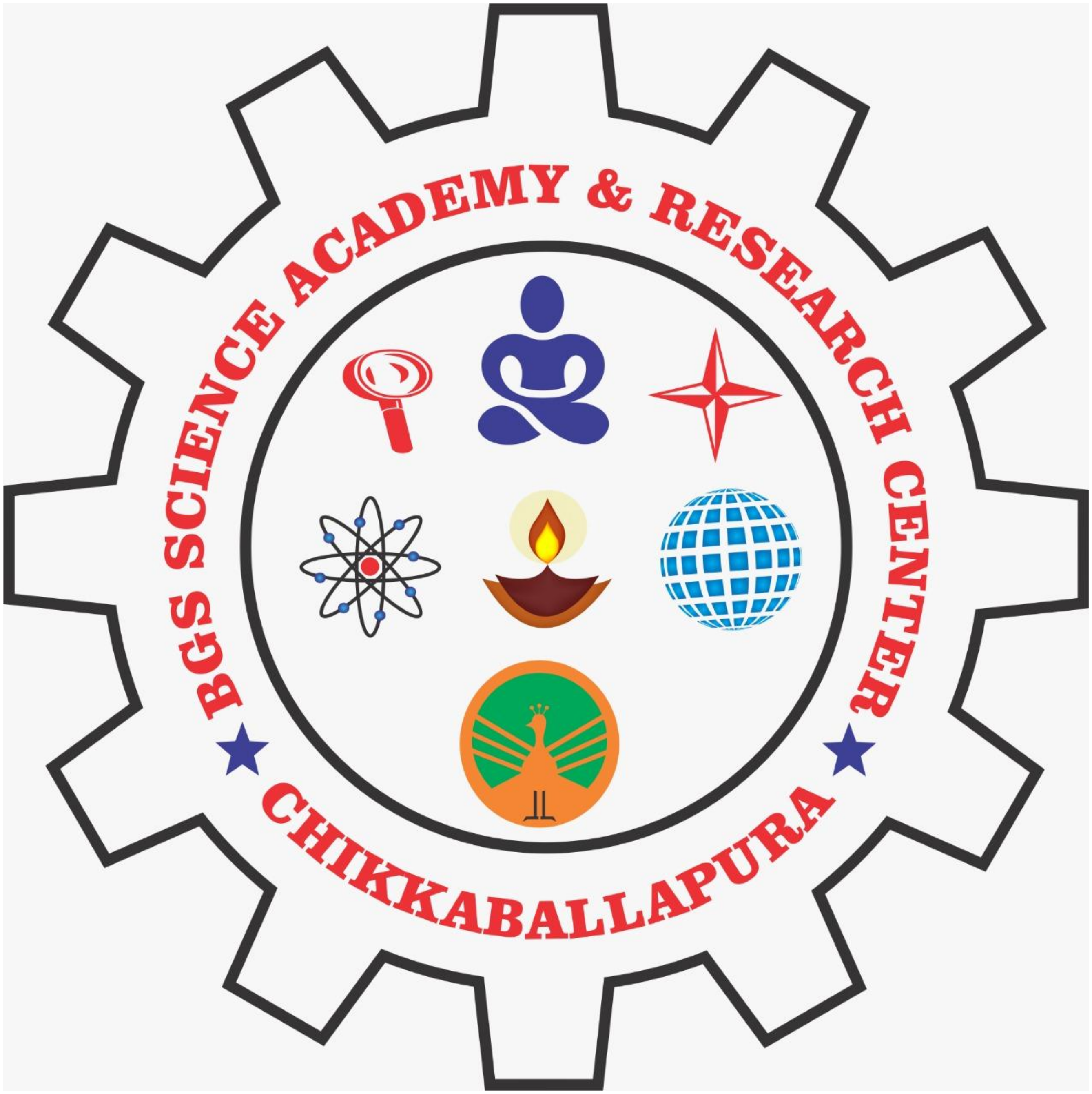


Fig. 13. *Chara*. Graphic life Cycle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CHIKKABALLAPURA

# ***Sargassum***

**Classification:**

Class : Phaeophyceae
Order : Fucales
Family : Sargassaceae
Genus : *Sargassum*

**Occurrence:** The genus *Sargassum* (Spanish sargazo, sea-weed) is represented by about 150 species, out of which 16 species are found in India. It is found in temperate, subtropical and tropical regions of both northern and southern hemispheres. It is very common in Africa, South America, Australia etc.

In West Africa, a part of Atlantic Ocean becomes densely occupied by *Sargassum* and the region is called as 'Sargasso sea'. *Sargassum filipendula*, a free-floating large kelp found in the Sargasso Sea, was discovered by Columbus in 1492, as the ships were held fast by the sea weeds. In India it is found in Porbandar, Bombay, Okha, Lakshadweep Island etc.

**Common Indian species:** *Sargassum ilicifolium*, *S. tenerrium*, *S. wightii*, *S. duplicatum*, *S. myriocystum*, *S. christifolium*, *S. carpophyllum*, *S. cinereum* and *S. plagiophyllum*.

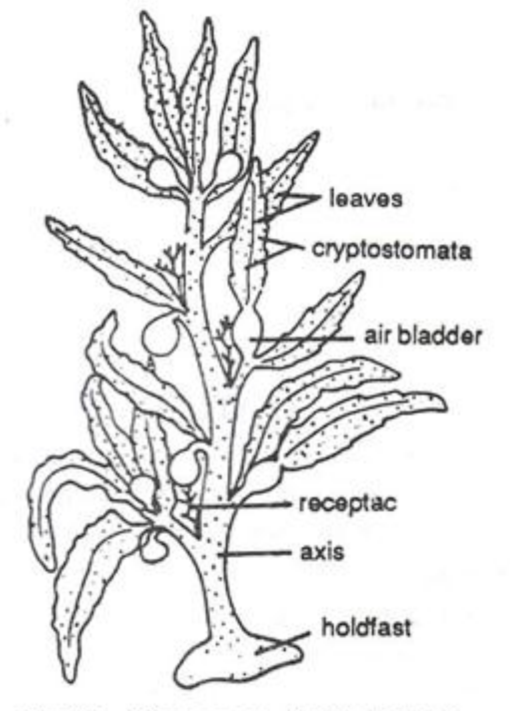

*Fig. 38. Sargassum. A mature plant.*

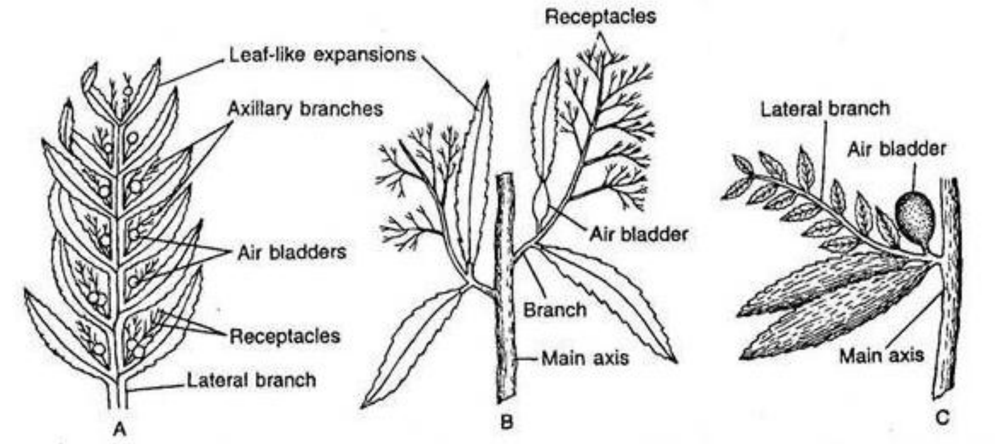

Fig. 3.116 : *Sargassum* sp. A. Portion of a branch with leaf-like expansions, air-bladders and receptacles, B. Portion of the main axis showing arrangement of branches, leaf-like expansions and receptacles, and C. Lower part of main axis with lateral branch and air bladder

**Plant Body:** The plant body is diploid (2n), erect and branched thallus (Fig. 3.116). The thallus is differentiated into a basal holdfast and an expanded, leafy, cylindrical main axis.

The holdfast is discoid and serves the function of anchorage with the substratum. The main axis is generally of 10 to 50 cm in length. It is erect, flattened or cylindrical structure. The main axis bears many primary laterals arranged spirally in a phyllotaxy of 2/5.

Due to its unlimited growth, the primary laterals are also called long shoots. The main axis and primary laterals (long shoots) bear flat' expanded structures, called secondary laterals or leaves.

The leaves are flat, simple structures with distinct midrib and dentate, serrate or entire margins, with an acute apex.

Sometimes, the leaves growing towards sunlight show many dots on both the surfaces. These dots are the ostioles i.e., openings of the sterile conceptactes. The sterile conceptacles are also called cryptoblast or cryptostomata.

On the main axis as well as on the primary laterals, the secondary laterals i.e., the leaves are replaced by many spherical, hollow bodies, called air bladders. The air bladders help to float them in water (Fig. 3.116).

The axils of leaves develop long much branched flattened or cylindrical structures called receptacles. The receptacle bears many fertile flask-shaped structures, the conceptacles. The conceptacles bear sex organs.

**Internal Structure:**

**Axis:** It is generally of circular in outline and differentiated into three regions: outer meristoderm, middle cortex and innermost medulla (Fig. 3.117A).

The meristoderm is made up of single layer of closely packed cells. The cells are meristema- tic in nature. The cells contain chromatophores and perform photosynthesis. This layer can store food material.

The cortex is situated next to meristoderm and occupies major part of the axis. It consists of compactly arranged parenchyma cells of polygonal shape, rarely with intercellular spaces. The cells are smaller in size than meristoderm. Like the outer layer this layer also stores food material.

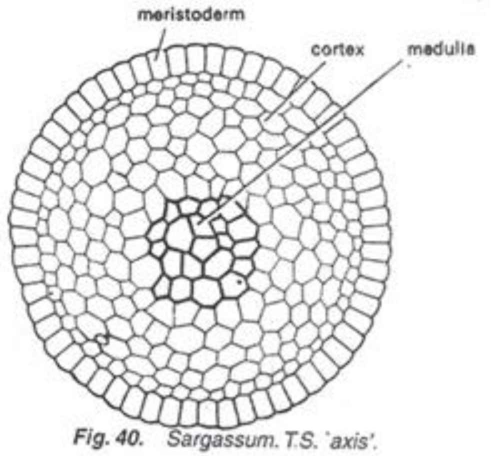

Fig. 40. Sargassum. T.S. 'axis'.

The medulla i.e., the inner layer consists of narrow, thick walled elongated cells. This layer possibly helps in conduction.

**Leaf:** It is flat and differentiated into outer meristoderm, middle cortex and inner medulla like the axis (Fig. 3.117B). The medulla is round and present in the middle region. On both surfaces of the leaf there are many sterile conceptacles, the cryptostomata or cryptoblasts (Fig. 3.117D).

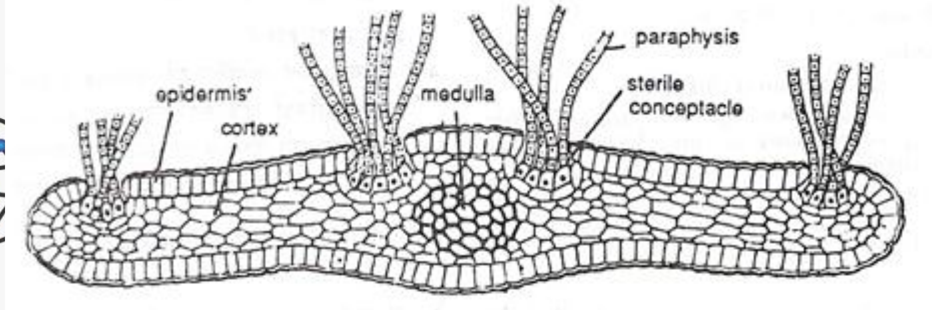

Fig. 41. Sargassum. T.S. "leaf".

These are flask-shaped with many sterile unbranched filaments, the paraphyses developed from the base. The paraphyses protrude out through the opening present on the outer side, the ostiole. The cells of the wall have many chromatophores.

**Air Bladder:**

Internally it is almost alike with the axis but without medulla (Fig. 3.117C). The central region is occupied by a large hollow cavity filled with air and gases. Outer to the cavity, cortex is present; which consists of a few layers and thinner cells than axis and finally it ends with a single layered outer meristoderm.

Thus the thallus shows division of labour along with differentiation of tissues. It serves the function of anchorage, photosynthesis, storage, conduction and support.

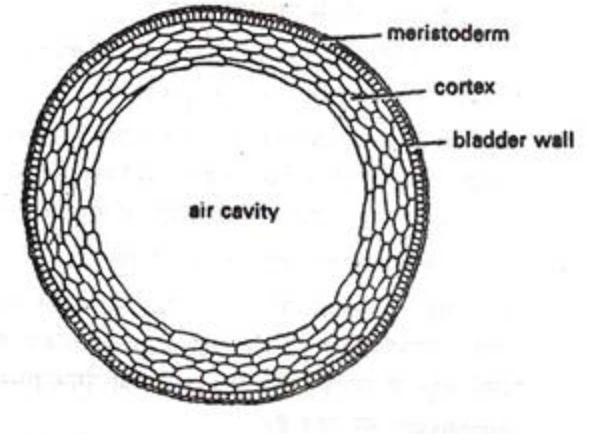

Fig. 42. Sargassum. T.S. through air bladder.

**Reproduction in Sargassum:**

It reproduces by both vegetative and sexual means. Asexual reproduction is absent.

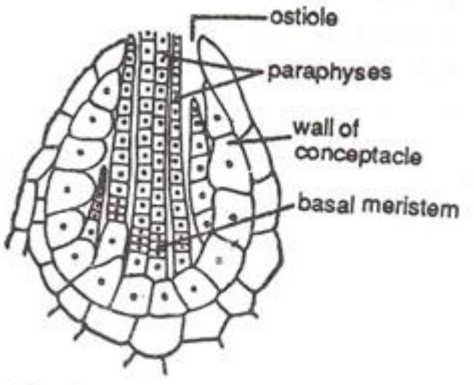

Fig. 43. Sargassum. V.S. young conceptacle.

**1. Vegetative Reproduction:**
It takes place by fragmentation. Due to death and decay of the older part, the younger region gets separated. The separated region grows and finally develops into a new individual like the mother. The free floating members like *S. hystrix* and *S. natans*, multiply only by this method.

**2. Sexual Reproduction:** It is of oogamous type and takes place by the union of antherozoid and egg, developed in antheridia and oogonia respectively. The sex organs develop in separate flask-shaped bodies the conceptacles, developed on branched receptacles. The conceptales with antheridia or oogonia are called male or female conceptacles. Plants are monoecious but a few species are dioecious. In monoecious plants also, the male and female sex organs are generally present in different .conceptacles. So, conceptacles are generally unisexual.

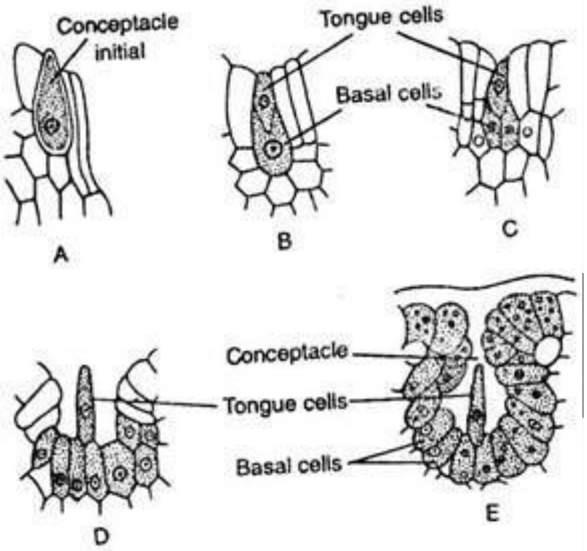

Fig. 3.118 : *Sargassum* sp. A-E Development of conceptacle

**Development of conceptacle-** The fertile and sterile conceptacle are almost similar. The difference lies in the activity of basal cells of the linear wall of conceptacle. In sterile conceptacle it only develops sterile hairs, the paraphyses, but in fertile conceptacle it develops either antheridia or oogonia and also paraphyses in some regions.

During development (Fig. 3.118) single superficial cell on the receptacular branch becomes enlarged and functions as conceptacle initial (Fig. 3.118A). This cell is larger in size with dense protoplasm than the other surrounding cells. The conceptacle initial becomes flask-shaped.

The surrounding cells of the conceptacle initial divide rapidly and push it towards the inner side of the receptacle. The conceptacle initial then undergoes mitotic division and by oblique septation it forms upper elongated tongue cell and lower broad basal cell (Fig. 3.118B).

The tongue cell elongates and gradually disappears. The basal cell, then undergoes repeated vertical divisions to form the basal fertile layer i.e., the inner layer of the conceptacle. The reproductive organs are developed from this inner layer.

**T.S. Receptacular Branch:**

1. Receptacle contains many flask-shaped fertile conceptacles.
2. Each conceptacle is in the form of a cavity opening outside by an ostiole.
3. Cells of conceptacle wall are filled with many chromatophores.
4. Wall of the conceptacle gives rise to many multicellular, branched or unbranched, hair-like paraphyses.
5. Each conceptacle contains either antheridia or oogonia, and known as male or female conceptacle, respectively.

**T.S. Through Male Conceptacle:**

1. In the male conceptacle are present many antheridia (Fig. 3.119H).
2. Each antheridium is a small, ovoid and stalked structure present generally on lower branches of paraphyses.
3. Many antheridia are present on a paraphysis (Fig. 3.119H).

4. Each antheridium contains many antherozoids.
5. Each antherozoid is unicellular, uninucleate and pear- shaped structure, with two laterally attached flagella.

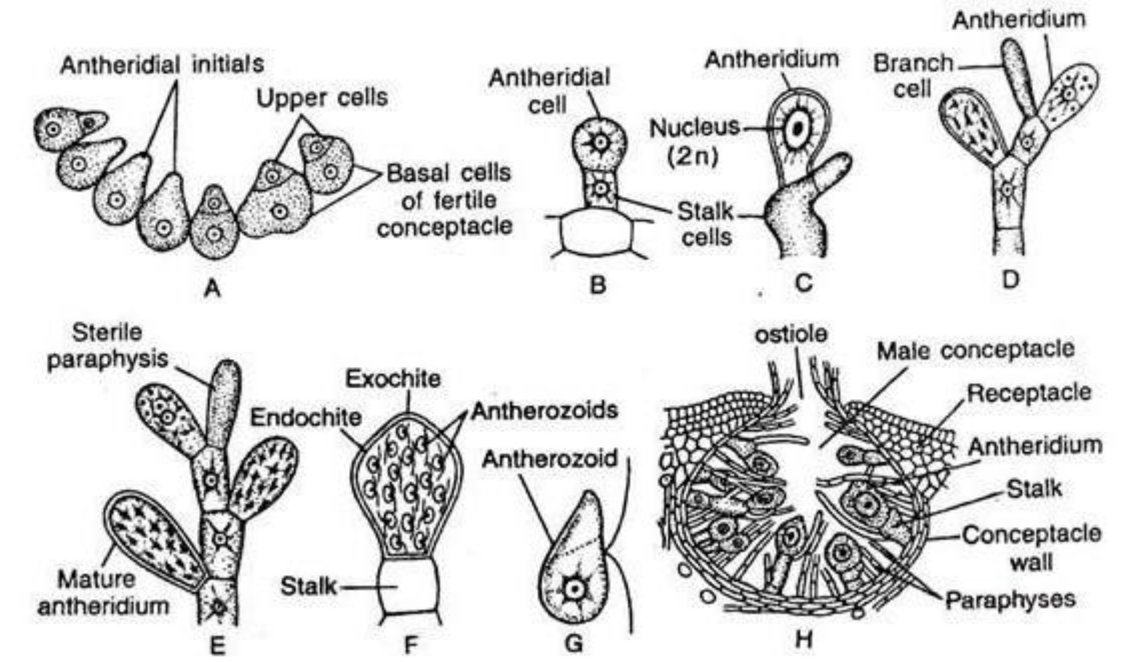

Fig. 3.119 : *Sargassum* sp. Development of antheridium : A. Cells of basal fertile layer of conceptacle, B-E. Development of antheridium, F. Mature antheridium, G. Single antherozoid, and H. V.S. of male conceptacle showing antheridium along with paraphyses

**T.S. Through Female Conceptacle:**

1. In structure, female conceptacles are the same flask- shaped cavities having many paraphyses, and opening by an ostiole (Fig. 3.120E).
2. Many oogonia (Fig. 3.120E) are present in the female conceptacle.
3. Each oogonium is rounded, and sessile when young, but contains long gelatinous stalk at maturity.
4. Oogonium remains surrounded by three-layered wall, i.e., exochite, mesochite and endochite.

5. Each oogonium contains a single uninucleate egg (Fig. 3.120F).

6.

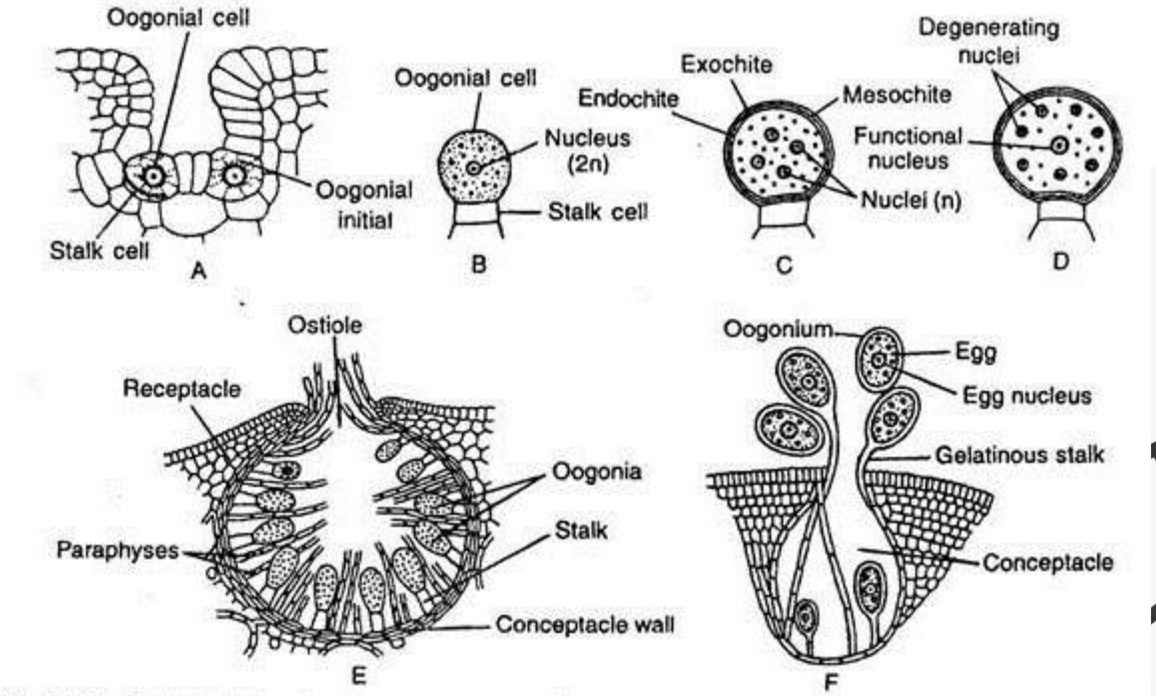

Fig. 3.120 : *Sargassum* sp. Development of oogonium : A-D. Development of oogonium, E. Vertical section of female conceptacle showing oogonia and paraphyses inside, and F. Release of oogonium from conceptacle

Fertilization is internal and zygote germinates without any resting period.

**Fertilisation:**

Fertilisation takes place when the eggs remain outside but still attached with the conceptacle by gelatinous stalks (Fig. 3.120F). Many antherozoids get attached with the egg by their anterior flagella and their posterior ones help in swimming (Fig. 3.121A).

Later on only one penetrates the oogonial wall. The remaining antherozoids get separated and gradually degenerate, Initially after fertilisation both the nuclei remain side by side (Fig. 3.121 B), but later they fuse together and form the zygote (Fig. 3.121C).

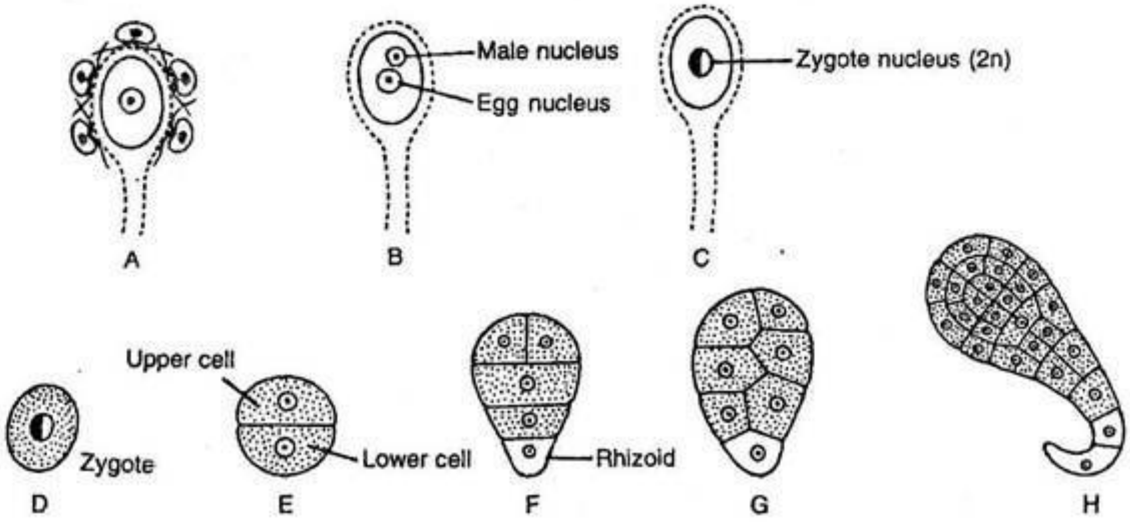

Fig. 3.121 : *Sargassum* sp. : A-C. Stages of fertilization, D. Zygote, E-H. Development of Zygote

**Germination of Zygote:**

Just after fertilization the zygote undergoes germination (Fig. 3.121D-H), while the oogonium still remains attached with the conceptacle. After some time it comes out of the gelatinous wall. After liberation, the zygote gets attached with any solid substratum.

The zygote then divides transversely and forms lower and upper cell. The lower cell develops into rhizoid and the upper cell undergoes repeated periclinal and anticlinal divisions, thus forming a thalloid sporophyte (2n) of Sargassum.

**Life Cycle Pattern of *Sargassum*:**

*Sargassum* shows diplontic life cycle without any alternation of generations (Fig. 3.122). The plant body is diploid except the antherozoids and eggs. The antherozoids and eggs i.e., the gametes, represent only the haploid (n) stage. After fusion zygote is formed. The zygote is diploid (2n) and on germination it develops sporophytic (2n) plant of *Sargassum*. Thus it shows a typical example of diplontic life cycle.

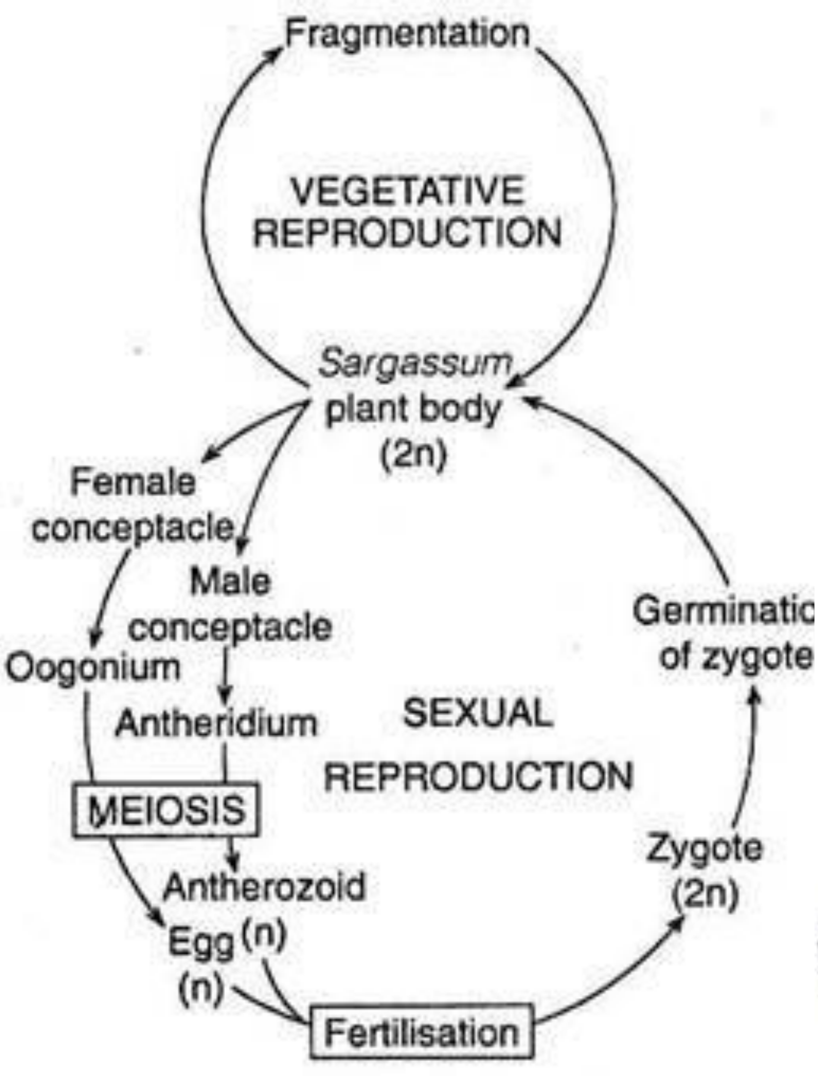

Fig. 3.122 : Graphic life cycle of *Sargassum* sp

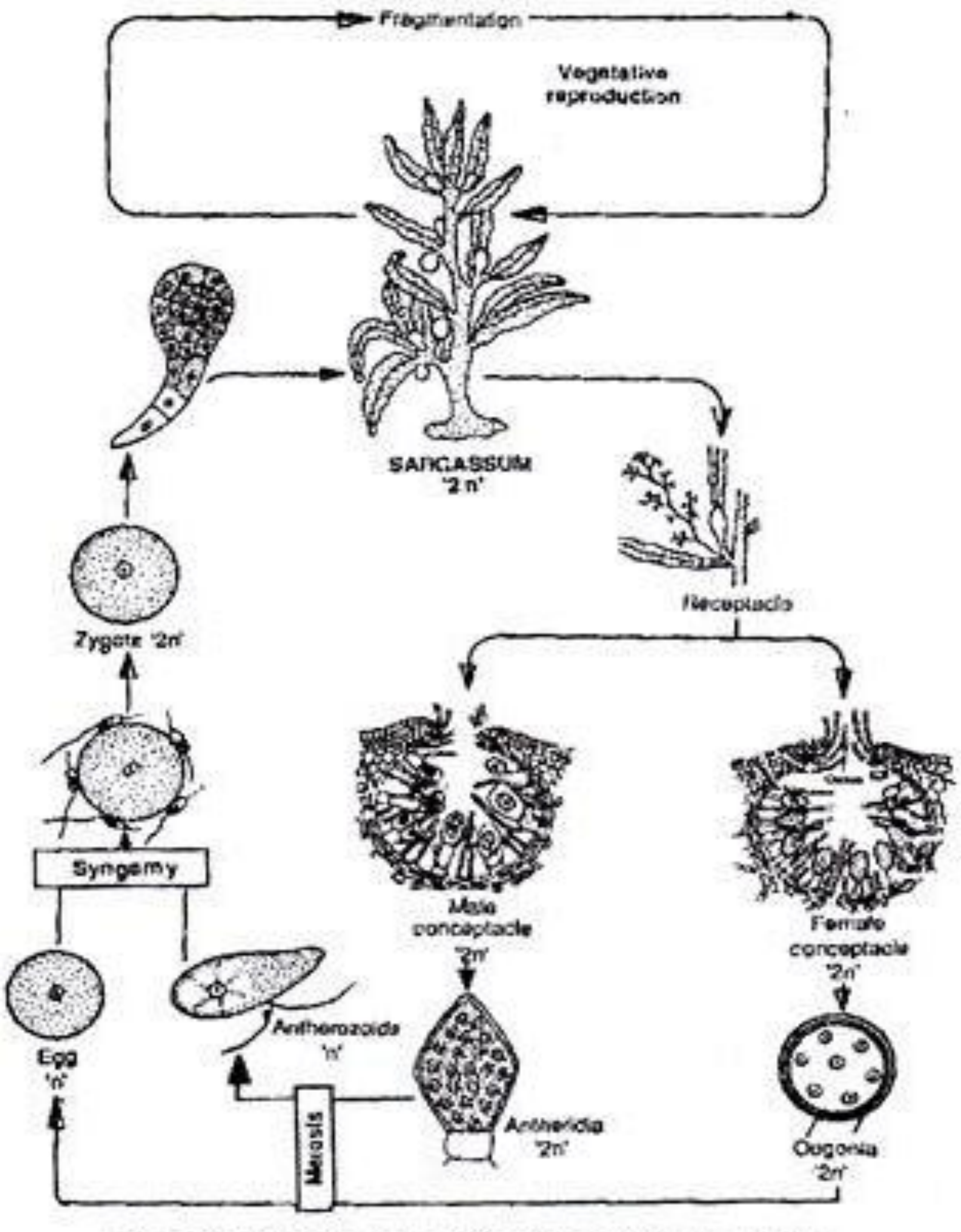

Fig. 10. *Sargassum*. Diagrammatic life cycle.

# POLYSIPHONIA

## SYSTEMATIC POSITION

Class : Rhodophyceae
Sub-class : Florideae
Order : Ceramiales
Family : Rhodomelaceae
Genus : *Polysiphonia*

**Occurrence:** The genus *Polysiphonia* (Gr. poly — many; siphon — tube) has 200 species, about 16 species are from India. They grow in marine habitat and are cosmopolitan in distribution.

Commonly found in littoral and sublittoral zones. In India they are found in western and southern coasts. Commonly, they grow as lithophytes i.e., on rocks or stones (e.g., *P. elongata*), some species like *P. urceola*, *P. terulacea* grow as epiphytes on *Laminaria*. *P. fastigiata* grows as semiparasite on *Ascophyllum nodosum*. **Indian Species:** *Polysiphonia tuticorinensis*, *P. sertularioides*, *P. platicarpa*, *P. suotilissima*, *P. unguiformis* etc.

**Plant Body:** It is multiaxial well branched thallus of dark brown, reddish or bluish red colouration appearing as a very small bush (Fig. 3.131 A). The height of the bush varies from a few to several centimeters. Most of the species are heterotrichous in habit, consisting of prostrate and erect systems.

**Prostrate System:** It may be multiaxial and well developed. From the lower side of the prostrate system many unicellular rhizoids are developed (Fig. 3.131B, C). The rhizoids are much lobed at the apex and form definite attachment discs (e.g., *P. urceolata*, *P. nigrescens*).

[In *P. elongata* and *P. violacea*, the prostrate system is absent and many rhizoids develop from the lower-most cells of the erect system and by aggregation they form massive attachment disc (Fig. 3.131C).]

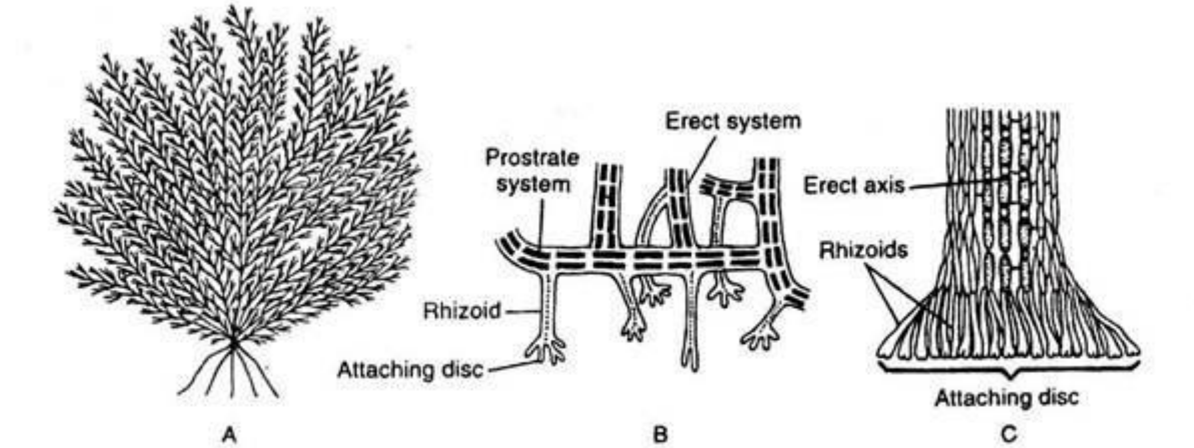

Fig. 3.131 : *Polysiphonia* sp. : A. Habit of Plant body, B. Lower portion of thalus with attaching disc and some erect filament developed on it, and C. Lower portion of *P. violacea* with a massive attaching disc

**Erect System:** The erect filaments develop from the prostrate system. The erect system consists of main axis and many branches (Fig. 3.132A). The branches are of two types: long branch and short branch.

The long branches are called branches of unlimited growth or long lateral branches and the short branches i.e., branches of limited growth are called trichoblasts. The long branches develop in a spiral or radial symmetry. The trichoblasts are spirally arranged, dichotomously branched, colourless and mostly annual structures bearing sex organs. The trichoblasts may develop both from main axis and long branches.

The main axis and long branches consist of a central siphon of many elongated cylindrical cells situated in vertical row (Fig. 3.132B, C). It is surrounded by 4-20 peripheral siphons. So the plant body is polysiphonous and named *Polysiphonia*. Only the central siphon is present at the apical region of both main axis and the long branches.

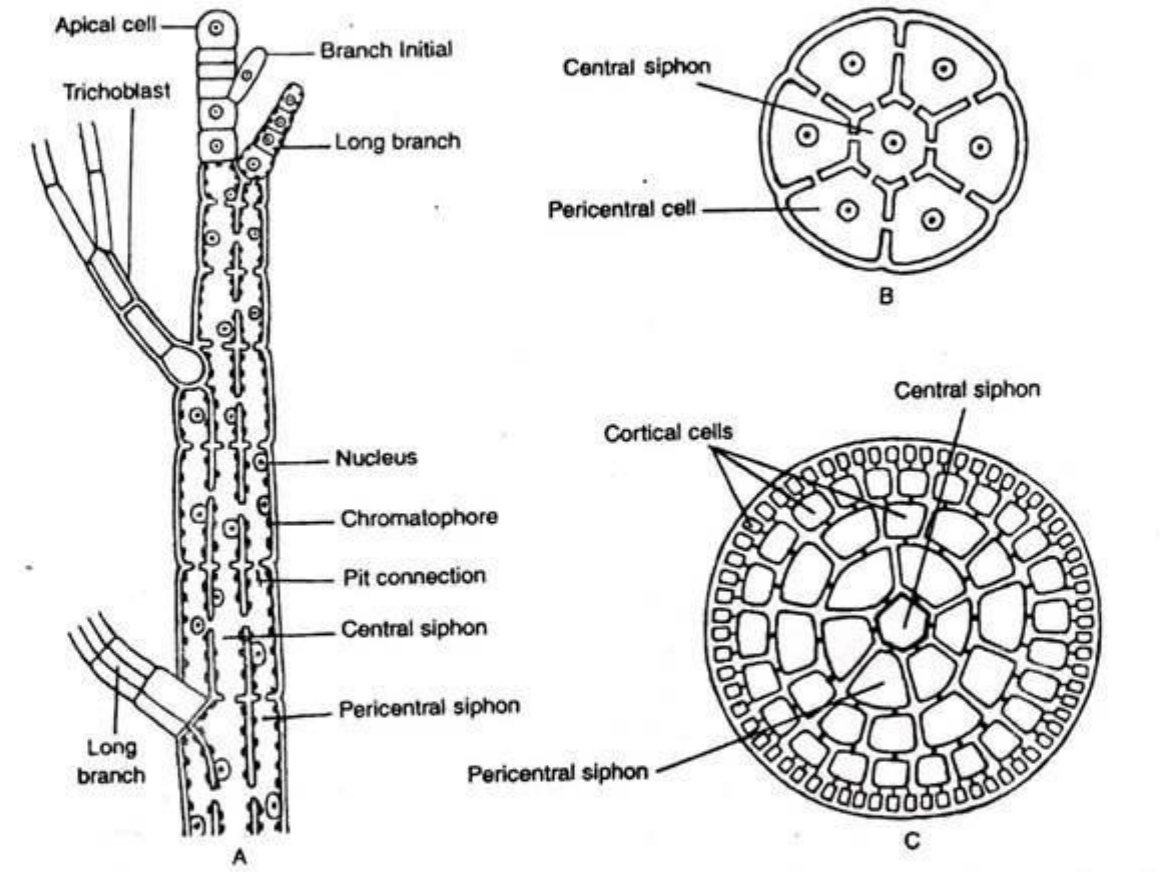

Fig. 3.132 : *Polysiphonia* sp. : A. Apical portion of a plant body showing central siphon, pericentral siphon, long branch and trichoblast, B. T.S. of thallus showing central siphon, surrounded by pericentral cells, and C. T.S. of old thallus showing cortical cells in addition to central and pericentral siphons

In most of the species, pericentral siphon is covered by 3 layers of cortical cells formed due to periclinal and anticlinal divisions of the cells of pericentral siphon. All cells of the plant body are connected with each other by pit connections (cytoplasmic connections). The short branches or trichoblasts are monosiphonous.

**Cell Structure:** The cells of central and pericentral siphons are cylindrical and elongated. The cell wall is differentiated into outer pectic and inner cellulosic layer. The cell contains a large central vacuole which is delimited by a membrane tonoplast. The cytoplasm is present between the cell wall and the central vacuole. The cell contains a number of red discoid chromatophores which lack pyrenoids.

The chromatophores contain pigments chlorophyll a, chlorophyll d, a carotene, (3 carotene, r-phycoerythrin and r-phycocyanin. The chromatophores are parietal in position (Fig. 3.132A). The central siphon cells and pericentral siphon cells possess single peripheral nucleus. The cytoplasm contains granules of floridean starch as food reserve.

**Growth:** The growth takes place by the dome shaped apical cell located on the tip of central siphon. The apical cell cuts many cells on lower side by transverse divisions which form the central siphon. Some of the lower cells divide vertically to form pericentral cells.

**Reproduction:** it reproduces both asexually and sexually. Sexual reproduction is of oogamous type. In the life cycle of *Polysiphonia* three kinds of plants are recognised.

**These are:**

1. Diploid tetrasporophyte,
2. Haploid gametophyte, and
3. Diploid carposporophyte (Fig. 3.138).

**1. Diploid Tetrasporophyte:**

It develops on direct germination of carpospore ($2n = 40$), thus the plant is diploid ($2n$). It is an independent plant which, instead of developing sex organs develops tetrasporangia. The diploid nucleus of tetrasporangia undergoes meiosis and develops four (4) haploid ($n = 20$) tetraspores.

**2. Haploid Gametophyte:**

It develops on direct germination of tetraspore (n); thus the independent plant is haploid (n). Most of the species are heterothallic, thus the spermatangia (male sex organ) and carpogonia (female sex organ) are developed on different plants.

**3. Diploid Carposporophyte:**

This stage is diploid (2n) and dependent on haploid gametophytic plants. The union between haploid (n) spermatium (developed inside spermatangium) and haploid female gamete (developed inside carpogonium) forms diploid (2n) nucleus inside the carpogonium.

Further development of diploid nucleus forms diploid carposporophyte. Later carpospores are formed by mitotic division of carposporangium. The carpospore on direct germination forms diploid tetrasporophyte plant.

**Asexual Reproduction:**

It takes place by haploid non-motile tetraspores.

The carpospores (2n) on direct germination develop diploid tetrasporophytic plants. The plants are independent and polysiphonous. Some pericentral cells of the thallus near apical region develop sac-like tetrasporangia. The diploid nucleus of tetrasporangium undergoes meiosis and forms four tetraspores. The spores are arranged tetrahedrally (Fig. 3.133A).

**Development of Tetraspores:**

Tetraspores are produced in tetrasporangia. Single pericentral cell of each tier, towards apical region functions as tetrasporangial initial (Fig. 3.133B). This initial cell is smaller than other pericentral cells of any particular tier. This initial cell divides vertically into inner and outer cells.

The inner cell functions directly into sporangial mother cell and the outer cell further divides and forms two or more cover cells. The sporangial mother cell divides transversely into lower stalk cell and upper tetrasporangial cell.

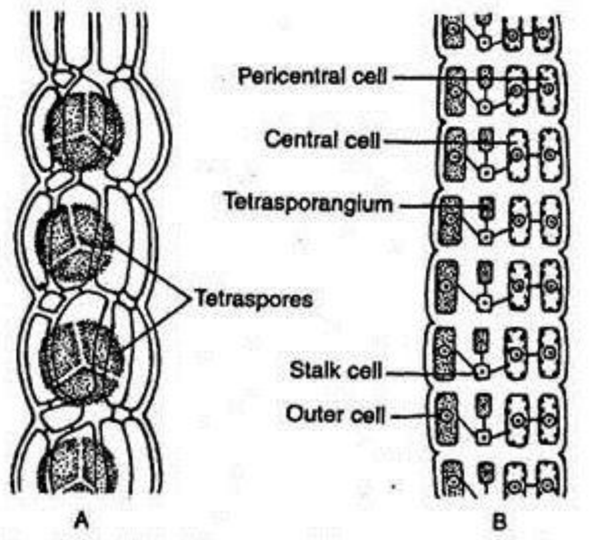

Fig. 3.133 : *Polysiphonia* sp. : A. Portion of tetrasporophytic plant (2n) with tetraspores, and B. Portion of tetrasporophytic plant showing development of tetraspores

The latter undergoes further enlargement and develops into a tetrasporangium. The diploid nucleus of tetrasporangium undergoes meiosis and forms 4 tetraspores or meiospores. The tetraspores are arranged tetrahedrally inside the tetrasporangium.

The mature tetraspores are liberated by rupturing the wall of the sporangium. On germination they develop gametophytic polysiphonous plant. Being heterothallic, out of four tetraspores, two produce male and the remaining two produce female gametophytic plants.

**Sexual Reproduction:**

Sexual reproduction is of oogamous type. Plants are commonly dioecious. The male sex organs i.e., spermatangia and female sex organs i.e., carpogonia, are developed on male and female plants, respectively.

**1. Male Reproductive Organ:**

It is called spermatangium or antheridium.

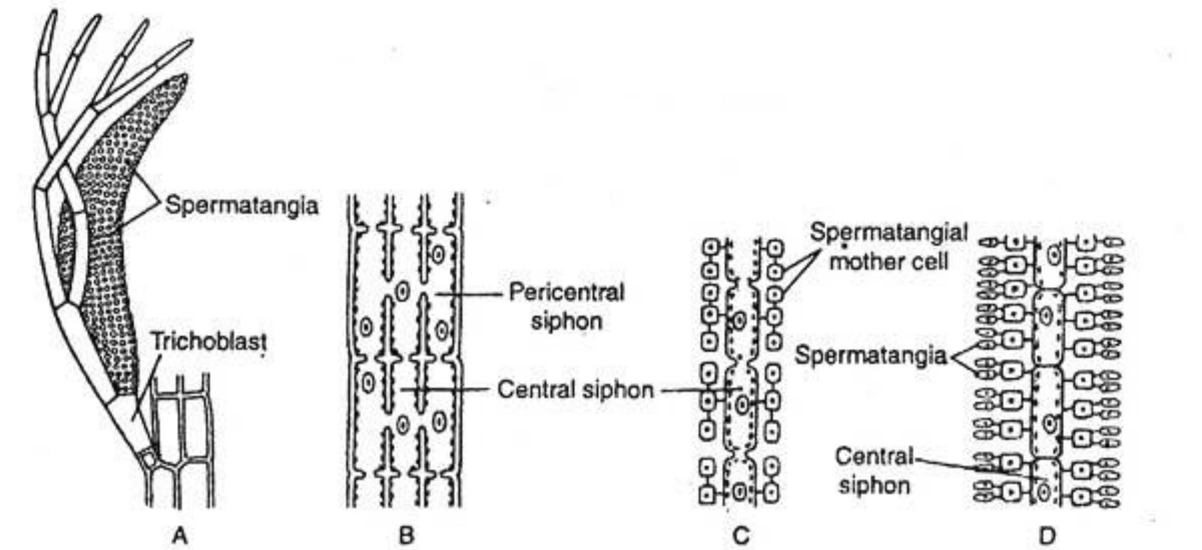

Fig. 3.134 : *Polysiphonia* sp. : Development of male reproductive organ. A. Portion of thallus with antheridial branch, and B-D. Sequential development of spermatangia

Initially male trichoblast develops as side branch on the plant body (Fig. 3.134A). It becomes branched. In some species both the branches become fertile, but in others only one remains fertile and the rest undergo repeated dichotomy to form dichotomous sterile structure.

The monosiphonous fertile branch(es) of male trichome bears many unicellular and spherical spermatangia. Each spermatangium is a uninucleate structure which produces single spermatium, the male gamete.

During development of spermatangium (Fig. 3.134B-D), all cells except a few basal cells, divide periclinally and form pericentral cells on both the sides. Each pericentral cell undergoes several divisions and forms spermatangial mother cells. Each one cuts off 2-4 unicellular bodies, the spermatangia. Each spermatangium develops into a single non-motile male gamete, the spermatium.

The spermatia are liberated from the spermatangium, through a narrow apical slit on the wall. The spermatia are dispersed through water.

**2. Female Reproductive Organ:**

The female reproductive organ is called carpogonium.

The carpogonium develops at the top of 2-5 celled carpogonial filament (Fig. 3.135). The carpogonial filament develops on the female trichoblast. The carpogonium is a flask-shaped body, with a basal swollen region containing an egg and an upper elongated neck region, the trichogyne.

During development of carpogonium, initially a female trichoblast initial is developed on central siphon, a few cells (3-4) below the apical cell. The female trichoblast initial, then undergoes repeated divisions and forms a female trichoblast of 5-7 cells. The lowermost three cells of the female trichoblast divide vertically and form three tiers of pericentral cells.

Any one of the pericentral cells of the middle tier towards the mother axis becomes the supporting cell. The supporting cell cuts off a small initial at its outside, the procarp initial (Fig. 3.135A). The procarp initially undergoes repeated divisions and forms a 4-celled branch, the procarp or carpogonial filament (branch) (Fig. 3.135B).

The apical cell of the carpogonial filament functions as carpogonium mother cell. The cell further develops into a carpogonium. The carpogonium has a swollen basal region containing egg and an elongated tubular region, the trichogyne (Fig. 3.135C).

At the later stage, the carpogonium develops two initials from the supporting cell, one at the base, the basal sterile filament initial (Fig. 3.135D) and another at the lateral side, the lateral sterile filament initial. The lateral sterile initial divides transversely and forms two-celled lateral sterile filament (Fig. 3.135E).

The carpogonium is ready for fertilisation at this stage. The pericentral cell adjacent to the supporting cell starts growing to cover the fertilised carpogonium. Later on they form sheath (the protective covering) around the fruit body, called as pericarp.

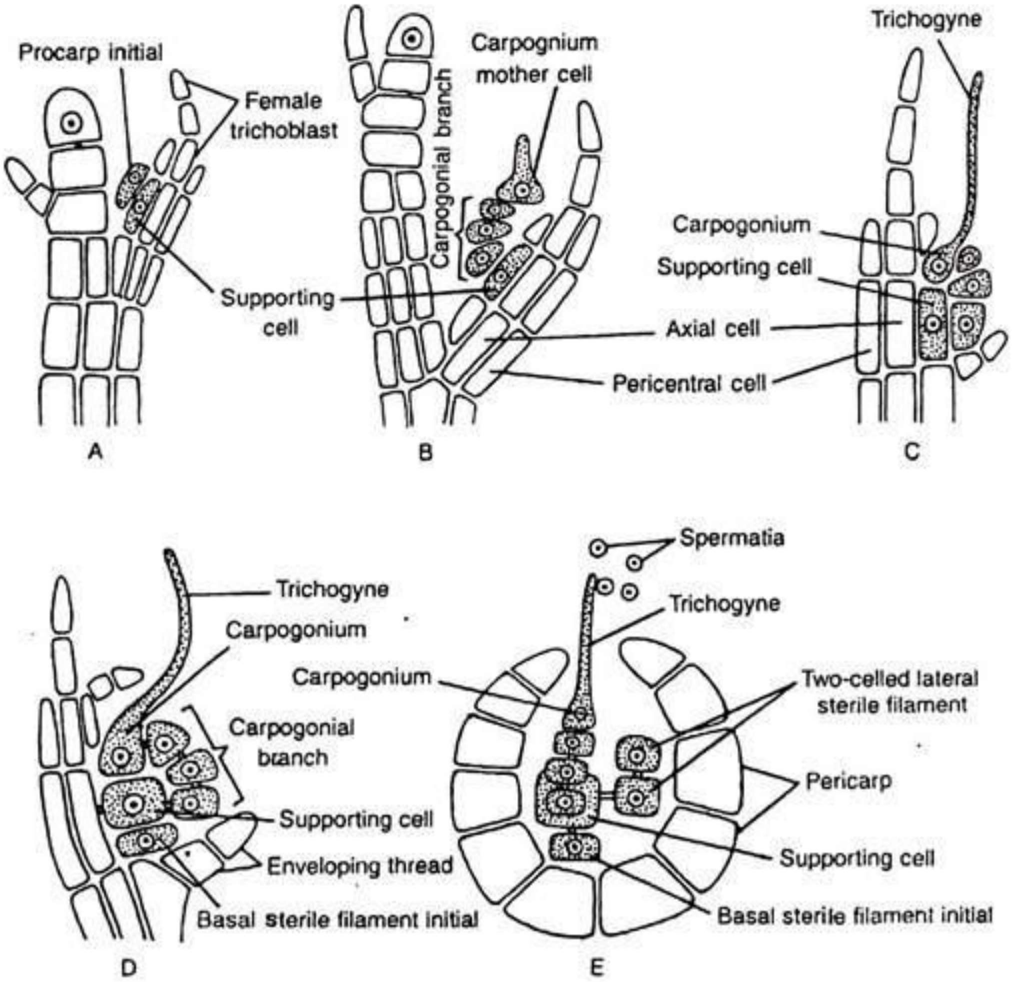

Fig. 3.135 : *Polysiphonia* sp. : A-E, Development of carpogonium

**Fertilisation:**

The spermatia are dispersed with the help of water. A few spermatia become attached at the tip of the. receptive trichogyne. Out of many, only one becomes successful. The common wall of successful spermatium and trichogyne dissolves at the point of contact and the male nucleus passes to the female nucleus present at the base of the carpogonium. The fusion between the nuclei results in the formation of zygote.

**Post-Fertilisation Changes:**

At the starting of this phase, an auxiliary cell is developed from the supporting cell situated just below the basal region of the carpogonium (Fig. 3.136A). Simultaneously, the lateral,.sterile filament increases in length (4-10 celled) by cell division as well as elongation and the basal sterile initial divides to form a two (2)-celled filament. The auxiliary cell has a single haploid nucleus.

A tubular connection is then developed between the auxiliary cell and carpogonium (Fig. 3.136B). The carpogonial nucleus (2n) divides mitotically into two nuclei, of which one is transported to the auxiliary cell and the other one remains in the carpogonium. Thus the auxiliary cell contains one haploid and one migrated diploid nuclei. The haploid nucleus (n) is degenerated. Gradually the trichogyne shrivels (Fig. 3.136B).

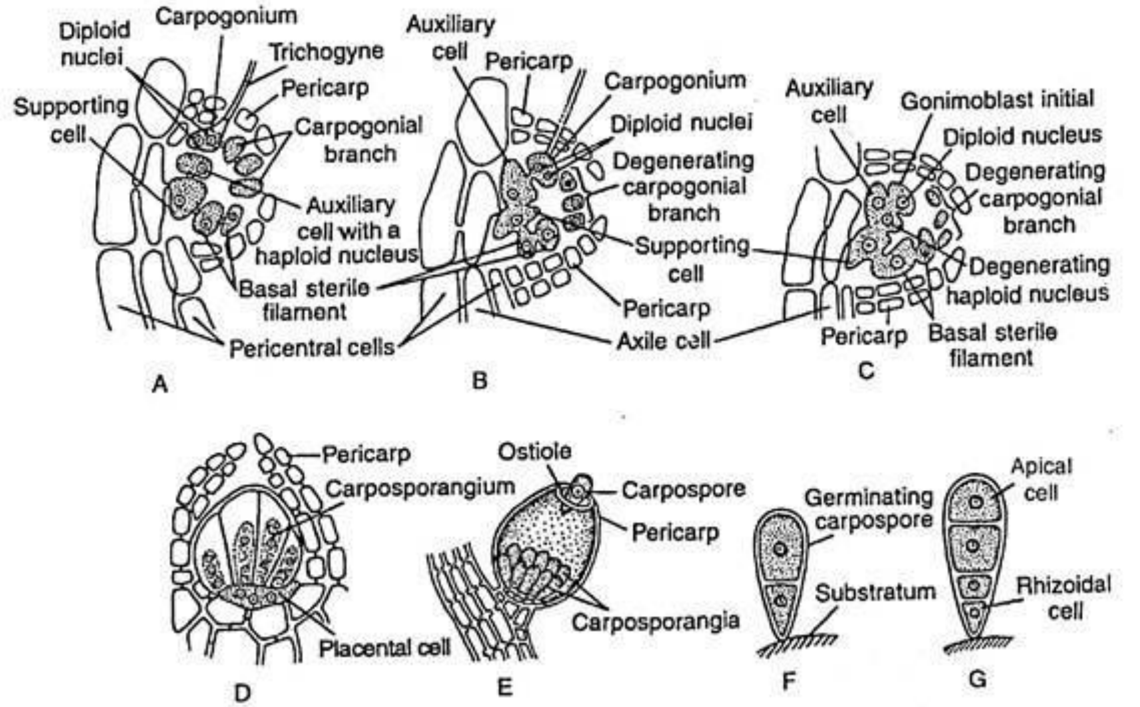

Fig. 3.136 : *Polysiphonia* sp. Post-fertilization changes : A. Fertilised carpogonium, B. Continuity between auxiliary cell and carpogonium, C. Degeneration of carpogonial filament, D. Formation of carposporophyte, E. Liberation of carpospore from mature cystocarp, F & G. Germination of carpospore

Many vegetative filaments then develop from the adjacent vegetative pericentral cells, which gradually develop the total covering. The diploid nucleus of auxiliary cell then divides mitotically and forms two nuclei. One of them then migrates into the outgrowth developed on the auxiliary cell.

This outgrowth after separating by a partition wall forms gonimoblast initial (Fig. 3.136C). In this way many gonimoblast initials can develop on auxiliary cell. Each initial by repeated mitotic divisions forms gonimoblast filament. The terminal cell of the gonimoblast filament develops into carposporangium, which forms single diploid carpospore inside (Fig. 3.136D, E).

During this development the auxiliary cell, supporting cell, carpogonium and some cells of basal and sterile filaments fuse together and form an irregular cell, the placental cell (Fig. 3.136D). The haploid nuclei (n) of the placental cell gradually degenerate and have simply a nutritive function.

The placental cell, gonimoblast filament and carpogonia are covered by many vegetative filaments and form an urn-shaped structure, the cystocarp (Fig. 3.136E, 3.137). The outer covering of cystocarp is called pericarp. The diploid part of the cystocarp represents the carposporophyte. Some cells of basal and sterile filament along with some cells of carpogonial filament gradually degenerate.

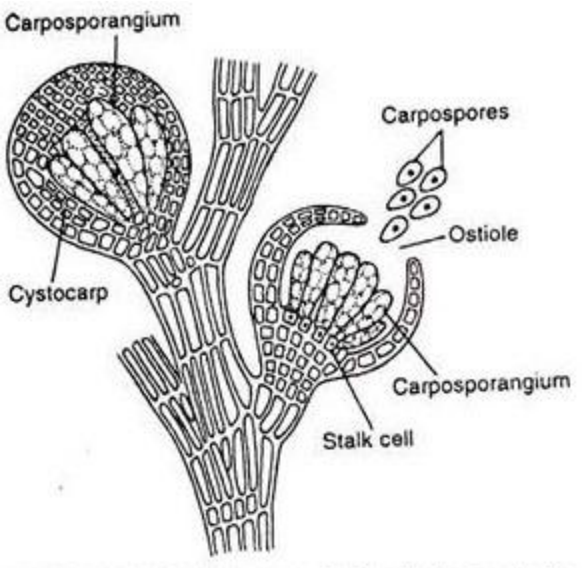

Fig. 3.137 : *Polysiphonia* sp. : A branch bearing cystocarps

The carposporangium develops single diploid carpospore. After liberating from the carpogonium they come out through the ostiole of cysto- carp (Fig. 3.137).

**Germination of Carpospore:**

Coming in contact with any solid surface, the diploid carpospore gets attached and then undergoes first mitotic division and forms large upper and small lower cells (Fig. 3.136F, G). Both the cells undergo mitotic division and form 4 celled stage.

The lower most cell forms the rhizoid, the upper one functions as apical cell and the rest cells undergo further development and form the polysiphonous body. This plant body is diploid i.e., the tetrasporophytic plant, which later develops the tetraspores and complete the cycle.

**Life Cycle of Polysiphonia:**

Life cycle of Polysiphonia consists of three distinct phases: diploid tetrasporophyte, haploid gametophytes and diploid carposporophyte.

Out of 4 tetraspores produced in tetrasporangia on diploid tetrasporophytic plant, two tetraspores develop haploid (gametophytic) male and other two haploid (gametophytic) female plants. The male gametophytic plants develop male gametes inside spermatangia and female gametophytic plants develop female gametes inside carpogonigia.

Zygote develops inside carpogonium after gametic fusion. With gradual development gonimoblast filament, carposporangia and carpospores are developed inside a composite structure, the cystocarp. It is the carposporophytic stage. Diploid carpospore on germination produces the diploid tetrasporophytic plant again.

Thus the life cycle is triphasic and haplo- diplobiontic type (Fig. 3.138).

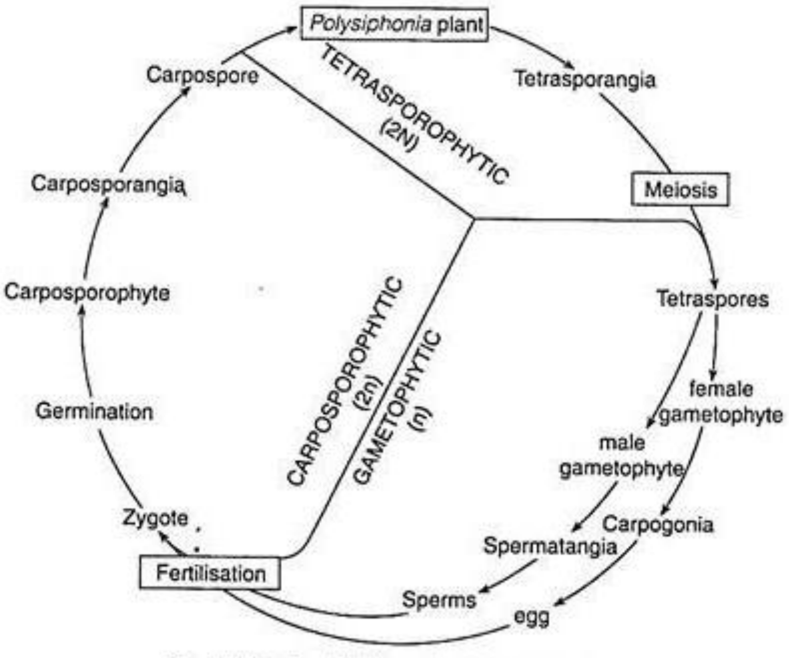

Fig. 3.138 : Graphic life cycle of *Polysiphonia* sp.

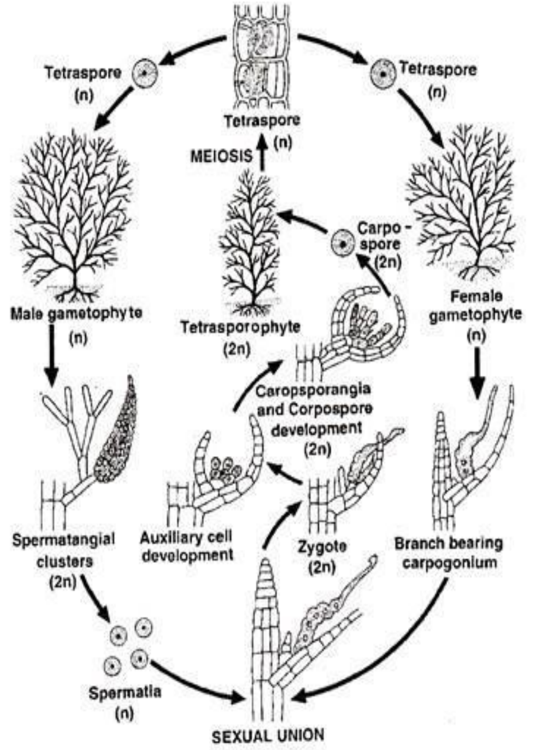

Fig. 8. *Polysiphonia*. Diagrammatic life cycle.