FIRST PART: Thallophytes (Algae and Fungi)

I. Algae

Algae are autotrophic photosynthetic living beings that always contain chlorophyll a and various other accessory pigments. They can be unicellular or multicellular. Algae are cryptogams (i.e., plants whose reproductive organs are hidden) and thallophytes (their vegetative body is a thallus). Their habitats are diverse, but their reproductive cycle absolutely requires water. Their morphology is highly diversified.

The classification of algae is also based on:

- The ultrastructure of plastids
- The presence of pigments : chlorophylls a, b, c, and accessory pigments, as well as :
- The morphology of the thallus
- The type of reserves and their localization
- Sexual reproduction

I.1. Prokaryotic Algae (Cyanophytes / Cyanobacteria)

Cyanophytes or cyanobacteria, also known as "blue-green algae," form a primitive group of algae and are the oldest chlorophyll-bearing plants. They include 150 genera and 2,000 species. They are the only prokaryotic algae. They contain chlorophyll a and possess phycobilisomes (accessory pigments). They never have flagella. Cyanobacteria are organisms composed of microscopic cells or filaments, but they often develop simultaneously to form colonies visible to the naked eye (clusters or filaments).

Cyanobacteria have ecological significance: they reduce CO_2 into organic matter (carbon sequestration), perform photosynthesis (O_2 production), and fix atmospheric nitrogen (a good nitrogen fertilizer). They also have economic importance: they produce proteins, vitamins, fatty acids, pigments, and dietary supplements (such as spirulina).

I.1.1. Cytological Characteristics

The cells of cyanobacteria are surrounded by a hygroscopic mucilaginous sheath of varying thickness, which is common to several cells. The role of this mucilaginous sheath is to enable cyanobacteria to move by gliding.

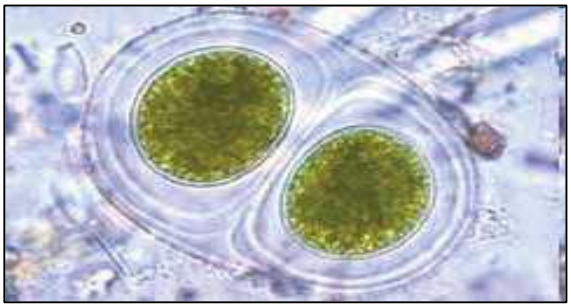


Figure: Cyanobacterial Cells Surrounded by a Mucilaginous Sheath (Chroococcus turgidus)

The cell wall consists of four layers. The first three layers are composed of carbohydrates, lipids, and proteins, while the innermost layer is made of muramic acid. This last layer is a complex peptidoglycan, where the basic glycoprotein unit consists of a disaccharide to which a lateral tetrapeptide is attached.

The ultrastructure of cyanobacteria reveals the absence of a nucleus and cellular organelles. Under an electron microscope, two distinct zones can be observed :

- **The centroplasm:** Located at the center of the cell, it contains DNA, circular plasmids, and storage reserves.
- **The chromatoplasm:** A peripheral zone that contains thylakoids (membrane compartments) responsible for photosynthesis, respiration, and nitrogen fixation (only in certain nitrogen-fixing species). In addition to photosynthetic pigments (chlorophyll a and c), the thylakoids also contain carotene, phycocyanin, and phycoerythrin.

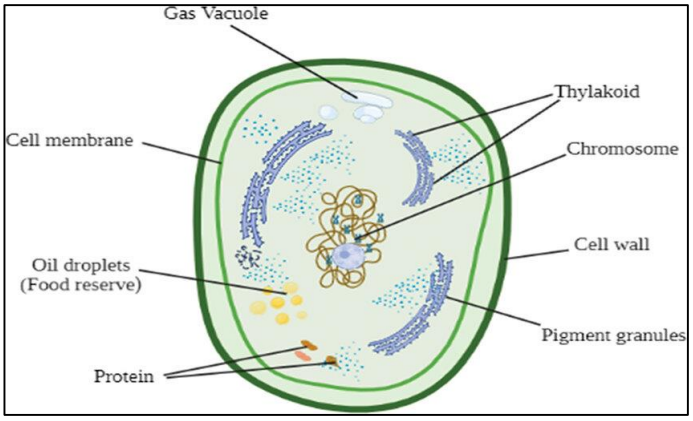


Figure: Morphology of a Cyanobacterial Cell

I.1.2. Morphology and Vegetative Structure of Cyanobacteria

Cyanobacteria exist either as unicellular organisms, in non-filamentous colonies, or in filamentous colonies. In filamentous forms, the row of cells is called a trichome, while the filament refers to the trichome

along with the mucilaginous sheath surrounding it when a sheath is present the vegetative structure is an archaic thallus (archéthalle).

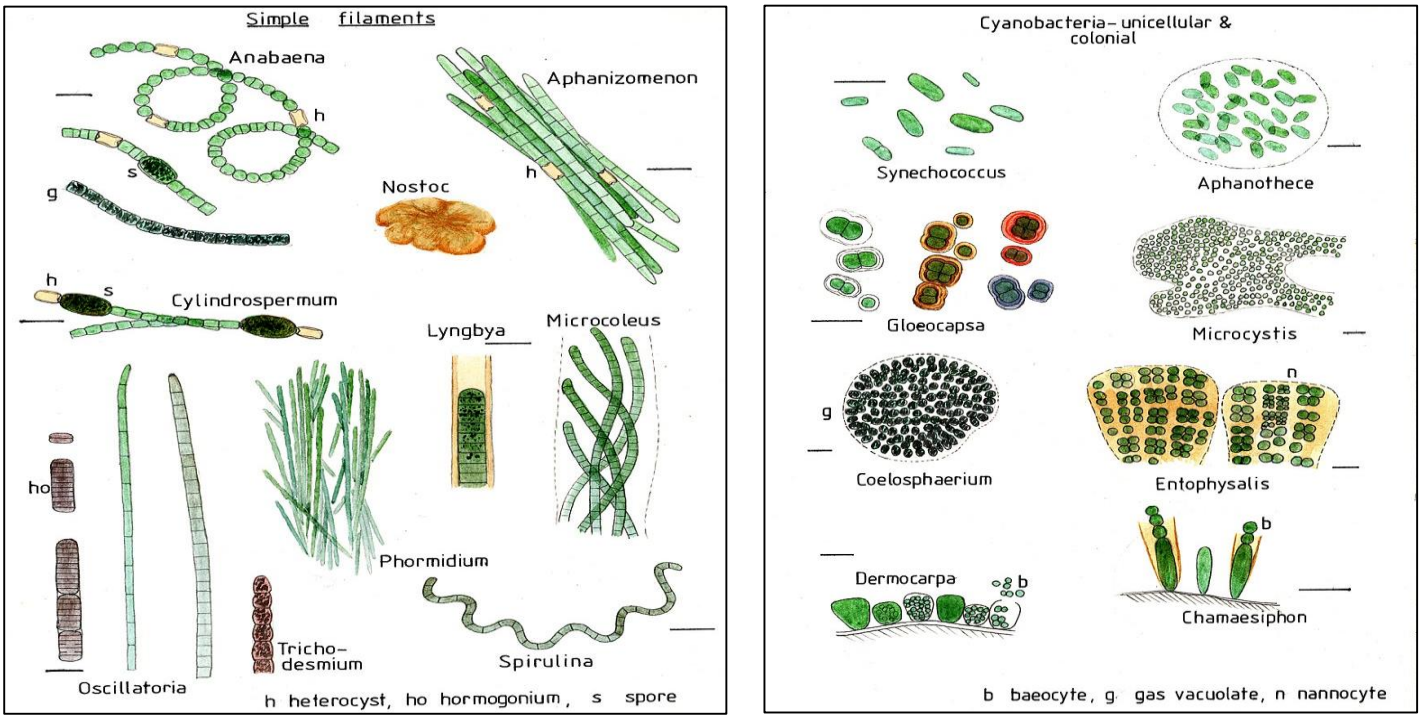


Figure: Different forms of Cyanobacteria under the microscope

In addition to the vegetative cell described above, two other types of cells can be found:

Heterocyst: A transparent, thick-walled cell, usually translucent, found in certain cyanobacteria (called heterocystous cyanobacteria). It is the site of nitrogen fixation and develops from vegetative cells under nitrogen-deficient conditions. Heterocysts are characterized by the presence of polar nodules at their attachment points to vegetative cells. Depending on the species, heterocysts can be intercalary or terminal. They can have different shapes, including circular, oval, triangular, rod-shaped, or rectangular.

Akinetes: These are immobile spores (lacking flagella) produced in heterocystous cyanobacteria. They are resistant to unfavorable conditions and remain viable for long periods by entering a state of slowed metabolism or dormancy. Akinetes form when environmental conditions become adverse, such as low light intensity, low temperatures, pH changes, low nutrient concentrations, or dehydration. Akinetes are distinguished by their large size, shape, modified pigmentation, thick wall, and the presence of numerous cytoplasmic granules. They can be either smooth or ornamented. Akinetes can form anywhere along the filament; however, they are often found preferentially near heterocysts.

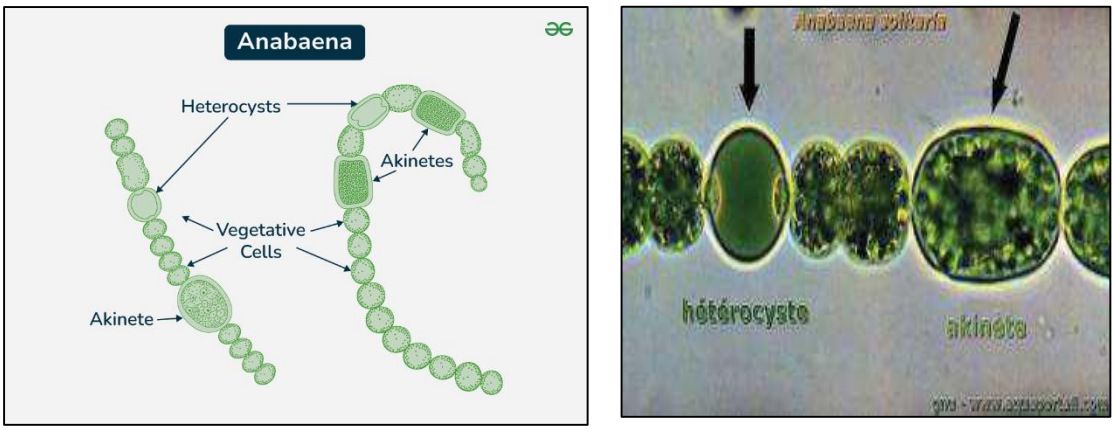


***Figure: Vegetative Cells, Heterocysts, and Akinetes (Nostoc sp.* and *Anabaena sp.*)**

I.1.3. Reproduction in Cyanobacteria

Cyanobacteria do not undergo sexual reproduction. They reproduce through **binary fission** (vegetative division).

Reproduction can also occur through unicellular spores (**coccospores**):

- **Endospores:** Form inside a vegetative parent cell, where the cytoplasm divides, and the parent cell wall becomes the envelope of the sporocyst.
- **Exospores:** Form through a series of transverse divisions, budding into spores or remaining attached in a chain-like structure.

Thus, fragments of the thallus that are released can grow and form a new thallus. These thallus fragments are called **hormogonia**.

Hormogonia: A group of cells that escape from the end of the sheath in certain filamentous cyanobacteria. Hormogonia can also result from the germination of akinetes.

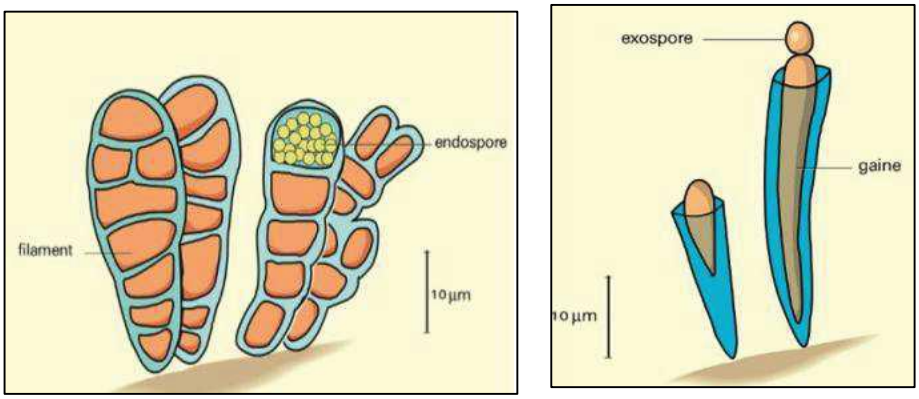


Figure: Endospores and Exospores in Cyanobacteria

I.1.4. Taxonomy of Cyanobacteria

The Cyanobacteria phylum consists of a single class, Cyanophyceae, which is further divided into two subclasses:

a) Subclass Coccogonophycidae

This group includes all cyanophytes that have a solitary, colonial, or sometimes filamentous form but lack hormogonia. They reproduce via coccospores. This subclass comprises three orders:

- **Order 1: Chroococcales** – Includes two families, with the most important being Chroococcaceae, represented by the genus Gleocapsa, Microcystis, and Merismopedia.
- **Order 2: Chamaesiphonales** – These reproduce through endospores and exospores. Representative genus : Chamaesiphon and Entophysalis.
- **Order 3 : Pleurocapsales** – Contains simple filaments and reproduces by endospores. Representative genus : Pleurocapsa.

b) Subclass Hormogonophycidae

This group includes cyanophytes that are generally filamentous, with simple or branched trichomes. In this subclass, species with heterocysts and akinetes are present. It comprises two orders :

- **Order 1 : Nostocales** – Contains three families:

Family 1: Oscillatoriaceae – Characterized by the absence of branching, heterocysts, and akinetes. Representative genus : Oscillatoria, with a simple filamentous thallus (trichome).

Family 2: Nostocaceae – Lacks branching but has specialized cells (heterocysts and akinetes). Representative genus : Nostoc and Anabaena.

Family 3: Rivulariaceae – Characterized by a tapered trichome with the presence of heterocysts and akinetes. Representative genus : Gleotricha and Calothrix.

- **Order 2 : Stigonematales** – Family : Stigonemataceae.

Example of Cyanobacteria :

The Genus *Arthrospira* (*Spirulina*)

Systematic Classification :

- **Kingdom :** Bacteria
- **Phylum :** Cyanobacteria
- **Class :** Cyanophyceae
- **Order :** Oscillatoriales
- **Family :** Phormidiaceae (or Microcoleaceae)
- **Genus :** *Arthrospira* (formerly *Spirulina*)
- **Notable Species :**
  - *Arthrospira platensis*
  - *Arthrospira maxima*
  - *Arthrospira fusiformis*

Reproduction :

***Spirulina* (*Arthrospira*)** reproduces asexually through binary fission and hormogonia. Because *Spirulina* lacks heterocysts and akinetes, it does not produce specialized resting spores. Instead, it relies on continuous division and fragmentation to thrive in warm, nutrient-rich waters.

These filamentous, spiral-shaped cyanobacteria are known for their high protein content and are widely used as a superfood and dietary supplement. extensive research has focused on its potential due to :

- Its high protein and vitamin content, with some commercial *Spirulina* containing up to 70% protein.
- The extraction of its unique blue, yellow, and red pigments, which are rare in living organisms and highly valued in the food industry.
- Its ability to produce a methane-generating biomass that can serve as an energy source.

Figure : Production of Spirulina

I.2. Eukaryotic Algae

Eukaryotic algae (unicellular or multicellular) can be green, brown, or red.

I.2.1. Morphology of the Vegetative Body

The vegetative body (thallus) of Phycophytes comes in a wide variety of forms, from the unicellular type to branched filaments. Thalli are classified according to their degree of complexity. Thus, we can distinguish:

a- Archethallus: A thallus where all the cells have the same role, in the form of :

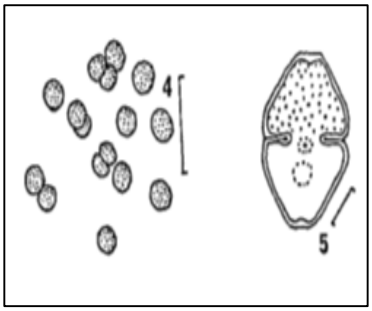
- **Unicellular thallus** : In the form of a single free cell, which may have flagella, making it mobile : monadoid (e.g., *Chlamydomonas*), or it may be non-flagellated, thus immobile: coccoid (e.g., *Chlorella*, Diatoms).
- **Colony thallus** : These are groups of cells often united by a gelatinous substance but remain free (colonial archethallus). These colonies can be in the form of a set of attached cells called "cenobes," which can be immobile (coccoid cenobial archethallus) or mobile (monadoid cenobial archethallus, e.g., *Volvox*).
- **Filamentous thallus** : With a single row of cells, unbranched filament (e.g., *Spirogyra*, *Ulotrix*) or branched filaments, either prostrate and/or upright (many Ulotrichales).

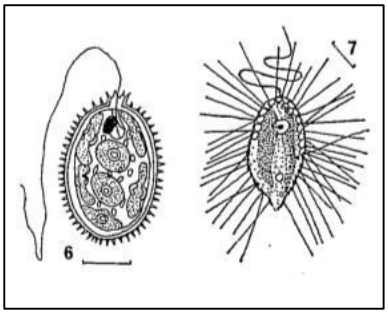
b- Protothallus (**Nematothallus)** : Thallus with specialization, including a growth zone, in the form of:

- **Tubular thallus**: The cells have united to form a hollow tube structure with a single layer of cells (e.g., *Enteromorpha*).
- **Foliaceous thallus**: It derives from the filamentous thallus by the juxtaposition of cells to form a blade that folds upon itself, with the thallus thus consisting of two layers of cells pressed against each other (e.g., *Ulva*).

c- Cladomothallus : Thallus with a preferential growth axis, the primary cladome.

- **Thallus with cladome** : More complex, the thallus is made up of several categories of axes with specific functions (e.g., *Chara*). The cladome is a structural organization comprising an upright axis with indefinite growth and lateral branches with defined growth: the pleuridia. The extreme diversity of cladome thalli allows the appearance of forms very similar to those of certain cormophytes.
- **Fucoid thallus** : Algae are always large in size in the adult state and show differentiation into **03** parts:
    - **Blade or frond**: The expanded part, which is generally flattened and floats.
    - **Stipe**: Supports the structure of the algae, it is a false stem often attached to the substrate by one or more holdfasts (haptera) and supports the frond (or blade).
    - **Holdfasts (Crampons)** : Hooks that anchor the algae to the ground





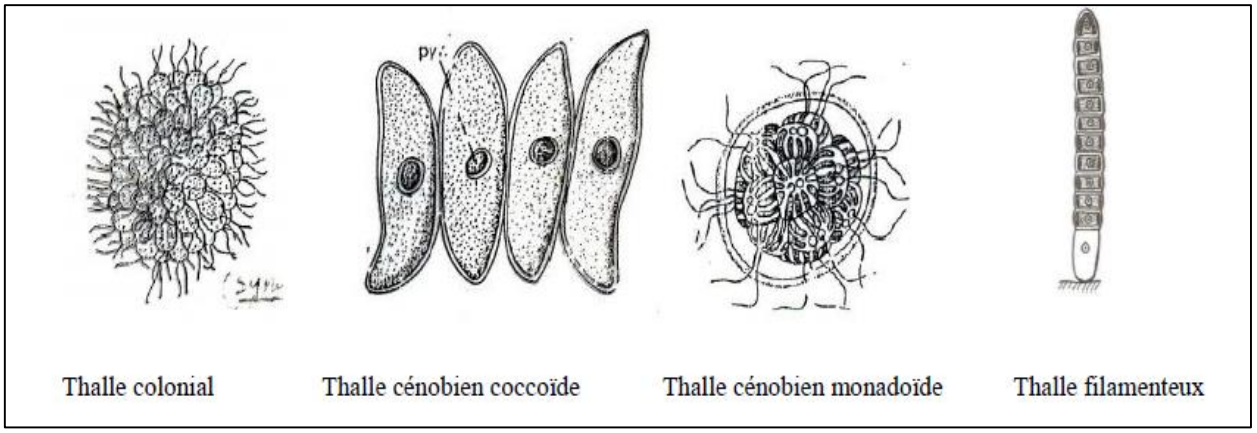


Figure : Archetallus

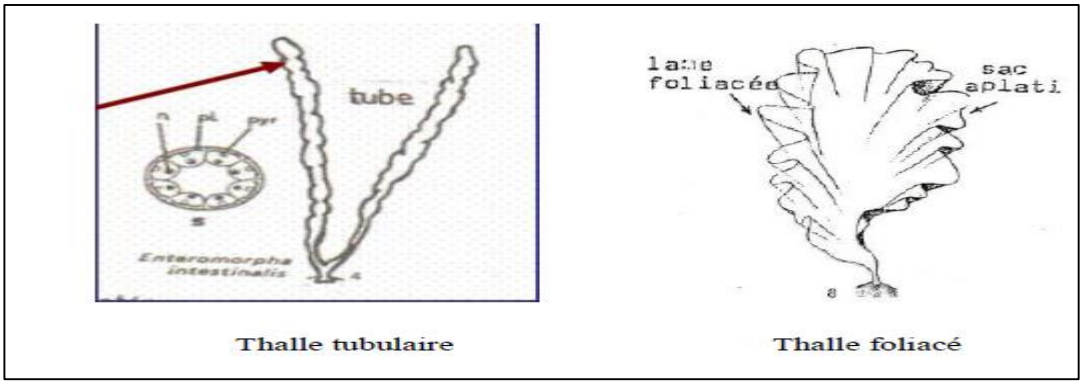


Figure : Protothallus

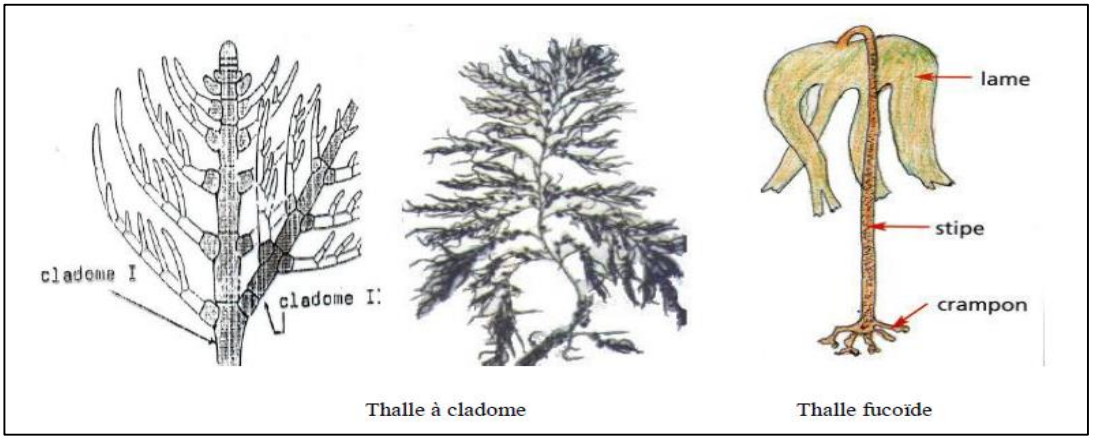


Figure : Cladomothallus

I.2.2.Cytology

Cell wall: Mostly pectocellulosic, but cellulose is often replaced by other carbohydrates or carbohydrate derivatives, and it is not always present in unicellular algae.

Nucleus: Comparable to that of higher plants but generally smaller.

Kinetic apparatus: Flagella in some unicellular algae and reproductive cells (spores, gametes) in most multicellular algae.

Plastids: In more primitive algae, there is a single plastid.

Pyrenoids: Formation of reserve carbohydrate grains (starch in green algae) and always chlorophyll a and carotenoids.

I.2.3. Reproduction :

a- Asexual reproduction : The most common mode of reproduction occurs through :

- Fragmentation of the thallus : each fragment regenerates an entire thallus
- Formation of spores or sporulation.
- Formation of propagules (small cellular masses with various appearances that differentiate at the margin or at the tip of the thallus).

b. Sexual reproduction: Sexual reproduction in algae involves meiosis and fertilization. It involves the formation of gametes. The fusion of a male gamete and a female gamete (fertilization or gamy) results in the formation of a diploid egg (zygote).

The types of fertilization are diverse :

- ***Isogamy***: Fertilization where 02 morphologically and physiologically identical gametes come together (*Chlamydomonas*).
- ***Anisogamy***: Fertilization where 02 gametes are morphologically and/or physiologically different (*Ulva lactuca*).
- ***Oogamy***: The female gamete is large and immobile (oosphere), and the male gametes are numerous, small, and mobile (spermatozoids) (*Fucus vesiculatus*).
- ***Trichogamy***: The female gamete (oosphere) remains in the gametophyte and emits a hair-like structure, the trichogyne, while the male gamete, which lacks a flagellum (spermatium), attaches to the trichogyne.
- ***Cystogamy***: Formation of a cytoplasmic bridge (or conjugation bridge) between 02 filaments; the gametes are never released outside the thallus (*Spirogyra*).

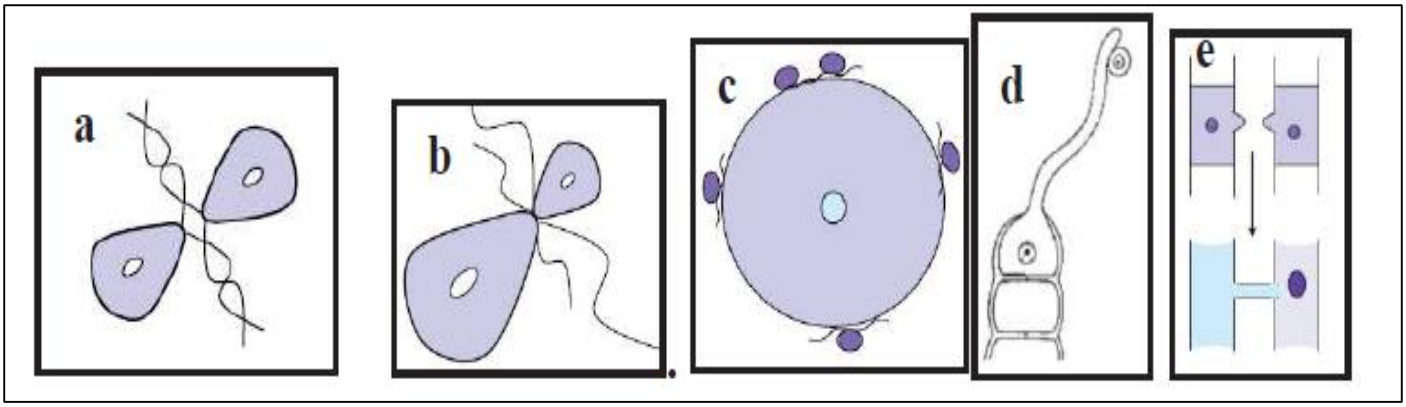


Figure: Sexual reproduction in algae (a: isogamy, b: anisogamy, c: oogamy, d: trichogamy, e: cystogamy)

I.2.4. Developmental Cycle

The developmental cycle involves 02 important concepts: the concept of **generation** and the concept of **nuclear phase**.

A- Generation:

A generation is a distinct phase in the life cycle of an organism, starting from a reproductive cell (such as a spore or zygote) and growing through a period of active development until it produces new reproductive cells. These new cells may either be identical to the original or represent a different stage in the cycle.

- If the generation produces **gametes** (sex cells), it is called a **gametophyte**.
- If it produces **spores** (asexual reproductive cells), it is called a **sporophyte**.

In algae, generations often alternate between **haploid (n) and diploid (2n) stages**.

The alternation of generations consists of **02** distinct parts:

- A **gametophyte (n)** that produces the male and female gametes of the plant. It begins with the germination of the spore and continues until the formation of gametes (n).
- A **sporophyte (2n)** that produces spores (n) after meiosis (meiotic spores or tetraspores or meiospores). The sporophyte starts after fertilization and the formation of a diploid zygote, continuing until the formation of meiospores through meiosis. This generation can be called a tetrasporophyte or meiosporeophyte.

B- Nuclear phase :

This refers to the stock of chromosomes. An individual can be haploid with **n** chromosomes or diploid with **2n** chromosomes.

When the developmental cycle is haploid, it is called a **haplophasic cycle** or **haplontic cycle**: This extends from meiosis to fertilization (fusion of gametes) and the formation of a zygote.

When the development cycle is diploid, we will speak of a **diplophasic** or **diplontic cycle**: from fertilization until meiosis.

There are several types of cycles defined by the relative importance of the periods separating meiosis from fertilization and fertilization from meiosis.

a. Monogenetic cycle: This cycle has only one generation, the **gametophyte**.

b. Digenetic cycle: This cycle involves the alternation of **02** generations:

- A **gametophyte (n)**, which develops from the germination of a meiospore.
- A **sporophyte (2n)**, which originates from a fertilized egg (zygote).

-If the gametophyte is morphologically similar to the sporophyte, it is called an **isomorphic digenetic cycle**.

-If the gametophyte is morphologically different from the sporophyte, it is called a **heteromorphic digenetic cycle**.

c. Trigenetic cycle: This cycle involves three generations; **01** gametophyte and **02** sporophytes.

On the cytological level, meiosis can occur at different points relative to **fertilization (gamy)**, resulting in **03** types of life cycles:

- **Haplophasic cycle:** Meiosis occurs immediately after fertilization. In this case, only the zygote is diploid (2n), while the entire plant exists as a haploid gametophyte (n)**.**
- **Diplophasic cycle:** Meiosis takes place right before fertilization. The organism remains diploid (2n) throughout its life, and only the cells resulting from meiosis are haploid (n) (gametes).
- **Diplo-haplophasic cycle:** Meiosis occurs midway through the cycle, meaning it is always somewhat separated from fertilization**.** This results in an alternation between a haploid phase (n) and a diploid phase (2n)**.**

<u>Reminder</u>: Alternation of generations

- **The sporophyte (2n)** produces **haploid spores (n)** through **meiosis**.
- **The spores (n)** germinate and develop into a **gametophyte (n)**.
- **The gametophyte (n)** produces **haploid gametes (n)** through **mitosis**.
- **Fertilization** between two **gametes (n)** forms a **diploid zygote (2n)**.
- **The zygote (2n)** develops into a new **sporophyte (2n)**.

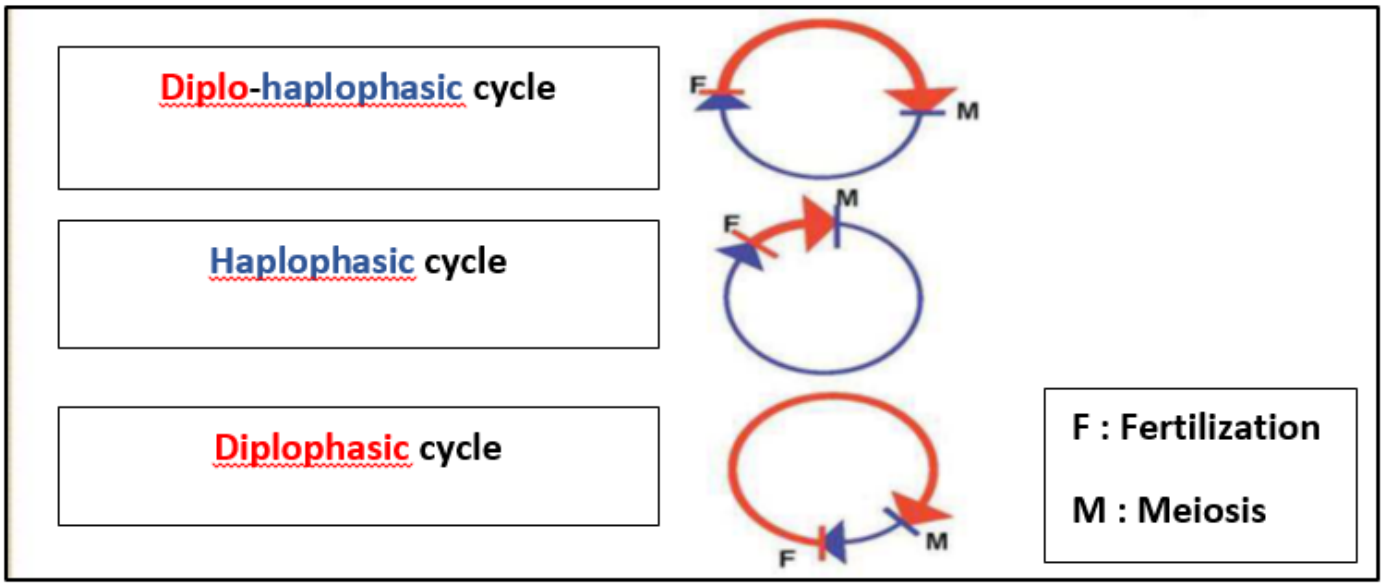


Figure: Life cycle in algae

Brown algae (Chromophytes)

Brown algae primarily contain chlorophyll A and C, along with other pigments. They are mostly marine algae. The Chromophyte phylum divided into **05** classes: **Chrysophyceae**, **Diatomophyceae**, **Xanthophyceae**, **Eustigmatophyceae**, **Phaeophyceae.**

The **Phaeophyceae** class includes the true brown algae, with about 1500 species ranging from a few millimeters to over 10 meters in length.

- Mostly found in cold and temperate seas, where they are attached to rocky substrates.
- Many species have vesicles filled with nitrogen, to help them float.

Their plastids contain chlorophyll A and C, along with fucoxanthin, a dark-colored pigment that allows them to absorb sunlight at greater depths. They are always multicellular.

Reproduction

- Asexual reproduction through fragmentation of the thallus and
- sexual Reproduction when the structure of the reproductive organs and the life cycle differentiate brown algae into **02** major subclasses:
    - **Phaeosporophycidae**
    - **Cyclosporophycidae**

Subclass 1: Phaeosporophycida: This subclass includes **11** orders, with the most significant being:

➤ **Order 1 : Ectocarpales**

- **Family 1 : Ectocarpaceae** **Genus :** *Ectocarpus*
- **Family 2 : Ralfsiaceae** **Genus :** *Ralfsia*

➤ **Order 2 : Culteriales**

- **Family : Culteriaceae** **Genus :** *Culteria*

➤ **Order 3 : Scytosiphoniales**

➤ **Order 4 : Laminariales**

- **Family 1 : Phyllariaceae** **Genus :** *Phyllaria*
- **Family 2 : Laminariaceae** **Genus :** *Laminaria*
- **Family 3 : Lessoniaceae** **Genus :** *Macrocystis*

Subclass 2: Cyclosporophycidae: This subclass contains only **01** order:

➤ **Order : Fucales**

- **Family 1 : Fucaceae** **Genus 1 :** *Fucus* **Genus 2 :** *Pelvetia* **Genus 3 :** *Ascophyllum*
- **Family 2 : Sargassaceae** **Genus :** *Sargassum*
-

Red algae (Rhodophytes)

Rhodophytes include about 500 genus and 5000 species, most of which are multicellular. They are mainly marine algae, with only around 30 freshwater genus. They can grow at great depths because they adapt well to low light conditions, attaching to rocks or mollusk shells.

Reproduction :

- Asexual Reproduction Occurs through fragmentation of the thallus or spores.
- Sexual Reproduction (Trichogamy)

Life cycle: Can be trigenetic (3 stages) or digenetic (2 stages), depending on the species.

Taxonomy:

The phylum Rhodophyta consists of a single class, Rhodophyceae, which is divided into 02 subclasses:

Subclass 1: Bangiophycidae: Simple forms, mostly asexual reproduction.

- **03 orders** : **Bangiales, Goniotrichales, Porphyridiales**

Subclass 2: Florideophycidae: Complex forms, with trigenetic sexual reproduction. **14 orders**, with the most significant : **Ceramiales**, **Compsopogonales, Corallinales, Cryptonemiales, Gigartinales, Nemaliales, Rhodymeniales.**

Green Algae (Chlorophytes)

Largest group of algae, with 6000 to 7000 species. Mostly freshwater species, but some are marine or terrestrial. Widespread across the globe. Contain chlorophyll a and b (like higher plants). Also, have carotenoids and xanthophylls. Vary greatly in shape and size. Serve as bioindicators of nitrate pollution in aquatic ecosystems.

Asexual reproduction → Binary fission or outgrowth formation.
Sexual reproduction → Diverse, including cystogamy, oogamy, anisogamy, and isogamy.
Life cycle → Either haplophase-dominant (n) or alternation of generations (n ↔ 2n).

Taxonomy:

The Chlorophytes phylum consists of **04** main classes: **Zygophyceae** (Freshwater species), **Chlorophyceae** (Protist-like unicellular or multicellular algae), **Prasinophyceae** (Primitive green algae), **Charophyceae** (Closest relatives of land plants)

1. Class: Zygophyceae: All species are freshwater. **02** main orders:

Order: Desmidiales (unicellular)

- **Family: Desmidiaceae** **Genus*:*** *Closterium* **Genus*:*** *Cosmarium*

Order: Zygnematales (filamentous, reproducing via cystogamy)

- **Family: Zygnemataceae** **Genus***: Zygnema* **Genus***: Spirogyra* **Genus***: Mougeotia*

2. Class: Chlorophyceae: A highly diverse group, classified under protists, not plants. Divided into **04 subclasses**:

Subclass: Monadophycideae (unicellular or colonial flagellated forms)

- **Order: Volvocales**
  - **Family*:* Chlamydomonaceae** **Genus***: Chlamydomonas* (free-living)
  - **Family: Volvocaceae** **Genus***: Pandorina*, *Volvox* **(** colonial)

Subclass: Coccophycideae (non-motile, coccoid forms)

- **Order: Chlorococcales**
  - **Family: Oocystaceae** **Genus:** *Chlorella*
  - **Family: Scenedesmaceae** **Genus:** *Scenedesmus*

Subclass: Septophycideae (filamentous or leaf-like forms)

- **Order: Ulothricales**
  - **Family: Ulothricaceae** **Genus:** *Ulothrix*
- **Order: Ulvales**
  - **Family: Ulvaceae** **Genus:** *Ulva, Enteromorpha*

Subclass: Siphonophycideae (large, tube-like forms)

- **Order: Siphonocladales**
  - **Genus:** *Cladophora*

3. Class: Prasinophyceae: A primitive class of green algae, mostly unicellular, includes:

Order: Chlorodendrales

- **Genus:** *Prasinocladus, Tetraselmis, Scherffelia*

Order: Prasinococcales

- **Genus:** *Prasinococcus*

Order: Pseudoscourfieldiales

- **Genus:** *Nephroselmis*, *Pycnococcus*, *Pseudoscourfieldia*

Order: Pyramimonadales

- **Genus:** *Monomastix*

4. Class : Charophyceae : A homogeneous class closely related to land plants (*Embryophytes*).

Order: Charales

- **Family: Characeae** **Genus***: Chara*