Algae is an extremely diverse group consisting predominantly of aquatic plants showing relatively little differentiation of tissues and organs as compared to bryophytes and tracheophytes. It includes both prokaryotic and eukaryotic photosynthetic organisms with chlorophyll *a* and other photosynthetic pigments, releasing O_2. Algal plant body ranges from unicellular to colonial, filamentous, siphonous, and even parenchymatous, and never contains roots, stems or leaves. Plant body may be as small as unicellular (e.g. *Chlamydomonas*, *Chlorella*; 0.5–8 μm) to as large as 50 meter or more in length (e.g. *Macrocystis*). As in morphology, algae also demonstrate great variation in reproduction. They reproduce by vegetative, asexual and sexual processes. Sex organs in algae are usually unicellular or multicellular with all cells fertile (except *Charales*). The zygote does not develop into a multicellular embryo within the female sex organ. Several algae show alternation of generations. Sexual reproduction, however, is absent from prokaryotic members. A feature that distinguishes algae from other cryptogams is the absence of a multicellular wall around the sporangia or gametangia (with the exception of *Charales*). Adaptation to an aquatic environment has led to the development of many distinctive biochemical traits in algae.

From the physiological and biochemical point of view, algae are more or less similar to other plants in many respects. Algae possess almost the same biochemical pathways as of higher plants. Resembling the higher plants, all algae possess chlorophyll *a* and have almost the same carbohydrate and protein end products. Due to these characteristics, algae are ideal experimental organisms to study several biochemical and physiological processes.

From the long fossil records of both prokaryotic and eukaryotic algal forms, it is evident that the prokaryotic algae were the first photosynthetic cellular plants. It is now

generally agreed amongst botanist that algae are the group from which all subsequent groups of cryptogamic plants, and finally the flowering plants, arose on the earth during the course of evolution.

The word "algae" (singular "alga") is derived from a Latin word "alga" (means seaweeds). The science that deals with their study is called *algology*. The Greek word for algae is *phykos*, and therefore their study is called *phycology* (Gr. *phykos*, sea-weeds; *logos*, study or discourse).

Laymen have variously named algae as "pond scums", "frog spittle", "water mosses", or simply "seaweeds".

1.3 DEFINITIONS

To give a precise definition of algae is very difficult, mainly owing to the varied nature of the plants comprising the group. Because of this, Bold and Wynne (1978) have rightly stated that sometimes "even the professional botanist and biologist find algae embarrasingly elusive of definition."

In spite of this, the definitions of algae, given earlier by some phycologists, are as follows:

1. *F.E. Fritsch (1935)*
   Unless purely artificial limits are drawn, the designation alga must include all holophytic organisms (as well as their numerous colourless derivatives) that fail to reach the higher level of differentiation characteristic of the archegoniate plants.
2. *G.M. Smith (1955)*
   Simple plants with an autotrophic mode of nutrition.
3. *V.J. Chapman (1962)*
   These plants (seaweeds of the seashore and green skeins in stagnant freshwater ponds and pools) which are among the simplest in the plant kingdom, belong to the group known as algae.
4. *G.W. Prescott (1969)*
   The algae are those chlorophyll-bearing organisms (and their colourless relatives) which are thalloid, i.e., having no true roots, stems and leaves or leaf-like organs.
5. *R.N. Singh (1974)*
   The algae are by and large simple plants which display a spectrum of photosynthetic pigments and evolve oxygen during the process of photosynthesis.
6. *The author of this book defines the algae as under:*
   The algae, variously ranked as an order[5], a class[6], a division[7] or a group[8] in different systems of classification, is an assemblage of chlorophyll-bearing autotrophic Thallophytes, bounded by a cell wall, made up of pure or mixed carbohydrates.

1.4 GENERAL CHARACTERS OF ALGAE

1. The group algae is represented by about 1560 genera and 17 535 species[9,10,11] (Smith 1955). Alexopoulos and Bold (1967) mentioned 1800 genera and 21 000 species in algae. The members are distributed in nearly all parts of the world and occur[12] in nearly all kinds of habitats.
2. Thallus organization[13] in algae varies greatly and shows a clear range. In brief, they are represented by the following habits:
    i. Motile unicellular, e.g. *Chlamydomonas* and *Phacus;*
    ii. Motile colonial, e.g. *Volvox*, *Pleodorina*, *Eudorina* and *Pandorina*;
    iii. Palmelloid, e.g. *Chlamydomonas*, *Tetraspora*, *Chlorosaccus* and *Palmella*;
    iv. Dendroid, e.g. *Ecballocystis* and *Prasinocladus*;
    v. Coccoid, e.g. *Chlorella*, *Hydrodictyon* and *Pediastrum;*
    vi. Filamentous, e.g. *Spirogyra*, *Zygnema*, *Ulothrix*, *Nostoc*, *Oedogonium*, *Oscillatoria*, *Lyngbya*, *Anabaena*, *Tribonema*, *Cladophora*, *Pithophora* and *Bulbochaete;*
    vii. Heterotrichous, e.g. *Fritschiella*, *Draparnaldiopsis*, *Ectocarpus* and *Stigeoclonium;*
    viii. Siphonaceous, e.g. *Vaucheria*, *Botrydium*, *Bryopsis* and *Codium;*
    ix. Uniaxial, e.g. *Batrachospermum*;
    x. Multiaxial, e.g. *Polysiphonia*;
    xi. Parenchymatous, e.g. *Ulva*, *Enteromorpha* and *Sargassum.*

3. The size of the algae also varies greatly. Most of them are microscopic and many are even unicellular (*Chlamydomonas*, *Dunaliella*, etc.) attaining a maximum size of 0.5 μ in diameter. *Micromonas pusilla* (1 × 1.5 μm) and species of *Chlorella* (5–8 μm) are also very small in size. On the other hand, there are large macroscopic genera attaining a size of 30 m or even more, e.g. *Macrocystis*. Regarding *Macrocystis pyrifera* Prescott (1969) reported "one unsubstantiated record claims a specimen to have been 700 feet (i.e. 213 m)—the longest plant in the world". All the other members come in between these limits.
4. Each cell[14] is bound by a typical cell wall, with a few exceptions like *Euglena* and *Gymnodinium* where a cytoplasmic membrane, called *pellicle*, is present.

   The cell wall is bilayered in most of the algal members and composed mainly of cellulose and partly of other substances like pectin, chitin, algin and fucoidin[15]. In some genera, the cell wall is impregnated with inorganic substances such as calcium, silica and magnesium carbonate.
5. Motile members, zoospores (Plate IA) and gametes of many representatives of algae, bear flagella which are the means of motility. Electron-microscopic studies have shown that in a cross-section, a flagellum consists of 2 central tubules, surrounded by 9 peripheral tubules, all enclosed by a membrane (Fig. 1.1).

   Flagella may be equal (Fig. 1.2 A) or unequal (Fig. 1.2 B), inserted apically (Fig. 1.2 A, B) or laterally (Fig. 1.2 E), and may be of tinsel (Fig. 1.2 C) or whiplash (Fig. 1.2 D) types. The whiplash type is smooth and regular throughout its length, whereas the tinsel type has small outgrowths throughout the length and appears like a feather.
6. In the cytoplasm are present structures like contractile vacuoles, mitochondria, eyespot, chloroplast, nucleus, pyrenoids, chondriosomes, Golgi bodies, various types of pigments, etc. In prokaryotic cells, however, structures such as mitochondria, Golgi bodies, endoplasmic reticulum and a definite nucleus, are absent.
7. Important pigments are chlorophyll-a, chlorophyll-b, β-carotene and xanthophylls, such as lutein, violaxanthin[16], fucoxanthin[17] and neofucoxanthin. Xanthophylls of Myxophyceae are myxoxanthin and myxoxanthophyll. Phycobilins are mainly present in Rhodophyceae and Myxophyceae.

8. *Reserve food* material is in the form of starch. But in the members of Bacillariophyceae, Xanthophyceae and Dinophyceae, fats and oils are present. Laminarin and mannitol are the reserve products in the members of Phaeophyceae, whereas in Rhodophyceae floridian starch, floridoside and mannoglycerate are the chief reserve products. In Myxophyceae, myxophycean starch and cyanophycin are the reserve products.
9. Sitosterol is the main sterol in the members of Chlorophyceae, whereas fucosterol is present in Phaeophyceae, Bacillariophyceae, Chrysophyceae and Rhodophyceae.
10. Hamana and Matsuzaki (1982) analysed the diamine and polyamine contents of Rhodophyta, Pyrrophyta, Chrysophyta, Phaeophyta, Euglenophyta, Chlorophyta and Charophyta. They detected putrescine and spermidine in all the studied algae of these seven groups.
11. *Growth* is controlled by the hormones or hormone-like growth regulators present within the cell. Growth in multicellular members may be of the following types:
    a. *Generalized growth* takes place throughout the body. All the cells of the organism divide. So, there is an overall increase in size of the plant, e.g. *Ulva*.
    b. *Localized growth* takes place by cell division in only certain restricted parts of the plant. The localized growth may be of any of the following three categories:
        (i) *Apical growth*: It is restricted only up to the extremities or tips of the plant, as in *Cladophora*, *Dictyota*.
        (ii) *Basal growth*: It is seen only in the basal parts, as in *Bulbochaete*.
        (iii) *Intercalary growth*: It is seen in one or many intercalary regions, and restricted neither at the base nor at the apex, as in *Oedogonium*.

12. Reproduction[18] in algae takes place by all the three means, i.e. vegetative[19], asexual and sexual.
13. Various means of vegetative reproduction are fragmentation, fission, akinete, tuber, hormogonia, formation of adventitious thalli, etc.
14. Asexual reproduction is a process in which the protoplast (or protoplasts) is released from the cell. This protoplast germinates into a new plant. It takes place by the formation of various types of spores like zoospore, synzoospore, aplanospore, hypnospore, autospore, auxospore, carpospore, tetraspore, cyst, etc.
    i. *Zoospores* (Plate IA) are flagellated, asexual reproductive bodies, usually each having an eyespot, e.g. *Chlamydomonas*, *Ulothrix* and *Cladophora*. Zoospores in *Chlamydomonas* are biflagellate; in *Cladophora* and *Ulothrix*, they may be biflagellate as well as quadriflagellate; and in *Oedogonium*, they are multiflagellate having a ring of paired flagella.
    ii. *Synzoospore* is a multinucleate and multiflagellated zoospore as in *Vaucheria*. It is also called *compound zoospore*.
    iii. *Aplanospore* is a non-motile, thin-walled zoospore formed by the cleavage of protoplast within a cell, e.g. *Vaucheria*, *Chlamydomonas*, *etc.*
    iv. *Hypnospore* is a thick-walled aplanospore, e.g. *Vaucheria*.

v. *Autospores* are the replicas of the parent cell and formed by the cell division., e.g. *Chlorella*, *Oocystis*.

vi. *Tetraspores* are haploid, thin-walled, non-motile spores formed after reduction division in diploid tetrasporangia of many Rhodophyta and also in some Phaeophyta (e.g. *Dictyota*)

15. *Sexual reproduction* takes place by the union of cytoplasm and nuclear material of two gametes of two organisms of the same species. It is of the following three types:

a. *Isogamy*: When two fusing gametes are morphologically identical, they are called *isogametes* and the process of their fusion (plasmogamy and karyogamy) is known as isogamy, e.g. *Chlamydomonas eugametos* (Fig. 24.16 A).

b. *Anisogamy*: When two fusing motile gametes are morphologically dissimilar, i.e. one is smaller and the other is larger, the gametes are called *anisogametes* and the process of their fusion is called anisogamy, as in *Chlamydomonas braunii* (Fig. 24.19 A–C).

c. *Oogamy*: In oogamy, one gamete becomes immobile. This functions as the female gamete. The male gamete is comparatively very small and motile. These gametes are called *oogametes* and their fusion process is known as oogamy. It takes place in many algal genera including *Chlamydomonas*, *Volvox*, *Fucus*, *Oedogonium*, *Vaucheria*, *etc.*

Classification of Algae:

Classification:

Scientific categorization of the organisms in a hierarchical series of groups is known as classification.

- The international code of Botanical Nomenclature has recommended the following suffixes for the different categories of algae.

Division	:	phyta
Sub-division	:	phytina
Class	:	phyceae
Sub-class	:	phycidae
Order	:	ales
Sub-order	:	inales
Family	:	aceae
Sub-family	:	oideae
Tribe	:	eae
Genus	:	A Latin name
Species	:	A Latin name
Variety	:	A Latin word
Form	:	A Latin word

- Though there are now existing 'varieties' and 'forms' but 'species' is generally considered the smallest group.

- More similar species are grouped together in a 'genus', similar genera are grouped into 'families', families into 'orders', orders into 'classes', classes into 'divisions' and divisions into 'kingdoms'.

- A kingdom is the highest taxonomic rank.
- The Greek word for algae is phykos, and according to International Rules of Botanical Nomenclature, a group of algae should necessarily be incorporated by the word 'phykos'.
- Because of such incorporation, the words such as chlorophyceae, phaeophyceae and Rhodophyceae indicate an idea of their relation with algae

Basis of Algal Classification:

Rarely only one, and usually a combination of a few or more of the following characters, are considered by the algal taxonomists while classifying algae

1) pigments:- their complement, relative amount, kinds chemical composition etc.

2) external form:- Size, shape, appendages and other structures.

3) chromatophore shape:- whether cup shaped, ~~set~~ stellate, reticulate, discoid, spiral, girdle shaped etc.

4) reserve food products:- starch, oil, etc. and ~~their~~ their chemical composition

5) Flagella:- structure, type, number,

position, anatomy and insertion on the body

6) cell wall :- submicroscopic wall, its chemical composition etc.

7) Nucleus :- presence or absence of a definite nucleus.

8) ~~L~~.

8) chromosome :- Number, arrangement, shape etc.

9) Life-history and reproduction :- type of Life history, method of reproduction, shape of reproductive bodies, presence or absence of sexual reproduction. etc.

10) Algal physiology :- different physiological details

11) Ecological data :- freshwater, marine etc.

- Regarding the algal classification there are two schools of thoughts
- according to one school the algae should be divided first into several phyta (division). and then in each "phyta" their should be different phyceae (class)

- The scientists supporting the second view have been the of the opinion that alge is itself equivalent to a division and therefore it can only be further divided into classes and Not into many divisions.

⊛ classification proposed by G.M. SMITH (1955)

- smith also belives that algae should be divided first into some divisions and then each division should contain some classes.

Division	
1. Chlorophyta	Chlorophyceae
	Charophyceae
2. Euglenophyta	Euglenophyceae
3. Pyrrophyta	Cryptophyceae
	Desmokontae
	Dinophyceae
4. Chrysophyta	Xanthophyceae
	Chrysophyceae
	Bacillariophyceae
5. Phaeophyta	Isogeneratae
	Heterogeneratae
	Cyclosporae
6. Cyanophyta	Myxophyceae
7. Rhodophyta	Rhodophyceae

1) Classification proposed by F.E. Fritsch

Fritsch believed that algae is equivalent to a division & therefore it should not be divided into any more "phyta" (= division) but it should be divided only into classes (= phyceae)

- Hence there are no chlorophyta, Phaeophyta or Rhodophyta.

- In the system proposed by Fritsch, algae are divided into following 11 classes:

1. Chlorophyceae
2. Xanthophyceae
3. Chrysophyceae
4. Bacillariophyceae
5. Cryptophyceae
6. Dinophyceae
7. Chloromonadineae
8. Euglenineae
9. Phaephyceae
10. Rhodophyceae
11. Myxophyceae

Chlorophyceae

1. Commonly called *green algae*, the principal pigments of Chlorophyceae are chlorophyll *a*, chlorophyll *b* (chlorophyll *c* in *Vaucheria*), α, β and γ-carotene, lutein, siphonoxanthin and siphonein.
2. Starch (amylase and amylopectin) is the major food reserve.
3. Chloroplast enclosed by a double membrane and lack an additional membrane of ER; thylakoids are present in stacks of 2–6 or more; grana may also be present.
4. Cell wall consists principally of cellulose, hydroxyproline, glycosides, mannans and xylans. It is calcified in some members.
5. Flagella, when present, are two (rarely four), equal, smooth and apically inserted.

   Examples: *Chlamydomonas, Eudorina, Pandorina, Ulothrix.*

Xanthophyceae

1. Commonly called *yellow-green algae*, the principal pigments of *Xanthophyceae* are chlorophyll *a*, β-carotene, diatoxanthin, diadinoxanthin and heteroxanthin (Because of the presence of chlorophyll *c* and vaucheriaxanthin in *Vaucheria*, some prefer to include this genus under Xanthophyceae).
2. Chlorophyll *b* is absent.
3. Food reserves are β-1,3-linked glucan, fats and oil. It is never starch.
4. Main feature of the chloroplast is the presence of two additional membranes of the chloroplast ER, of which the outer membrane is in continuation with the outer membrane of the nuclear envelope. Thylakoids are in stacks of three.

5. The cell wall consists of cellulose, glucose and uronic acids. In several members, many bipartite walls are present.
6. Motile cells are naked with usually two unequal flagella, of which the anterior flagellum is longer and hairy while the posterior one is shorter and smooth. (Compound zoospore of *Vaucheria* bears numerous pairs of unequal flagella, each of which lacks hairs). Examples: *Botrydium*, *Tribonema*, *Ophiocytium*.

Chrysophyceae

1. Commonly called *golden-brown algae*, the principal pigments of Chrysophyceae are chlorophyll *a*, chlorophylls *c1* and *c2* and fucoxanthin. Fucoxanthin gives the cells their golden-brown colour.
2. Principal food reserve is chrysolaminarin, which is β-1, 3-glucopyranoside.
3. Chloroplast features include the presence of (i) two additional membranes of chloroplast ER, of which the outer membrane is in continuation with the outer membrane of the nuclear envelope, and (ii) thylakoids in stacks of three.
4. The cells are naked. In some members, however, scales and cell envelope or lorica are present.
5. Flagella are usually two and unequal, of which the anterior flagellum is hairy and longer while the posterior one is smooth and shorter.
6. Presence of statospores or stomatocysts is the special feature of Chrysophyceae.

Examples: *Ochromonas*, *Paraphysomonas* (Photoplate

Bacillariophyceae

1. Commonly called *diatoms*, the major pigments of *Bacillariophyceae* are chlorophyll *a*, chlorophyll *c*, β-carotene, fucoxanthin, diatoxanthin and diadinoxanthin.
2. Diatoms are largely unicellular and microscopic algae, and only sometimes they are colonial or pseudofilamentous. Diatom cells are uninucleate. They possess heavily silicified walls with beautiful ornamentations (Photoplate, 80).
3. The major food reserves of diatoms are chrysolaminarin and lipids.
4. Out of the two additional membranes of chloroplast ER, the outer one is continuous with outer membrane of nuclear envelope. The thylakoids remain in stacks of three.
5. Cell possess a silica exoskeleton (frustule) made up of two halves (valves).

6. The male gametes are flagellated, and each possesses a single hairy flagellum in which central microtubules are absent.

Examples: *Thalassiosira, Cocconeis, Melosira,*

Cryptophyceae

1. Commonly called *cryptomonads*, the principal pigments of the members of this class are chlorophyll *a*, chlorophyll *c*, α-carotene, diatoxanthin, phycoerythrin and phycocyanin.
2. Differing from the phycobiliproteins (phycocyanin and phycoerythrin) of blue-greens and red algae, the phycobiliproteins of cryptomonads are located in intra- thylakoidal spaces and not in phycobilisomes.
3. Food reserves are starch-like.
4. The special features of chloroplast include (i) two additional membranes of chloroplast ER, and (ii) thylakoids in pairs.
5. The outer cell covering is a periplast, with proteinaceous plates arranged in helical pattern.
6. Motile bodies are biflagellate, with both the flagella being apical or lateral, hairy and equal or slightly unequal.
7. Growth is by binary fission. Sexual reproduction has not been clearly demonstrated.

Examples: *Hemiselmis brunnescens* (Photoplate 11A, B).

Dinophyceae

1. Commonly called *dinoflagellates*, the principal pigments of *Dinophyceae* are chlorophyll *a*, chlorophyll *c2* , β-carotene, peridinin and neoperidinin.
2. Oil and a starch, similar to that of higher plants are the principal food reserves of dinoflagellates.
3. Chloroplast features include (i) two additional membranes of chloroplast ER not continuous with the nuclear envelope, and (ii) thylakoids, present in stacks of three.
4. The cell covering is a multilayered theca, and made up of an epicone and hypocone, divided into many thecal plates; a sulcus runs perpendicular to the girdle in the cell covering.
5. Motile unicells bear two flagella, of which one is transverse and encircles the cell usually in a groove-like girdle. It possesses an outer axoneme and an inner stranded band. The other flagellum is smooth and runs posteriorly.
6. Pyrenoids and eyespots may also be present.

Examples: *Ceratium, Stylodinium, Peridinium, Pyrodinium.*

Euglenophyceae

1. Commonly called *euglenoids*, the principal pigments of these members are chlorophyll *a*, chlorophyll *b*, β-carotene, astaxanthin, antheraxanthin, diadinoxanthin and neoxanthin.
2. Paramylon (β-1, 3–glucan) is the principal food reserve. Chrysolaminarin may also be stored.
3. Main features of the euglenoid chloroplast include (i) one additional chloroplast ER membrane; (ii) the latter is not in continuation with the nuclear membrane, and (iii) thylakoids are in stacks of three or more.
4. Cell wall is made up of proteinaceous pellicle, made up of several helically arranged interlocking strips.
5. Flagella are usually two, hairy and unequal; of these, one flagellum is often not emergent. All cells have two basal bodies.
6. An eyespot is typically present. It is independent of chloroplast but associated with paraflagellar swelling.
7. Euglenoids reproduce solely by cell division. Sexual reproduction has not been reported.

Example: *Euglena.*

Phaeophyceae

1. Commonly called *brown algae*, the principal pigments of *Phaeophyceae* are chlorophyll *a*, chlorophyll *c1* and *c2*, β–carotene and the carotenoid is fucoxanthin.
2. Almost all brown algae are marine and multicellular. Unicellular species are unknown.
3. Plant body ranges from microscopic, branched, filamentous forms to macroscopic parenchymatous plants showing highest degree of anatomical differentiation in algae (e.g. *Laminaria*, *Macrocystis*).
4. Main food reserves are laminarin and mannitol.
5. Principal characteristics of chloroplast include (i) two additional membranes of chloroplast ER, of which the outer membrane is in continuation with the outer membrane of nuclear envelope, and (ii) thylakoids are in stacks of 2–6.
6. The cell wall is bilayered, of which the outer layer is made up of alginic acid and fucoidan and inner layer is of cellulose.
7. Motile bodies have usually two unequal flagella.

Examples: *Ectocarpus, Dictyota, Punctaria, Sargassum, Fucus.*

Rhodophyceae

1. Commonly called *red algae*, the members of *Rhodophyceae* have their principal pigments in the form of

chlorophyll *a* (rarely also chlorophyll *d)*, r -phyco-cyanin, allophycocyanin,c-phycoerythrin, α-carotene and β-carotene.

2. Chief food reserve is floridean starch.
3. Major features of chloroplast include (i) bilayered chloroplast envelope, (ii) absence of chloroplast ER, and (iii) presence of unstacked thylakoids.
4. Cell wall composed of cellulose, and in certain species of xylans and galactans, particularly the commercially important *agar* and *carrageenin*. Calcification of cell wall occurs in many red algae.
5. Presence of "*pit connection*" or "*pit-plug*" in majority of red algae is a specialized feature.
6. Mucilage may comprise up to 70% of the dry weight of the cell wall.
7. Flagella, and therefore motile bodies, are absent.

Examples: *Bangia, Porphyra, Dumontia, Palmaria, Polysiphonia.*

Cyanophyceae or Myxophyceae

1. Commonly called *blue-green algae*, the nuclear material in these members is not enclosed in a nuclear envelope.
2. Nucleolus and organized chromosomes are absent.
3. Plastids, mitochondria, Golgi bodies and other unit membrane organelles are absent.
4. Principal pigments are chlorophyll *a*, β-carotene, c–phycoerythrin, c-phycocyanin and allophycocyanin.
5. Food reserves in phycocyanin granules (arginine and aspartic acid).
6. Chloroplasts are absent. Thylakoids are unstacked and remain free in the cytoplasm. Phycobilisomes are present.
7. Ultrastructural studies show that the cell wall is four-layered; peptidoglycan (murein) is the principal component.
8. Flagella are absent.
9. True sexual reproduction is absent. However, some species show a low-frequency occurrence of genetic recombination by transformation (Devilly and Houghton, 1977; Stevens and Porter,1980)

Examples: *Nostoc, Anabaena, Gloeocapsa, Oscillatoria.*