ZENITH EDUCATION

Botany · Assistant Professor Master (MP Edition)

UNIT 1: LOWER PLANT DIVERSITY

A-Series Definitive Reference Manual · English Medium

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NOTE Chapters labelled G, AP, UP and MP are supplements for Assistant Professor syllabi; other chapter numbers follow the master volume. Chapters outside the Madhya Pradesh Second Paper syllabus were omitted, so numbering is not continuous.

Chapter 1. Scope, Classification and Evolutionary Framework

1.1 What the unit covers and how to use it

This unit covers the four groups traditionally called "lower plants": **algae** (including cyanobacteria, which are still treated under the algal code in phycology), **fungi** (with the fungus-like protists that exam papers group with them), **lichens** and **bryophytes**. The label "lower plants" is a teaching convenience from the thallophyte–bryophyte–pteridophyte scheme. It is not a clade, and it is not a classification that a modern paper will treat as natural. Fungi are not plants, cyanobacteria are bacteria, and "algae" is a functional grouping that spans at least five eukaryotic lineages plus one bacterial phylum.

EXAM FOCUS Examiners at Scientific Officer, CSIR-NET Life Sciences, GATE (Botany, XL-R / XL2) and Assistant Professor level routinely test (a) group-wise pigments, reserve foods and wall chemistry, (b) life-cycle ploidy and where meiosis occurs, (c) named genera with the correct group, and (d) the "why is this wrong?" style of statement analysis. Every table in this unit is built for those four tasks.

EXAMINER TRAP Never write that algae are "heterotrophic with some autotrophic", that Chlorophyta have vascular tissue, or that algae "lack cell walls". All three statements appear in older coaching notes and all three are wrong. Algae are predominantly photoautotrophic (a few are mixotrophic or secondarily heterotrophic, e.g. Polytoma, Prototheca), none has xylem or phloem (kelp has phloem-like trumpet hyphae, which are analogous, not homologous), and every major algal group except the naked flagellates and some stages has a defined wall.

1.2 The five-kingdom, three-domain and modern views

Whittaker (1969) placed bacteria and cyanobacteria in Monera, algae (except cyanobacteria) in Protista or Plantae depending on the author, and fungi in their own kingdom Fungi. Woese (1990) added the domain level: Bacteria, Archaea, Eukarya. Modern eukaryote classification (Adl et al., 2019) uses supergroups defined by molecular phylogeny, and this is why the same textbook chapter now has to explain that brown algae and diatoms are close relatives (both Stramenopila), that oomycetes such as Phytophthora are closer to brown algae than to fungi, and that fungi are closer to animals (Opisthokonta) than to plants.

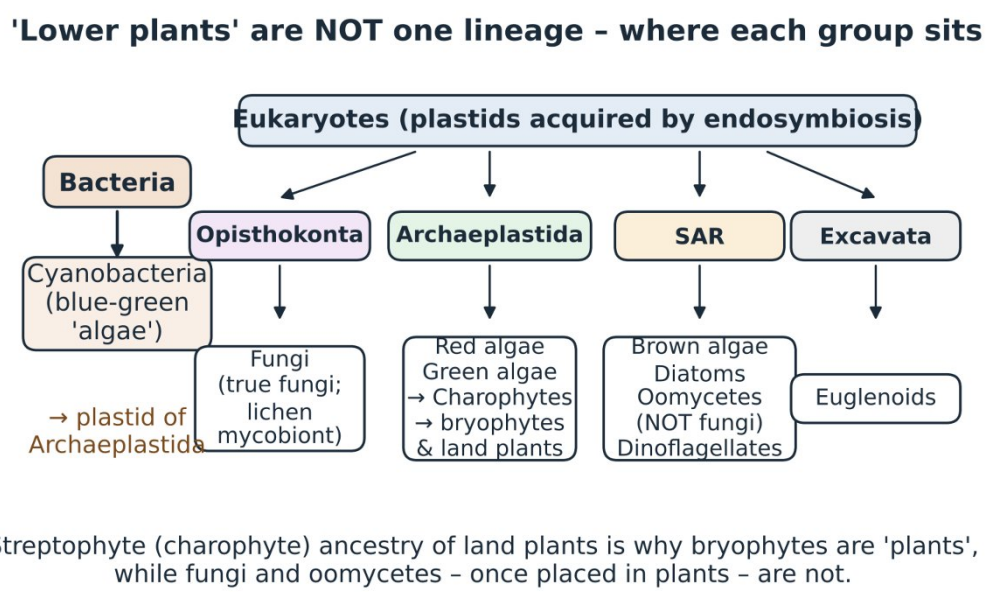


Figure 1. Placement of the "lower plant" groups in current eukaryote phylogeny. Cyanobacteria are bacteria; their descendants live on as plastids in Archaeplastida and, through secondary endosymbiosis, in other lineages.

Table 1. Traditional versus current placement of the groups in this unit

Group	Traditional placement	Current placement	Exam-safe statement
Cyanobacteria	Algae (Myxophyceae/Cyanophyceae)	Bacteria (oxygenic phototrophs)	Prokaryotic; peptidoglycan wall; no membrane-bound organelles
Green algae	Plantae (Chlorophyta)	**Archaeplastida**: Chlorophyta and Streptophyta (charophytes)	Zygnematophyceae are the closest algal relatives of land plants on current phylogenomic evidence; Charales and Coleochaetales are more distant (older texts name Charales)
Red algae	Plantae (Rhodophyta)	**Archaeplastida**: Rhodophyta	No flagella, no centrioles at any stage
Brown algae, diatoms, golden algae	Plantae / Protista	Stramenopila (heterokonts) within SAR	Plastid from secondary endosymbiosis of a red alga; chlorophylls a and c
Dinoflagellates	Algae	Alveolata	Dinokaryon; peridinin
Euglenoids	Algae / protozoa	Excavata	Plastid from secondary endosymbiosis of a green alga; no cell wall
True fungi	Plantae (thallophytes)	**Opisthokonta**: Fungi	Chitinous wall; absorptive heterotrophs
Oomycetes (water moulds, downy mildews)	Fungi (Phycomycetes)	Stramenopila (Oomycota)	Cellulose–glucan wall; diploid vegetative body; heterokont zoospores
Slime moulds	Fungi (Myxomycetes)	Amoebozoa	Phagotrophic plasmodium; not fungi
Lichens	Plantae (thallophyta)	Fungi (Ascomycota mostly) in symbiosis	Named and classified by the fungal partner (mycobiont)
Bryophytes	Plantae	Embryophyta (land plants, non-tracheophytes)	Whether bryophytes form one clade or a grade is a live research question (see Chapter 11)

1.3 Endosymbiosis and why "algae" is not one group

All plastids trace to the engulfment of a cyanobacterium. In **primary endosymbiosis** a heterotrophic eukaryote retained a cyanobacterium; the resulting plastid is bounded by two membranes (the cyanobacterial inner and outer membranes) and defines Archaeplastida: glaucophytes, red algae and green algae with their land-plant descendants. In **secondary endosymbiosis** a second eukaryote engulfed a red or green alga: the plastid then has three or four membranes. Euglenoids (and chlorarachniophytes) acquired a green-algal plastid; cryptophytes, haptophytes, stramenopiles (brown algae, diatoms, golden algae) and dinoflagellates acquired a red-algal one, in the case of dinoflagellates sometimes replaced later by serial or tertiary events.

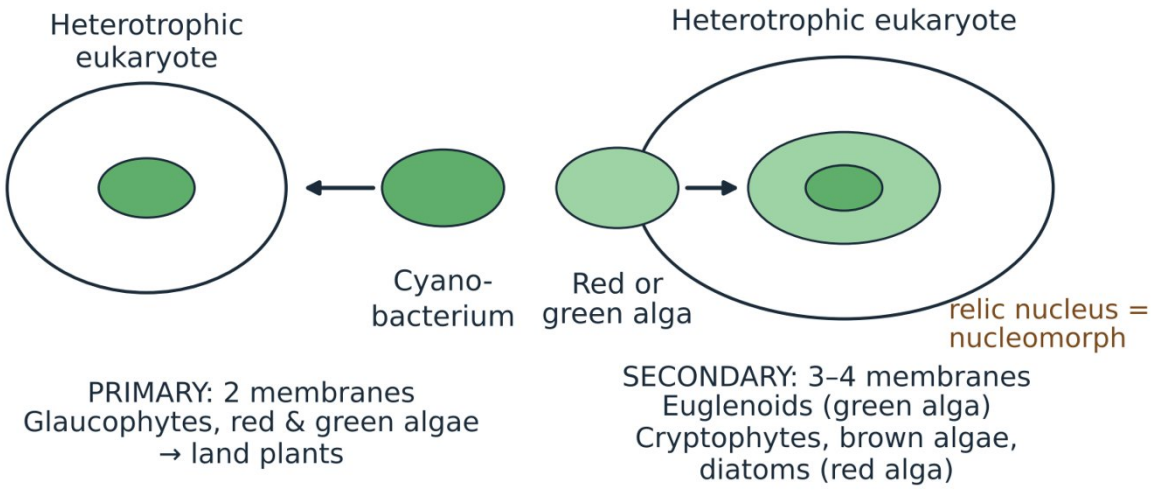


Figure 2. Primary and secondary endosymbiosis. A nucleomorph (a vestigial nucleus of the engulfed alga) survives in cryptophytes and chlorarachniophytes.

MEMORY AID Plastid membrane count: **2** = primary (Archaeplastida). **3** = euglenoids and most dinoflagellates. **4** = cryptophytes, haptophytes, stramenopiles. Four membranes with a nucleomorph between the inner and outer pairs = cryptophytes.

1.4 Comparison of the four groups (rectified master table)

Table 2. Algae, fungi, lichens and bryophytes compared

Feature	Algae (incl. cyanobacteria)	Fungi	Lichens	Bryophytes
Domain / kingdom	Bacteria (cyanobacteria); Eukarya (others)	Eukarya, Fungi	Not a taxon; fungus + photobiont	Eukarya, Plantae (Embryophyta)
Nutrition	Photoautotrophic (rare mixotrophy or heterotrophy)	Absorptive heterotrophic (saprotroph, parasite, mutualist)	Mycobiont heterotroph; photobiont autotroph	Photoautotrophic
Photosynthetic pigments	Chl a always; b, c, d, phycobilins, fucoxanthin by group	None	Those of the photobiont	Chl a, b; carotenoids
Cell wall	Peptidoglycan (cyanobacteria); cellulose + other polymers (alginate, agar, carrageenan, silica, etc.)	Chitin + glucans	Fungal chitin-glucan; photobiont wall	Cellulose, hemicellulose, pectin; no lignin
Reserve food	Starch (variants), laminarin, paramylon, chrysolaminarin	Glycogen, trehalose, lipids	Polyols and glycogen (fungus); photobiont starch/ribitol	Starch, lipids
Body	Unicell, colony, filament, parenchymatous or siphonous thallus	Yeast cells or hyphae/mycelium	**Thallus**: crustose, foliose, fruticose etc.	Thalloid or leafy gametophyte
Vascular tissue	None (true xylem/phloem absent)	None	None	None (hydroids and leptoids only in some mosses)
Habitat	Mostly aquatic; some aerial, soil, symbiotic	Mostly terrestrial; some aquatic	Terrestrial epiphytes, epiliths, soil	Moist terrestrial; a few aquatic
Dominant generation	Varies by group	Haploid or dikaryotic	Fungal thallus	Gametophyte (n)
Main sexual structure	Gametangia (unicellular wall) or whole cell	Gametangia, somatogamy, spermatization	Fungal asci/basidia	Multicellular archegonia and antheridia with sterile jacket

EXAMINER TRAP "Bryophytes are non-vascular land plants lacking rhizoids" – reversed. Bryophytes have rhizoids (unicellular in liverworts, multicellular in mosses), not roots. Also, "gametophyte-dominant, unicellular sporophyte" is wrong in every direction: the bryophyte sporophyte is multicellular, diploid, short-lived and nutritionally dependent on the gametophyte.

1.5 Alternation of generations and ploidy terms used throughout

• **Haplontic (zygotic meiosis)**: the only 2n cell is the zygote; meiosis happens at zygote germination (Chlamydomonas, Spirogyra, Volvox, Oedogonium, Chara; most Zygomycota and Ascomycota in the sexual phase).

• **Diplontic (gametic meiosis)**: the body is 2n; meiosis produces gametes (Fucus, diatoms, Oomycota, the animal pattern).

• **Haplo-diplontic (sporic meiosis)**: multicellular haploid and diploid bodies alternate; **isomorphic** if they look alike (Ulva, Ectocarpus, Dictyota, Polysiphonia) or **heteromorphic** if they differ (Laminaria; all bryophytes with a dominant gametophyte, all pteridophytes with a dominant sporophyte).

• **Triphasic**: two diploid phases (carposporophyte and tetrasporophyte) and one haploid phase (red algae).

• **Dikaryotic (n+n)** phase: fungal cells with two genetically distinct haploid nuclei that have not fused; long in Basidiomycota, short in Ascomycota.

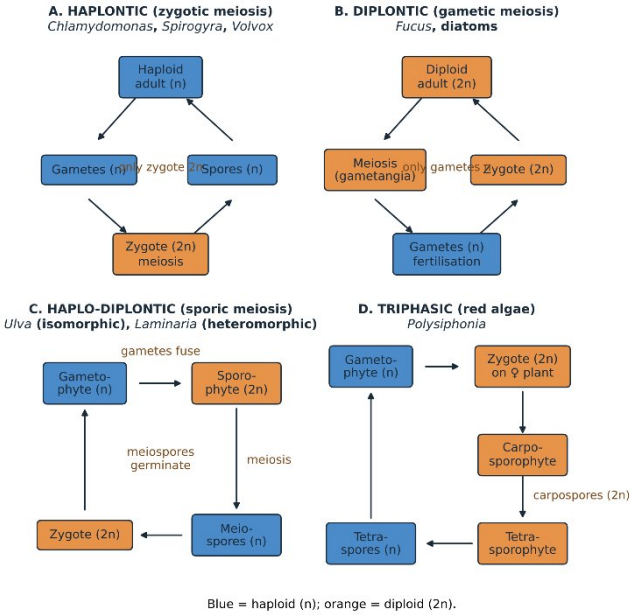


Figure 3. The four algal life-cycle patterns with ploidy colour-coded. Meiosis location is the diagnostic feature.

MEMORY AID Where does meiosis happen? **Z**ygote → haplontic (Z-meiosis). **G**ametes → diplontic. **S**pores → sporic (haplo-diplontic). Remember the order Z-G-S as "zygotic, gametic, sporic".

Chapter 2. Algae: General Biology

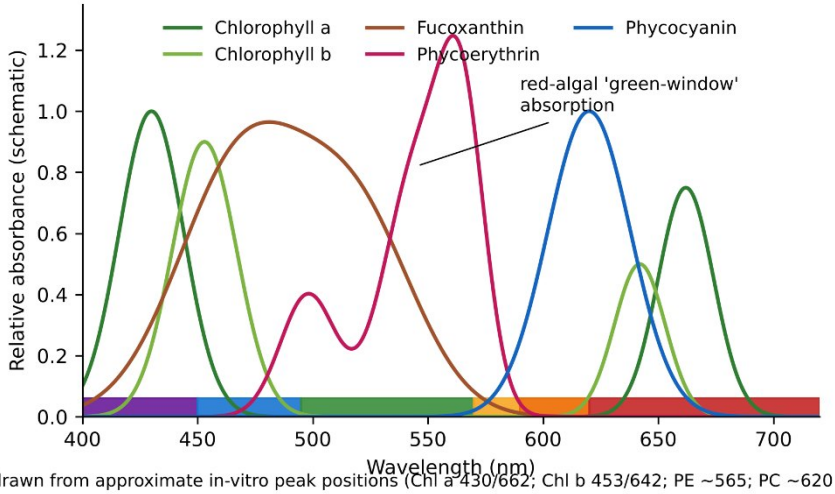
2.1 Defining characters

Algae are oxygenic, mostly aquatic photoautotrophs whose bodies are thalli lacking true roots, stems, leaves and vascular tissue, and whose reproductive cells are either single cells or are produced in gametangia lacking a multicellular sterile jacket (the Charales are the main exception, with a jacket around the oogonium). Cyanobacteria are included because algal nomenclature (the International Code of Nomenclature for algae, fungi and plants) still governs their names, although they are bacteria in every other respect. Thallus organisation ranges through these grades. Each is a body-plan term that an examiner can ask directly.

Table 3. Thallus organisation in algae

Grade	Description	Example
Unicellular, motile	Single flagellate cell	Chlamydomonas
Unicellular, non-motile	Coccoid cell	Chlorella
Colonial (coenobium)	Fixed number of cells; no cell increase after formation	Volvox, Pediastrum, Hydrodictyon
Palmelloid	Non-motile cells in a gelatinous matrix	Tetraspora
Filamentous, unbranched	One row of cells	Spirogyra, Ulothrix, Oedogonium
Filamentous, branched	Heterotrichous in many	Cladophora, Ectocarpus
Siphonous (coenocytic)	Multinucleate tube without cross-walls	Vaucheria, Caulerpa, Bryopsis
Parenchymatous	Cells divide in three planes	Ulva (2 layers), Fucus, Laminaria
Pseudoparenchymatous	Dense filaments simulating tissue	Many red algae, Polysiphonia axes

2.2 Pigments, reserve foods, walls and flagella (the diagnostic table)



Schematic curves drawn from approximate in-vitro peak positions (Chl a 430/662; Chl b 453/642; PE ~565; PC ~620 nm); in vivo peaks shift.

Figure 4. Schematic absorption curves for the principal algal photopigments. Fucoxanthin and the phycobilins fill the green region where chlorophylls absorb weakly, which is why red and brown algae can live deeper than green algae.

Table 4. Main algal groups compared (the core exam table)

Group	Chlorophylls and accessory pigments	Reserve food	Cell wall	Motile cells and flagella
Cyanobacteria	Chl a; phycocyanin, allophycocyanin, phycoerythrin (phycobilisomes)	Cyanophycean starch (α-glucan, in cytoplasm); cyanophycin (N reserve)	Peptidoglycan (gram-negative type) with mucilage sheath	None (gliding motility; gas vesicles)
Chlorophyta (green algae)	Chl a, b; β-carotene, lutein	True starch in the chloroplast (often around the pyrenoid)	Cellulose (some xylan or mannan; calcified in some)	2 or 4 (or many) equal, smooth (whiplash) flagella
Charophyta (stoneworts and relatives)	Chl a, b	Starch	Cellulose; Charales calcified	Biflagellate sperm (Charales), laterally inserted
Euglenophyta	Chl a, b; carotenoids	Paramylon (β-1,3 glucan) outside the plastid	None; proteinaceous pellicle	1 long flagellum emerges (a second is short)
Xanthophyta (yellow-green)	Chl a, c; no fucoxanthin; excess xanthophylls	Oil and chrysolaminarin (leucosin)	Pectic with silica or cellulose, often of two overlapping pieces	**2 unequal**: one tinsel, one whiplash
Chrysophyta (golden algae)	Chl a, c; fucoxanthin	Chrysolaminarin and oil	Scales or lorica; silica cysts	2 unequal
Bacillariophyta (diatoms)	Chl a, c; fucoxanthin	Chrysolaminarin and oil	Silica frustule of two valves	Male gametes of centric diatoms uniflagellate (tinsel)
Dinophyta (dinoflagellates)	Chl a, c; peridinin	Starch; oils	Cellulose plates in the amphiesma (theca)	2: one transverse, one longitudinal
Phaeophyta (brown algae)	Chl a, c; fucoxanthin	Laminarin (β-1,3, β-1,6 glucan) and mannitol	Cellulose with alginic acid and fucoidan	**2 unequal, lateral**: anterior tinsel, posterior whiplash
Rhodophyta (red algae)	Chl a (some Chl d); phycoerythrin, phycocyanin	Floridean starch (in cytoplasm, α-glucan)	Cellulose with agar or carrageenan (sulphated galactans); calcified in corallines	None at any stage; spermatia are non-motile
EXAMINER TRAP Reversal alert. Agar and carrageenan come from **red algae** (Rhodophyta); alginate and laminarin come from **brown algae** (Phaeophyta). A fact bank that reads "Phaeophyta supplies agar" or "Chlorophyta supply agar, carrageenan and alginates" is wrong. Floridean starch lies **outside** the chloroplast; true starch of green algae lies **inside**.				
MEMORY AID **A–B–C** of wall polymers: **A**lginate = **B**rown; **C**arrageenan and agar = **R**ed ("Red = agar-and-carrageenan, Brown = alginate"). Pit connections = red algae. Pyrenoid with starch sheath = green algae.				

2.3 Cell structure of a model unicellular alga (Chlamydomonas)

Chlamydomonas reinhardtii is a haploid biflagellate green alga with a single cup-shaped chloroplast containing one basal **pyrenoid** (the site of RuBisCO concentration, wrapped in a starch sheath), an **eyespot** (stigma; carotenoid-rich globules in the chloroplast that, together with plasma-membrane channelrhodopsins, mediate phototaxis), two apical **contractile vacuoles** (osmoregulation), a nucleus, and a cellulose-free glycoprotein (hydroxyproline-rich) wall. It is a standard model for photosynthesis, flagellar assembly (intraflagellar transport) and the cell cycle, and its genome was sequenced in 2007.

2.4 Reproduction in algae

• **Vegetative:** binary fission (unicells; cyanobacteria), fragmentation (filaments; Spirogyra), hormogonia (cyanobacteria), propagules and stolons (brown algae), bulbils (Chara).

• **Asexual spores:** zoospores (flagellate; Ulothrix, Cladophora), aplanospores (non-motile, formed within the sporangium), autospores (miniature copies of the parent in Chlorella), hypnospores/akinetes (thick-walled resting cells), tetraspores (red algae,

formed by meiosis in the tetrasporangium, hence **haploid**), carpospores (red algae, **diploid**, formed mitotically by the carposporophyte).

• **Sexual:** isogamy (equal gametes, Ulothrix, Chlamydomonas spp.), anisogamy (unequal motile gametes, Chlamydomonas braunii), oogamy (large non-motile egg, small motile sperm: Volvox, Oedogonium, Chara, Fucus, Laminaria), and **conjugation** (fusion of non-flagellate gametes through a tube: Spirogyra, Zygnema).

EXAM FOCUS A frequent question: "Which algal groups never form flagellated cells?" Cyanobacteria and Rhodophyta (also, among green algae, the Zygnematophyceae such as Spirogyra). Red algae also lack centrioles; cyanobacteria are prokaryotes. Do not write "red algae have planogametes" (the old fact-bank error): the male gametes of red algae are non-motile spermatia carried passively by water, and carpospores are **diploid** mitospores, not megaspores.

Chapter 3. Algae: Major Groups and Type Studies

3.1 Cyanobacteria (Cyanophyta, blue-green algae)

Cyanobacteria are gram-negative-type bacteria that perform oxygenic photosynthesis with chlorophyll a and phycobilins (phycocyanin, allophycocyanin, phycoerythrin) organised in **phycobilisomes** on unstacked thylakoids lying freely in the cytoplasm. They contain **carboxysomes** (polyhedral bodies packing RuBisCO), **gas vesicles** in planktonic forms, and storage granules of cyanophycean starch, cyanophycin (a nitrogen-rich co-polymer of arginine and aspartate) and polyphosphate. Walls are of peptidoglycan with an outer membrane and usually a mucilage sheath. There is no sexual reproduction or meiosis; genetic exchange occurs by transformation, conjugation or transduction.

NOTE Chlorophyll d is the main pigment of the cyanobacterium Acaryochloris marina; Prochlorococcus (the most abundant marine photoautotroph, a few hundred nm to a micron in cell diameter) uses divinyl chlorophylls a and b. Neither alters the rule "cyanobacteria: Chl a plus phycobilins" for standard exam use.

Filamentous nitrogen fixers

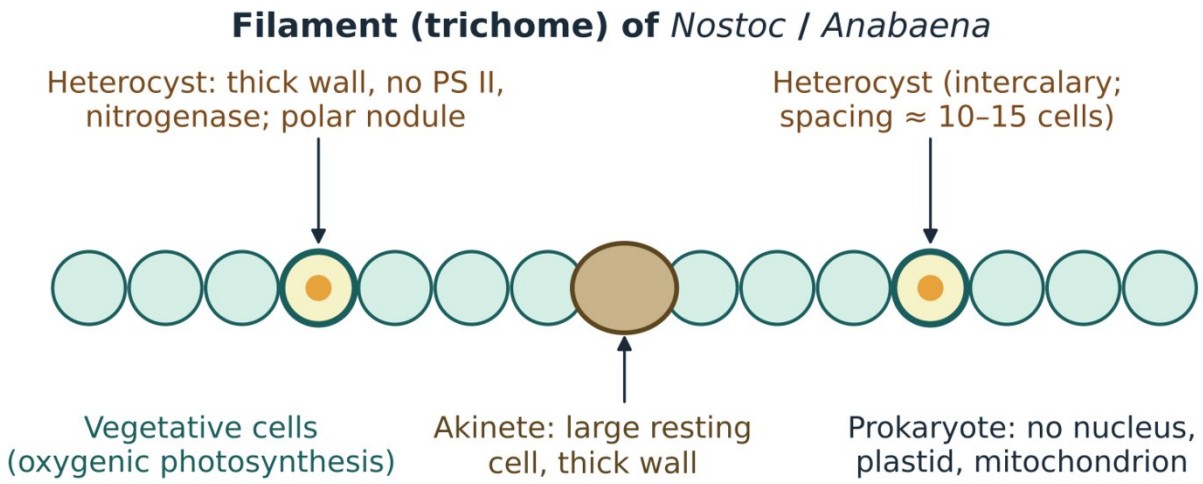


Figure 5. A heterocystous cyanobacterial filament. The heterocyst lacks photosystem II, so the oxygen-sensitive nitrogenase works in a micro-oxic compartment; the thick glycolipid envelope slows O_2 entry.

Nostoc, Anabaena, Aulosira, Tolypothrix, Cylindrospermum and Scytonema produce **heterocysts** (terminally or intercalary) where nitrogenase (encoded by nifHDK) reduces N_2 to NH_3, supplying glutamine to vegetative cells in return for fixed carbon. **Akinetes** are enlarged resting cells with thick walls; **hormogonia** are short motile fragments that disperse the filament. Oscillatoria (gliding oscillation of trichomes), Lyngbya and Spirulina (Arthrospira) have no heterocysts. Anabaena azollae (now Nostoc azollae) lives in leaf cavities of the water fern Azolla; Anthoceros cavities host Nostoc; cycad coralloid roots host Nostoc/Anabaena; lichen cephalodia host cyanobacteria. In rice fields in India, Aulosira, Tolypothrix, Nostoc and Anabaena contribute biological nitrogen fixation and are produced as **blue-green algal biofertiliser** (IARI pioneered mass production).

Toxins, blooms and ecology

Eutrophic freshwater blooms of Microcystis, Anabaena, Aphanizomenon and Nodularia release hepatotoxic peptides (microcystins, nodularin) and neurotoxins (anatoxin-a, saxitoxins). Cyanobacteria were the agents of the Great Oxidation Event ($\approx$2.4 Ga) and build stromatolites. Cyanobacteria-like microfossils have been reported from rocks about 3.5 Ga old, but their biogenicity and identity are debated.

EXAMINER TRAP "Spirulina is a green alga" and "cyanobacteria have a nucleus and chloroplasts" are both wrong. Single-celled protein from Spirulina is cyanobacterial biomass, rich in protein (up to 60 percent of dry weight) and phycocyanin.

3.2 Chlorophyta (green algae)

Green algae have chlorophylls a and b, store true starch in plastids, and have cellulose walls. They dominate freshwater, with marine groups too (Ulva, Caulerpa, Codium, Halimeda). The type studies below are those most often set.

Chlamydomonas and the volvocine line

The volvocine series shows the evolution of multicellularity: Chlamydomonas (unicell) → Gonium (4–16 cell plate) → Pandorina, Eudorina (16–32) → Pleodorina → **Volvox** (up to tens of thousands of cells; only a small number of large gonidia reproduce, while the somatic cells with flagella and eyespots are terminally differentiated). In Volvox the daughter colonies are formed inside the parent by **inversion**: the young colony turns inside out through a phialopore so that flagella face outward. Cells remain linked by cytoplasmic strands (plasmodesmata-like bridges). Reproduction is oogamous in most species; all are haplontic.

Filamentous types

• **Ulothrix**: unbranched filament with a basal holdfast cell and a single girdle-shaped (band-shaped) chloroplast with pyrenoids. Asexual reproduction by quadriflagellate **zoospores** (macro- and microzoospores); sexual by biflagellate isogametes; zygote forms a thick-walled hypnozygote that undergoes **zygotic meiosis**, so the plant is haplontic.

• **Oedogonium**: unbranched, with a net-like (reticulate) chloroplast, **cap cells** from repeated apical divisions, and **stephanokont** zoospores (a ring of numerous flagella). Oogamous; antheridia produce two sperms; some species have **dwarf males** (nannandrous), which develop from androspores on or near the oogonium. Haplontic.

• **Spirogyra**: unbranched; **spiral ribbon-shaped chloroplasts** with pyrenoids; cells joined by plug-like end walls; no flagellate stage at all. Sexual reproduction is by **conjugation**, either **scalariform** (ladder-like, between two filaments) or **lateral** (between adjacent cells of the same filament). The male cell is physiologically active and the female passive (physiological anisogamy). The zygote becomes a thick-walled zygospore; on germination meiosis occurs (zygotic meiosis) and, of the four haploid nuclei, three degenerate.

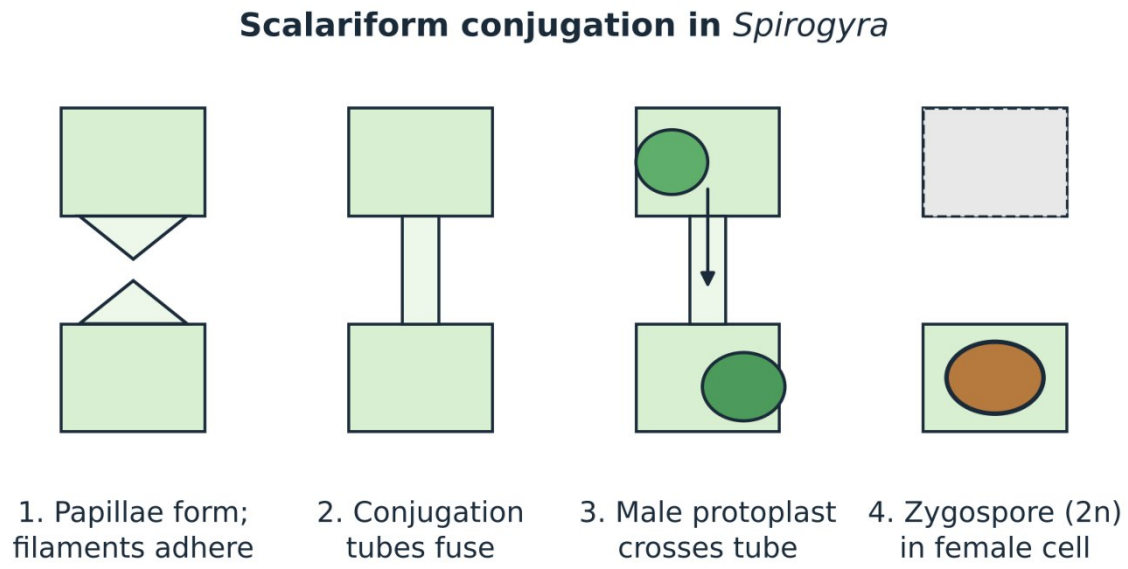


Figure 6. Stages of scalariform conjugation in Spirogyra. The zygospore is the only diploid structure in the life cycle.

• **Cladophora**: branched, coenocytic cells; cell wall with cellulose I; some species show isomorphic alternation of generations, others are haplontic, depending on species and strain.

• **Ulva** (sea lettuce): a two-cell-layer sheet attached by a holdfast; **isomorphic haplo-diplontic**; the gametophyte (n) makes biflagellate gametes, the sporophyte (2n) makes quadriflagellate meiospores (zoospores by meiosis). Environmental and nutrient pollution can cause "green tides" of Ulva (formerly Enteromorpha).

• **Caulerpa**: a siphonous marine green alga whose single huge coenocytic cell shows stolon, rhizoid and "leaf" like differentiation; cell wall has xylan instead of cellulose in some layers; an invasive species (Caulerpa taxifolia) in the Mediterranean.

Charophyta (Charales and relatives)

Chara and Nitella grow in freshwater (often hard water) as branched axes of **nodes and internodes**, with whorls of branchlets and a single **apical cell**. Each node bears the sex organs: an orange-red spherical **globule** (antheridium: eight shield cells, manubria, capitula and many antheridial filaments producing biflagellate sperms) and an oval **nucule** (oogonium: a single egg cell wrapped by five spirally arranged tube cells that form a coronula of five cells in Chara, ten in Nitella). The zygote's wall becomes thick and calcified (oospore; the calcified remains are fossil **gyrogonites**), and meiosis at germination gives a haploid protonema, so Chara is

haplontic. Charales share with land plants a sterile jacket around the oogonium, plasmodesmata, an apical cell, phragmoplast-mediated cytokinesis, and the cell-wall and sperm characters of Streptophyta; yet recent phylogenomic work (e.g. Wickett et al. 2014; One Thousand Plant Transcriptomes 2019) places **Zygnematophyceae** (Spirogyra, Zygnema, Mesotaenium) as the closest algal relatives of land plants, with Charales and Coleochaetales more distant.

EXAMINER TRAP Do not equate "closest relative of land plants" with "Chara" in a statement-based question unless the question specifies the older view. Record the textbook view and the phylogenomic view separately.

3.3 Euglenophyta

Euglena is a freshwater flagellate with a flexible **pellicle** of proteinaceous strips beneath the plasma membrane (no cell wall), a long emergent flagellum and a short non-emergent one that meet in the **reservoir** at the anterior end, an eyespot (stigma) next to a **paraflagellar body** (the photoreceptor), a contractile vacuole emptying into the reservoir, paramylon granules, and chloroplasts with three envelope membranes (secondary green-algal origin). Nutrition is mixotrophic; in the dark it loses chloroplast function and feeds osmotrophically. Reproduction is longitudinal binary fission; sexual reproduction is unknown. The nucleus has permanently condensed chromosomes during mitosis and an endosome (a "nucleolus-like" body), features that are exam favourites.

3.4 Xanthophyta, Chrysophyta and Bacillariophyta

• **Xanthophyta** (yellow-green algae): **Vaucheria** is a siphonous, coenocytic filament with many discoid chloroplasts lacking pyrenoids, oil as food reserve (no starch), and a pectic wall. Asexual reproduction is by a multiflagellate **synzoospore** (a whole sporangial contents compound zoospore) and aplanospores; sexual reproduction is oogamous, with the antheridium and oogonium side by side on the same filament, and the oogonium opening by a beak. Zygotic meiosis (haplontic). It is often misdescribed as parasitic; it is not.

• **Chrysophyta** (golden algae): chlorophylls a and c, fucoxanthin; silica-scaled or loricate flagellates (Ochromonas, Dinobryon); the resting stage is a silicified **stomatocyst**.

• **Bacillariophyta (diatoms)**: unicells in a **silica frustule** of two overlapping valves, the larger **epitheca** over the smaller **hypotheca**, joined by girdle bands. **Centric** diatoms are radially symmetrical (Coscinodiscus, Thalassiosira) and oogamous; **pennate** diatoms are bilaterally symmetrical and many have a longitudinal slit, the **raphe**, for gliding (Navicula, Pinnularia); they are isogamous. Diatoms are diploid for most of their life (diplontic); gametes are produced by meiosis. Because each division produces one daughter the size of the smaller valve (MacDonald–Pfitzer rule), average cell size falls until an **auxospore** restores it by sexual or asexual growth. Fossil frustules form **diatomite** (diatomaceous earth, kieselguhr), used in filters, dynamite stabilisation, abrasives and insulation. Diatoms fix about a fifth of global primary production and are key in silicon cycling and the oceanic biological pump.

3.5 Dinophyta (dinoflagellates)

Dinoflagellates have two dissimilar flagella: a **transverse** flagellum in the girdle (cingulum) and a **longitudinal** one in the sulcus. The amphiesma consists of vesicles with cellulose plates (armoured/thecate forms). Chlorophylls a and c with the carotenoid **peridinin** give a golden-brown colour. The nucleus is a **dinokaryon**: permanently condensed chromosomes with very little histone (replaced by dinoflagellate viral-nucleoprotein-like basic proteins). Reproduction is mostly by binary fission; many form cysts. Ecologically they include:

• **Red-tide** formers and toxin producers: Karenia brevis (brevetoxin), Alexandrium (Gonyaulax) catenella (saxitoxin; paralytic shellfish poisoning), Dinophysis (okadaic acid; diarrhetic shellfish poisoning).

• **Bioluminescent** Noctiluca scintillans (a large heterotrophic dinoflagellate whose blooms are of rising concern in the northern Arabian Sea).

• **Symbionts**: Symbiodiniaceae ("zooxanthellae"), the photosynthetic partners of reef corals; their expulsion under heat stress is **coral bleaching**.

EXAMINER TRAP Domoic acid (amnesic shellfish poisoning) comes from the **diatom** Pseudo-nitzschia, not a dinoflagellate. Ciguatera comes from the benthic dinoflagellate Gambierdiscus.

3.6 Phaeophyta (brown algae)

Brown algae are almost exclusively marine, with chlorophylls a, c_1 and c_2, **fucoxanthin** (brown colour), laminarin and mannitol, cellulose–alginate walls with fucoidan, and heterokont flagella. Some of the largest algae are brown: the kelps. The body ranges from branched filaments (Ectocarpus) to a differentiated thallus with **holdfast, stipe and blade** (Laminaria, Macrocystis), and kelps contain **trumpet hyphae**, sieve-tube-like cells with sieve plates that translocate photosynthate (analogous, not homologous, to phloem). Growth is usually by an **intercalary meristem** (kelps) or an apical cell/apical groove (Fucus, Dictyota). Phlorotannins (polyphenols) deter herbivores.

Table 5. Life cycles of three type brown algae

Genus	Life cycle	Sporophyte	Gametophyte	Gametes	Meiosis occurs in

Genus	Life cycle	Sporophyte	Gametophyte	Gametes	Meiosis occurs in
Laminaria	Heteromorphic haplo-diplontic	**Large kelp**: holdfast, stipe, blade (2n)	Microscopic filament (n), dioecious	Oogamous; sperm biflagellate	**Zoosporangium**: 4 meiotic nuclei then 3 mitoses give 32 zoospores
Fucus	Diplontic	Plant body (2n) with **receptacles** containing **conceptacles**	None (gametes produced directly)	Oogamous; 8 eggs per oogonium, 64 sperm per antheridium	Oogonium and antheridium mother cells
Sargassum	Diplontic (like Fucus)	Leafy, with air bladders (vesicles)	None	Oogamous	Gametangia
Dictyota	Isomorphic haplo-diplontic	Flat dichotomous thallus, apical cell	Similar	Oogamous; tetraspores (4 non-motile meiospores per sporangium)	Tetrasporangium

WORKED NUMERICAL Fucus gamete number. One oogonium mother nucleus undergoes meiosis (→ 4) and one post-meiotic mitosis (→ 8): 8 eggs. One antheridium mother nucleus undergoes meiosis (→ 4) and four further mitoses (4×2^4): **64** sperm. Laminaria zoosporangium: meiosis (→ 4) and three mitoses (4×2^3): **32** zoospores. Do not assume the "meiosis gives 4" rule alone gives the gamete count.

Macrocystis pyrifera (giant kelp) can exceed 40 m and grow up to about 0.5 m per day; Sargassum forms floating mats in the Sargasso Sea; Laminaria, Saccharina (kombu) and Undaria (wakame) are food; Ascophyllum and kelps are industrial sources of alginate, iodine and mannitol.

3.7 Rhodophyta (red algae)

Red algae are mostly marine and span intertidal to the deepest known photic zone. Chlorophyll a (rarely d), phycoerythrin and phycocyanin organised in phycobilisomes on unstacked thylakoids, **floridean starch** free in the cytoplasm, cell walls of cellulose with sulphated galactans (agar, carrageenan) and calcium carbonate in coralline algae (Corallina, Lithothamnion; reef-builders). The body is pseudoparenchymatous, usually of filaments joined by **pit connections** (cytoplasmic bridges plugged by a proteinaceous **pit plug**, a red-algal hallmark). There are no flagella or centrioles at any stage.

Life cycle of Polysiphonia (triphasic)

Polysiphonia is a branched filament with a central axial cell encircled by **pericentral** cells (polysiphonous). It is dioecious and shows **isomorphic** gametophytes and tetrasporophytes plus a parasitic **carposporophyte**:

1. The male gametophyte (n) produces non-motile **spermatia** (male gametes) in spermatangial branches.

2. The female gametophyte (n) bears a **carpogonium** with a long **trichogyne**; a spermatium adheres to the trichogyne and transfers its nucleus.

3. The fertilised nucleus (2n) is passed, in the Florideophyceae, to an **auxiliary cell**, which forms **gonimoblast filaments** (the carposporophyte, 2n, remaining on the female plant, enclosed in a **cystocarp**/pericarp).

4. Each gonimoblast terminal cell becomes a carposporangium releasing one **carpospore** (2n, mitotic).

5. The carpospore germinates into the free-living **tetrasporophyte** (2n), identical to the gametophyte.

6. Tetrasporangia undergo meiosis, forming four **tetraspores** (n), usually arranged tetrahedrally (the source of the term "tetrahedral tetraspores"); tetraspores germinate into gametophytes.

Because one fertilisation can yield thousands of carpospores, the carposporophyte amplifies each zygote.

Batrachospermum (freshwater; a beaded blue-green-red filament), Porphyra/Pyropia (nori; a conchocelis phase is the diploid filamentous sporophyte), Gelidium and Gracilaria (**agar** sources: agarophytes), Chondrus crispus, Kappaphycus alvarezii and Eucheuma (**carrageenan** sources: carrageenophytes), and Palmaria/dulse are the usual type organisms.

Table 6. Reading algal-group statements at speed

Statement	True or false	Why
Red algae form planogametes	False	No flagella; spermatia are non-motile
Carpospores are haploid megaspores	False	Diploid mitospores from the carposporophyte
Agar is obtained from Gelidium	True	Red alga
Brown algae supply agar	False	They supply alginate, mannitol and iodine
Diatoms are haplontic	False	Diplontic (gametic meiosis)
Chara oogonium is enclosed by five spiral tube cells	True	And the coronula has five cells in Chara
Vaucheria stores starch	False	Oil (and leucosin)
Euglena has a cellulose wall	False	Pellicle

3.8 Economic and ecological importance of algae

• **Primary production and oxygen:** phytoplankton (cyanobacteria, diatoms, dinoflagellates, haptophytes, green algae) account for roughly half of global net primary production, about 45–50 percent, though by biomass they are far less than land plants.

• **Food and feed:** Spirulina, Chlorella, Porphyra (nori), Laminaria/Saccharina (kombu), Undaria (wakame), Caulerpa, Ulva.

• **Phycocolloids:** agar (Gelidium, Gracilaria; bacteriology, tissue culture, pharmaceutics), carrageenan (Kappaphycus, Chondrus; dairy, desserts), alginate (kelps, Ascophyllum; textile printing, dental impressions, wound dressings).
• **Fuels and bioremediation:** lipid-rich microalgae (Botryococcus, Chlorella, Nannochloropsis) for biodiesel and bioethanol research; algae and cyanobacteria remove N and P from wastewater and take up metals.
• **Biofertilisers:** nitrogen-fixing cyanobacteria and Azolla–Anabaena in rice.
• **Harm:** eutrophication, harmful algal blooms, toxins, biofouling, algal-induced oxygen depletion.

Chapter 4. Algal Cell Biology and Physiology

This chapter deepens Chapters 2 and 3 with the mechanisms that CSIR-NET and GATE questions probe: how light is harvested, how carbon dioxide is concentrated, how nitrogen is fixed, and how algae defend themselves chemically. Read it after the group tables, because every mechanism below is tied to a group.

4.1 Light harvesting: antennae, phycobilisomes and photoprotection

Every algal group uses chlorophyll a in the reaction centres but differs in the antenna that delivers energy to them. The antenna is the diagnostic character behind the pigment table of Chapter 2.

Table 7. Light-harvesting systems of algal groups

Group	Antenna system	Location and notes
Cyanobacteria, red algae, glaucophytes	**Phycobilisome**: phycobiliproteins with covalently bound open-chain tetrapyrroles	Attached to the stromal (cytoplasmic) face of unstacked thylakoids; red-algal photosystem II has no membrane antenna of its own
Cryptophytes	Phycobiliproteins (phycoerythrin or phycocyanin)	Free in the thylakoid **lumen**, not in phycobilisomes
Green algae and land plants	LHC proteins binding Chl a, Chl b, lutein	Integral to stacked or appressed thylakoids
Brown algae, diatoms, golden algae	**FCP** (fucoxanthin–chlorophyll a/c protein)	Thylakoids in stacks of three
Dinoflagellates	**PCP** (peridinin–chlorophyll a protein, water-soluble, in the lumen) and membrane-bound LHCs	Peridinin gives the golden-brown colour

A **phycobilisome** of the hemidiscoidal type has a core of **allophycocyanin** (APC, absorption maximum ≈ 650 nm) from which radiate rods of **phycocyanin** (PC, ≈ 620 nm) and, in red algae and some cyanobacteria, **phycoerythrin** (PE, ≈ 565 nm) at the distal ends. Linker polypeptides position the discs, and a core-membrane linker anchors the core to the thylakoid next to photosystem II.

Energy passes **downhill** along the rod: PE → PC → APC → terminal emitter (≈ 680 nm) → Chl a of the reaction centre, with transfer efficiencies above 90 percent. The chromophores are **phycoerythrobilin**, **phycocyanobilin** and related bilins, bound to cysteine residues of the apoprotein by thioether bonds; they are ring-opened tetrapyrroles without a central metal atom (unlike chlorophyll, which has Mg).

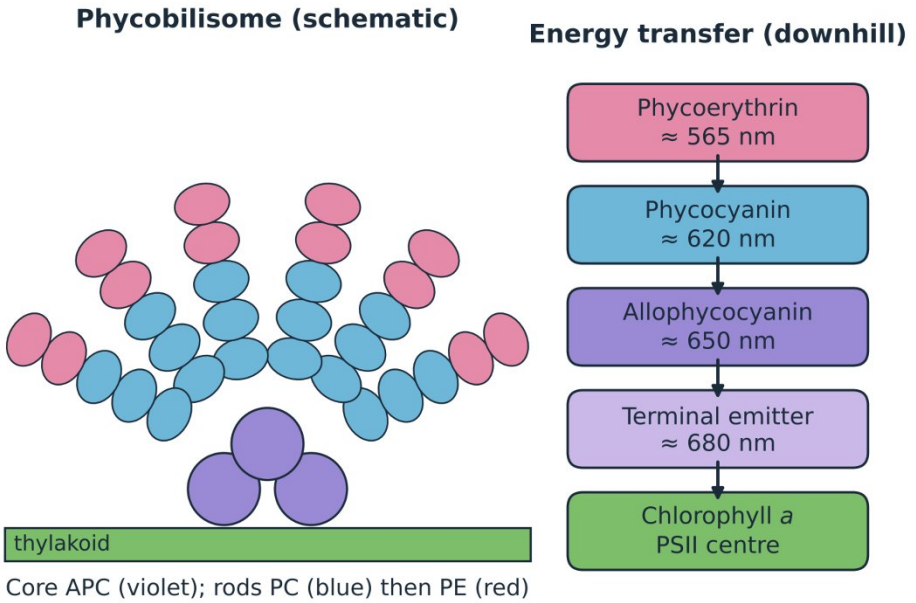


Figure 7. Phycobilisome (left) and the energy cascade it drives (right). Each step moves energy to a pigment that absorbs at a longer wavelength.

Complementary chromatic adaptation. Some cyanobacteria alter the PE : PC ratio with the colour of the light: more PE (cells look red) in green light, more PC (blue-green) in red light.

Photoprotection. Excess light is dissipated as heat by non-photochemical quenching (NPQ). Three exam-relevant mechanisms: (i)