Discipline Courses-I
Semester-I
Paper: Phycology and Microbiology
Unit-VII
Lesson: Chlorophyceae- reproduction
Lesson Developer: Mani Arora
College/Department: Hindu College, University of Delhi

Table of Contents

Chapter: Chlorophyceae- reproduction

Introduction:

Reproduction in Chlorophyceae shows a great diversity, ranging from simple vegetative fragmentation to well differentiated sexuality. The reproduction in Chlorophyceae may be either vegetative, or asexual or sexual.

After studying this unit you will learn:

- How Chlorophycean algae produce offsprings
- Which environmental factors can control sexuality in Chlorophyceae
- Vegetative, asexual and sexual methods of reproduction in Chlorophyceae
- Life cycle patterns in Chlorophyceae and other green algae

How do the members of Chlorophyceae reproduce?

In the **vegetative mode** of reproduction, the algal body cuts off or break and gives rise to new individuals. This process is known as **fragmentation**. Vegetative reproduction also occurs by the formation of **akinetes** which are specially thickened vegetative cells. In the colonial *Dictyosphaerium* and in some filamentous forms, fragmentation is common, whereas forms like *Pleurococcus* and desmids are characterized by multiplication by ordinary cell division. **Asexual reproduction** by **zoospores** is widespread in *Ulothrix*, *Chlorococcum*. In some cases, the zoospores are non-motile and are known as arrested zoospores or **aplanospores**. These spores in some forms have thickened wall and are capable of enduring prolonged dessication and these are called **hypnospores**. In a number of algae, production of zoospores never takes place, although reproductive cells are formed. The cells contents divide and new cell walls are formed around the divided protoplasts. These cells acquire all the distinctive features of the parent, while still enclosed in the parent cell. These bodies are known as **autospores**. The formation of autospores is common in Chlorococcales.

Sexual reproduction is either **isogamous** or **anisogamous** or **oogamous** with specialized reproductive cells. Isogamy implies the fusion of morphologically similar gametes and the isogamous forms do not show differentiated organs for the production of sexual gametes. The gametes are always naked and uninucleate. Generally gametes from the same parent cell do not fuse, indicating an incipient dioecism. Since there is a lack of sexual dimorphism in isogamy, the gametes are designated as positive and negative. When

motile isogametes of opposite signs are brought together, within a few seconds the gametes form big aggregates and this phenomenon is known as clump-formation.

Can sexuality in Chlorophyceae be controlled by altering certain environmental factors?

Available evidences indicate that sexuality in green algae is largely controlled by environmental factors like **light**, **pH**, **temperature** and **nutrition**. In a growing population, sexually active cells first appear at the end of exponential phase as observed in cultures of *Chlamydomonas* and *Pandorina*. In certain cases **depletion of nitrogen** results in the formation of sexual gametes, whereas a rapid loss of sexuality occurs as a result of high concentrations of nitrogen. The pH of the medium does not seem to have any marked effect and mating has been reported in media ranging from 4-8.5. Temperature has a remarkable influence on mating. Under certain conditions, a rise in temperature increases the proportion of gametes in the population of *Chlamydomonas*. Of all the environmental factors light plays an important role in inducing sexuality. In *Pandorina* morum subjected to 16:8 hr light-dark period, mating occurs only during a certain period of light period. It has been suggested that light acts through photosynthetic assimilation leading to the depletion of the available nitrogen supply in the medium, which triggers sexuality. The production of gametes in light also requires oxygen. A rapid reduction in the proportion of active gametes has been observed in *Chlamydomonas eugametos*. In oogamous chlorophytes like *Oedogonium* active egg substances attractive to the spermatozoids have been observed. Mating involves a certain degree of clumping of flagellum to flagellum as in *Chlamydomonas.* The clump inducing substance in *Chlamydomonas eugametos* has been shown to be glycoproteins. Temperature also has a critical effect in clumping.

Methods of reproduction in Chlorophyceae:

In Chlorophyceae reproduction takes place by any one or all of the following three methods, vegetative, asexual and sexual.

1. Vegetative Reproduction: Vegetative reproduction in Chlorophyceae takes place by the fragmentation, cell division, akinete formation. It involves only vegetative cells and the parent cell wall is retained after reproduction. Many forms multiply largely by vegetative means such as:

(i) **Fragmentation:** In Oedogoniales, vegetative reproduction takes place by the development of detached fragments of the thalli into a new individual. Fragmentation involves breaking up of the thallus into two or more pieces or fragments in colonial (*Dictyosphaerium*) and filamentous forms (*Spirogyra*, *Ulothrix*, *Oedogonium* etc.). Each fragment functions as a reproductive unit and grows into a new filament after undergoing cell division and the subsequent growth of component cells. Fragmentation may be because of some external mechanical pressure or by dying out of intercalary asexual or sexual reproductive bodies.

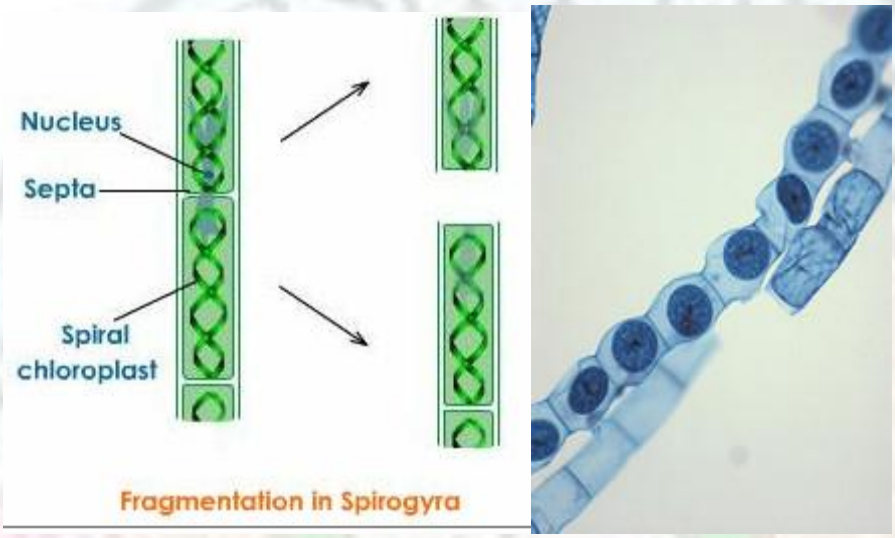

Figure: Fragmentation in *Spirogyra*

Source: http://science9ldssblock1.wikispaces.com/Kelly's, http://quizlet.com/1659486/spirogyra-flash-cards/

(ii) **Cell division:** Multiplication by ordinary cell division is a characteristic feature of some Chlorophyceans. It is also called **fission** and is a common method of reproduction in unicellular forms. The cell division is preceded by **mitotic** division of the nucleus. The nuclear division is simultaneously followed by the cleavage of the cytoplasm, which starts and continues by a median constriction of the cell. The constriction deepens and finally cuts the cytoplasm into two parts.

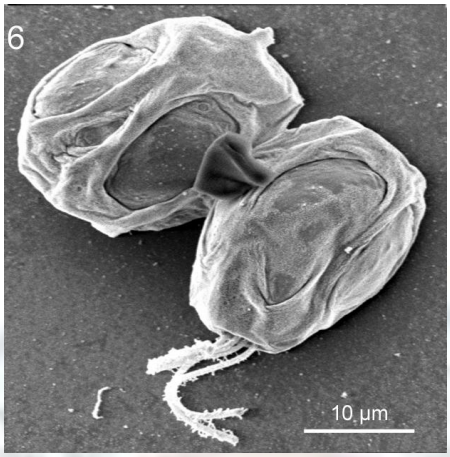

Figure: Cell division in a green alga by fission

Source: Author

Embed Video: Cell division in *Micrasterias*

Source: http://www.youtube.com/watch?v=Uc9ppqqCMmI

(iii) **Akinetes:** An akinete is a large, one-celled, oblong, non-motile, **thick walled**, spore like modified resting vegetative structures derived by the thickening of the wall of a vegetative cell. Akinetes have very thick cell wall and are enriched in food materials. Akinete can withstand unfavourable conditions and with the onset of favourable conditions, they can germinate to form a new individual. Akinetes are commonly formed in *Pithophora, Ulothrix,* and *Chlamydomonas*.

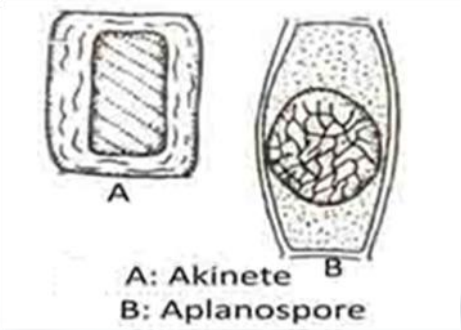

Figure: Showing the structural difference between akinete (vegetative reproduction) and aplanospore (a type of spore involved in asexual reproduction)

Source: http://nyagyaa.blogspot.in/2012/09/algae.html

Figure: *Pithophora*, akinetes are the large oblong thick walled cells rich in food reserves

Source: http://university.uog.edu/botany/474/fw/pithophora.htm

2. Asexual reproduction: It takes place by the formation of some specialized reproductive cells called **spores**. The spores are produced endogenously in some specialized bodies called **sporangia**. Most commonly they are formed by repeated **mitotic** division of protoplasts and hence may be called **mitospores**. Mitospores are asexual spores and are different from the sexual spores which are formed meiotically and thus called meiospores. Mitospores may be motile or nonmotile. Various kinds of spores are zoospores, aplanospores, hypnospores, autospores etc.

(i) **Zoospores:** Asexual reproduction by zoospores is very widespread in Chlorophyceae. Zoospores are flagellated asexual spores. They may be biflagellate (*Chlamydomonas*), bi-as well as quadri-flagellate (*Ulothrix*), and multiflagellate with a ring of flagella (*Oedogonium*).

Zoospores develop either in modified cells called **zoosporangia** or in vegetative cells. Zoospores are often formed during night and are then liberated in the morning from the parent cell through a pore in the surrounding cell wall or by rupturing of the cell wall (Chapman and Chapman, 1973) and remain motile from 3 min. to 3 days. The liberated zoospore from zoosporangia contains a nucleus, an eyespot, one or more chloroplast and 2 to many flagella of equal length (isokont) which are inserted at the anterior end. On settling over a suitable substratum, the zoospore germinates into a new thallus similar to that of its parent. Zoospore formation is the most effective and rapid way of reproduction under favourable environmental conditions.

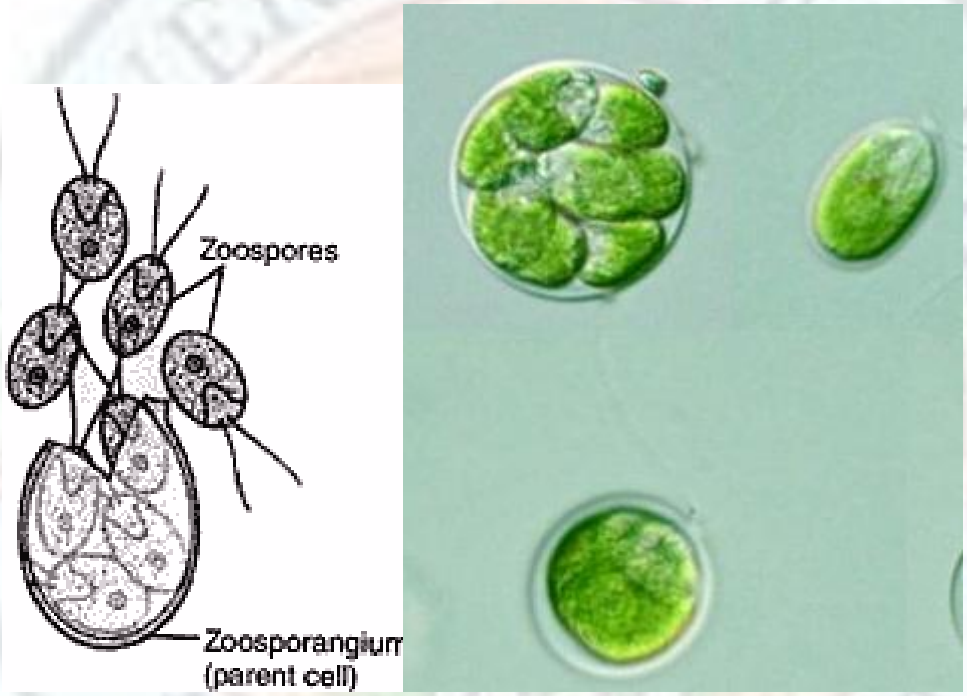

Figure: Zoospores in *Chlamydomonas*

Source:
http://protist.i.hosei.ac.jp/pdb/images/chlorophyta/chlamydomonas/Euchlamydomonas/nasuta/sp_13.html

(ii) **Aplanospores:** Non-flagellate, non-motile zoospores which secrete a thin wall of their own, are called aplanospores. Aplanospores are arrested zoospores which have skipped the motile phase. Each aplanospore germinates into a new individual resembling the parent.

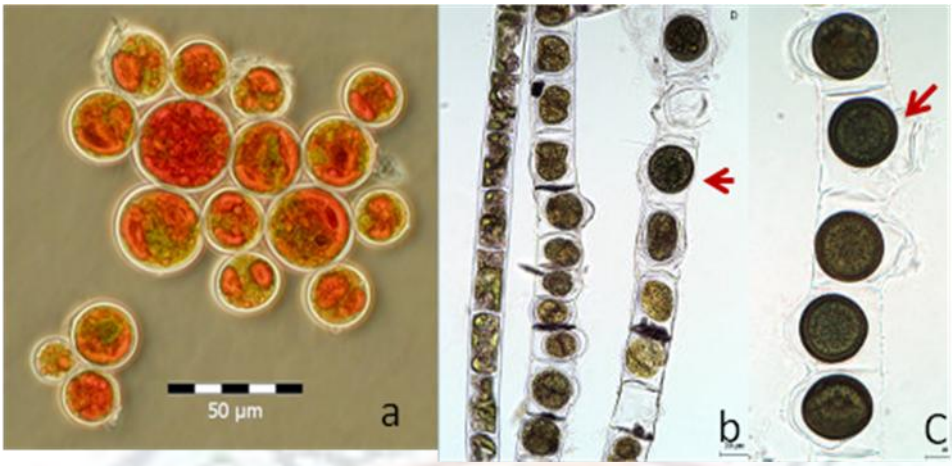

Figure: Aplanospores of **a,** *Haematococcus pluvialis* **b & c** *Zygnema aplanosporum*

Source:http://commons.wikimedia.org/wiki/File:Haematococcus_pluvialis_aggregate.jpg,http://dbmuseblade.colorado.edu/DiatomTwo/sbsac_site/images/Zygnema_aplanosporum/Zygnema_aplanosporum4_230p.jpg,http://dbmuseblade.colorado.edu/DiatomTwo/sbsac_site/images/Zygnema_aplanosporum/Zygnema_aplanosporum6_230p.jpg

(iii) **Hypnospores:** Under certain conditions the aplanospores secrete thick walls around them and store abundant food reserves. These thick walled aplanospores are called the hypnospores. Because of the thick wall, hypnospore may undergo a long resting period and may survive even in some unfavourable conditions (*Ulothrix*).

(iv) **Autospores:** The aplanospore which appears identical to the parent cell are called autospores (*Chlorella*).

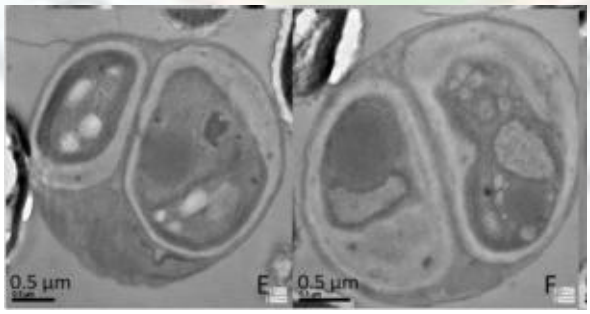

Figure: Autospore formation

Source: http://www.biotechnologyforbiofuels.com/content/4/1/47 (CC)

3. Sexual Reproduction: Sexual reproduction occurs in almost all members of Chlorophyceae. It involves the fusion of two specialized reproductive cells called the **gametes**. The fusion of the cytoplasm of the gametes is known as **plasmogamy** and the fusion of the gamete nuclei is termed as **karyogamy** or fertilization. Both the gametes fuse and form a **zygote** which has a **diploid** nucleus.

In monoecious or homothallic species the two fusing gametes are produced by the same thallus whereas in dioecious or heterothallic species the fusing gametes are produced by the two separate thalli. Sexual reproduction always involves three steps:

(i) Gamete production

(ii) Gamete fusion (syngamy and fertilization)

(iii) Zygote germination

Sexual reproduction is of three kinds: isogamy, anisogamy and oogamy.

Figure: Various types of sexual reproduction in Chlorophyceae

Source: Author

(i) **Isogamy:** It is a primitive type of sexual reproduction and mostly occurs in lower forms. The fusing gametes are morphologically **similar** in size, form and structure and are called **isogametes**. Isogamous sexual reproduction is common in some species of *Chlamydomonas*. The isogametes are usually naked, without any cell wall and are often flagellated. They are produced in ordinary vegetative cells called the gametangia by the division of the cell protoplast into several daughter protoplasts. Each daughter protoplasts

aquire flagella and is called an isogamete. These isogametes are smaller than zoospores. The gametes digest the parental cell wall with the help of certain enzymes (wall autolysins) and are released into the surrounding water.

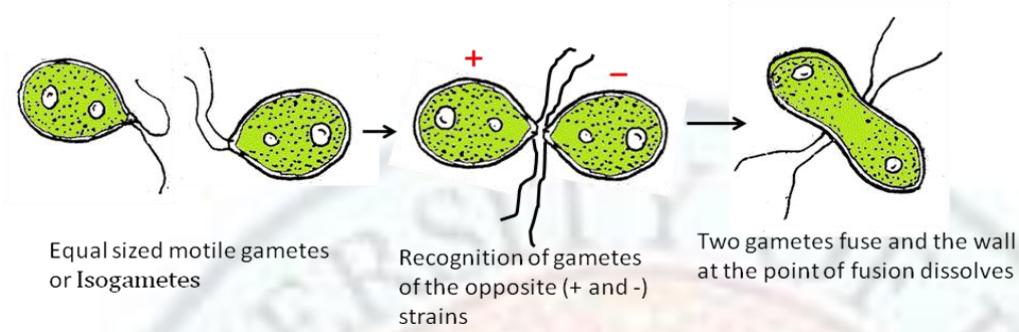

Figure: Isogamy in *Chlamydomonas*

Source: Author

(ii) **Anisogamy:** In anisogamy the fusion takes place between **dissimilar** gametes, the **anisogametes**. Anisogamy can be categorized into physiological anisogamy and morphological anisogamy. In physiological anisogamy (common in *Chlamydomonas monoica, Spirogyra*) the fusing gametes are morphologically identical but different in their behavior e.g. one gamete may be more active than the other. The gametes of *Spirogyra* are discernible by their degree of motility. In morphological anisogamy (common in *Chlamydomonas braunii*) the fusing gametes differ noticeably in size. In most of the members of Chlorophyceae the anisogametes are of two different kinds and can be designated as male and female. Gametes are produced in specialized cells called gametangia. The male gamete is small and active whereas the female gamete is large and passive. These gametes fuse externally after their release from the parent cell wall. Physiological anisogamy is a primitive type of anisogamy whereas morphological anisogamy is an advanced type of anisogamy.

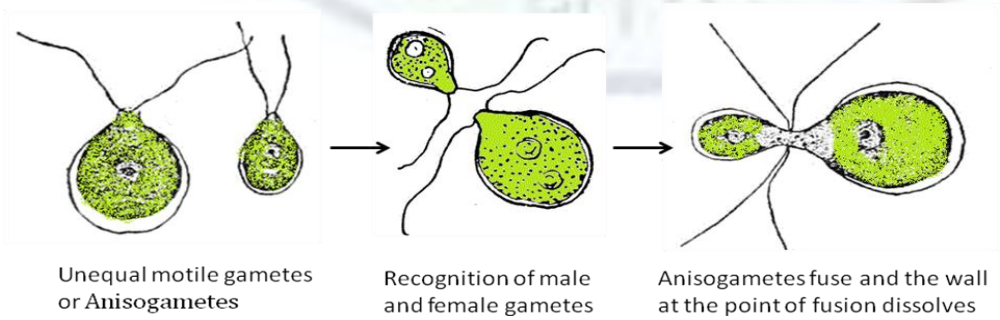

Figure: Anisogamy in *Chlamydomonas*

Source: Author

(iii) **Oogamy:** Oogamy is the most advanced type of sexual reproduction and occur in higher forms. The fusing gametes (male and female) in oogamy differ from each other in every aspect such as size, motility, behavior and structure and are called heterogametes. Distinct **sex organs** are formed. Male sex organ is called an **antheridium** and the female is termed as **oogonium**. Inside the antheridia small, active flagellated gametes are produced which are called as sperms. Sperms are produced in huge numbers and on maturity they are released in the surrounding water. The female gametes are produced singly and are large and passive. The female gamete is retained within the oogonium. The sperm swims in the direction of the egg and fuses with it. The resulting fusion cell is called the zygote. Oogamous sexual reproduction is common in *Chlamydomonas coccifera, Volvox, Chlorogonium, Pandorina, Oedocladium* etc. The order Oedogoniales is purely oogamous.

Figure: Oogamy: A sperm and an egg of *Pleodorina starrii* that are about to interact

Source:(Photo by H. Nozaki)
http://www.sciencedirect.com/science/article/pii/S0960982206024547

Zygote

The wall at the point of fusion between the two gametes soon dissolves. The **quadriflagellate** zygote in **isogamy** initially swims for a while, furthermore the flagella are resorbed soon and the non motile zygote settles down. At this stage it has, two nuclei, two chloroplasts and two eyespots. Zygote secretes a thick wall around it and becomes a resting spore called **zygospore**. The cytoplasm, nuclei and chloroplast of the gametes fuse and a thick, ornamented secondary wall is laid down. The zygote or zygospore is the diploid structure in the life cycle.

In Chlorophyceae, zygote always passes through the resting stage. The zygote accumulates fats and reserve food materials and turns orange red in colour. Zygote can endure drought and waits for the return of favorable conditions for germination.

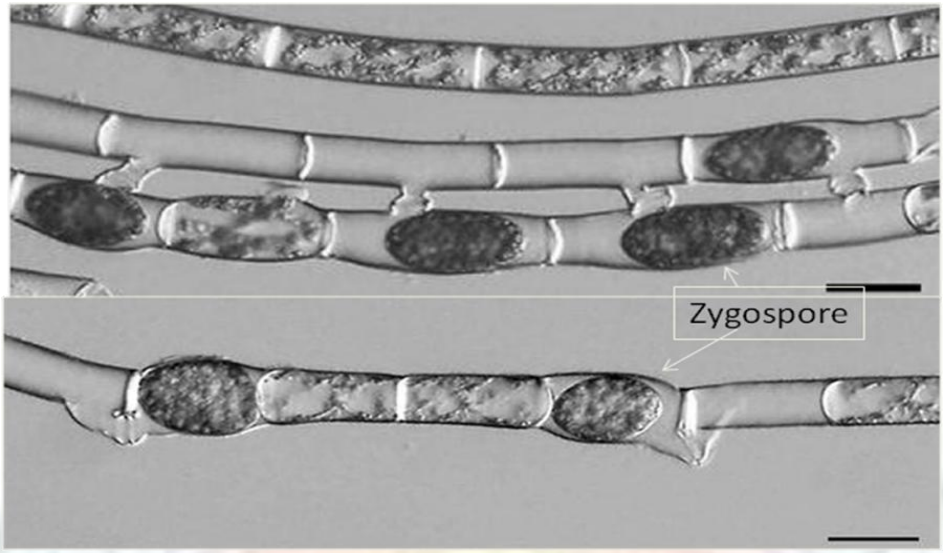

Figure: Zygospores formed in *Spirogyra*

Source:http://www.biomedsearch.com/nih/Studies-conjugation-Spirogyra-using-monoclonal/22006213.html (CC)

Germination of Zygospore:

When the zygote encountors favorable conditions (water) it germinates. The diploid nucleus of zygote undergoes meiosis resulting into the formation of 4 haploid nuclei. At this stage segregation of the nuclei of opposite mating types (+ and -) takes place.

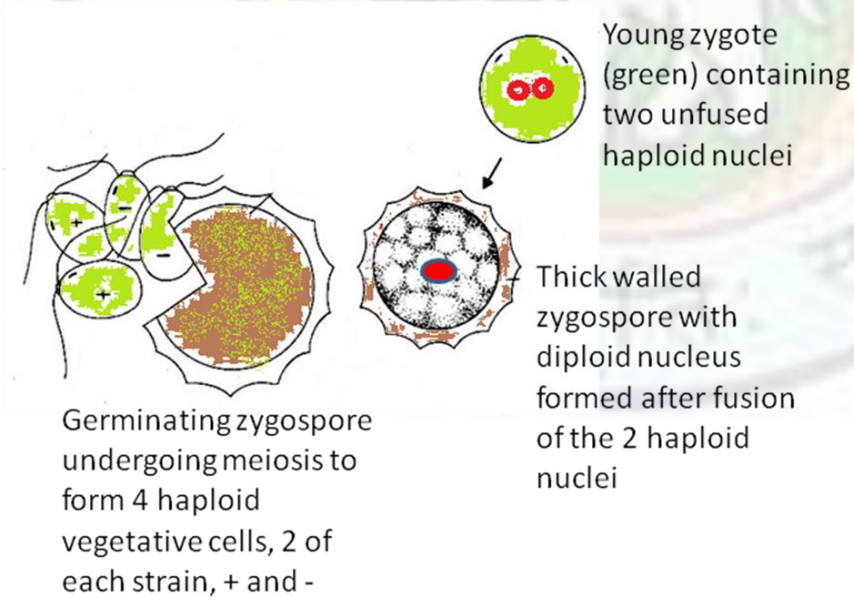

Figure: Germination of zygote (*Chlamydomonas*)

Source: Author

Zygotic meiosis and haploid generation:

In Chlorophyceae (*Spirogyra*) the diploid nucleus of zygote undergoes meiosis termed as zygotic meiosis. Zygotic meiosis results into the formation of four haploid daughter nuclei out of which three degenerate. The protoplast of the zygote containing the existing haploid nucleus directly develops into a new gametophyte filament or vegetative thallus. In *Ulothrix* and *Oedogonium* zygotic meiosis occurs and all the four resultant haploid nuclei remain functional. These four functional nuclei organize themselves into meiospores. Each meiospore liberates from the zygote and gives rise to a haploid or gametophyte filament. Hence the filament is formed by meiospore and not from the parent zygote.

Life cycle patterns in Chlorophytes

The perpetuation of an alga passes through a cycle of events involving a sexual or an asexual phase or both. The life cycle is characterized by the occurrence of two individuals

a) sporophyte and b) gametophyte.

Sporophyte is diploid and is concerned with the production of haploid meiospores after meiosis whereas **gametophyte** is haploid and is responsible for sexual reproduction. Gametophyte produces the haploid gametes. Sporophyte and gametophyte usually follow each other in a single life cycle and this progression is called alternation of generations.

We owe our understanding of the life histories of algae to Svedelius, who in 1931 classified the algal life history on the basis of nuclear phases. Most of the Chlorophytes show haplontic life cycle. Some members (e.g., Siphonales) show diplontic life cycle while a few others show isomorphic alternation of generations between haploid and diploid plants (e.g. *Cladophora*)- called diplohaplontic life cycle.

(a) Haplontic life cycle: This is the simplest and most primitive type of life cycle. The main vegetative plant body (gametophyte) is haploid and is the dominant generation. It bears haploid gametes. The gametic fusion which is known as syngamy produces zygote which is the only diploid phase (sporophyte) in the life cycle. By the reduction division of zygote (meiosis) haploid meiospores are formed which germinate into haploid gametophyte plant. Here the unicellular or filamentous gametophyte alternates with one celled zygote or sporophyte, the only diploid stage in life. e.g., *Spirogyra, Ulothrix, Oedogonium.*

In most of the members of Chlorophyceae (e.g., *Spirogyra, Chlamydomonas, Oedogonium*), the thallus is haploid and bears the haploid gametes. The haploid gametes fuse to form the diploid zygote or zygospore. Zygote is the only diploid structure. The diploid zygote nucleus undergoes reduction division (meiosis) and four haploid daughter nuclei are formed. Three of these disintegrate and one remains functional. The functional daughter nucleus becomes the nucleus of the first cell of the new haploid or gametophyte filament. In *Ulothrix* and *Oedogonium* the the zygospore, at the time of germination divides by meiosis and is arranged into four haploid spores. Each haploid spore on germination gives rise to a gametophyte filament.

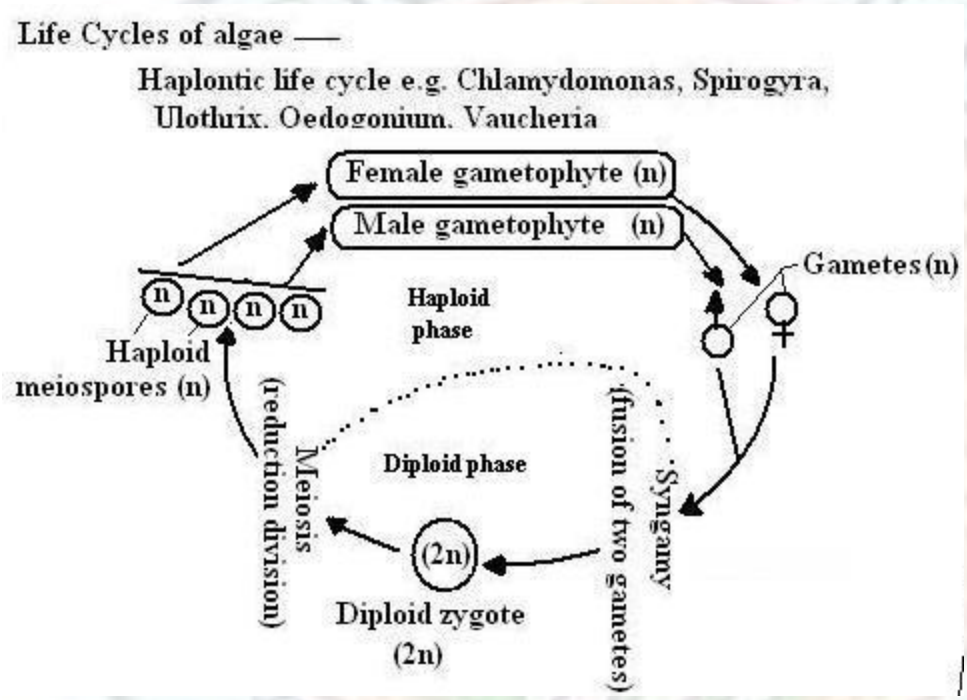

Figure: Haplontic life cycle

Source: http://www.peoi.org/Courses/Coursesen/bot/frame15.html

(b) Diplontic life cycle: Gametes are haploid and meiosis takes place during gametogenesis. In some members (Siphonales) the entire vegetative or somatic phase is diploid. The reduction division takes place at the time of gamete formation. After gametic union a diploid zygote is formed which develops into a diploid plant by mitotic divisions. The dominant sporophyte alternates with haploid gametes, the only haploid stage in life history e.g., *Codium*.

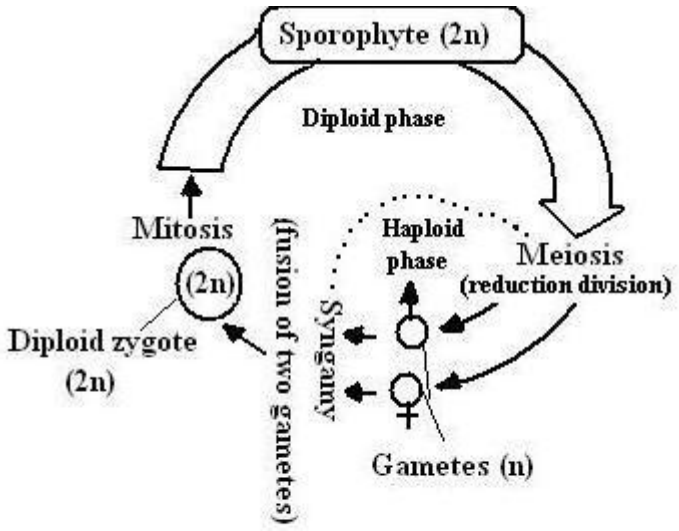

Figure: Diplontic life cycle

Source: http://www.peoi.org/Courses/Coursesen/bot/frame15.html

(c) Diplohaplontic life cycle: 'Isomorphic alternation' of a haploid and diploid generation. e.g. *Ulva, Cladophora, Ectocarpus*. When both spore producing multicellular sporophytes and the gamete producing gametophyte are formed and both are free living, the life cycle is diplohaplontic. Vegetative phase include both a haploid and a diploid phase. Both diploid **sporophyte** and haploid **gametophyte** vegetative plants are **morphologically identical/isomorphic** and come **alternately** in life cycle. In such cases the zygote undergoes repeated mitotic divisions and develops into a free living diploid filament or plant and there is a delay in meiosis. Meiosis does not occur at the time of germination of the zygote. Meiosis results in the formation of meiospores. These meiospores develop into haploid plants. The haploid plants produce gametes which after fusion develop into zygote.

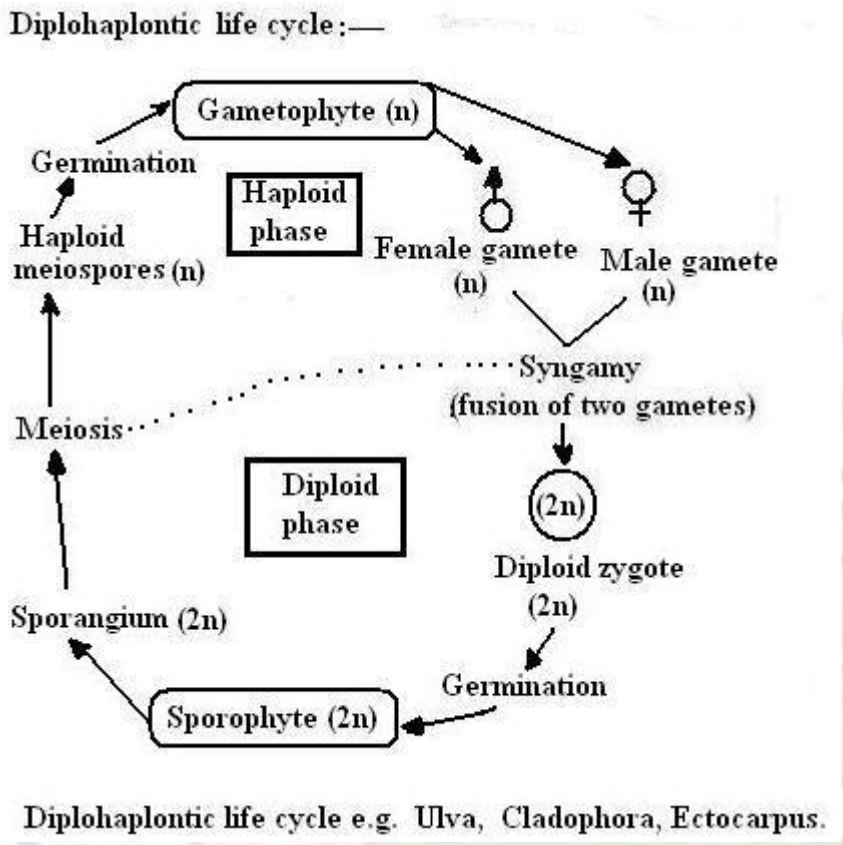

Figure: Diplohaplontic life cycle

Source:http://www.peoi.org/Courses/Coursesen/bot/frame15.html

Summary

Members of Chlorophyceae reproduce by vegetative, asexual and sexual methods. The vegetative propagation takes place by cell division and fragmentation. Akinetes, zoospores and aplanospores are the main asexual spores. Zoospores are often formed during night and are then liberated in the morning. Sexual reproduction occurs in all members except some Chlorococcales and Chlorodendrales. Sexuality in Chlorophyceae can be controlled by certain environmental factors such as the amount of ammonium nitrogen, intensity of light, temperature etc. Sexual reproduction may be isogamous, anisogamous or oogamous. The zygote or zygospore secretes a thick wall and undergoes a resting period. It germinates under favourable conditions and forms a new thallus. The sex organs are always unicellular. Zygote generally is the only diploid structure in the life cycle. Most of the Chlorophyceae are haploid showing haplontic life cycle.

Exercises

1. How do the members of Chlorophyceae propagate?

2. Write short notes on:

   (i) Akinetes

   (ii) Aplanospore

   (iii) Haplontic life cycle

   (iv) Fragmentation

   (v) Anisogamy

   (vi) Germination of zygospore in Chlorophyceae

   (vii) Various steps involved in sexual reproduction in Chlorophyceae

   (viii) Oogamous sexual reproduction

3. Describe in detail the various modes of asexual reproduction in Chlorophyceae.

4. Describe the various modes of sexual reproduction in Chlorophyceae.

5. Describe the environmental factors controlling sexuality in Chlorophyceae?

6. Give a description of the haplontic, diplontic and diplohaplontic life cycles with the help of suitable diagrams. What is isomorphic alternation of generations?

7. Fill in the blanks:

   (i) Fusion between the similar gametes is called…….

   (ii) Fusion between dissimilar gametes is called…….

   (iii) In Chlorophyceae the diploid nucleus of the zygote undergoes meiosis termed as ……meiosis.

   (iv)In haplontic life cycle…… (gametophyte/sporophyte) is the dominant generation.

Glossary

Agglutinin: chemical substances involved in the recognition of gamete of the opposite strain.

Agglutination: adherence of gametes of different mating types by their flagellar tips.

Antherozoid: male gamete

Autospore: aplanospore with the same shape as the parental cell.

Egg: Large nonmotile female gamete

Fragmentation: a kind of asexual reproduction in which a thallus breaks into parts and each part forms a new thallus.

Gametangium: structure in which gemetes are formed.

Gametophyte: generation which produces the gametes, generally haploid.

Hypnospore: aplanospore with a much thickened wall.

Isogamy: fusion of similar gametes

Karyogamy: fusion of two nuclei of the gametes.

Meispore: spore formed by meiosis.

Monoecious: male and female gametangia borne on the same plant or thallus.

Oogamy: fusion of a small motile sperm with a large nonmotile egg.

Oogonium: single celled female gametangium.

Plasmogamy: fusion of cell protoplast.

Zygospore: thick walled resting spore formed from the zygote.

References/ Bibliography/ Further Reading

1. Alexopoulos C.J. & Bold H.C. 2003. Algae and Fungi. Texas.

2. Arora M. *et al.* 2013. *Tetraselmis indica*, a new species isolated from salt pans (Chlorodendrophyceae, Chlorophyta). *European Journal of Phycology.* 48: 61-78.

3. Desikachary T.V. 1957. Electronmicroscopy and algology. *Proceedings of the Indian academy of Sciences*. 46:54

4. Fritsch F.E. 1935. The structure and reproduction of algae. Vol.I, Camb. Univ. Press.

5. Fritsch F.E. 1944. Present day classification of algae. *Botanical Review.* 10:233.

6. Graham, L.E. & Wilcox, L.W. 2000. Algae, Prentice-Hall, Inc.

7. Lee, R.E. 2008. Phycology, Fourth ed. Cambridge University press.

8. Leliaert F. *et al.* 2012. Phylogeny and molecular evolution of the green algae. *Critical Reviews in Plant Sciences.* 31: 1-46

9. Leliaert F. *et al.* 2011. Into the deep: Into the deep: new discoveries at the base of the green plant phylogeny. *BioEssays.* 33: 683–692

10. Pickett-Heaps J.D. 1975. Green Algae: structure, reproduction and evolution in selected genera. Sinauer Associates, Inc. Publishers, Massachusets.

11. Round F.E. 1965. The biology of the Algae. Edward Arnold Ltd. London.

12. Smith G.M. (Ed). 1951. Manual of Phycology. *Chronica Botanica*, Waltham mass.

13. Sambamurty A.V.S.S. 2005. A text book of algae. I.K. International, New Delhi.

14. Van den Hoek, C., Mann, D.G., Jahns, H.M. (Ed.) 1995. Algae: An Introduction to Phycology. Cambridge University Press, Cambridge.

15. Venkataraman G.S. *et al.* 1974. Algae: Form and function, Today and Tomorrow's Publ., New Delhi.