

Part 2: Algology

1. Definition and general characteristics of algae

Algae are eukaryotes, autotrophic, and photosynthetic. They can be unicellular or multicellular. The size of these organisms varies greatly, ranging from a few micrometers to several meters. Although microscopic algae are unicellular or filamentous, their cellular structures and thalli are much more developed than those of fungi.

Algae are aquatic; they live primarily in oceans and freshwater. However, some species are also found on very wet soils (Eichhorn et al. 2014). These organisms have three main colors resulting from photosynthetic pigments: when chlorophyll pigments are predominant, the algae are green. Conversely, when chlorophyll is more or less masked by other carotenoid pigments, the algae take on a red or brown color.

2. Structure and morphology of algae

2.1. Structure of algae

Algae have a structure common to all plant structures. They are equipped with a nucleus, mitochondria, storage vacuoles, ribosomes, a Golgi apparatus, an endoplasmic reticulum, maintenance vacuoles, a pyrenoid, a cytoskeleton, a cytoplasmic membrane, a cell wall, etc. (Figure 01).

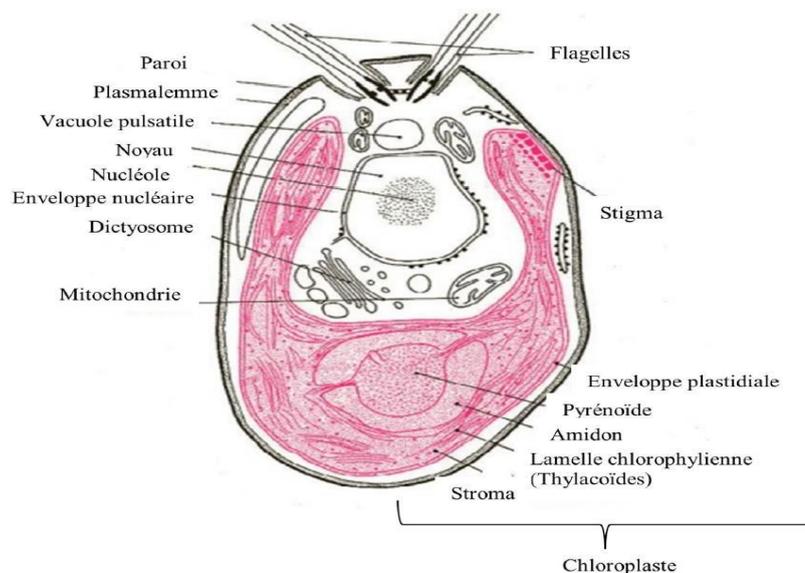


Figure 01 : Structure of Chlamydomonas

However, this structure is characterized by:

- **Cell wall** Composed of carbohydrates (cellulose and pectic compounds), it surrounds the living matter of the cell. It may be absent in some flagellated algae that possess only a thin envelope formed by the outer layer of the cytoplasm. Despite the cytoplasmic nature of this layer, it sometimes displays ornamentation arranged in a network or spiral pattern (for example, in Euglenophyceae of the genus *Phacus*).

The carbohydrate cell wall is generally formed of several layers; the outer layer is sometimes viscous.

- **Core:**It generally occupies the center of the cell and includes a nucleolus. It is sometimes suspended from the center of the cell by cytoplasmic struts, as in *Spirogyra* or naviculoid diatoms.

In genera with multinucleate cells (primarily in Rhodophytes), the nuclei are generally located in the cytoplasm between the vacuoles and plastids. In general, the structure does not differ from that of the nucleus in higher plant cells, but it is smaller.

- **Plastes:**They participate in the synthesis of reserve forms such as starch. They carry chlorophyll and accessory pigments. They are of very varied but characteristic and constant shapes for each species. The pyrenoid is a type of plastid in Chlorophytes responsible for the production of starch grains.
- **Flagella:**in zoospores and are formed during the multiplication of certain algae and vegetative cells; thus in certain motile microalgae ex: *Chlamydomonas*.
- **Pulsatile vacuole:**an osmoregulatory organelle, particularly important for species that live in fresh water, it allows the active evacuation of water (from inside the cell to the outside).
- **The Stigma:**Eye spot: a photosensitive element that enables phototactical responses. Orientation of movement relative to light.

2.2. Morphology of algae

Algae exist as free cells, colonies, or multicellular thalli. Based on their morphology, three types of thalli are easily distinguished:

* **The archethallus** Some algae are free-living cells that live independently of one another. They can be motile by means of flagella or non-motile (Figure 2). These algae are called "unicellular archethalli." Examples include Euglena, Diatoms, and Dinoflagellates.

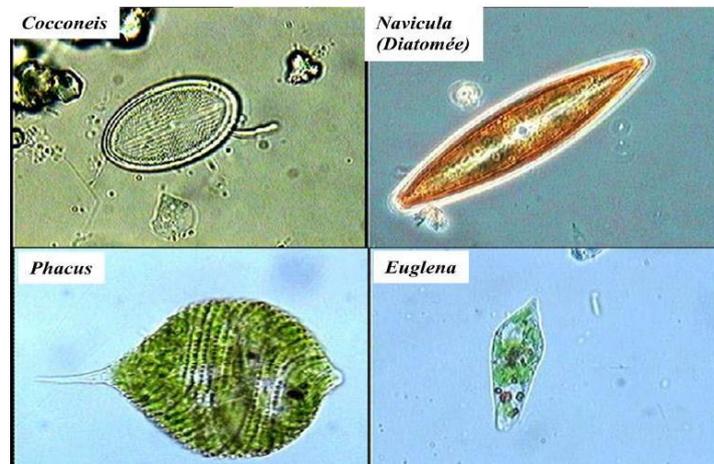


Figure 02:Examples of some unicellular archethalli

Other unicellular algae tend to assemble into colonies using an adhesive jelly or mucilage (Figure 3). They then form structures called "multicellular archethalli." Examples: Scenedesmus, Pediastrum, Gonium, Volvox

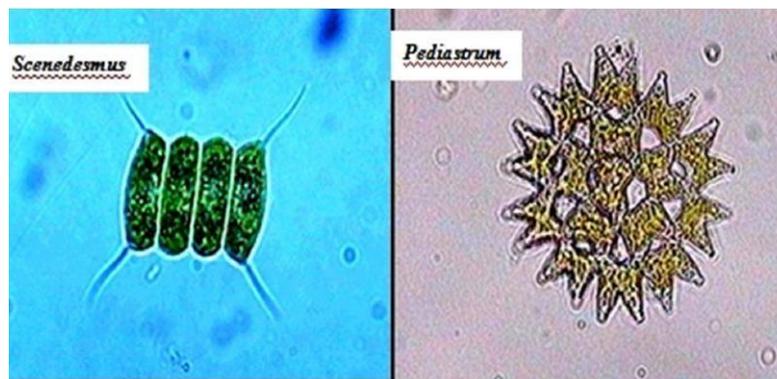


Figure 03:Examples of some archethalli

* Nematothalli or prothalli: These are filamentous algae composed of an anchoring part and a free-floating part. The latter grows along a single axis and may be branched or unbranched, prostrate or erect. In nematothalli, the filaments may be formed by one or more rows of cells: "haploid thalli".

and "polystic thalli" respectively. However, prothalli can be limited to a single cell, giving rise to "unicellular thalli" (Figure 04).

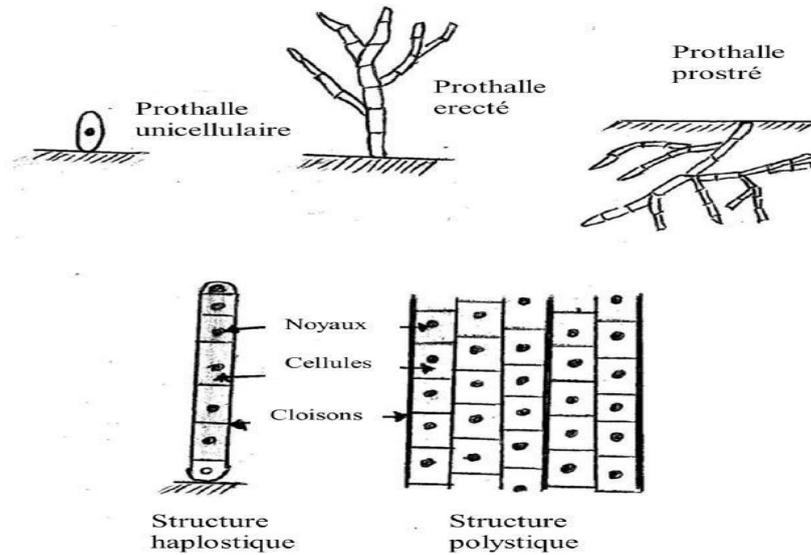


Figure 04:General diagram of nematothalli

* **Cladothalls (cladomes)** These are the most developed algae. They have a fixation part and a free part. Unlike nematothalli, the free part of cladothalli has indefinite growth. It can develop along a main axis and secondary axes: "multiaxial thallus", or along a single axis: "uniaxial thalli" (Figures 05 and 06).

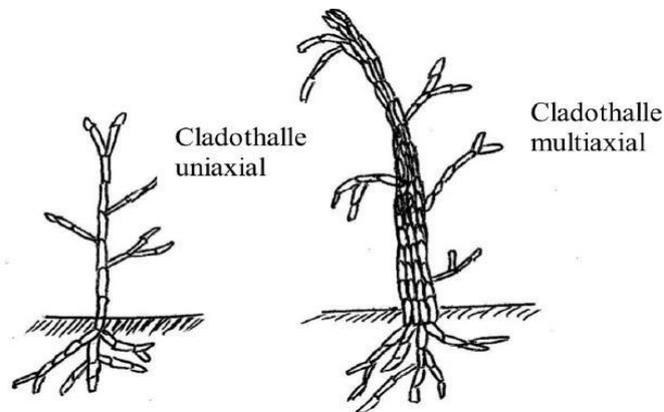


Figure 05:Cladothall growth axes

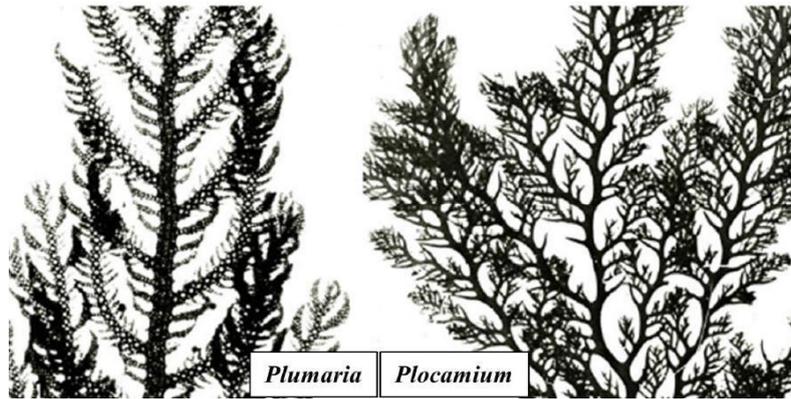


Figure 06: Examples of some multiaxial cladothalli

3. Algal reproduction cycles

Algae can reproduce sexually or asexually:

❖ Asexual reproduction:

For unicellular algae, reproduction occurs through binary fission, producing daughter cells identical to the parent cells. In contrast, for multicellular algae, asexual reproduction occurs through:

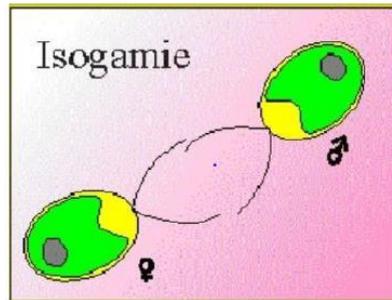
- Fragments of the thallus detach and give rise to new individuals identical to the previous ones.
- Flagellated spores with $2n$ chromosomes. They can be immobile (aplanospores) or motile by means of flagella (zoospores or planospores).
- Spores produced by budding of the thallus or in the form of propagules.

❖ Sexual reproduction:

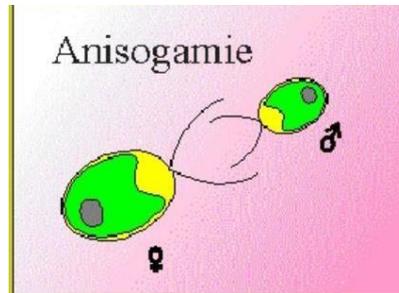
In unicellular algae, sexual reproduction occurs through meiosis, producing sexual gametes. In multicellular algae, it relies on gametocysts, which produce male and female gametes. If the gametocysts of opposite sexes belong to the same gametophyte, the species is described as "monoecious" or "bisexual." And if they belong to male or female gametophytes, the species is described as "dioecious" or "monosexual."

The known modes of sexual reproduction in algae are:

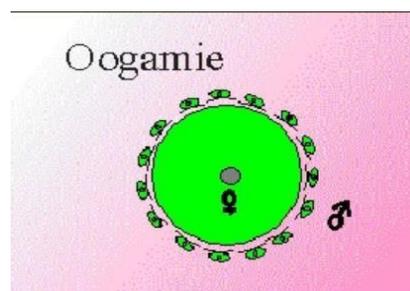
- **Isogamy** This is the fusion between opposite-sex gametes that are identical from a morphological and physiological point of view. Ex. *Chlamydomonas*.



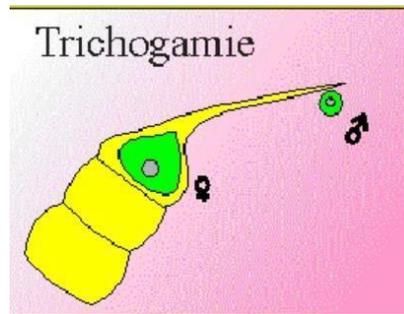
- **Anisogamy** : She represents there merger of two gametes whipped morphologically and/or physiologically different. Ex: Ulva.



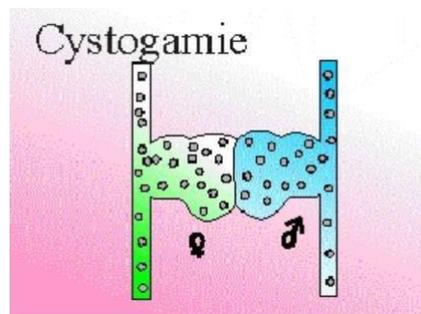
- **Oogamy** : This is fertilization between a large, immobile female gamete rich in reserves and a small, flagellated male gamete. Example: Fucus.



- **Trichogamia** : This refers to the situation where the female gamete remains within the gametophyte and forms an elongation called a "trichogyne." The immobile male gamete attaches itself to the trichogyne and is directed towards the female gamete. Example: Rhodophytes.

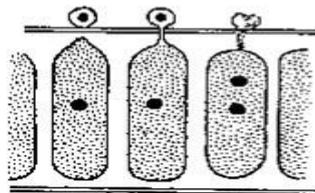


- **Cystogamy:** It represents the formation of several conjugation bridges between the cells of a male thallus and the cells of a female thallus. Ex: Spirogyra.



- **Aplanogamy :** Fertilization occurs between a non-motile male gamete released into the environment and a non-motile female gamete that remains within the gametophyte. The male gamete has a papilla on its surface to facilitate fertilization. Example: Porphyra

Aplanogamie



Isogamy, anisogamy and oogamy are called Planogamy where at least one of the gametes is mobile.

Planogamy and aplanogamy are forms well adapted to the aqueous environment.

4. Taxonomy of algae

The classification of algae is based on several criteria, the most important being the type of thallus, photosynthetic pigments, cell wall composition, reproductive method, ecology, and mobility. Taking these parameters into account, five divisions of algae are distinguished:

4.1. Chlorophytes (Chlorophyta or green algae)

Chlorophytes can be unicellular or multicellular. These algae are all characterized by the presence of chlorophyll b in their plastids. In addition to this pigment, chlorophyll a is often present, but chlorophyll c is rarely. The plastids may also contain carotenoids (carotenes and xanthophylls). Chlorophytes contain starch in their storage vacuoles. Unicellular forms (single-celled species or reproductive spores) are often motile by means of flagella (generally two or four). These algae are found in both fresh and marine waters. They are autotrophic, heterotrophic, or mixotrophic.

4.2. The Paeophytes (Paeophyta or brown algae)

Phaeophytes are algae found almost exclusively in marine environments. They are always multicellular and can reach several meters in length. These algae are unique in possessing fucoxanthin in their plastids, which gives them their brown color. In addition to this pigment, chlorophylls a and c, xanthophylls, and other carotenoids may also be present. Brown algae are always starch-free, instead containing laminarin and mannitol.

4.3. Rhodophytes (Rhodophyta or red algae)

Rhodophytes are found in freshwater, marine waters, and on very humid surfaces. They are characterized by their phycobiliprotein content, including phycoerythrins and phycocyanin. These pigments allow them to live in various ecosystems, including deep waters where light is low.

These algae have storage vacuoles that contain Florida starch (also called rhodamylon).

4.4. The Bacillariophytes (Bacillariophyta or Diatoms)

Bacillariophytes are unicellular algae characterized by a cell wall composed of silica plates or fibrils associated with organic materials. The cell wall is formed by two "valves" that fit together perfectly, like a box and its lid, to form the "frustule".

Based on the shape of the frustule, diatoms are divided into "central diatoms" (also called centric diatoms) and "pennate diatoms" (or pinnate diatoms). The former have axial symmetry and radiating ornamentation, while the latter have bilateral symmetry and ornamentation arranged on either side of a median slit called the "raphe." (Figure 7)

These microorganisms play a very important ecological role as they carry out nearly a quarter of the planet's photosynthesis and are considered, along with dinoflagellates, to be the largest primary producers. They are found in fresh water, oceans, and moist soils.

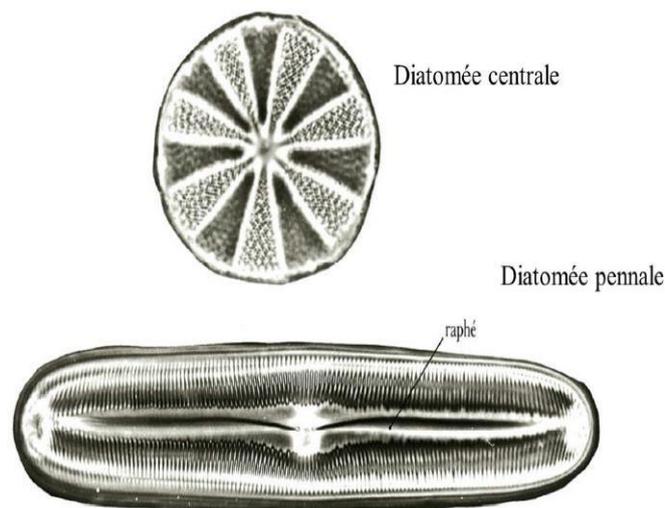


Figure 07:Photos of a Central Diatom and a Pennate Diatom

4.5. Dinoflagellates (Dinoflagellata or Dinoflagellates)

Dinoflagellates are unicellular algae found in both marine and freshwater environments. Their defining characteristic is the presence of thecae (hard coverings) that protect the cell. These thecae are composed of rigid cellulose plates embedded with silica (Figure 08 A).

The cell wall of Dinoflagellates is traversed by two perpendicular flagella. One passes through the equatorial groove and allows a rotational movement, the other crosses the posterior groove and ensures a progressive movement (Figure 08 B).

Dinoflagellates are at the base of several food chains. Together with diatoms, they make up the majority of plankton in fresh and marine waters. Some species are autotrophic or mixotrophic, while others are exclusively heterotrophic.

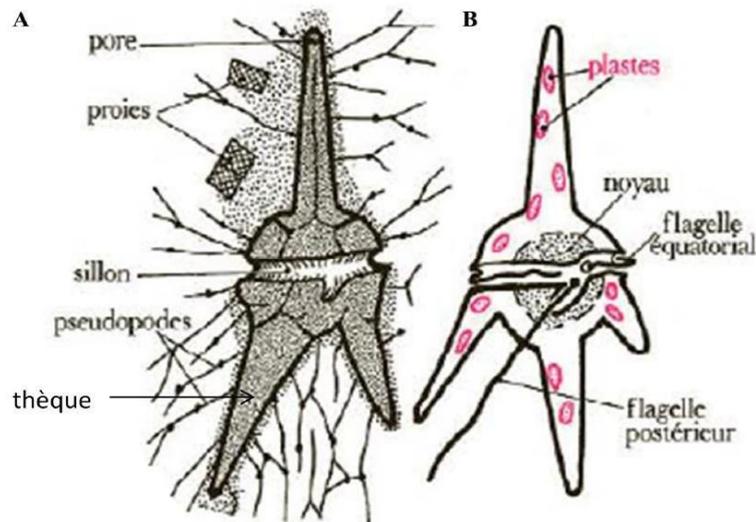


Figure 08:An example of a Dinoflagellate is the genus *Ceratum*.

A: External appearance. B: Position of the flagella.

5. Importance of algae

Algae are capable of producing metabolites of great interest to humans. They are notably used in the pharmaceutical, culinary, and cosmetic industries. Current uses of algae include:

* **The production of agar** Agars are extracted from several species, but especially from those belonging to the genera *Gelidium*, *Gelidiella* and *Gracilaria*. These compounds are used as thickeners in the culinary industry (sauces, pastries, icings, etc.) or as solidifying agents to enable certain biological processes (e.g., electrophoresis gels, agars for culturing microorganisms).

***Phycocyanin production** Phycocyanin is extracted from species of the genus *Porphyra* (red algae) and *Arthrospira platensis* (a cyanobacterium) (Sampath-Wiley and

(Neefus 2007; Esquivel-Hernández *et al.* 2016). This substance facilitates the differentiation of stem cells within the bone marrow, thus enabling the production of platelets, red blood cells, and white blood cells. It also induces apoptosis of cancerous cells and optimizes the functioning of the immune system. Due to all these properties, phycocyanin is used in the therapeutic industry to inhibit the progression of various cancers.

*** Production of alginic acid and alginates :** Alginic acid and alginates are highly hydrophilic compounds produced by Phaeophytes, particularly Laminaria. They are used in the pharmaceutical industry for coating medications and in the food industry as gelling, humectant, and thickening agents.

Alginic acid and alginates are also used to treat obesity. By forming a gelatinous mass in the stomach, they ensure the digestive tract is full and reduce the feeling of hunger.

*** Direct consumption of algae** Some species are cultivated for direct consumption. Among them are *Porphyra tenera* (nori) and *Laminaria japonica* (konbu), which are widely used in Japan; *Palmaria palmata* (dulse), which is consumed in North America; and *Chondrus crispus* (small seaweed), which is mainly sold in France.

The consumption of seaweed in its raw form is encouraged in these countries due to its richness in vitamins (A, B12, C, E, etc.), trace elements, and various bioactive compounds. Furthermore, certain species, such as *Chondrus crispus*, can stimulate the immune system and enhance the body's ability to fight infections.

6. Harmful effects of algae

Algae play a very important role in the ecological balance, but they can also cause major disruptions to ecosystems. Among the harmful effects of algae, we can mention the following two:

Effect 1:

When conditions are favorable, protist algae tend to grow exponentially. Among them are dinoflagellates, which are often toxic to fish, invertebrates, and mammals. These species produce very potent neurotoxins that cause paralysis in organisms that consume them.

Crustaceans and mussels that feed on dinoflagellates accumulate toxins, acting as the first line of defense against them. Then, all the organisms that follow in the food chain accumulate more and more toxins, until they reach the final consumer (humans, animals, or large fish). This final consumer will then suffer from severe, often fatal, poisoning.

In humans, the poisoning results in paralysis of the mouth and then the entire face in just a few hours.

Effect 2:

This effect is also observed when conditions become favorable for algae. They then proliferate in aquatic systems, enriching them with dissolved oxygen. Once dead and decomposing, the algae provide a wide variety of organic matter. The environment then becomes conducive to the proliferation of heterotrophic and aerobic microorganisms (bacteria, yeasts, etc.), followed by aerobic organisms (crustaceans, fish, etc.). As these organisms grow, they deplete the water of oxygen and gradually die. Only anaerobic species, particularly bacteria, then remain. This phenomenon is called eutrophication».