Discipline Courses-I

Semester-I

Paper: Phycology and Microbiology

Unit-VII

Lesson: Morphology and life cycles of *Chlamydomonas* and *Oedogonium*

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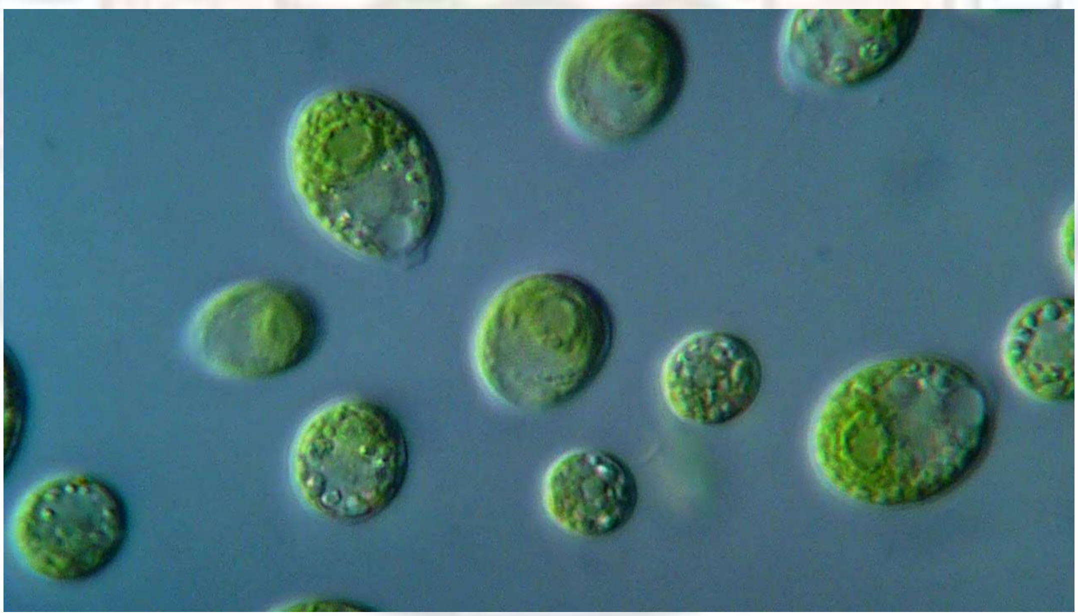
Chlamydomonas

Introduction

The name of the genus is derived from the greek words "**chlamys**" (mantle) + "**monas**" (unit). *Chlamydomonas* belongs to the Class Chlorophyceae and is a unicellular motile freshwater green alga. *Chlamydomonas* occurs as a biflagellate, spherical, ellipsoidal or pear shaped unicell having a single cup shaped, massive parietal chloroplast. *Chlamydomonas* cells are phototactic. All *Chlamydomonas* species are capable of autotrophic growth. *Chlamydomonas reinhardtii* can grow in the dark utilizing acetate as a source of organic carbon. *Chlamydomonas renhardtii,* has been mainly well studied, and has become a model system for the study of eukaryotic cell structure and function. *Chlamydomonas* is commonly used in the laboratory work, mostly in molecular genetics for the reason that it is haploid, easy to cultivate, grows rapidly, and sexual reproduction can easily be induced. *Chlamydomonas* is an excellent system for studying chloroplast genetics, maternal inheritance, role of dynein in flagellar function and centrin in the cytoskeleton.



Video: *Chlamydomonas:* Note the two flagella involved in the movement of the unicellular thallus.

Source: https://www.youtube.com/watch?v=EMNFZnDt75c&noredirect=1

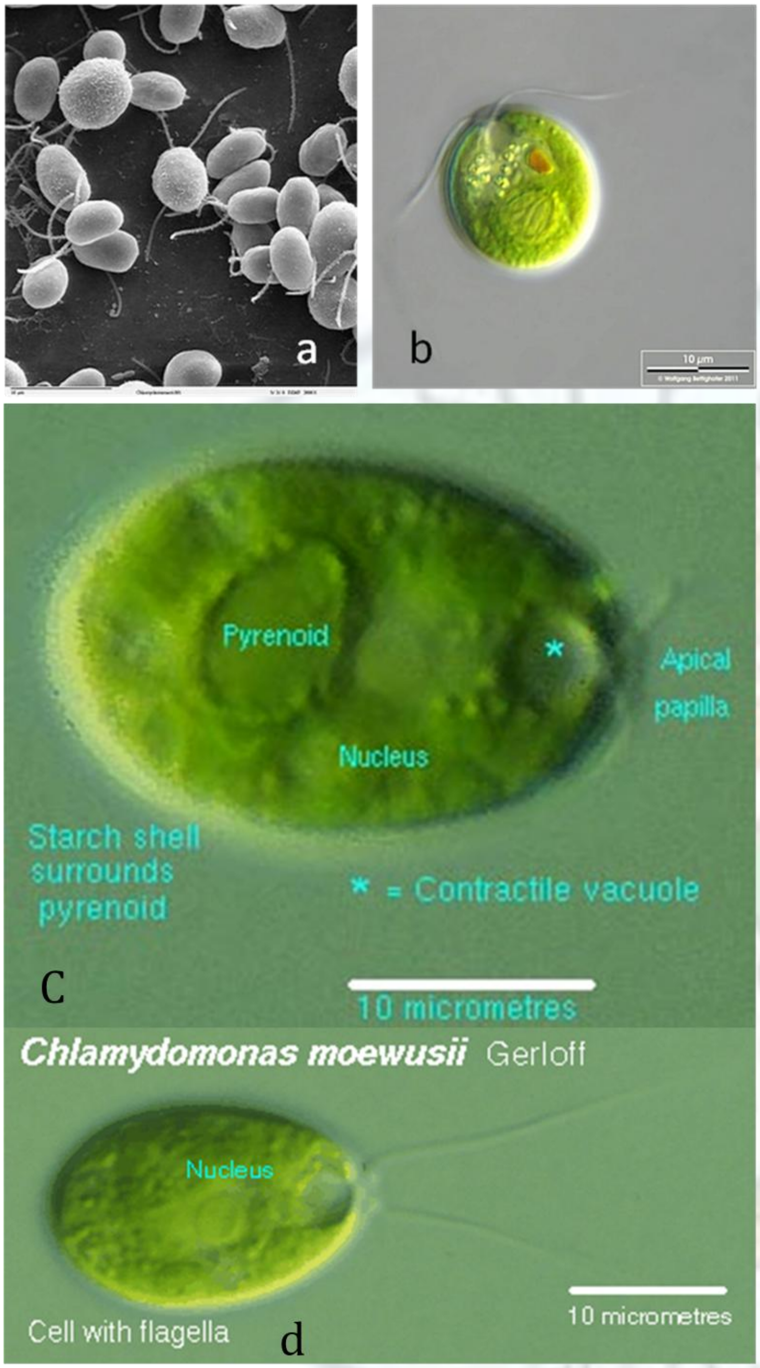


Figure: a- Scanning electron micrograph (SEM) of *Chlamydomonas* cells, b-d Light micrograph (LM) of *Chlamydomonas* cell

Source: http://en.wikipedia.org/wiki/Chlamydomonas_reinhardtii

http://starcentral.mbl.edu/microscope/portal.php?pagetitle=assetfactsheet&imageid=27241

http://www.jochemnet.de/fiu/bot4404/BOT4404_28.html

Systematic position of *Chlamydomonas*

According to the **morphological** concept- Fritsch's classification (1935)

Class – Chlorophyceae

Order - Volvocales

Sub-order - Chlamydomonadinae

Family - Chlamydomonadaceae

Genus - *Chlamydomonas*

According to **ultrastructure** of algal cells and life cycles- (Round, 1984)

Division - Chlorophyta

Class – Chlorophyceae

Order – Chlamydomonadales

Family – Chlamydomonadaceae

Genus - *Chlamydomonas*

According to the **molecular phylogenetic** concept- Lewis & McCourt (2004); Becker & Marin (2009)

Kingdom-Viridiplantae*

Division- Chlorophyta

Class- Chlorophyceae

Order- Chlamydomonadales

Family- Chlamydomonadaceae

Genus- *Chlamydomonas*

* Kingdom **Viridiplantae** is the expansion of the traditional **Plant Kingdom** to include **green algae**. Viridiplantae comprises of two divisions Chlorophyta & Streptophyta (land plants/Charophytes).

Source: http://www.ncbi.nlm.nih.gov/Taxonomy/Browser/wwwtax.cgi?id=33090

Occurrence

Chlamydomonas is a very common organism. There are about 500 described species. *Chlamydomonas* is frequently found free swimming in freshwater of all types such as in ponds, pools and lakes. A few species occur in brackish and marine waters.

What are marine and brackish waters?

Water bodies can be classified based upon salinity into various types. Brackish water has more salinity than that of fresh water but less than the marine water.

Water salinity based on dissolved salts			
Fresh water	**Brackish water**	**Marine water**	**Brine**
< 0.05%	**0.05% – 3%**	**3% – 5%**	**> 5%**

Table: Classification of water bodies based upon salinity

Source: http://en.wikipedia.org/wiki/Salinity

C. braunii is a fresh-water species whereas *C. perpusilla* is found in brackish waters. *C. ehrenbergii* occurs in marine waters. *C. reinhardtii* is common in both fresh water and brackish water. Some species of *Chlamydomonas* form a green scum above the surface of water. *Chlamydomonas* generally prefers habitat rich in ammonium compounds. Some species are also found in terrestrial habitats such as moist soil, in snow and ice. *C. nivalis* occurs on snow and can colour the snow red due to the accumulation of pigment known as haematochrome (red carotenoids) in its cells. A few species of *Chlamydomonas* are epizoic, living symbiotically on the external surface of animals (e.g., *C. hydrae* on the surface of fresh-water polyp).

Morphology and ultrastructure

Chlamydomonas thallus is a unicellular, green, motile, biflagellate structure. Shape of the *Chlamydomonas* cell could be oval, spherical, ellipsoidal, oblong or pear shaped in different species. The cell is delimited by a definite cell wall. It is pinched out anteriorly into a papilla in several species. Inner to the cell wall is present a protoplast which is differentiated into a plasma membrane, a single distinct nucleus, cytoplasm, two contractile vacuoles, a massive cup shaped chloroplast, pyrenoid, an eyespot and other cell organelles such as mitochondria, endoplasmic reticulum, Golgi bodies, and true vesicles. Vacuoles and numerous dense granules called volutin granules (polyphosphate bodies) are present in the cytoplasm. The anterior side of the cell has two whiplash type (the flagella with a smooth surface without hairs) of flagella which are of equal length. Flagella are associated with neuromotor apparatus which provides a connection between the flagella and the nucleus. Chloroplast is parietal (located in the peripheral part of the cytoplasm) in position. In each chloroplast there is a pyrenoid with starch sheath. Eyespot is an oval photoreceptive organ and is present on the anterior side of the chloroplast. Many ribosomes are present in the cytoplasm.

Dimensions of the *Chlamydomonas* vegetative cell are: about 30 μm in length and about 20 μm in diameter.

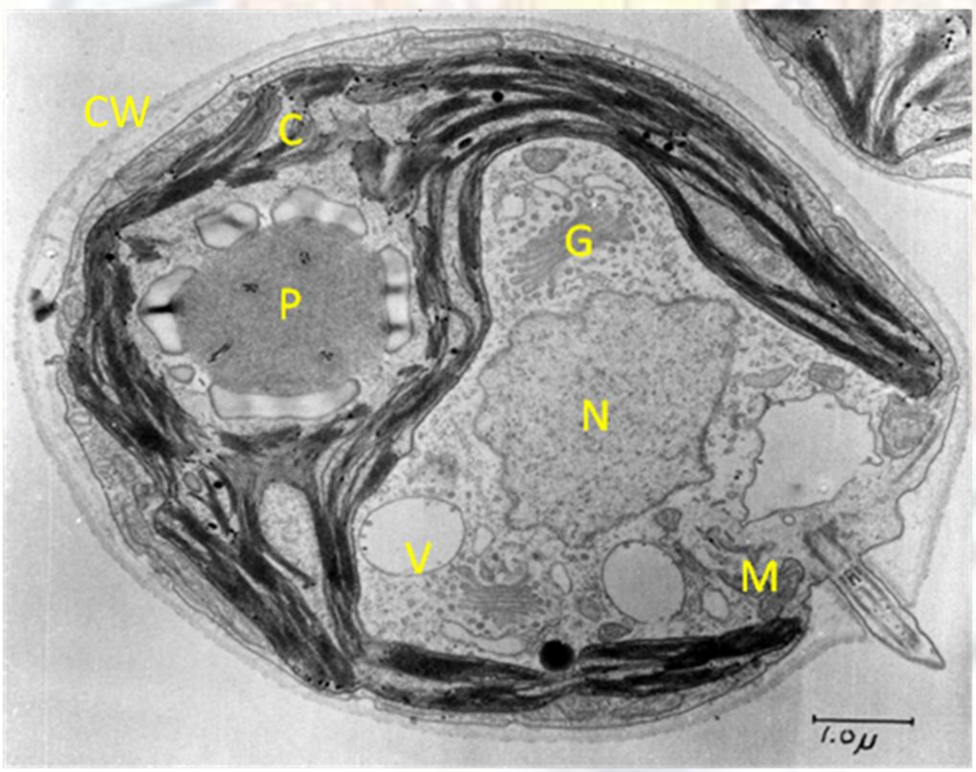


Figure: *Chlamydomonas reinhardtii* electron micrograph showing ultrastructural details of the cell, the single cup shaped chloroplast with pyrenoid (storage granule) surrounds the central nucleus and other organelles; CW- cell wall, C- cup-shaped chloroplast, M-mitochondria, N- nucleus, V- vacuole, P- pyrenoid.

Source: http://am.celllibrary.org/ascb_il/render_image/37252/0/0/

Cell wall

Early reports referred to *Chlamydomonas* cell wall as cellulosic and this mistaken statement is still occasionally seen in some textbooks. The multilayered cell wall is not composed of cellulose, but rather the major constituents are **hydroxyproline rich glycoproteins**. In *C. reinhardtii* the wall is a complex structure containing seven layers. The wall is not very rigid in *Chlamydomonas*. Flagella emerge through pores in the cell wall.

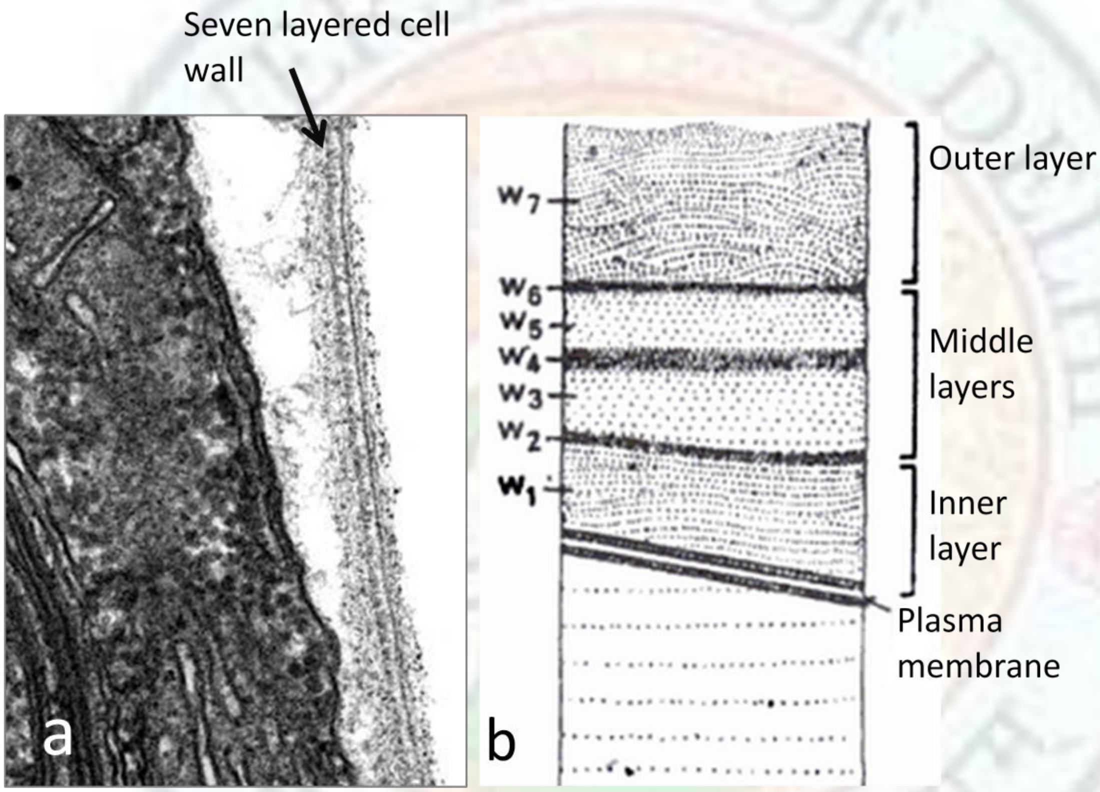


Figure: (a) Electron micrograph of *Chlamydomonas reinhardtii* showing seven layered cell wall (b) Diagrammatic representation of the complex seven layered cell wall of *C. reinhardtii*

Source: Roberts et al. 1972

Mucilage

When growing in conditions in which liquid water is limiting, cells may occur as palmelloid stages that are groups of nonflagellate cells held together by common mucilage rich in hydroxyproline and sugars. When palmelloid aggregates are exposed to water, the mucilage gets dissolved and the cells typically transform to flagellates.

Flagella

Two flagella are present on the anterior side of the cell. Both are of whiplash type (with a smooth surface) and are inserted at the apical end of the cell. Each flagellum originates from a **basal granule/body** or **blepharoplast** and shows a typical **9+2 arrangement** of microtubules. Each flagellum consists of a thin axial filament of **axoneme** surrounded by a cytoplasmic membrane or **sheath**. In a transverse or cross section the axoneme consists of 11 (9 peripheral+2 central) microtubules. Two of these are situated in the centre and hence are called **central tubules**. Central microtubules are single microtubules having 13 protofilaments. These central microtubules are surrounded by nine, **peripheral**, doublet microtubules arranged in a circle. Each peripheral doublet microtubule consists of A and B tubules: the A tubule is a complete microtubule with 13 protofilaments, whereas the B tubule have 11 protofilaments. All the peripheral doublet microtubules are surrounded by a common cytoplasmic sheath.

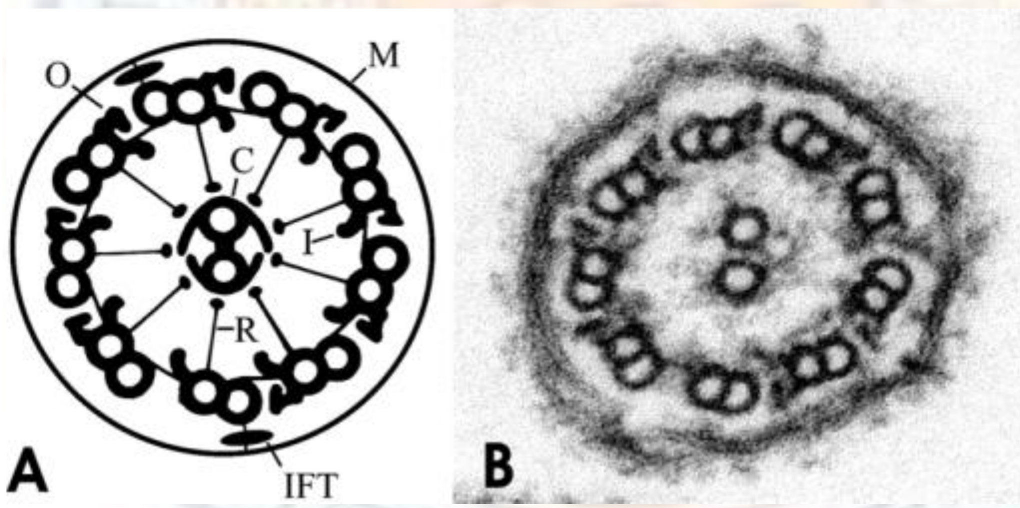


Figure: Flagellar structures of *C. reinhardtii* (A) Diagrammatic and (B) electron micrograph of a cross section of a motile flagellum; where C-Central pair of microtubules, I- inner dynein arm, IFT- Intraflagellar transport particle arrays between axoneme and flagellar membrane, M- flagellar membrane, O- outer dynein arm, R- radial spoke.

Source: http://openi.nlm.nih.gov/detailedresult.php?img=2171396_200504008f1&req=4

Neuromotor apparatus: Flagella are connected with the **nucleus** through the neuromotor apparatus of the cell. The neuromotor apparatus consists of three main parts:

i) **Basal body** or blepharoplast

ii) **Paradesmos**, a transverse fibre connecting the two blepharoplasts

iii) **Rhizoplast**, a delicate, descending connecting one of the blepharoplasts with the centrosome. The centrosome stays connected with the nucleolus by many thin fibrils. Centrosome could be intranuclear or may be situated outside the nucleus.

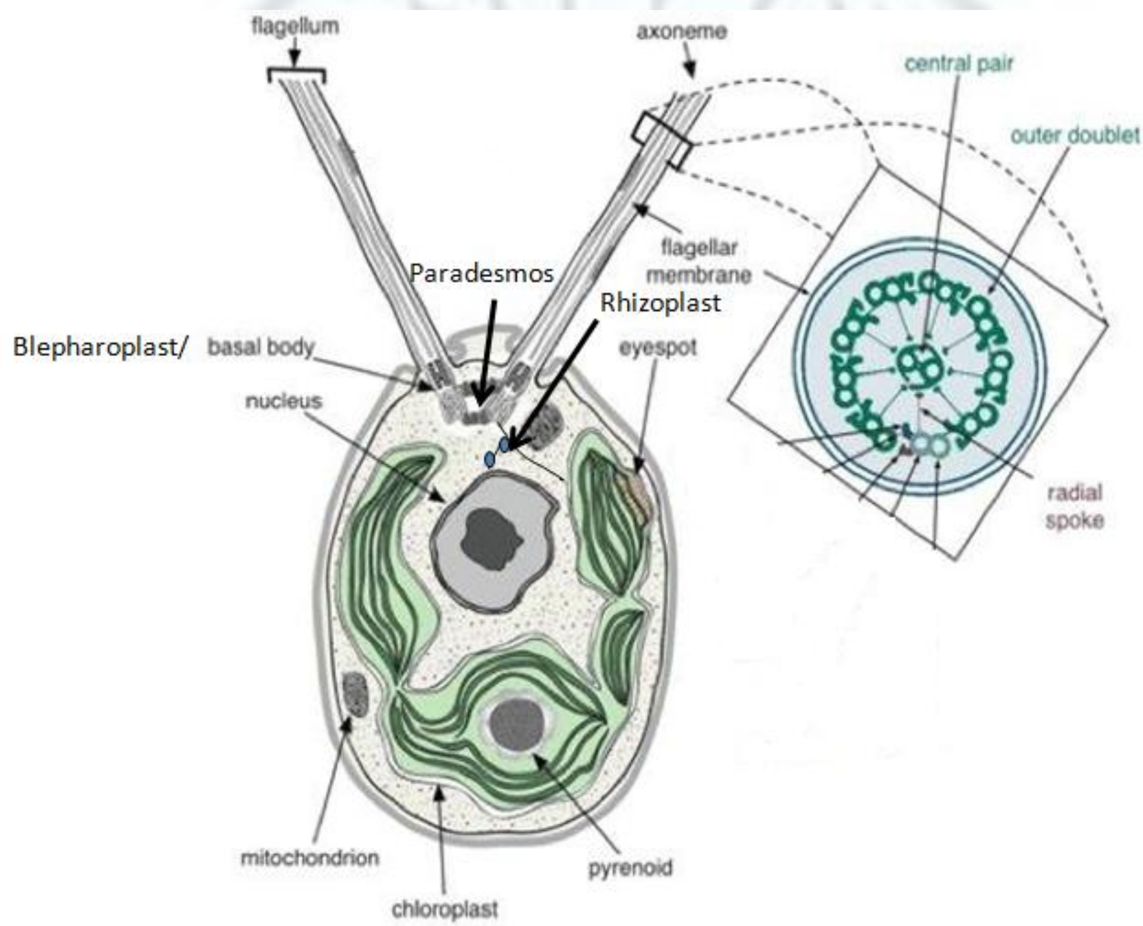


Figure: *Chlamydomonas* cell as seen under the electron microscope showing neuromotor apparatus

Source:http://deepaksirshyamsvyas.blogspot.in/2012/01/lesson-7-plant-kingdom-classification.html

Chloroplast

Chloroplast in *Chlamydomonas* is usually single, massive and **cup-shaped** and is needed for photosynthesis. Chloroplast is **parietal** in position (located in the peripheral part of the cytoplasm). The chloroplast is surrounded by a double membrane system. It bears a number of flattened photosynthetic lamellae in the form of bands called **thylakoids**. The lamellae or thylakoids contain all the chlorophyll pigment of the chloroplast and are lipoproteinaceous in nature. Thylakoids remain dispersed in a homogenous granular matrix called **stroma**. Three to six thylakoids are stacked to form **grana-like bodies**. Ribosomes and osmiophillic globules are present in the stroma.

Eyespot

The motile vegetative and reproductive cells of *Chlamydomonas* have a small pigmented bright reddish or brownish red eye-spot or stigma which senses light. In *Chlamydomonas* the eyespot remains embedded in the chloroplast. It is considered as a **photoreceptive** organ or the "**eye**" of the green algal cell and is involved in phototaxis (light dependent movement responses). It consists of a curved pigment plate carrying the pigment and a biconvex hyaline lens in front. The size of the eyespot is ~ 1 μm^2. It can be easily seen in the light microscope because of the huge accumulation of **carotenoids**. In a vertical section (ultrastructure) the eye-spot consists of one to four rows of closely packed carotenoid rich lipid **globules**/granules. Each globule is about 80 nm in diameter. The ultrastructure of the *Chlamydomonas reinhardtii* eyespot apparatus is described in the figure below.

The eyespot of *Chlamydomonas reinhardtii* is composed of two ordered layers of lipid (carotenoid) globules surrounded by the chloroplast. The outermost carotenoid rich globule layer is in contact with the specialized regions of the two surrounding chloroplast membranes and the bordering plasma membrane. Isolation of the eyespot apparatus as a structural unit can be done using sucrose density gradient centrifugation (Figure). The plasma membrane and the surrounding outer chloroplast membrane above the eyespot are characterized by the presence of numerous **intramembrane particles**. The photoreceptors are believed to be situated in that plasma membrane patch. *Chlamydomonas* accomplishes phototaxis by the modulation of intensity of light reaching to its photoreceptors present in the eyespot apparatus.

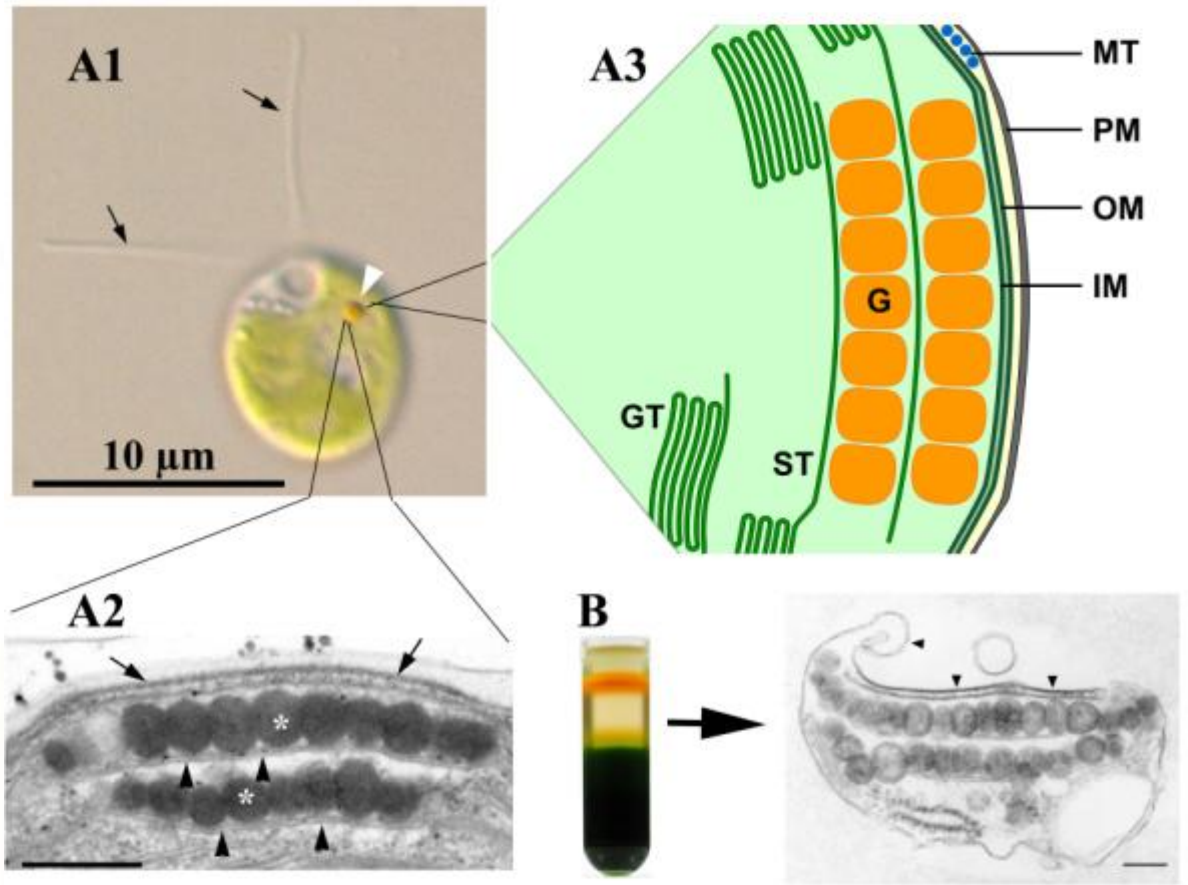


Figure: *Chlamydomonas reinhardtii* (A1) eyespot apparatus as seen in the light microscope (white arrow-head), (A2) as seen in the transmission electron microscope (A3) a schematic drawing (B) eyespot apparatus can be isolated as a structural unit by sucrose density gradient centrifugation.

Source: http://www.zellbio.nat.uni-erlangen.de/English/research/kreimer/index.shtml

Pyrenoid

In *Chlamydomonas,* the pyrenoid is located in the lower part of the chloroplast. Usually a single pyrenoid is present however it may be two to several in some species. The pyrenoid has a **central granular proteinaceous core** surrounded by minute by tightly packed **starch plates**. Pyrenoid functions as a centre around which starch is formed. Pyrenoids are important components of the **carbon concentrating mechanism (CCM)**. A large amount of enzyme RuBisCO (Ribulose-1, 5-bisphosphate carboxylase oxygenase) is located in the pyrenoid and CO_2 is concentrated around this RuBisCO, permitting the enzyme to work at a higher efficiency. Inflated tubule-like structures of the thylakoids that penetrate into the pyrenoid appear to be the path of CO_2 into the pyrenoid. Pyrenoids become reduced or diminish if the alga experience conditions of starvation and reappear once the conditions become favorable.

Contractile vacuoles

In *Chlamydomonas,* two contractile vacuoles are present at the anterior end of the cell, one near the base of each flagellum. Contractile vacuoles contract rhythmically and regulate the water contents of the cell by discharging their contents regularly at short intervals. These vacuoles are fed by smaller vesicles that expel water and solutes to the outside of the cell and hence function as **osmoregulators**.

In addition *Chlamydomonas* cell also contains other usual membrane bound cell organelles such as **mitochondria, Golgi bodies, endoplasmic reticulum and nucleus**.

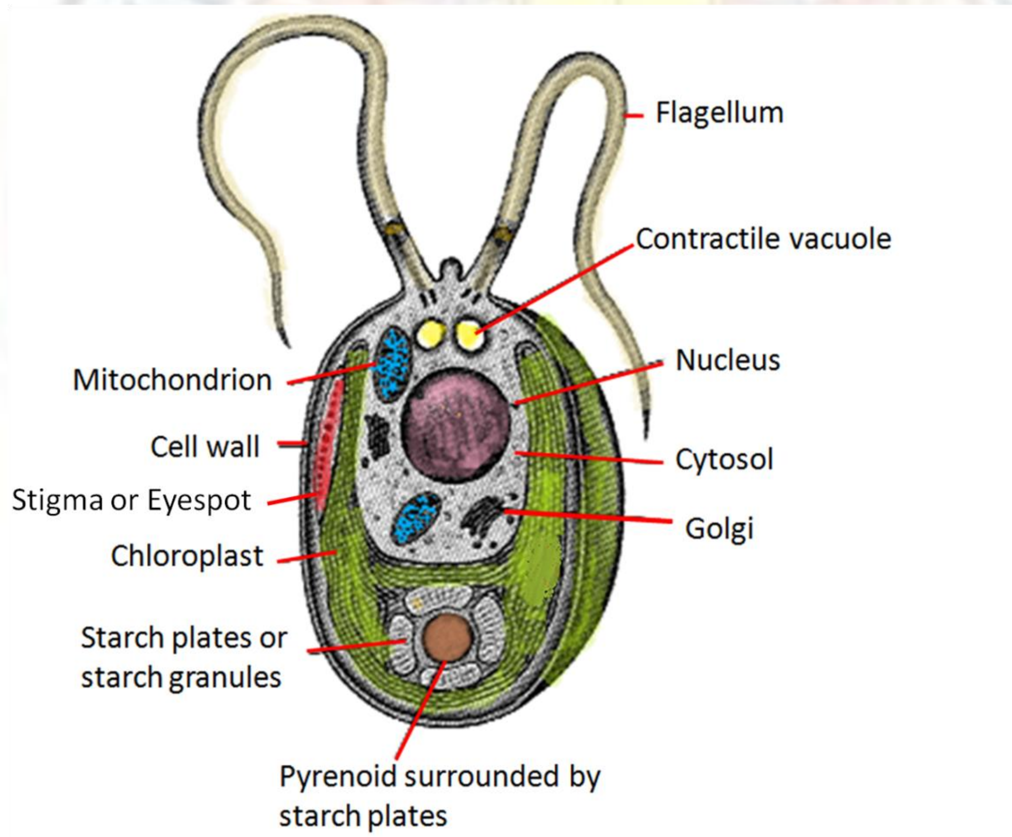


Figure: *Chlamydomonas* cell structure

Source: http://www.jochemnet.de/fiu/bot4404/BOT4404_28.html

Reproduction

Chlamydomonas reproduces by **asexual** and **sexual** methods.

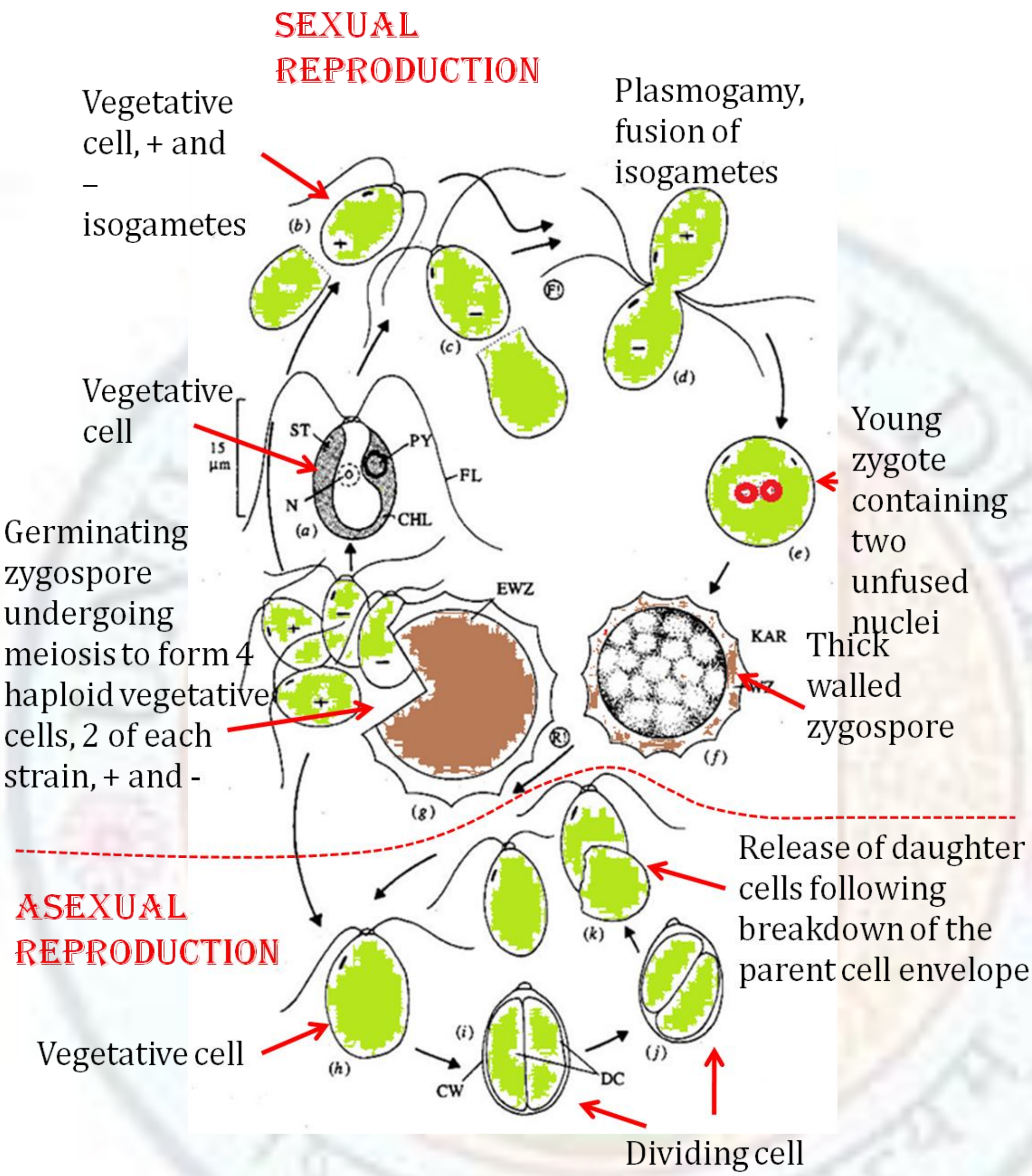


Figure: Reproduction in *Chlamydomonas*: most cells are produced by asexual reproduction (below the dotted line, h-k), sexual reproduction is isogamous (above the dotted line), anisogamous or oogamous.

Source: Author

Asexual reproduction in *Chlamydomonas*

It takes place mainly by **zoospores** but can also occur through **aplanospores**, **hypnospores** and **palmella stage**.

(a) **Zoospore formation:** Generally zoospores are formed during the night. At the time of zoospore formation parent cell comes to rest, withdraws its flagella, contractile vacuoles disappear and the protoplast withdraws from the cell wall. In this immobile state the cytoplasm, chloroplast and the nucleus divide longitudinally into two daughter protoplasts. The second division is at right angles to the first division. In this way 4, 8 or 16 uninucleate protoplasts are formed by successive mitotic divisions within the parent cell wall. Mitosis is closed and the cytokinesis involves phycoplast microtubules. Cytokinesis occurs by furrowing. Each daughter protoplast secretes a new cell wall, develops flagella, contractile vacuoles and a neuromotor apparatus.

The flagellate daughter cells are **similar to the parent cell** in shape and structure but are **smaller** in size. The parent cell wall ruptures or gelatinizes and the daughter cells are released. The daughter cells are released from the parental cell wall by production of specific wall autolysins that digest the cell wall. These daughter cells are called zoospores or mitozoospores. The liberated zoospores increase in size and are capable of producing new zoospores after 24 hrs hence the process is repeated. Under certain conditions zoospores fail to escape from the gelatinous parent cell wall and remain clustered together. This stage is known as palmella stage.

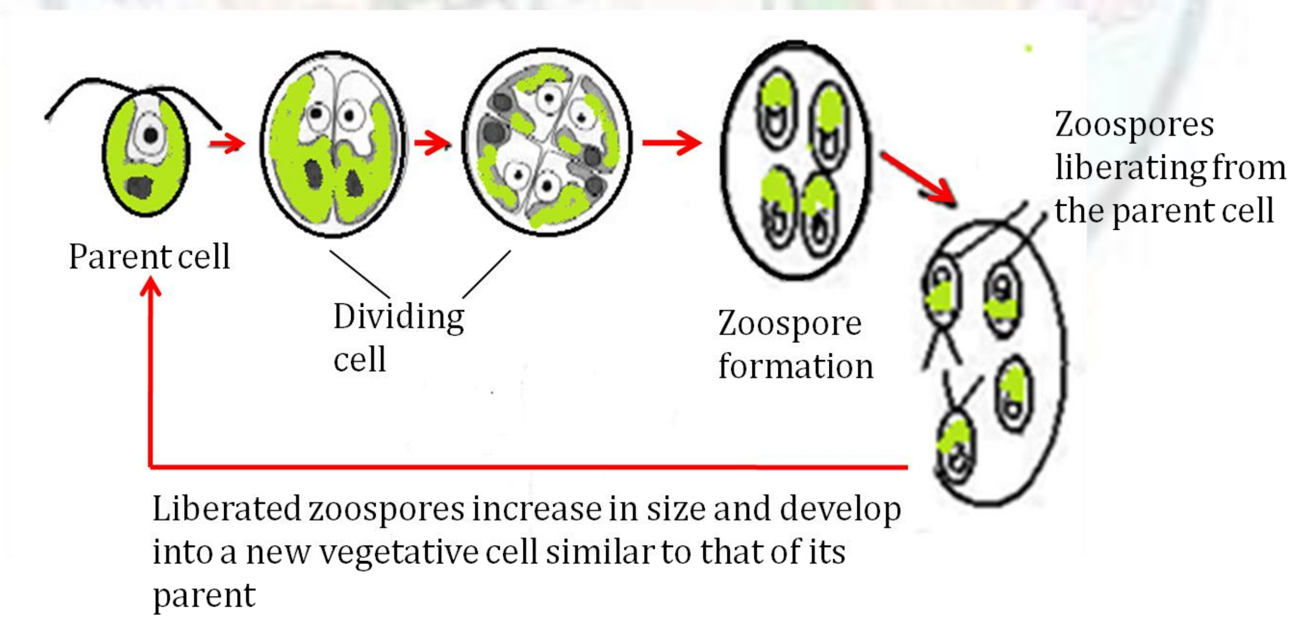


Figure: Formation of zoospores in *Chlamydomonas*.

Source: Author

(b) **Aplanospore formation:** Under unfavorable conditions such as drought, the *Chlamydomonas* cells come to rest and withdraw their flagella. The protoplast withdraws from the parent wall and rounds up. Protoplast divides into daughter protoplasts and each daughter protoplast secretes thin wall around itself but does not develop flagella. Each aplanospore germinates into a new individual resembling the parent. To survive severe drought conditions aplanospore secretes a **thick wall** around it. This thick walled resting spore is called a hypnospore.

(c) **Palmella stage:** Under certain unsuitable conditions the protoplast of the parent cell divides to form 4-8 daughter cells. The daughter cells do not develop flagella and thus fail to escape out. These non-motile cells stay clustered together within the mucilaginous matrix formed by gelatinization and swelling of the parent cell wall. This assemblage of cells in a common gelatinous matrix is called palmella stage. This stage is temporary **perennating** stage and is of brief duration. Under favorable conditions (e.g., presence of water) the individual cells in these palmelloid phases readily develop flagella and return to the motile condition. These cells then escape out from the mucilaginous matrix and mature into large vegetative cells. Sometimes in severe drought conditions the individual cells of the palmella stage secrete a thick wall around them and develop into red non-motile resting spores called the hypnospores. Contents of hypnospores include a red pigment called haematochrome which imparts red colour to the hypnospore.

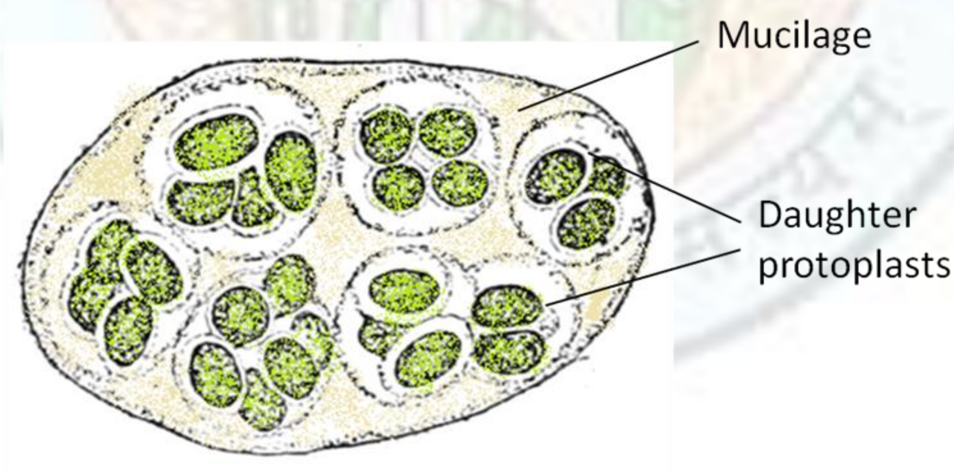


Figure: *Chlamydomonas:* Palmella stage

Source: Author

Sexual Reproduction

Sexual reproduction in *Chlamydomonas* is regulated by certain environmental factors such as:

i) Depletion of Nitrogen/ ammonium
ii) Absence or deficiency of nutritional substances
iii) Light and temperature
iv) High CO_2 concentration and presence of Calcium

Some species are isogamous, some are anisogamous and a few are primitive oogamous.

(a) **Isogamy:** It is a primitive type of sexual reproduction and most species of *Chlamydomonas* are isogamous. Isogamous reproduction is characterized by a **similarity** in size, form and structure between the fusing gametes. The sexual reproduction starts with the division of the cell protoplast into 8, 16, 32 or 64 daughter protoplasts. Each daughter protoplasts aquire two flagella and is called a gamete or isogamete. The biflagellate gamete is usually naked and has no cell wall. These gametes are smaller than zoospores. The gametes are released from the parental cell wall by production of specific wall **autolysins** that digest the cell wall. The liberated gametes swim in the surrounding water for a while. The flagellar surface of gametes is covered by linear glycoprotein molecules called agglutinins. These chemical substances are involved in the recognition of gametes of the opposite strains and promote the adhesion of flagella of cells of opposite mating types. These molecules are absent in the flagella of the vegetative cells. In isogamous forms mating types are usually designated as mt^+ and mt^-. Tips of the flagella adhere initially; afterwards the flagellar pairs become attached through their whole length. The gametes of both the strains fuse at their anterior ends. Isogamous sexually reproducing species can be classified into homothallic (*C. debaryanum, C. longistigma, C. media*) and heterothallic (*C. reinhardtii, C. moewusii*). In homothallic species fusion takes place between the gametes produced in the same parent cell. Once the gametes are released from the parent cell wall they swim for a while in the surrounding water and then fuse in pairs and form a zygote. In heterothallic species fusion takes place between the gametes produced in two different parent cells of opposite mating strains. One of these is designated as a plus strain (+) and the other as minus (-) strain. Once the gametes of plus strain get into contact with a minus strain they fuse to form a zygote. Hence the isogametes are morphologically similar but functionally different as one belongs to the plus strain and the other to the minus strain.

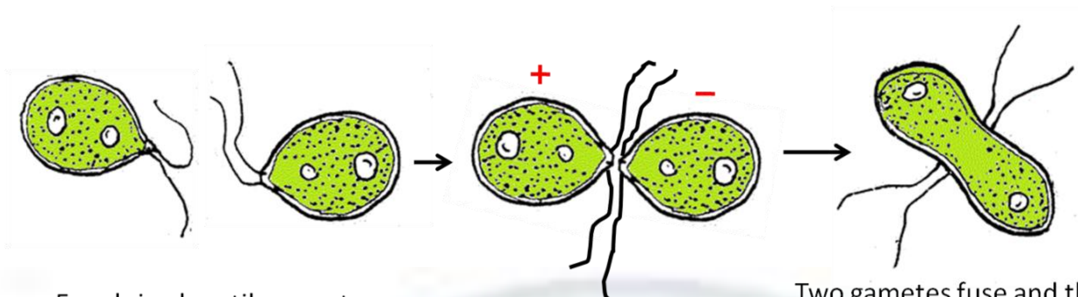


Figure: Isogamy in *Chlamydomonas*

Source: Author

(b) **Anisogamy:** In anisogamy the fusion takes place between **dissimilar** gametes, the anisogametes. Anisogamy in *Chlamydomonas* can be categorized into **physiological** anisogamy and **morphological** anisogamy. In physiological anisogamy (e.g., *C. monoica*) the fusing gametes are morphologically identical but different in their behavior i.e., one gamete may be more active than the other.

In morphological anisogamy the fusing gametes (male and female) differ noticeably in size e.g., *C. braunii*. The anisogametes differing in their size can be designated as male and female. Physiological anisogamy is a primitive type of anisogamy whereas morphological anisogamy is an advanced type of anisogamy. Gametes are produced in specialized cells called gametangia. The male gamete is small and active whereas the female gamete is large and passive. These anisogametes come in contact with each other through their anterior end and the wall at the point of fusion dissolves.

Fusion of the gametes takes place externally in the surrounding water. The protoplast of one of the gamete (microgamete) escapes from its cell wall and flows entirely into the envelope of the other gamete (the macrogamete) to fuse with it (Figure). A zygote is formed in the cell envelope of the macrogamete. The anisogamous species are all heterothallic or dioecious.

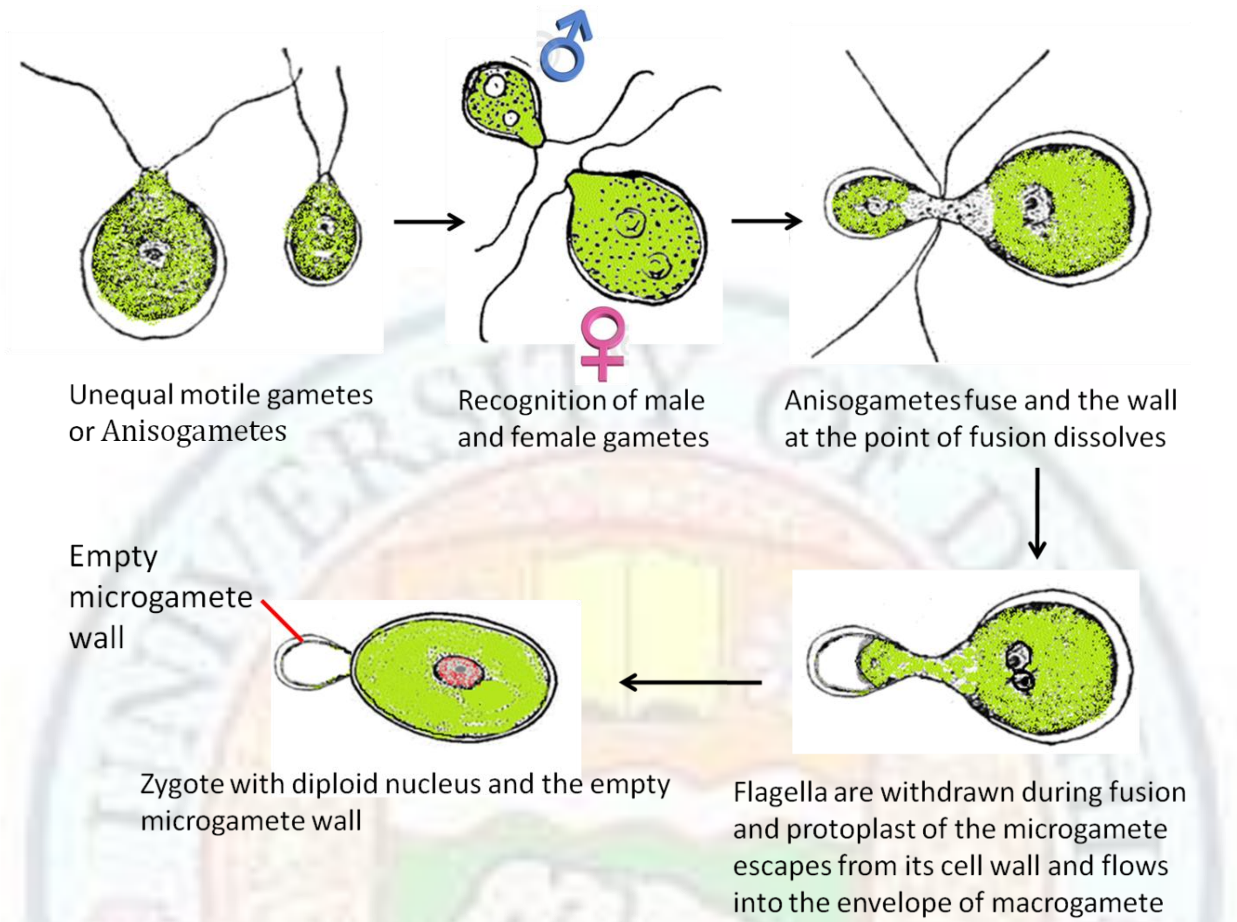


Figure: Anisogamous reproduction in *Chlamydomonas*

Source: Author

(c) **Oogamy:** Oogamous sexual reproduction is the most advanced type of sexual reproduction and has been observed in *C. coccifera and C. ooganum*. **Distinct male and female sex organs** are formed**.** The female mother cell withdraws its flagella and its protoplast rounds off to form a single globose macrogamete or female gamete which is considered equivalent to egg cell. The large globose macrogamete does not have any flagella and is immobile. Male parent cell divides by four divisions to form sixteen spherical biflagellate microgametes or male gametes. Both microgamete and macrogamete have a cell wall. The male gametes or microgametes on maturity are released in the surrounding water. The active male gamete swim in the direction of immobile female gamete and the two unite at their anterior ends. The intervening walls at the point of union between the two gametes dissolve and the flagella of the male gamete are resorbed. The protoplast of the male gamete detaches from its cell wall and moves into the envelope of female gamete.

Plasmogamy and karyogamy occurs and the two protoplasts fuse to form a non-motile zygote. It is a primitive type of oogamy as the motile male gametes or microgametes are not typical spermatozoids.

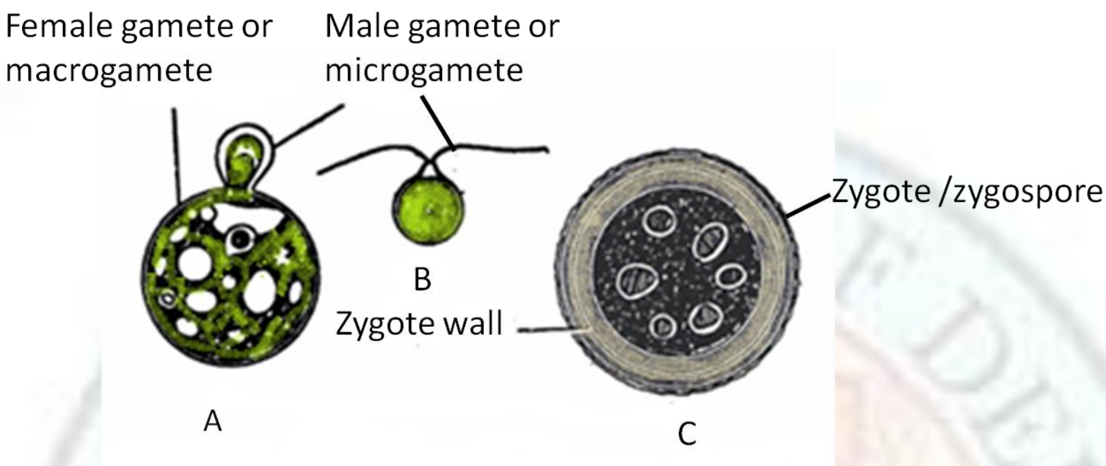


Figure: Oogamy in *Chlamydomonas coccifera*

Source: Goroschankin, 1905.

Zygospore

The newly formed zygote in **isogamy** remains **motile** for few hours to several days depending upon the species. The zygote has four flagella, two chloroplasts, two nuclei and two eyespots. Shortly the flagella are withdrawn and the zygote comes to rest by settling down on some substratum. Soon the cytoplasm, nuclei and chloroplast of the gametes fuse. The **non-motile zygote** secretes a primary and a secondary wall around it and is converted into a resting zygospore. The zygote or zygospore is the **only diploid structure** in the life cycle. Zygote always passes through a 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.

Germination of Zygospore

When the zygospore encounters **favorable conditions** (water) it germinates. The red colour of the zygospore changes to green before germination. The diploid nucleus of the zygospore undergoes **meiosis** resulting into the formation of four to eight haploid nuclei. In the heterothallic species + and – strains become distinct at this point by **segregation** of the nuclei of opposite mating types (+ and -). Each haploid nucleus is incorporated into some protoplast and and forms a **biflagellate meiozoospore** which is motile. Each meiozoospore secretes a cell wall around it. At this stage the inner wall of the zygospore gets dissolved and the outer wall splits open, liberating the meiozoospores. Each released meiozoospore grows into a fully developed *Chlamydomonas* cell.

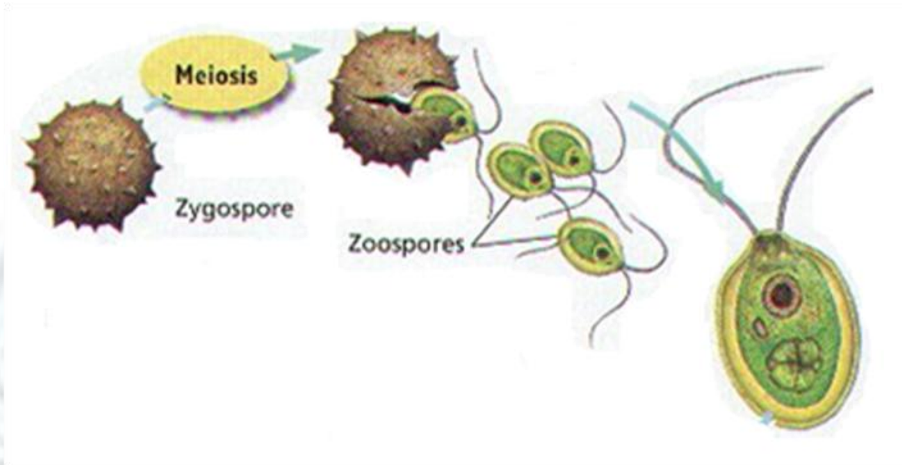


Figure: *Chlamydomonas:* Germination of zygospore and the release of meiozoospores

Source:http://www.biologyjunction.com/algal__fungal_protist_notes_b1.htm

Origin, evolution and differentiation of sex in *Chlamydomonas:*

Under favorable environmental conditions *Chlamydomonas* reproduces by the formation of biflagellate, motile zoospores. Each zoospore is capable of growing into a new *Chlamydomonas* individual resembling the parent. In this process there is no fusion of gametic cells and hence this process is called as **asexual reproduction**.

The origin of **gametic cells** is the origin of sex. At the end of a growing season when environmental conditions become unfavorable (e.g., nitrogen depletion), *Chlamydomonas* resorts to sexual reproduction. **Isogamy** is the primitive form of sexual reproduction in which fusion occurs between similar gametic cells. Isogamy occurs in *C. debaryanum, C. longistigma, C. media* and *C. reinhardtii*. **Anisogamy** is a further advanced form of sexual reproduction in which fusion occurs between dissimilar gametes. Anisogamy in *Chlamydomonas* can be categorized into **physiological anisogamy** and **morphological anisogamy**. Physiological anisogamy occurs in *C. monoica* and the fusing gametes are morphologically identical but different in their behavior. In morphological anisogamy occurs in *C. braunii* and the fusing gametes differ noticeably in size. Physiological anisogamy is a primitive type of anisogamy whereas morphological anisogamy is an advanced type of anisogamy.

Oogamy is the most advanced level of sexual reproduction and can be traced in *Chlamydomonas*. *C. coccifera* exhibits oogamous reproduction in which the nonmotile female gamete or egg cell is fertilized by biflagellate microgametes. In *C. coccifera* it is a primitive type of oogamy as the motile male gametes or microgametes are not typical spermatozoids.

Life cycle

The life cycle of *Chlamydomonas* consists of haploid and diploid phases. The motile vegetative *Chlamydomonas* cell is haploid. It produces haploid gametes. The haploid gametes fuse and the diploid phase is attained in the zygote. The diploid nucleus of the zygote undergoes meiotic division followed by formation of haploid meiozoospores. This way Chlamydomonas terminates its diploid phase. Each haploid meiozoospore grows into a haploid vegetative *Chlamydomonas* cell. The life cycle of *Chlamydomonas* having haploid *phases* represented by unicellular vegetative thallus, zoospores, gametes and meiozoospores and a diploid phase which is only restricted to the zygote (zygotic meiosis) is described as **haplontic**.

Vegetative cells of *C. reinhardtii* are haploid with 17 chromosomes (the size of nuclear genome is 121 Mb or 121,000,000 base pairs and it is divided into 17 linkage groups or chromosomes). Under unfavorable conditions haploid gametes are produced. Haploid gametes are identical in appearance and are designated as mt(+) and mt(-). These haploid gametes fuse and form a diploid zygote. The diploid zygote perennates in soil and germinates on the return of favorable conditions. The diploid zygote undergoes meiotic division and liberates four biflagellate haploid cells. These cells grow into fully developed haploid vegetative cells and resume the life cycle of *C. reihardtii.*

Under favorable growth conditions, haploid vegetative cells of *C. reinhardtii* undergo two or three mitotic divisions resulting into the formation of 4 or 8 haploid daughter cells or zoospores per mother cell. These zoospores give rise to haploid vegetative cells of *C. reinhardtii* and resume the life cycle.

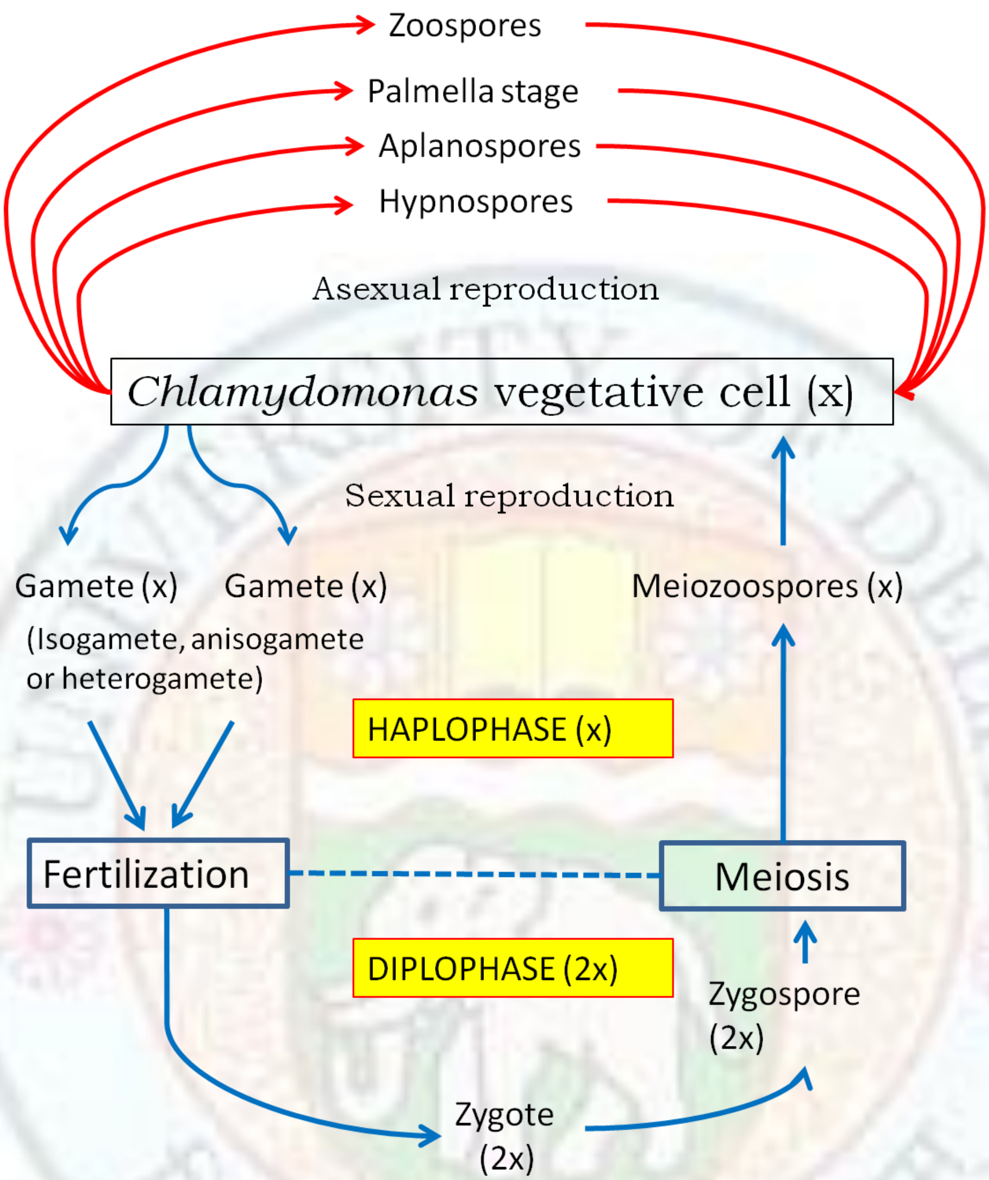


Figure: Graphic life cycle of *Chlamydomonas*

Source: Author

Oedogonium

Introduction

The name of the genus is derived from the greek words “**oidos**” (swelling) + “**gonos**” (reproductive structures). *Oedogonium* belongs to the Class Chlorophyceae. *Oedogonium* is a filamentous alga commonly occurrs **attached** to submerged substrates in shallow fresh-waters. *Oedogonium* thallus is an **unbranched filament** which can be easily identified by characteristic **rings** at the apical ends of certain cells. Different species of *Oedogonium* vary in dimensions of the vegetative cells, structure of oogonia, zygote wall ornamentation, and position of antheridia (Prescott, 1951). Some species of *Oedogonium* are edible and are consumed in a few subtropical areas. Occasionally, the alga can form conspicuous blooms.

Systematic position of *Oedogonium*

According to the **morphological** concept- Fritsch's classification (1935)

Class – Chlorophyceae

Order - Oedogoniales

Family - Oedogoniaceae

Genus - *Oedogonium*

According to **ultrastructure** of algal cells and life cycles- (Round, 1984)

Division - Chlorophyta

Class – Chlorophyceae

Order – Oedogoniales

Family – Oedogoniaceae

Genus – *Oedogonium*

According to the **molecular phylogenetic** concept- Lewis & McCourt (2004); Becker & Marin (2009)

Kingdom - Viridiplantae

Division - Chlorophyta

Class - Chlorophyceae

Order - Oedogoniales

Family - Oedogoniaceae

Genus - *Oedogonium*

Occurrence

The genus has around 400 described species of which around 114 species are found in India. *Oedogonium* is a **submerged epiphytic freshwater** alga. *Oedogonium* commonly occurs attached to the submerged plants and other substrates such as stone, wood etc. in freshwater ponds, pools, lakes, rivers and slow running streams. The filaments remain attached to the substratum with the help of a basal cell called **holdfast**, which is specially differentiated for this purpose. Young filaments remain attached to substratum whereas older filaments of *Oedogonium* get detached and freely float on the water surface. *Oedogonium* is more common in standing or stagnant water than that of running water and forms green silk or scum of standing water. Some *Oedogonium* species are terresetrial also e.g., *O. terrestris* and *O. randhawae* grow on moist soil. *O. oblengellum*, *O. cardiacum*, *O. tenuis* and *O. elegans* are some common Indian species of *Oedogonium*.

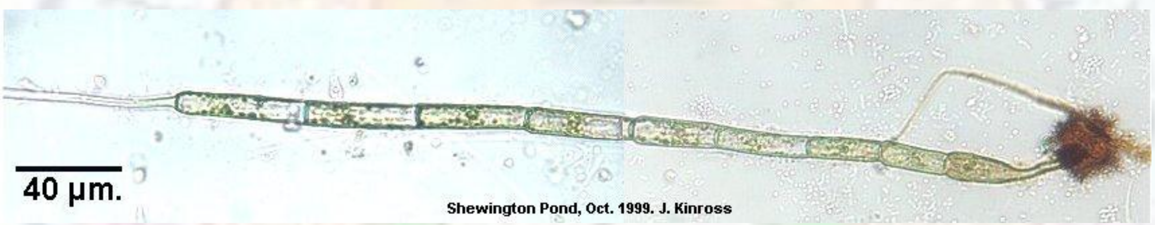


Figure: *Oedogonium* Filament

Source:http://algalweb.net/oedo6-a.jpg

Organization of thallus

The plant body is a thallus showing **apical basal polarity**. Thallus is a long unbranched filament made up of a single row of elongated cells placed end to end and are connected by plasmodesmata. The filament has three types of cells:

(i) A club shaped **basal cell** or rhizoidal cell or **holdfast**

(ii) Dome shaped **apical cell**

(iii) Intercalary cells

The filament is generally attached at the lower end by means of a basal cell or holdfast which is **achlorophyllous** and is expanded into a flattened disc with finger like projections.

In terrestrial species the holdfast shows rhizoid like outgrowths. The free end of the terminal cell at the upper part of the filament is broadly rounded forming a dome shaped apical cell which is **chlorophyllous**. The apical cell does not show division. Cells present between the basal cell and apical cell are termed as intercalary cells. A distinctive feature of *Oedogonium* is the presence of characteristic fragile rings at the apical ends of some intercalary cells. These rings are formed at the time of cell division and are called **apical rings** or **apical caps**. Only those cells which have the apical rings divide again and the cells that have undergone many such divisions display several rings.

Cell structure:

Cells of the vegetative filament are elongated and cylindrical with a rigid cell wall enclosing the protoplast. The cell wall (except that of the holdfast) is differentiated into three layers. The outer layer is formed of chitin, middle layer of pectin material and inner cellulose layer. The outer chitinous layer prevents the dissolving away of the pectic layer therefore the filaments remains wet. Inner to the cell wall is present a plasma membrane. The plasma membrane encloses the cytoplasm, a single large **parietal** chloroplast with a **number of pyrenoids,** a single parietal nucleus and other membrane bound organelles such as mitochondria, Golgi bodies and endoplasmic reticulum. There is a large central vacuole filled with cell sap. In *Oedogonium,* the chloroplast is a large, **reticulate** structure made up of hollow cylindrical network with meshes (meshes may be broad or narrow). The chloroplast is parietal in position and extends from one cell to the other. The chloroplast of *Oedogonium* contains microtubules which provide support to the large chloroplast. Pyrenoids are present at the anastamoses or intersecting points of the meshes of the reticulate chloroplast. Pyrenoids accumulate starch and are surrounded by starch sheath. A series of transverse parallel fragile rings run across the apical ends of intercalary cells. These rings are formed as a result of cell division and the cells with these rings are known as cap cells (Figure).

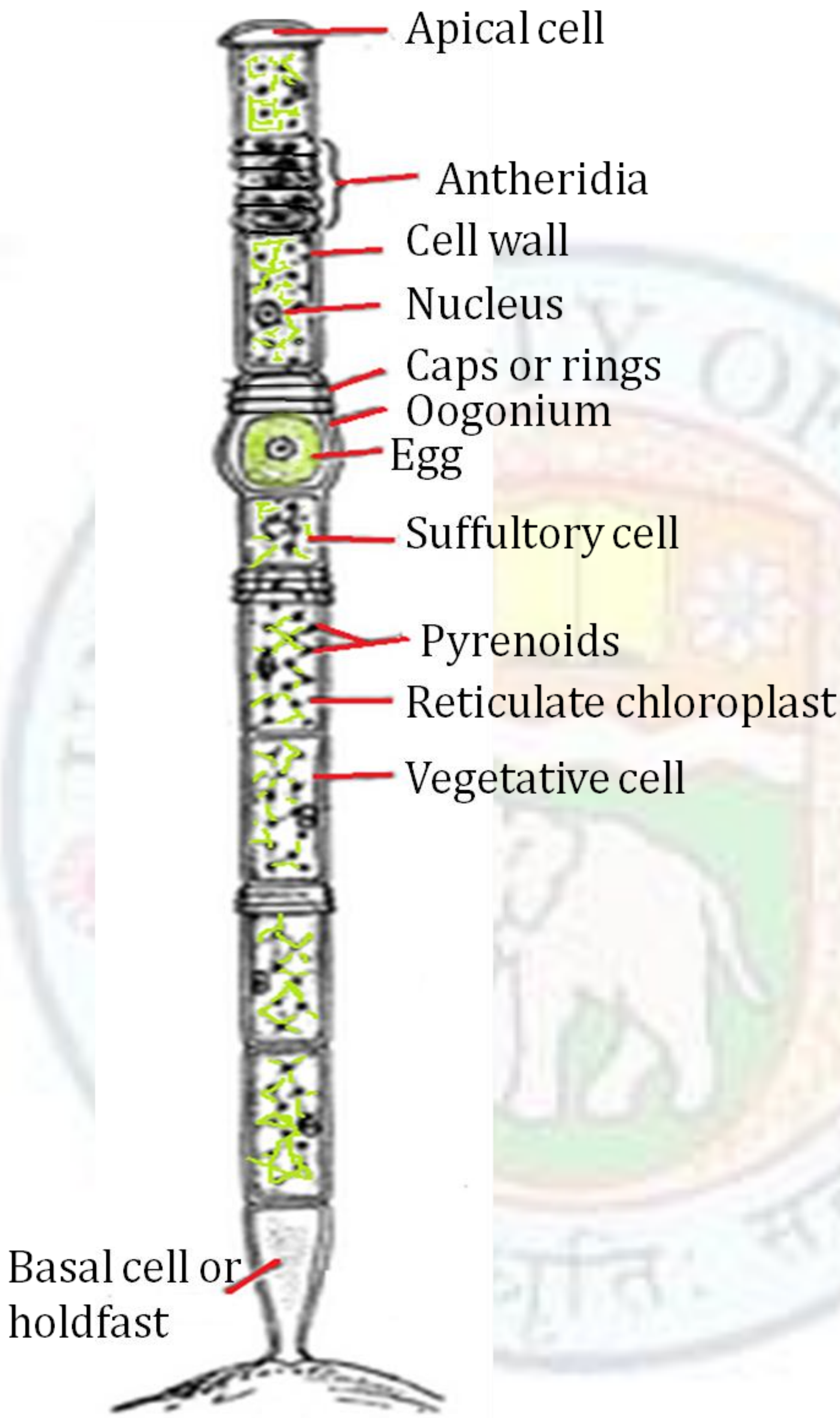


Figure: A filament of monoecious species of *Oedogonium*

Source: Author

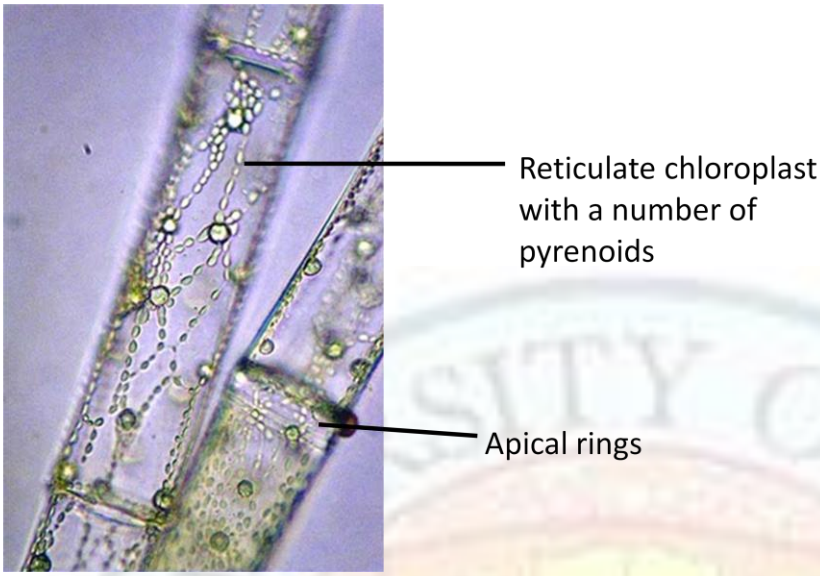


Figure: *Oedogonium* filament showing the elongated intercalary cells placed end to end. Three rings are visible in the lower cell on the right, indicating that cell has divided three times.

Source:http://beyondthehumaneye.blogspot.in/2010_07_01_archive.html

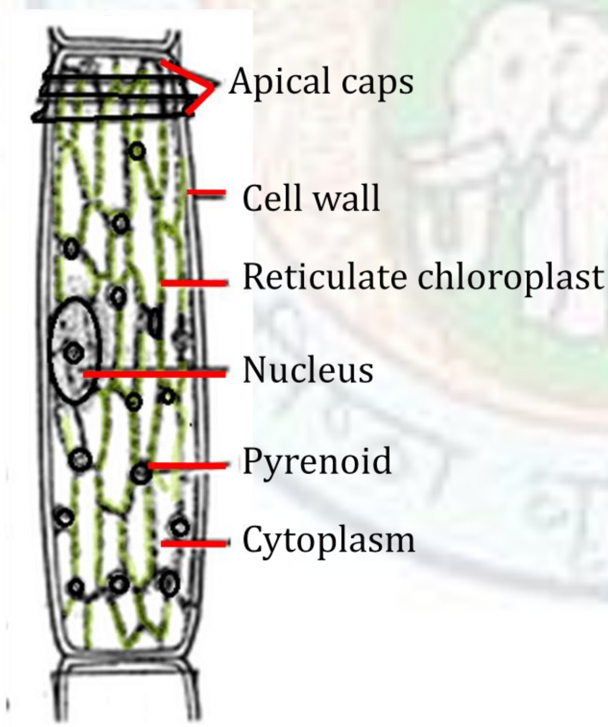


Figure: A mature single intercalary cell of *Oedogonium* showing the presence of apical caps/rings and a reticulate chloroplast with many pyrenoids.

Source: Author

Growth and Cell division in *Oedogonium*

Oedogonium exhibits a unique mode of cell division which results into the formation of ring like scars near the anterior end of a cell.

1. Once a cell is ready to divide, two main events occur at the initiation of a division. (i) **Movement** of the peripherally located nucleus into the centre of the cell. (ii) A transverse thickened ring like **ingrowth** of the wall material appears from the inner face of the lateral wall in the anterior portion of the cell. The ring is formed by **intussusception** (the increase in the surface area of a cell due to the accumulation of new wall material between the existing materials of the cell wall).

2. The ring gradually increases in thickness and turns into a **grooved structure** due to the continuous buildup of wall material transported from the cytoplasmic vesicles. About the same time, the nucleus migrates towards the upper part of the cell. Here the nucleus begins to divide **mitotically**.

3. Nuclear division is followed by formation of an incomplete septation of floating cytoplasmic strands between the two daughter nuclei. This results into the formation of a **floating septum** which is not connected with the lateral walls.

4. After some time the outer and middle wall layers of the mother cell external to the grooved inner wall ring rupture due to the gradual increase in the size of the ring. The grooved ring **expands** completely and forms a cylindrical structure.

5. By the expansion of the inner wall, the parent cell elongates to approximately double its length. Progressively the floating septum between the two daughter nuclei migrates upwards to the base of the daughter cell and develops into a **complete septum** of mature cross wall. Consequently the process of cell division is completed resulting into the formation of two daughter cells. The wall of the upper cell is completely made up of the **extended inner wall material**.

6. The **remnants** of the ruptured parent cell wall form an **apical cap** at the upper end of the newly formed daughter cell and a **bottom sheath** formed by the ruptured portion of the parent wall on the lower part of the same daughter cell.

Cell division takes place only in those cells which have cap-like apical rings or apical caps. These cells are called cap cells. Therefore, after each cell division one of the daughter cells (the upper one) divides actively whereas the other daughter cell remains quiescent. A new cap develops after each cell division. Thus the number of caps on a cell denotes the number of times a cell has divided.

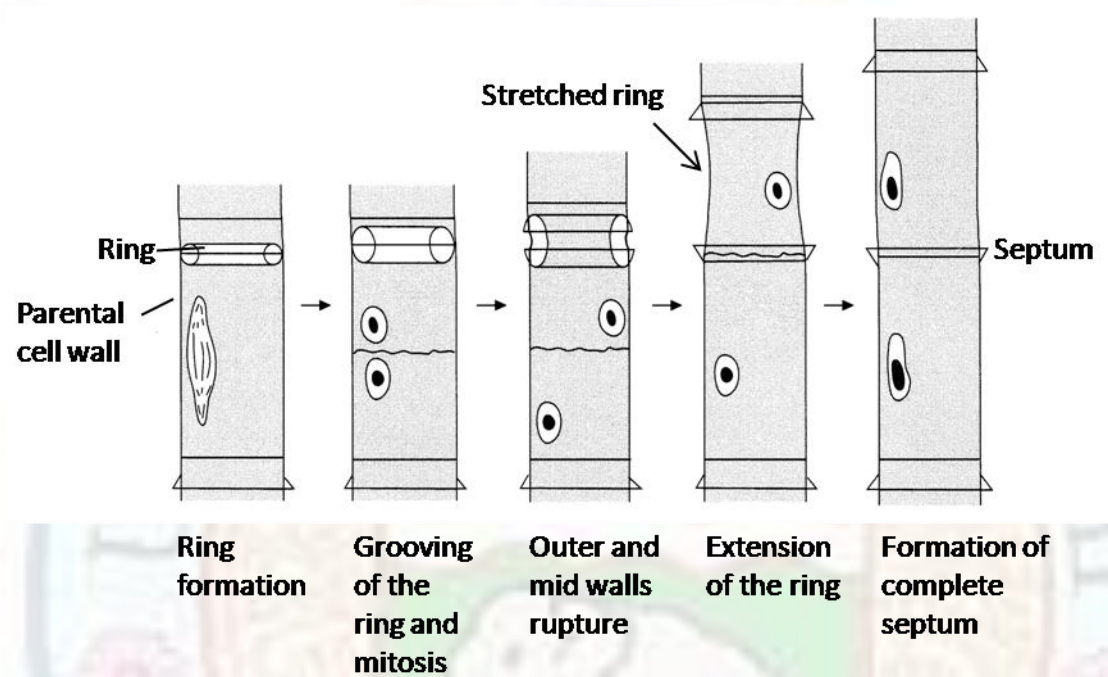


Figure: Various stages of cell division in *Oedogonium*

Source: Pickett-Heaps, 1975

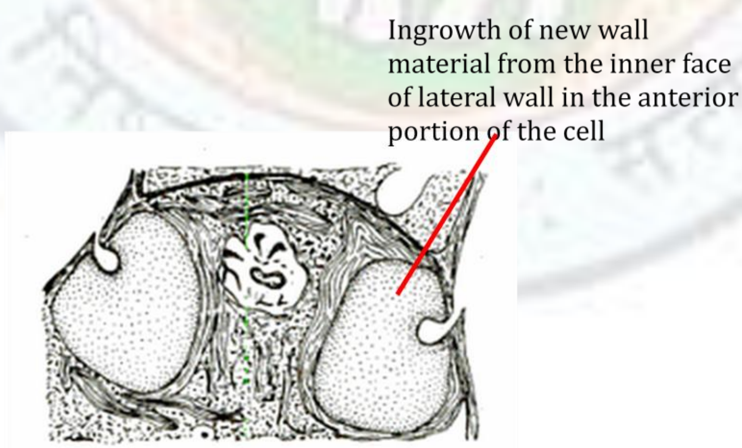


Figure: Diagrammatic representation of thickening during ring formation in the anterior part of the cell as seen under electron microscope.

Source: Pickett-Heaps, 1975.

Reproduction

Oedogonium reproduces by **vegetative**, **asexual** and **sexual** methods.

Vegetative reproduction

a) By **fragmentation**: This type of reproduction is especially found in free floating species and rarely in permanent attached forms. It occurs by **breaking** of the filament into a number of small fragments. Each small fragment by cell division and further growth develop into a new separate plant. Fragmentation takes place by dying out of some intercalary cells, due to accidental breaking of the filament, through the conversion of intercalary cells into zoosporangia or gametangia, or in adverse environmental conditions.

b) By **akinetes**: In some species the vegetative akinetes are developed during unfavorable conditions for vegetative growth. Akinetes contain abundant reserve food material such as starch and oil. Usually akinetes are produced in the chains, each inside a small and inflated cell. The akinetes are thick walled, rounded, reddish orange structures. Under favorable conditions akinetes germinate into new filaments.

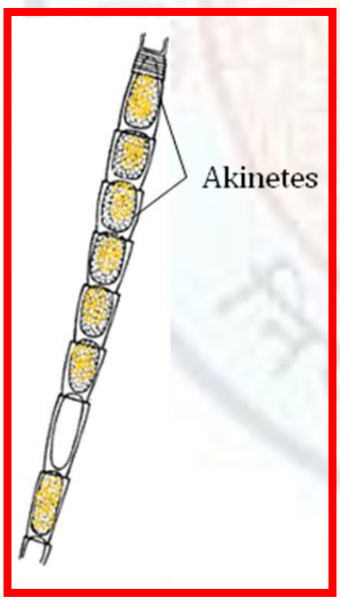


Figure: *Oedogonium:* Akinetes in chain

Source: Author

Asexual reproduction

Asexual reproduction in *Oedogonium* takes place by the formation of **stephanokontean** type (numerous short flagella arranged in the subapical portion) of **zoospores**. All cap cells of the filament are capable of producing zoospores. The cap cell becomes a zoosporangium and zoospore is produced **singly** inside the **zoosporangium**. The zoosporangial cell is usually rich in food materials.

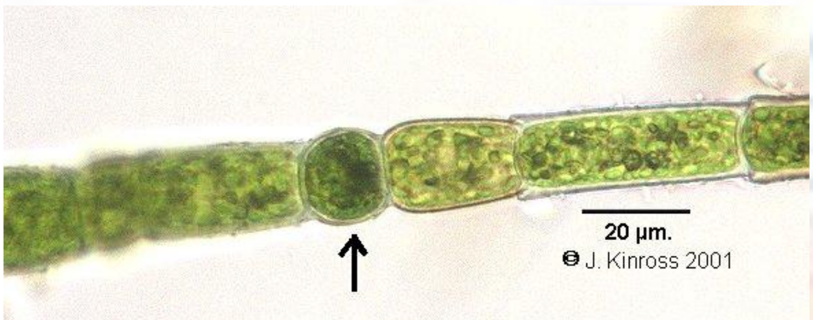


Figure: *Oedogonium:* Zoosporangium

Source: http://algalweb.net/oedo-b.jpg

At the time of zoospore formation the entire protoplast of the zoosporangium withdraws from the cell wall as a single unit. Its nucleus retracts somewhat and moves towards one side. The entire protoplast rounds up. On one side, **a hyaline region** appears adjacent to the nucleus (in between the cell wall and the nucleus). Along the margin of this hyaline region a circlular ring of **blepharoplast granules** is developed. One single flagellum develops from each of these granules thus forming a ring of flagella and the entire structure becomes a **multiflagellate zoospore**.

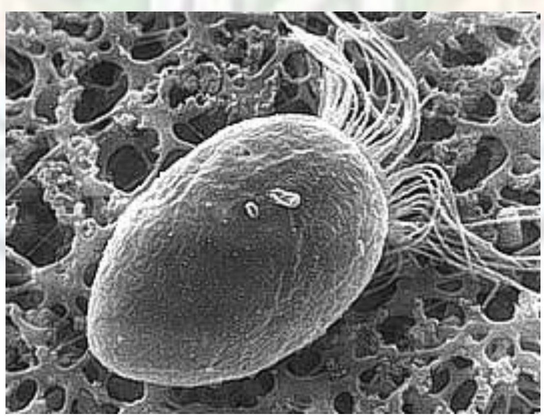


Figure: *Oedogonium* zoospore (SEM) with stephanokont flagella (numerous small flagella placed in the subapical portion)

Source: http://www.biologie.uni-hamburg.de/b-online/d44/18.htm

Liberation and germination of zoospore:

Once the zoospore is fully developed, it breaks the cell wall of the zoosporangium transversely in the cap region and starts to come out in a thin mucilaginous vesicle. The vesicle dissolves soon and the zoospore escapes in water within a few minutes from the vesicle. The released zoospore is a green ovoid or pear shaped structure and have an eyespot, a chloroplast and many contractile vacuoles. The zoospore swims for about an hour and then settles down on some solid substratum with its colourless anterior side (flagellar side with the hyaline spot) downwards. At this stage flagella are withdrawn and the structure elongates considerably (Figure). This elongated structure divides transversely by an apical ring and the apical (upper) cell forms a new filament by repeated cell divisions. The holdfast develops from the basal (lower) cell cut off by transverse division and does not divide again. The structure of the holdfast depends upon the type of substratum and the *Oedogonium* species. If the substratum is rough, the holdfast is much branched and if it is smooth then the holdfast is simple and unbranched.

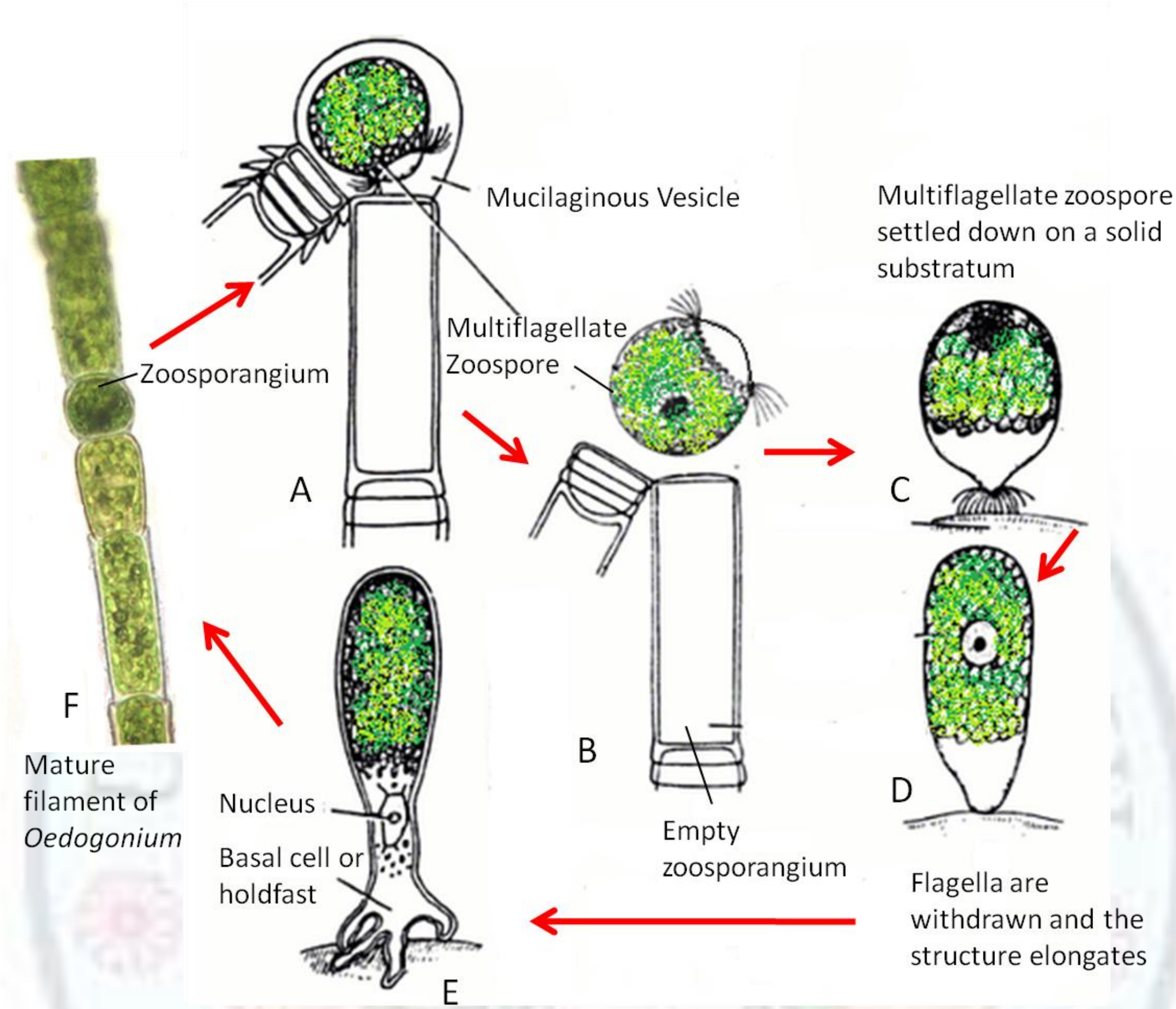


Figure: *Oedogonium:* Liberation and germination of zoospore into a new filament

Source: Author

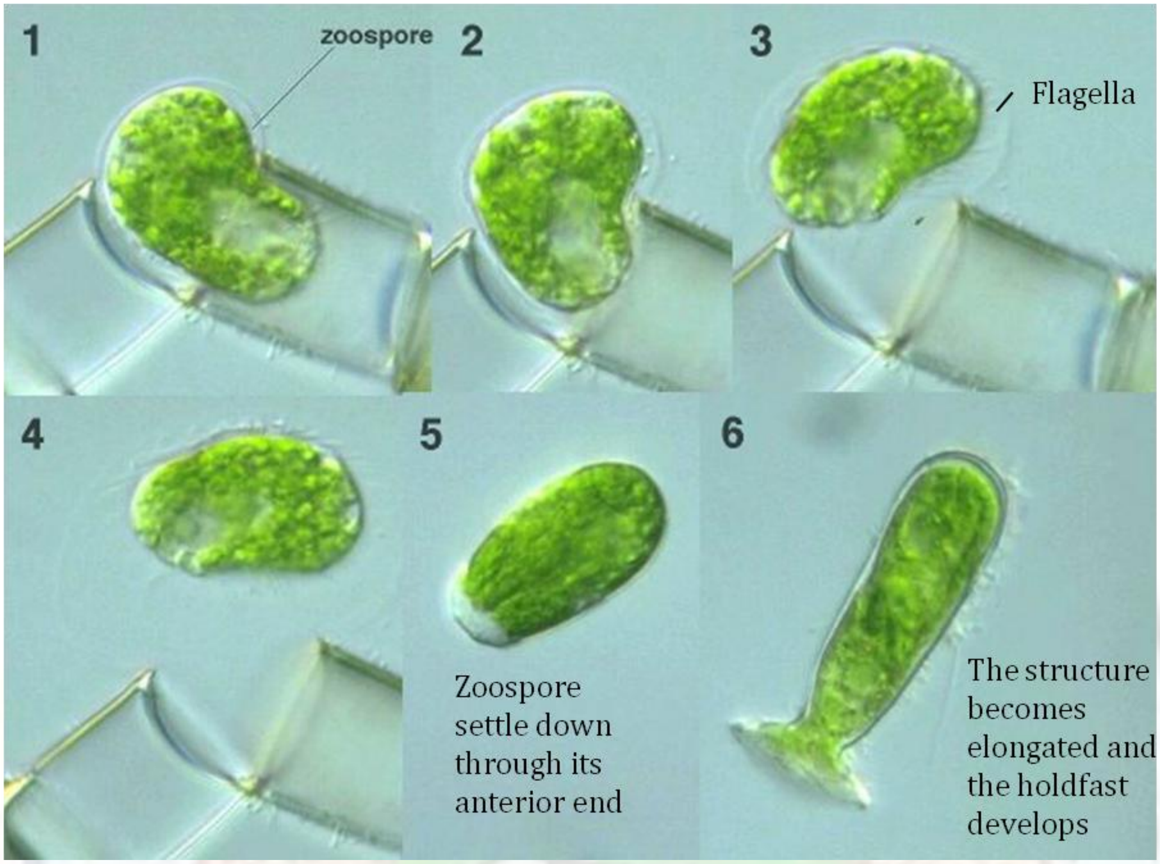
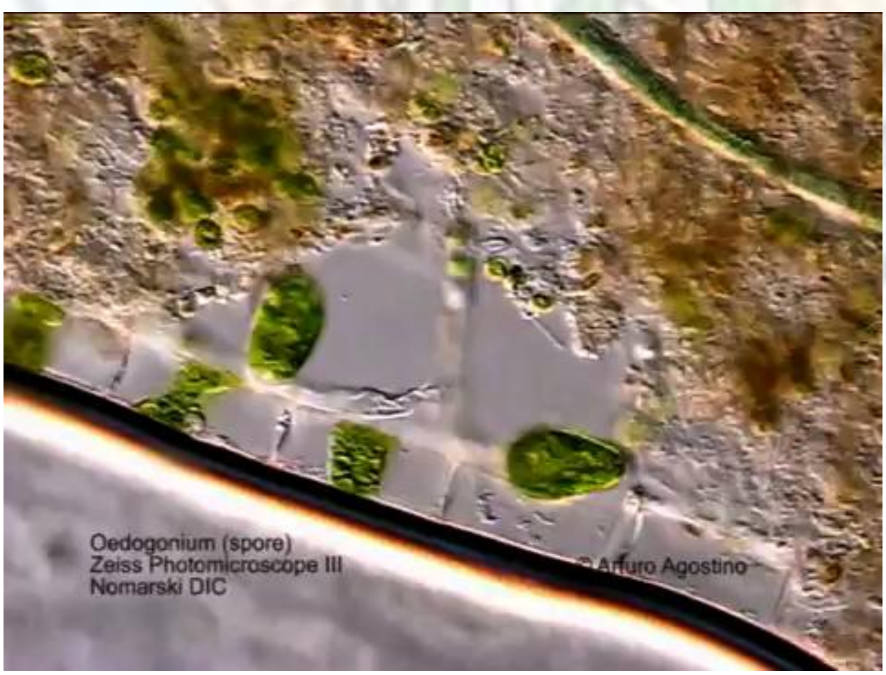


Figure: *Oedogonium* asexual reproduction: Liberation and germination of zoospores.

Source: http://protist.i.hosei.ac.jp/pdb/images/Chlorophyta/Oedogonium/sp_10c.html



Video: *Oedogonium:* liberation of zoospores and their movement

Source: http://www.youtube.com/watch?v=PARdvRQ-oes

Sexual reproduction

Sexual reproduction in *Oedogonium* is always advanced oogamous. There are distinct male and female gametes showing a drastic difference in their structure and function. The sexual gametes are formed in specific reproductive organs called gametangia. These gametangia are formed by the modification and differentiation of certain vegetative cells of the filament. Male gametangium is termed as antheridium and the female gametangium is called the oogonium. The species can be homothallic or heterothallic. Sexual reproduction may be of macrandrous or nannandrous type depending upon the pattern of distribution of sex organs. Sexual reproduction is of common occurrence in still water and rarely occurs in flowing waters.

Development of antheridia (male gametangium)

(a) In macrandrous species, the antheridia are borne on the filaments of normal size. In **macrandrous monoecious** species oogonia or antheridia develop on the same filament (monoecious or homothallic or bisexual) e.g., *O. nodulosum*, *O. fragile*. In **macrandrous dioecious** antheridia and oogonia are borne on two different or separate filaments (dioecious or heterothallic or unisexual) e.g., *O. aquaticum, O. gracilius, O. crassum*. The antheridia are produced by the rapid and repeated transverse division of antheridial mother cell. Any cap cell of the filament can function as antheridial mother cell. This cell divides transversely into two unequal cells, the upper smaller antheridial cell and a lower larger sister cell. The lower sister cell divides repeatedly resulting into the formation of a row of flat cells and a chain of 2-40 uninucleate antheridia is produced. The nucleus of each antheridium divides mitotically into two nuclei. These nuclei are enclosed by some cytoplasm and metamorphose to form two antherozoids or sperms. The antherozooids are unicellular, uninucleate and multiflagellate structure which resemble zoospores in structure and shape only with the difference that they are somewhat smaller in size and with few numbers of flagella (Figure). Unlike zoospores, antherozoids are yellowish because of their reduced plastids. The antherozooids liberate in the same way as zoospores coming out by transverse splitting of the wall of the antheridium and are enclosed in thin hyaline mucilaginous vesicles.

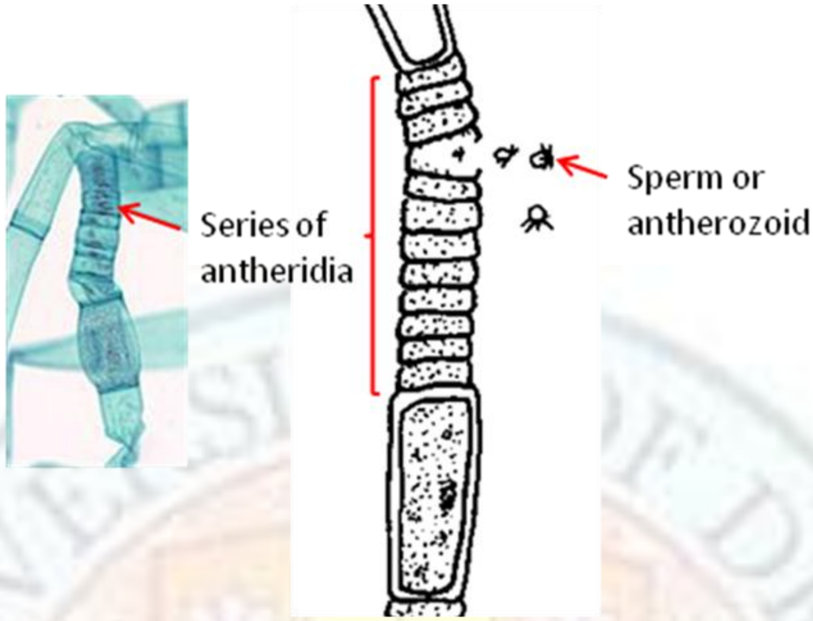


Figure: *Oedogonium* filament showing antheridia in chain each bearing two antherozoids

Source:Author

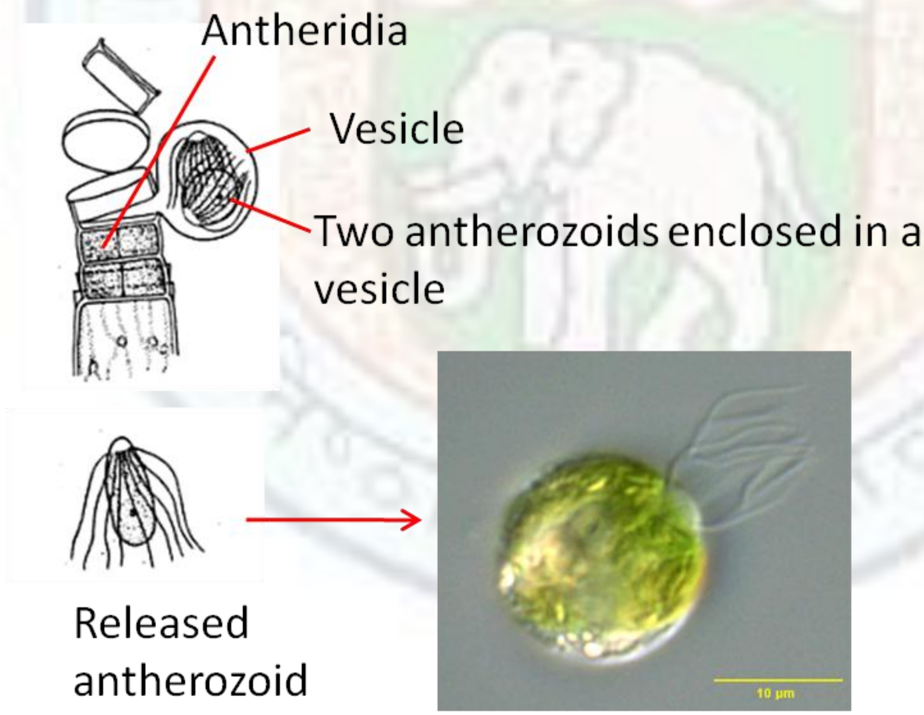


Figure: *Oedogonium*: liberation of antherozoids/sperms and a multiflagellated antherozoid.

Source:http://starcentral.mbl.edu/microscope/portal.php?pagetitle=assetfactsheet&imageid=17191

(b) In nannandrous species, the antheridia are produced on special very small 2-4 celled filaments called dwarf males or nannandria. These dwarf males grow epiphytically attached to the female filaments. Hence nannandrous species are always heterothallic or dioecious, i.e. antheridia and oogonia develop on separate filaments. A dwarf male is produced by germination of a particular type of spore called androspore. The development of androspores takes place within androsporangia (Figure b).

In nannandrous species if the androsporangia and oogonia are borne on **same filament** the species is called **gynandrosporous**. If the androsporangia and oogonia are borne on **different filament** the species is called **idioandrosporous**. **Androsporangia** are produced by repeated transverse divisions of the vegetative cells of the *Oedogonium* filament. In each androsporangium develops an **androspore**.

The androspore is a unicellular, uninucleate and multiflagellate structure and is similar to zoospores in shape and structure. Androspores are rather smaller than zoospores and bigger than antherozooids. On being liberated form the androsporangium, the androspores are enclosed in a thin vesicle which soon disappears and the androspore swims briefly. Following their brief swarming period, androspores attach either to the oogonium or to one of the adjacent cells by its anterior end. Then the androspore germinates by undergoing elongation and cuts off one or more flat cells and finally develops into a dwarf male or nannandria. The tip cells or flat cells of nannandria are called antheridia. Hence the nannandrium consists of one basal cell attached to the oogonium or adjacent cell, and one or more flat cells, the antheridia. The nucleus of each antheridium undergoes mitotic division to form two nuclei which along with some cytoplasm metamorphose into two **antherozoids**. These antherozoids are similar in structure to the antherozoids produced by macrandrous species. Antherozoid and egg fuse to form a diploid zygote.

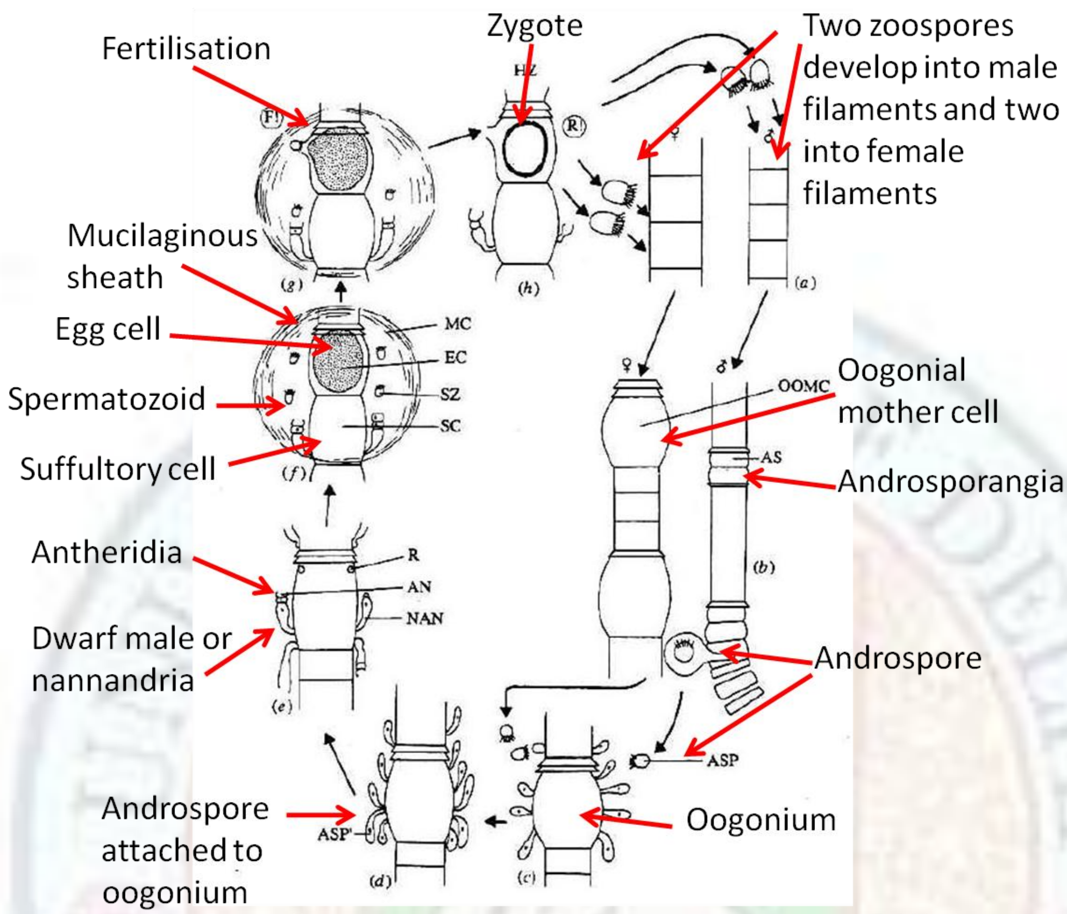


Figure: Sexual reproduction in nannandrous species of *Oedogonium*

Source: Van den Hoek, 1995

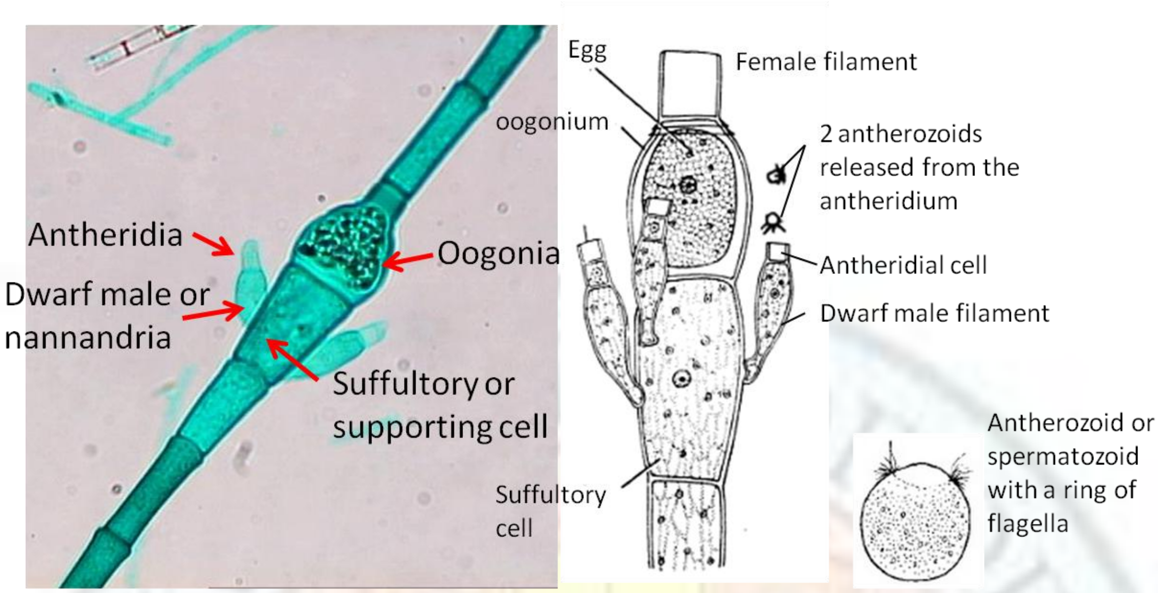


Figure: *Oedogonium:* Dwarf males or nannandria attached to suffultory cell

Source: Smith G.M., 1955

Development and structure of oogonia

The structure and development of oogonium is same in both macrandrous and nannandrous species and the oogonia develop by terminal or intercalary oogonial mother cells. The oogonial mother cell divides transversely into two daughter cells. The upper daughter cell always develops into an oogonium whereas the lower daughter cell forms the supporting cell or 'suffultory cell'.

Oogonium contains a large non-motile spherical egg cell in it. The egg cell is uninucleate with a centrally placed nucleus and is green in colour because of the presence of chlorophyll. On maturity the nucleus migrates to the periphery of the egg cell and a hyaline spot called receptive spot is visible near the upper end. Oogonium has one or more distinct caps on its upper end. Mature oogonium develops a small slit or pore near its upper end above the receptive hyaline spot.

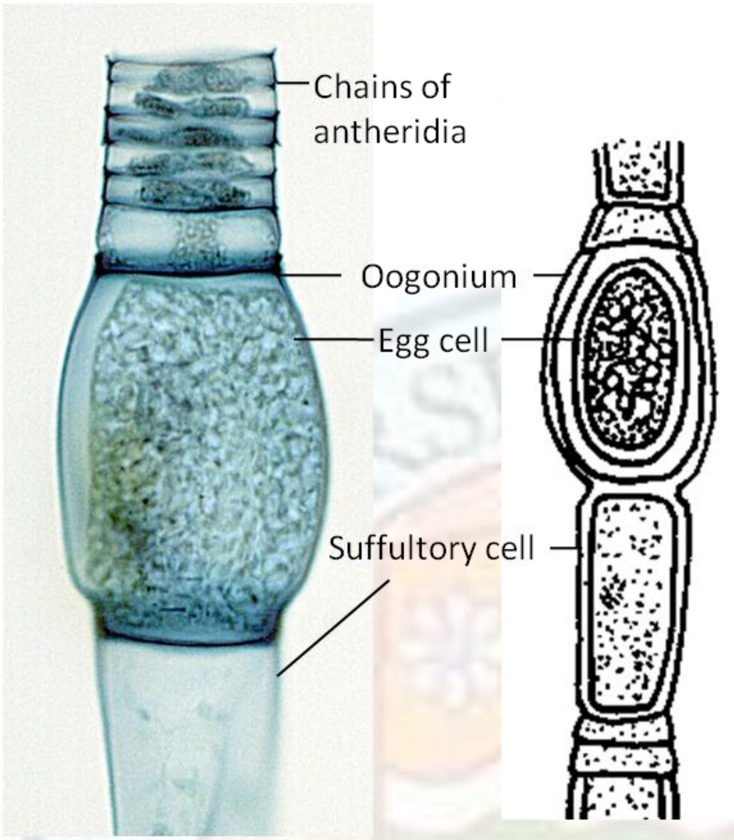


Figure: A dioecious filament of *Oedogonium* showing oogonia and antheridia.

Source: Author

Fertilization

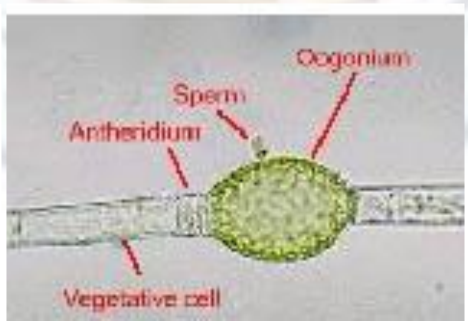


Figure: Fertilization of egg cell by sperm (oogamy) in *Oedogonium*

Source: http://www.jochemnet.de/fiu/bot4404/BOT4404_28.html

Fertilization occurs both in macrandrous and nannandrous species by the swimming antherozoid or sperm which approaches the oogonium at the receptive hyaline spot. The antherozoid swims through the pore or slit in the oogonial wall. The antherozoids are attracted chemotactically towards the oogonium due to the extrusion of some chemical substance by the mature egg. After entering into the oogonium through the pore, only one antherozoid (the one which arrives first) penetrates the egg at the hyaline receptive spot and the subsequent entry of any other antherozoid is prevented by the egg membrane.

The flagella of the antherozoid are retracted and plasmogamy takes place, which is soon followed by fusion of male and female nucleus resulting into the formation of a diploid zygote.

Shortly after fertilization the zygote retracts from the oogonial wall and secretes thick three layered wall around it. When the zygote is young it has a green colour due to the presence of chloroplast but as it passes into the resting stage its colour change from green to red or brown. The zygote liberates by the decay of oogonial wall and undergoes a period of rest which varies from 12 to 14 months.

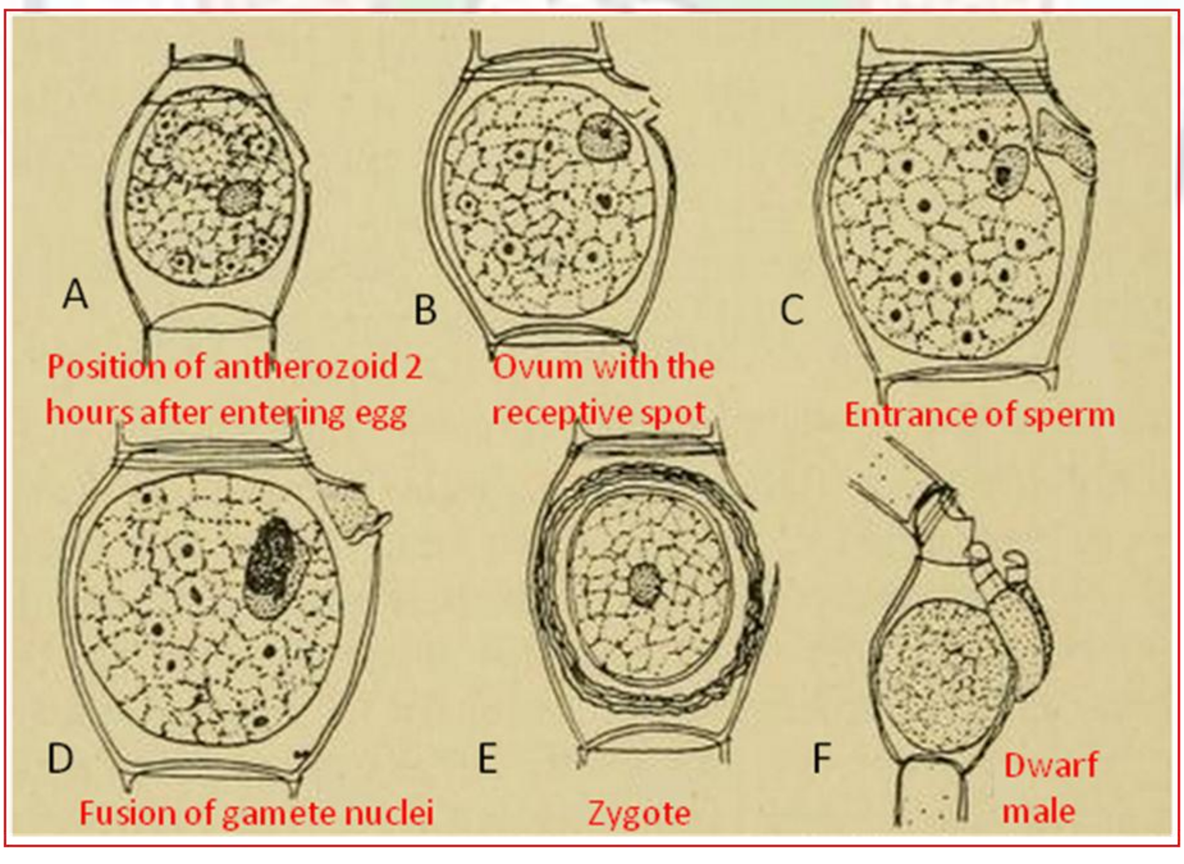


Figure: *Oedogonium*: **A** shows the position of antherozoid 2 hours after entering egg, **B-E** stages in the fertilization of ovum, **F** Dwarf male attached to oogonium.

Source: Chapman V.J., 1962

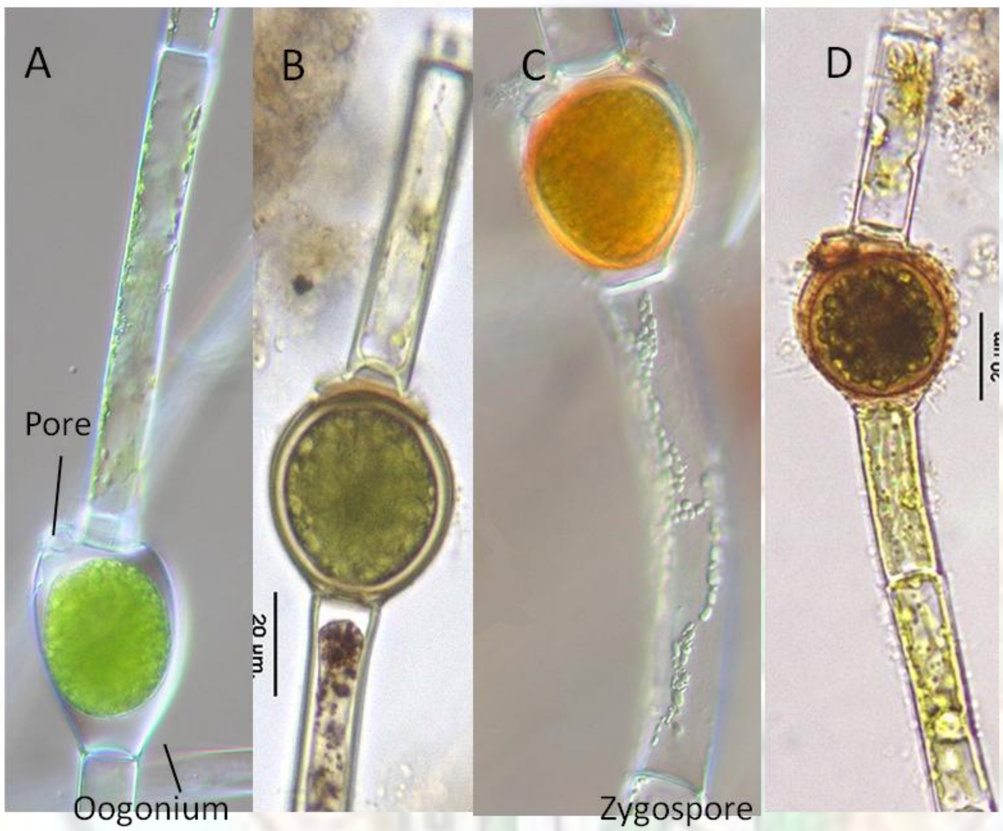


Figure: *Oedogonium:* (A) Oogonium, (B-D) various stages of zygospore

Source: http://algalweb.net/Islay03/oedo14zygo-a.jpg

http://university.uog.edu/botany/474/fw/oedogonium.htm

Germination of Zygote

The zygote germinates under favorable conditions. Prior to germination, during the resting period diploid nucleus of the zygote undergoes meiotic division resulting into the formation of four haploid nuclei. Hence zygotic meiosis re-establishes the haploid nucleus of the vegetative stage of the *Oedogonium*. The haploid protoplast turns green and divides into four daughter cells. Each of the daughter protoplasts acquires a crown of flagella and metamorphoses into a meiozoospore. These meiozoospores are liberated by rupturing the zygote wall and remain enclosed in a vesicle which soon disappears. These meiozoospores resemble with the vegetatively produced zoospores. The liberated multiflagellate meiozoospores swim freely in water for some time and then settle on some substratum by their anterior ends, withdraw their flagella and germinate into new haploid vegetative filaments of *Oedogonium*. In macrandrous diecious species out of the four meiozoospores, two meiozoospores germinate into male filaments and the remaining two germinate into female filaments.

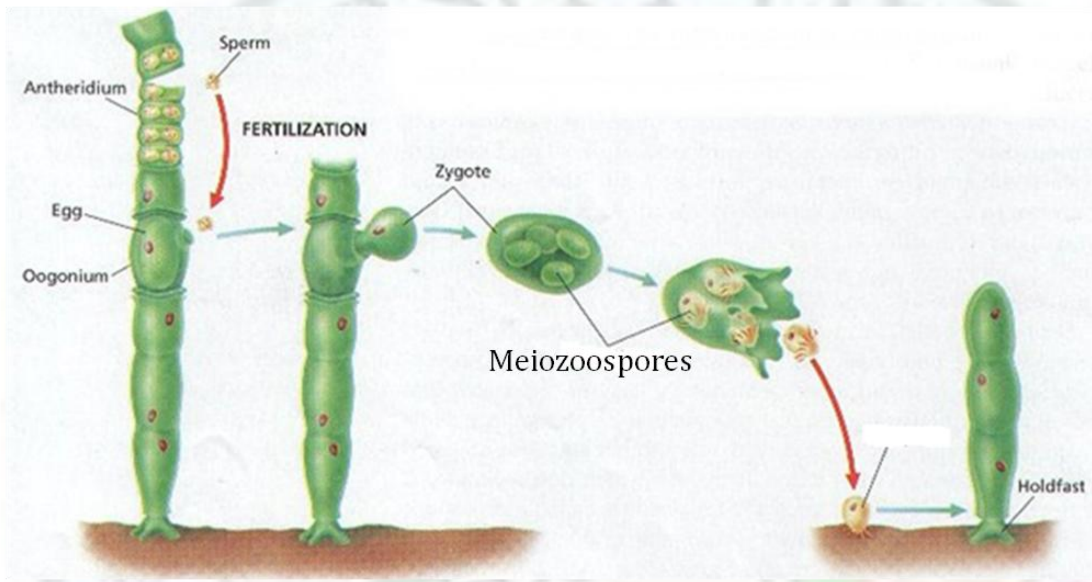


Figure: *Oedogonium:* Germination of zygote

Source:http://www.biologyjunction.com/algal__fungal_protist_notes_b1.htm

Life cycle

Oedogonium has a haplontic life cycle. The filamentous plant body in all species is always haploid. Haploid male and female gametes fuse to form a diploid zygote. Zygote is the only diploid stage in the life cycle. The zygote soon undergoes meiosis to form haploid meiozoospores. The meiozoospores germinate into new haploid filaments.

1. Life cycle of macrandrous monoecious species:

The antheridia and oogonia develop on the same plant of normal size and produce haploid male gamete (antherozoids) and haploid female gamete (egg). Both these gametes fuse to form a diploid zygote. The zygote divides by meiotic division to form four haploid meiozoospores. These meiozoospores germinate into new haploid filaments of *Oedogonium*.

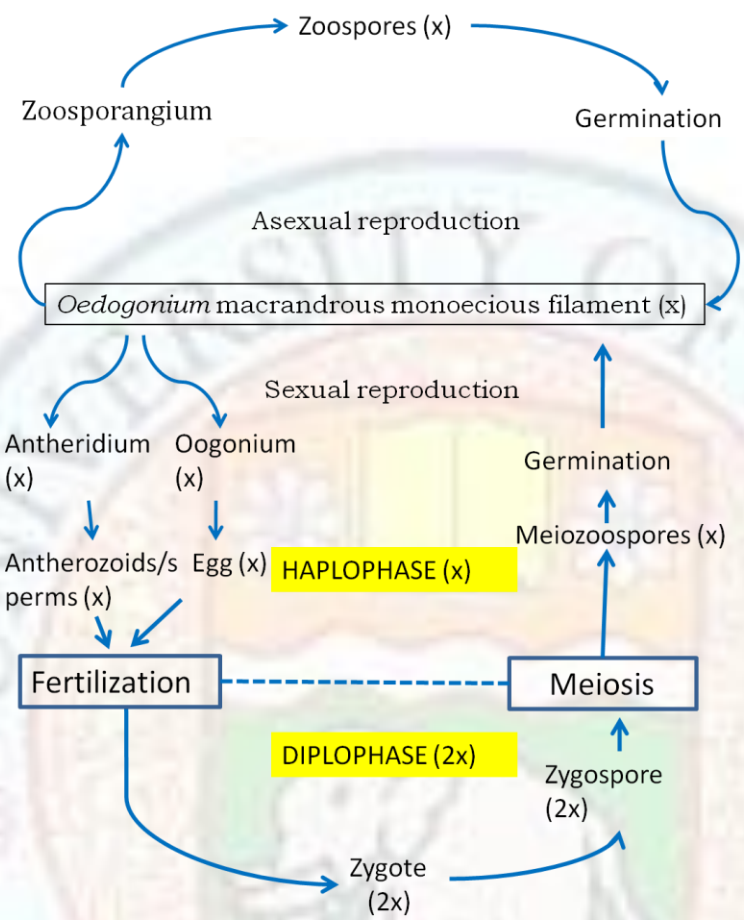


Figure: *Oedogonium*: Graphic Life cycle of Macrandrous monoecious species

Source: Author

2. Life cycle of macrandrous dioecious species:

The antheridia and oogonia develop on two separate haploid filaments of normal size and produce haploid male gamete (antherozoids) and haploid female gamete (egg) in separate filaments. Both these gametes fuse to form a diploid zygote. The zygote divides by meiotic division to form four haploid meiozoospores. Out of these four meiozoospores, two germinate into male filaments and the other two into female filaments.

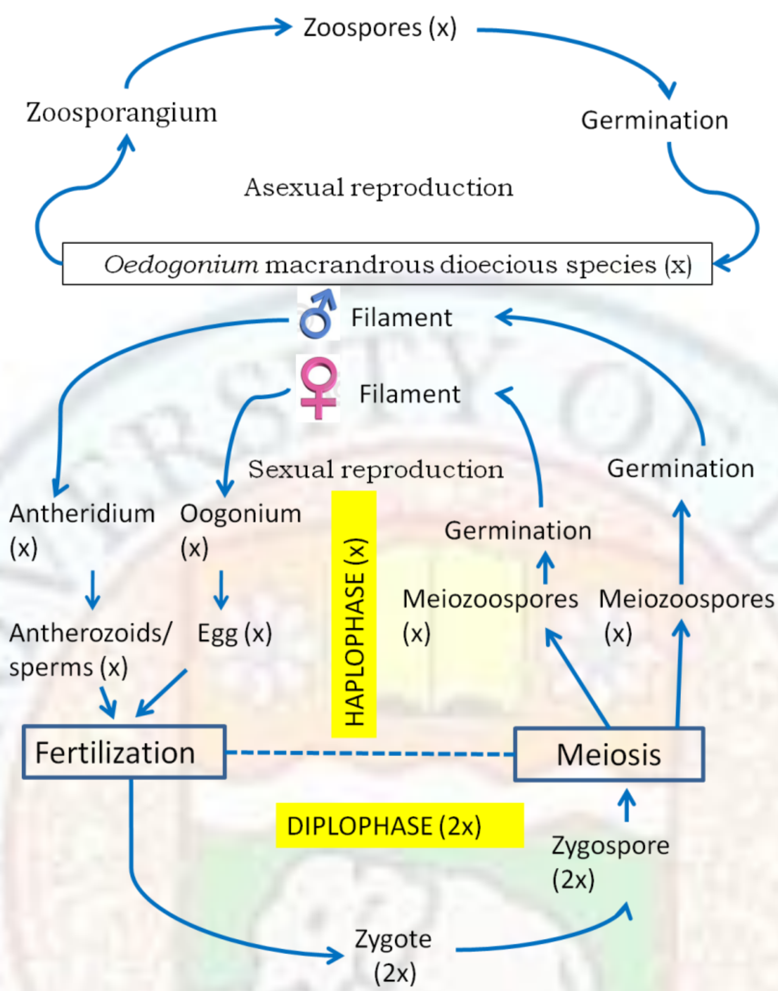


Figure: *Oedogonium*: Graphic Life cycle of Macrandrous dioecious species

Source: Author

3. Life cycle of nannandrous gynandrosporous species:

A few cells of the haploid filament of *Oedogonium* divide repeatedly to form a row of androsporangia. The same filament also bears the oogonium. In each androsporangium develops an androspore. The androspore is released and settles either on oogonium or on the suffultory cell of the filament. After getting settled the androspore develops into a short filament which is called dwarf male or nannandrium. Tip cell of the dwarf male develop into antheridia, in each of which develop two antherozoids. The antherozoids are liberated, fuse with eggs and develop into zygotes. The zygote divides by meiotic division to form four haploid meiozoospores. These meiozoospores germinate into new haploid filaments of *Oedogonium*.

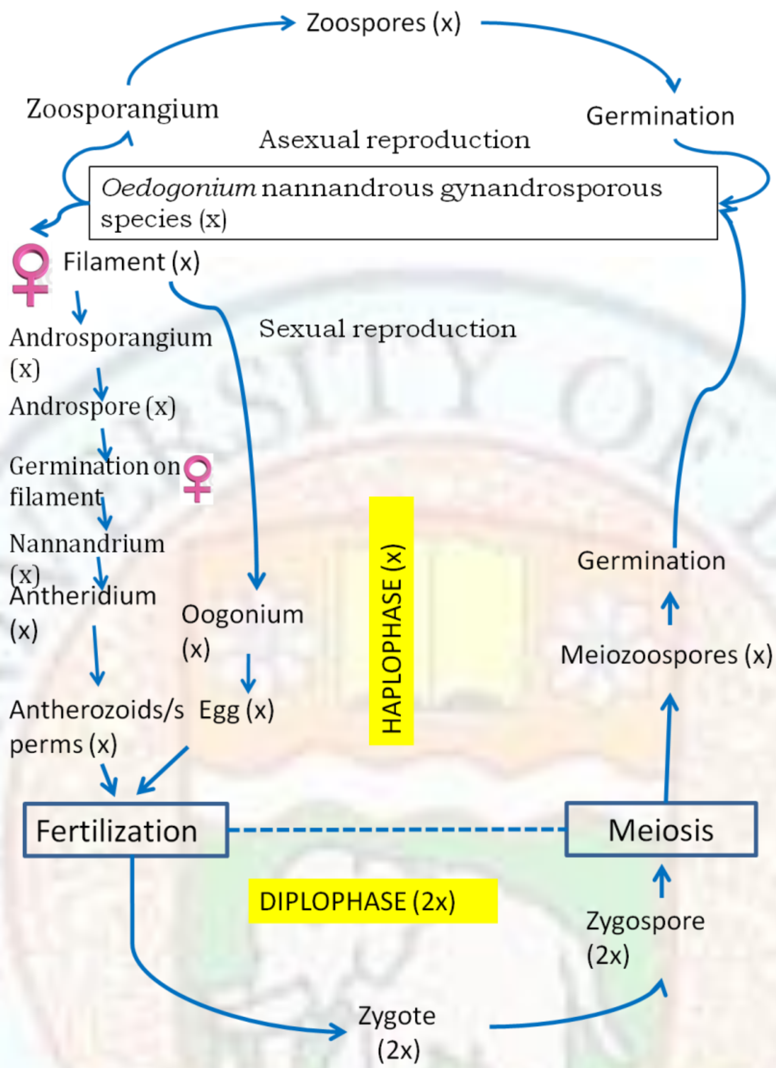


Figure: *Oedogonium*: Graphic Life cycle of Nannandrous gynandrosporous species

Source: Author

4. Life cycle of nannandrous idioandrosporous species:

Oogonium and androsporangia develop on two separate haploid filaments. In each androsporangium develops an androspore. The androspore gets liberated and settles either on oogonium or on the suffultory or supporting cell of the female filament, and develops into dwarf male filament. Tip cells of nannandria develop into antheridia. Each antheridia produce two antherozoids. Antherozoid and egg fuse to form a diploid zygote. The zygote divides by meiotic division to form four haploid meiozoospores. Out of these four meiozoospores, two germinate into androsporangiate male filaments and the other two into oogonia producing female filaments.

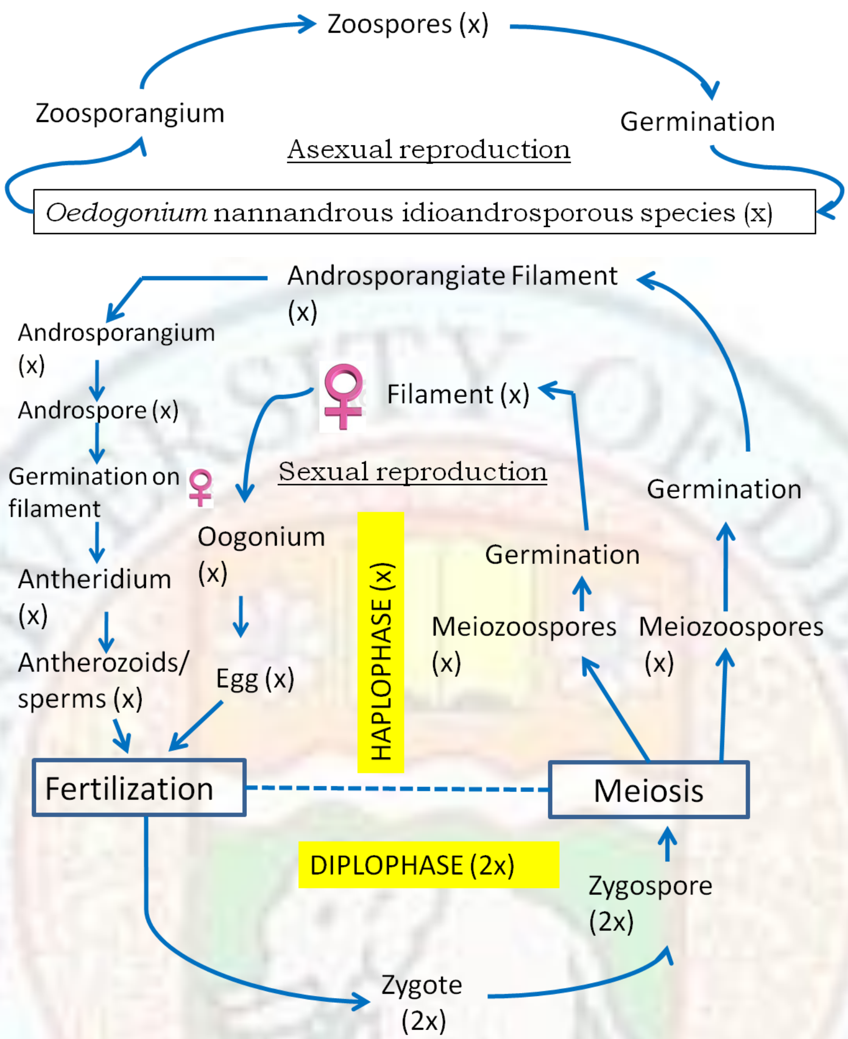


Figure: *Oedogonium*: Graphic Life cycle of Nannandrous idioandrosporous species

Source: Author

Summary

Chlamydomonas occur as a unicellular, biflagellate, spherical, ellipsoidal or pear shaped unicell having a single cup shaped, massive parietal chloroplast. Cell wall of *Chlamydomonas* is multilayered mainly composed of hydroxyproline rich glycoproteins. *Chlamydomonas* cell contains pyrenoid, eyespot, contractile vacuoles, membrane bound cell organelles such as mitochondria, Golgi bodies, endoplasmic reticulum and nucleus. *Chlamydomonas* reproduces by both asexual and sexual methods. Asexual reproduction takes place mainly by the formation of zoospores but can also occur through aplanospores, hypnospores and palmella stage. Sexuality in *Chlamydomonas* 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 haploid gametes fuse to form a diploid zygote. The zygote or zygospore secretes a thick wall and undergoes a resting period and undergo meiosis to form haploid meiozoospores. Zygospore germinates under favorable conditions and the liberated meiozoospores develop into a new haploid unicellular thallus. The Zygote is the only diploid structure in the life cycle. The life cycle of *Chlamydomonas* is predominated by haploid stages and is therefore haplontic.

Oedogonium thallus is a long unbranched filament made up of a single row of elongated cells placed end to end. The cells in the filament contain haploid nuclei. The filament is generally attached at the lower end by means of a basal cell or holdfast. The free end of the terminal cell does not show division. Cell division usually produces characteristic fragile rings at the apical ends of the cells. Only those cells which have the apical rings divide again. Cells contain single, large, parietal and reticulate chloroplasts with a number of pyrenoids. *Oedogonium* reproduces by vegetative, asexual and sexual methods. The vegetative propagation takes place by cell division and fragmentation. Zoospores are the main asexual spores. Zoospores are often formed during night and are then liberated in the morning. Sexual reproduction in *Oedogonium* is advanced oogamous with distinct male and female gametes formed in specific reproductive organs called gametangia (antheridium and oogonium). The species can be homothallic or heterothallic. Sexual reproduction may be of macrandrous (antheridia are borne on the filaments of normal size) or nannandrous type (antheridia are produced on vary small filaments called nannandria). Structure of oogonium is same in both types. Zygote is formed after fusion of the gametes and is the only diploid stage in the life cycle. The zygote undergoes meiosis to form haploid meiozoospores which germinate into new haploid filaments. *Oedogonium* has a remarkable sexual life history and the life cycle is haplontic. The filamentous plant body in all species is always haploid.

Exercises

1. Describe the thallus structure in *Chlamydomonas*.

2. Write a short note on neuromotor apparatus in *Chlamydomonas*.

3. Give an account of asexual reproduction in *Chlamydomonas*. What is Palmella stage?

4. What is anisogamy?

5. Give a brief account of sexual reproduction in *Chlamydomonas.*

6. Explain the evolution of sex in *Chlamydomonas.*

6. Describe the life history of *Chlamydomonas*.

7. Describe the thallus structure in *Oedogonium*.

8. Describe in detail the process of cell division in *Oedogonium*. Explain the formation of cap cells.

9. Give an account of vegetative and asexual reproduction in *Oedogonium*.

10. Compare the structure of zoospores in *Chlamydomonas* and *Oedogonium.*

11. Differentiate between a zoospore, antherozoid and androspore in *Oedogonium*.

12. Write a short note on dwarf males or nannandria in *Oedogonium*.

13. Describe the structure and reproduction in macrandrous species of *Oedogonium*. How does the macrandrous species in *Oedogonium* differs from the nannandrous species in the process of sexual reproduction?

14. What is the difference between gynandrosporous and idioandrosporous species of *Oedogonium*.

15. Give a description of the life history within *Oedogonium*.

15. Write true/false against the following statements:

(i) Palmella stage is a perennating structure in *Chlamydomonas*.
(ii) Two contractile vacuoles are present in the unicelled alga *Chlamydomonas*.
(iii) There is a single cup shaped chloroplast is present in *Chlamydomonas*.
(iv) In *Chlamydomonas* sexual reproduction ranges from isogamy to oogamy.
(v) In *Chlamydomonas* the reduction division takes place at zygospore stage.
(vi) In nannandrous species of *Oedogonium* if the androsporangia and oogonia are borne on same filament the species is called idioandrosporous.

(vii) Asexual reproduction in *Oedogonium* takes place by the formation of stephanokontean (multiflagellate) zoospore.

(viii) Cells of *Oedogonium* are characterized by the presence of a large, reticulate Chloroplast with a number of pyrenoids.

(ix) Some *Oedogonium* species reproduce vegetatively by forming akinetes.

(x) Gynandrosporous filaments of *Oedogonium* bear both oogonia and androsporangia.

(xi) Nannandrous speices of *Oedogonium* are always heterothallic or dioecious.

(xii) Volutin granules are polyphosphate bodies present in *Chlamydomonas.*

15. Fill in the blanks:

(i) Asexual reproduction in *Chlamydomonas* takes place by the formation of…………………….

(ii) Neuromotor apparatus is present in……………………….

(iii)The number of blepharoplasts in *Chlamydomonas* is………………

(iv) In nannandrous species of *Oedogonium*, the antheridia are produced on special very small 2-4 celled filaments called ……………………….

(v) A distinctive feature of *Oedogonium* is the presence of characteristic fragile rings at the apical ends called ……………………….

(vi)In *Oedogonium* dwarf male is formed by the ……………………….

(vii) A species of *Oedogonium* in which antheridia are produced on special dwarf males is called………………………….

(viii) The oogonial mother cell in *Oedogonium* divides transversely into an upper oogonium and a lower ………………………… cell.

(ix) ………………………….is an epizoic species of *Chlamydomonas*.

(x) ………………………… is a terrestrial species of *Oedogonium*.

16. Give the generic name of an alga that has

(i) Palmella stage

(ii) Cap cells

(iii) Nannandria

17. Write short notes on:

(i) Androsporangia and androspores in *Oedogonium*

(ii) Cap cells in *Oedogonium*

(iii)Anisogamous sexual reproduction in *Chlamydomonas*

(iv)Akinetes in *Oedogonium*

(v) Evolution of sex in *Chlamydomonas*

(vi) Palmella stage in *Chlamydomonas*

17. Given below is a diagrammatic representation of life history of *Chlamydomonas*. Answer the following questions on the basis of this diagram and on the basis of your knowledge of the topic.

(i) Name the stages A, B, C, and E.

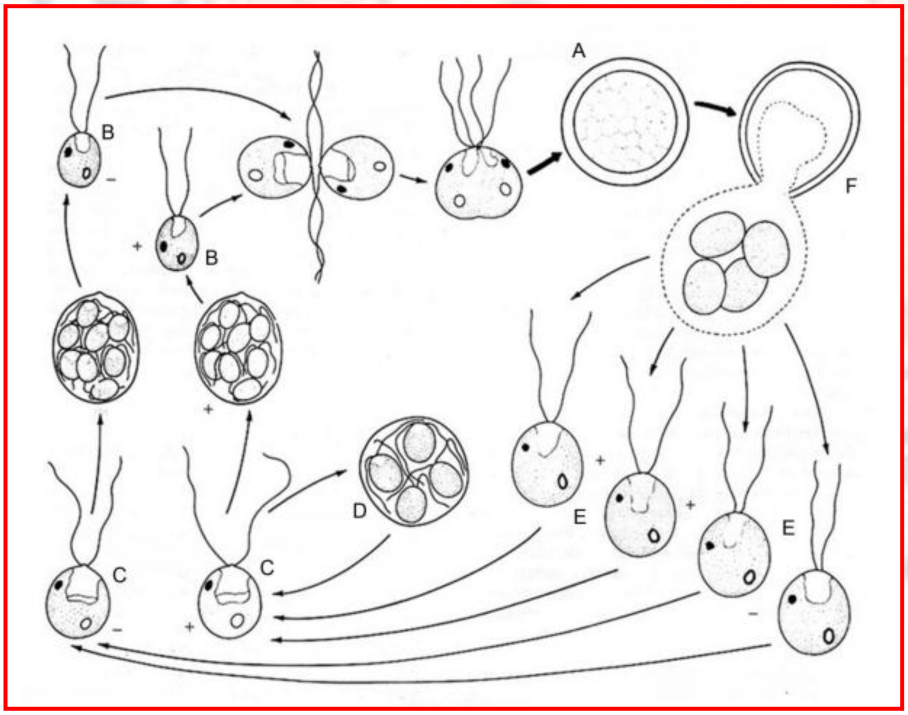
(ii) What is occurring at stage F and D?

(iii)Between which two letters does meiosis occurs?

(iv)Between which two letters does fertilization occur?

(v) What type of life history is this?

(vi) What environmental factors might trigger the events between C and B?



Glossary

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

Axoneme: Central two and nine peripheral doublet microtubules of a flagellum.

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.

Basal body: bottom part of a flagellum beneath the transition zone; basal bodies divide to perpetuate the flagella.

Carotenoid: yellow, orange, or red hydrocarbon fat-soluble pigment

Cellulose: polysaccharide composed of -1, 4 linked glucose molecules that forms the main skeletal framework of most algal cell walls.

Chlorophyll: fat soluble, green pigment

Chloroplast: plastid with chlorophyll

Contractile vacuole: vacuole fed by smaller vesicles that expel water and solutes rhythmically to the outside of the cell.

Disc or Thylakoid: membrane sac in the chloroplast

Egg: Large nonmotile female gamete

Eyespot: red to orange area in a cell, composed of lipid droplets

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.

Phototaxis: movement of a whole organism toward (positive) or away from (negative) light.

Plasmogamy: fusion of cell protoplast.

Pyrenoid:proteinaceous area of the chloroplast associated with the formation of storage product.

Ultrastructure: is the detailed structure of a biological specimen as seen only under electron microscope.

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. Becker B. & Marin B. 2009. Streptophyte algae and the origin of embryophytes. *Annals of Botany.* 103: 999–1004.

3. Chapman V.J. 1962. The Algae. London, Macmillan; New York, St. Martin's Press.

4. Desikachary T.V. 1957. Electron microscopy and algology. *Proceedings of Indian academy of Sciences.* 46:54

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

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

7. Goroschankin J. 1905. *Chlamydomonas coccifera*, *Flora* 24: 420-423

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

9. Harris E.H. *et al.* (Ed.) 1989. The *Chlamydomonas* sourcebook. Vol.I, II & III, New York: Academic Press.

10. Lee, R.E. 2008. Phycology, fourth ed. Cambridge univ. press.

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

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

13. Lewis Louise A. & McCourt R.M. 2004. Green algae and the origin of land plants. *American Journal of Botany.* 91: 1535–1556

14. Sharma O.P. 2007. Textbook of Algae. McGraw-Hill Co.

15. Smith G.M. 1955. Cryptogamic botany, Vol. I, McGraw-Hill Co., New York.

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

17. Prescott G. W. 1951. Algae of the Western Great Lakes Area, Michigan.

18. Pröschold T. *et al.* 2001. Molecular phylogeny and taxonomic revision of *Chlamydomonas* (Chlorophyta). I. Emendation of *Chlamydomonas* Ehrenberg and *Chloromonas* Gobi, and description of *Oogamochlamys* gen. nov. and *Lobochlamys* gen. nov. *Protist*, 152: 265-300

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

20. Roberts K. 1974. Crystalline glycoprotein cell walls of algae: their structure, composition and assembly, *Phil. Trans. R. Soc. Lond.* (B) 268: 129-146

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

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