**Chlorarachniophyta**

- These algae (Fig. 1) represent an intermediate stage in the evolution of two membranes of chloroplast endoplasmic reticulum.
- This group has a small number of green amoebae that have ingested green algal cells in the past, with the green algal cells evolving into endosymbionts within the amoeba host (Fig. 3).

Fig. 1 Examples of algae in the Chlorarachniophyta.

- *Chlorarachnion reptans* is a marine amoeba that forms large plasmodia with the individual cells linked by a network of reticulopodia or filopodia.
- *Chlorarachnion* means "green spider" for the web-like network of reticulopodia (pseudopodia) in which are embedded the green amoeboid cells.
- The cells are naked and contain a number of lobed chloroplasts, each with a central pyrenoid (Fig. 3) and has a nucleomorph.
- A vesicle containing the storage product carbohydrate, paramylon (β-1,3-glucan) caps the pyrenoid.
- The cells move over the reticulopodia and ingest other algal cells and bacteria as a food source.

Fig. 3 Semidiagrammatic drawing of the cell structure of *Chlorarachnion reptans*.

- Asexual reproduction is carried out by either normal mitotic cell division or zoospore formation.
- Under nutrient deprivation, the star-shaped vegetative cells become resting cells by retracting their reticulopodia, rounding up and secreting a thin cell wall.
- The resting cells apparently rely principally on photosynthate from the chloroplasts as a food source.
- The resting cells germinate to star-shaped vegetative cells by retracting their reticulopodia, rounding up and secreting a thin cell wall.
- The zoospores settle to produce the star-shaped vegetative cells.
- Sexual reproduction characterized by heterogamy and occurs when a non-motile female gamete is approached by a motile, star-shaped, male gamete.
- The gametes fuse producing a zygote that germinates into a star-shaped vegetative cell.

Fig. 4 *Chlorarachnion reptans*.

**Cryptophyta**

- The chloroplast (e.g., endosymbiont chloroplast) contains chlorophylls a and b and xanthophylls.
- The chloroplast is surrounded by four membranes, the innermost two membranes are those of the chloroplast envelope of the endosymbiont. The next membrane is the plasma membrane of the endosymbiont and the outer membrane represents the food-vacuole membrane of the amoeba host.
- A nucleomorph or reduced nucleus is present between the second and third envelope of each chloroplast.
- The origin of this organelle is different from the origin of the cryptophytes nucleomorph, because the chlorarachniophytes originated from a green algal endosymbiont.
- The reduced nature of the nucleomorph implies that some of the functions originally coded by the DNA of the endosymbiont nucleus have been taken over by the nucleus of the host amoeba.

Fig. 3 Semidiagrammatic drawing of the cell structure of *Chlorarachnion reptans*.

- Asexual reproduction is carried out by either normal mitotic cell division or zoospores formation.
- Under nutrient deprivation, the star-shaped vegetative cells become resting cells by retracting their reticulopodia, rounding up and secreting a thin cell wall.
- The resting cells apparently rely principally on photosynthate from the chloroplasts as a food source.
- The resting cells germinate to star-shaped vegetative cells by retracting their reticulopodia, rounding up and secreting a thin cell wall.
- The zoospores settle to produce the star-shaped vegetative cells.
- Sexual reproduction characterized by heterogamy and occurs when a non-motile female gamete is approached by a motile, star-shaped, male gamete.
- The gametes fuse producing a zygote that germinates into a star-shaped vegetative cell.

Fig. 4 *Chlorarachnion reptans*. 

**Prymnesiophyta (Haptophyta)**

- The origin of this organelle is different from the origin of the cryptophytes nucleomorph, because the chlorarachniophytes originated from a green algal endosymbiont.
- The reduced nature of the nucleomorph implies that some of the functions originally coded by the DNA of the endosymbiont nucleus have been taken over by the nucleus of the host amoeba.

Fig. 3 Semidiagrammatic drawing of the cell structure of *Chlorarachnion reptans*.
There are two apically or laterally attached flagella at the base of a depression.

- Each flagellum is approximately the same length as the body of the cell.
- Depending on the species, there are one or two rows of microtubular hairs attached to the flagellum.
- Small, organic scales (Fig. 9.2) are common on the flagellar surface and sometimes on the cell body.
- The Corps de Maupas (CM) is a large vesicular structure in the anterior portion of the cell. Its main function is probably that of disposing of unwanted protoplasmic structures by digestion.

- The chloroplast most likely evolved from a symbiosis between phagocytic organism and a red alga.
- The chloroplast is surrounded by two membranes of chloroplast endoplasmic reticulum and the two membranes of the chloroplast envelope.
- Between the outer pair of membranes and the inner pair of membranes of the chloroplast endoplasmic reticulum (periplastidal space) are starch grains and a nucleomorph, probably the remainder of the nucleus of the endosymbiont in the event that led to chloroplast E.R.
- The nucleomorph contains three minute paired-chromosomes with 531 genes that encode 38 proteins targeted into the chloroplast.
- The nucleomorph is surrounded by an envelope that has pores similar to those in a nuclear envelope.
- The cryptophytes are the only algae that form their storage product in the periplastidal space.
- The starch is an α-1,4-glucan composed of about 30% amylose and amylpectin.
- Cryptophycean starch is similar to potato starch and dinoflagellates.
- Sometimes an eyespot formed by spherical globules is present inside the plastid.

- The asymmetric cell shape results in a peculiar swaying motion during swimming.
- The cell body is asymmetric with a clearly defined dorsiventrally construction.
- The primary method of reproduction is simply by longitudinal cell division, but sexual reproduction has recently been documented.

• Both sizes of ejectisomes have the same structure; they are made up of two unequal-sized bodies enclosed within a single membrane (Fig. 9.5).
• The discharge of the ejectisome results in a movement of the organism in the opposite direction. The discharge of the ejectisome could function as an escape mechanism, or it could be a direct defense mechanism causing damage to an offending organism.

- In the chloroplast, the thylakoids are grouped in pairs (Fig. 9.3), and there are no connections between adjacent thylakoids. The Cryptophyta is the only group to have this arrangement of thylakoids.
- Chlorophylls a and c₅ are present.
- The major carotenoid present is α-carotene, and the major xanthophyll, diatoxanthin.
- Phycoerythrins are present in the thylakoid lumen rather than in phycobilisomes on the stromal side of the thylakoids as occurs in the cyanobacteria and red algae.
- Each photosynthetic cryptophyte has only one species of phycobiliprotein – either α phycoerythrin or a phycocyanin – but never both.
- No allophycocyanin is present.
In comparison with other algal groups, the Cryptophyta appear to be especially light sensitive, often forming the deepest living populations in clear oligotrophic lakes. Because of the low light intensity under snow and ice cover, these algae concentrate in surface waters to receive sufficient light for photosynthesis. Survival at these extremely low light levels depends not only on a highly efficient photosynthetic system, but also on
- slow rates of cell respiration at low water temperatures and
- reduced winter zooplankton grazing.

In spring, with the disappearance of snow and resulting sudden increase in light in Arctic and mountain lakes, cryptomonads suffer considerable light stress, such that the algal populations move to deeper waters.

Cryptophytes will often undergo diel vertical migrations with an amplitude less than 5 meters.

In small humic forest lakes, species of Cryptomonas are positively phototactic in the morning, moving into the phosphorus-depleted upper layer. Later in the day the cells move away from the uppermost water layer, avoiding high levels of irradiance, and move into the phosphorus-rich hypolimnion. A further advantage of this cycle is the reduction of grazing pressure by zooplankton (for which cryptophytes are a preferred food) which often migrate in the reverse direction.

Cryptophyte algae are mixotrophic, capable of phototrophy and phagotrophy. Phagocytic ingestion of bacteria is thought primarily to provide a source of phosphorus and nitrogen in nutrient limiting conditions. These algae are also chemotactic, swimming in a straight line until they reach a patch of high-nutrient concentration.

Cryptophytes are the dominant algae in the freshwater lakes of Antarctica. The lakes are fed by glacial melt streams that flow for 6–10 weeks during the brief austral (southern) summer. Cryptophytes dominate the lower stratified levels where they live heterotrophically during winter months, taking up about one bacterium per hour by phagocytosis. During the summer months, the cryptophytes are mixotrophic (combining heterotrophy and autotrophy by photosynthesis). A key to the survival of cryptophytes in this environment is maintaining the population in the vegetative state, rather than entering a resting state. The cryptophyte population can respond quickly when "good" conditions return in the short Antarctic summer.

Cryptophyte algae are mixotrophic, capable of phototrophy and phagotrophy. Phagocytic ingestion of bacteria is thought primarily to provide a source of phosphorus and nitrogen in nutrient limiting conditions. These algae are also chemotactic, swimming in a straight line until they reach a patch of high-nutrient concentration.

Cryptophytes are the dominant algae in the freshwater lakes of Antarctica. The lakes are fed by glacial melt streams that flow for 6–10 weeks during the brief austral (southern) summer. Cryptophytes dominate the lower stratified levels where they live heterotrophically during winter months, taking up about one bacterium per hour by phagocytosis. During the summer months, the cryptophytes are mixotrophic (combining heterotrophy and autotrophy by photosynthesis). A key to the survival of cryptophytes in this environment is maintaining the population in the vegetative state, rather than entering a resting state. The cryptophyte population can respond quickly when "good" conditions return in the short Antarctic summer.

Cryptophyte algae are mixotrophic, capable of phototrophy and phagotrophy. Phagocytic ingestion of bacteria is thought primarily to provide a source of phosphorus and nitrogen in nutrient limiting conditions. These algae are also chemotactic, swimming in a straight line until they reach a patch of high-nutrient concentration.

Cryptophytes are the dominant algae in the freshwater lakes of Antarctica. The lakes are fed by glacial melt streams that flow for 6–10 weeks during the brief austral (southern) summer. Cryptophytes dominate the lower stratified levels where they live heterotrophically during winter months, taking up about one bacterium per hour by phagocytosis. During the summer months, the cryptophytes are mixotrophic (combining heterotrophy and autotrophy by photosynthesis). A key to the survival of cryptophytes in this environment is maintaining the population in the vegetative state, rather than entering a resting state. The cryptophyte population can respond quickly when "good" conditions return in the short Antarctic summer.

Cryptophyte algae are mixotrophic, capable of phototrophy and phagotrophy. Phagocytic ingestion of bacteria is thought primarily to provide a source of phosphorus and nitrogen in nutrient limiting conditions. These algae are also chemotactic, swimming in a straight line until they reach a patch of high-nutrient concentration.

Cryptophytes are the dominant algae in the freshwater lakes of Antarctica. The lakes are fed by glacial melt streams that flow for 6–10 weeks during the brief austral (southern) summer. Cryptophytes dominate the lower stratified levels where they live heterotrophically during winter months, taking up about one bacterium per hour by phagocytosis. During the summer months, the cryptophytes are mixotrophic (combining heterotrophy and autotrophy by photosynthesis). A key to the survival of cryptophytes in this environment is maintaining the population in the vegetative state, rather than entering a resting state. The cryptophyte population can respond quickly when "good" conditions return in the short Antarctic summer.

Cryptophyte algae are mixotrophic, capable of phototrophy and phagotrophy. Phagocytic ingestion of bacteria is thought primarily to provide a source of phosphorus and nitrogen in nutrient limiting conditions. These algae are also chemotactic, swimming in a straight line until they reach a patch of high-nutrient concentration.

Cryptophytes are the dominant algae in the freshwater lakes of Antarctica. The lakes are fed by glacial melt streams that flow for 6–10 weeks during the brief austral (southern) summer. Cryptophytes dominate the lower stratified levels where they live heterotrophically during winter months, taking up about one bacterium per hour by phagocytosis. During the summer months, the cryptophytes are mixotrophic (combining heterotrophy and autotrophy by photosynthesis). A key to the survival of cryptophytes in this environment is maintaining the population in the vegetative state, rather than entering a resting state. The cryptophyte population can respond quickly when "good" conditions return in the short Antarctic summer.

Cryptophyte algae are mixotrophic, capable of phototrophy and phagotrophy. Phagocytic ingestion of bacteria is thought primarily to provide a source of phosphorus and nitrogen in nutrient limiting conditions. These algae are also chemotactic, swimming in a straight line until they reach a patch of high-nutrient concentration.

Cryptophytes are the dominant algae in the freshwater lakes of Antarctica. The lakes are fed by glacial melt streams that flow for 6–10 weeks during the brief austral (southern) summer. Cryptophytes dominate the lower stratified levels where they live heterotrophically during winter months, taking up about one bacterium per hour by phagocytosis. During the summer months, the cryptophytes are mixotrophic (combining heterotrophy and autotrophy by photosynthesis). A key to the survival of cryptophytes in this environment is maintaining the population in the vegetative state, rather than entering a resting state. The cryptophyte population can respond quickly when "good" conditions return in the short Antarctic summer.

Cryptophyte algae are mixotrophic, capable of phototrophy and phagotrophy. Phagocytic ingestion of bacteria is thought primarily to provide a source of phosphorus and nitrogen in nutrient limiting conditions. These algae are also chemotactic, swimming in a straight line until they reach a patch of high-nutrient concentration.

Cryptophytes are the dominant algae in the freshwater lakes of Antarctica. The lakes are fed by glacial melt streams that flow for 6–10 weeks during the brief austral (southern) summer. Cryptophytes dominate the lower stratified levels where they live heterotrophically during winter months, taking up about one bacterium per hour by phagocytosis. During the summer months, the cryptophytes are mixotrophic (combining heterotrophy and autotrophy by photosynthesis). A key to the survival of cryptophytes in this environment is maintaining the population in the vegetative state, rather than entering a resting state. The cryptophyte population can respond quickly when "good" conditions return in the short Antarctic summer.

Cryptophyte algae are mixotrophic, capable of phototrophy and phagotrophy. Phagocytic ingestion of bacteria is thought primarily to provide a source of phosphorus and nitrogen in nutrient limiting conditions. These algae are also chemotactic, swimming in a straight line until they reach a patch of high-nutrient concentration.

Cryptophytes are the dominant algae in the freshwater lakes of Antarctica. The lakes are fed by glacial melt streams that flow for 6–10 weeks during the brief austral (southern) summer. Cryptophytes dominate the lower stratified levels where they live heterotrophically during winter months, taking up about one bacterium per hour by phagocytosis. During the summer months, the cryptophytes are mixotrophic (combining heterotrophy and autotrophy by photosynthesis). A key to the survival of cryptophytes in this environment is maintaining the population in the vegetative state, rather than entering a resting state. The cryptophyte population can respond quickly when "good" conditions return in the short Antarctic summer.

Cryptophyte algae are mixotrophic, capable of phototrophy and phagotrophy. Phagocytic ingestion of bacteria is thought primarily to provide a source of phosphorus and nitrogen in nutrient limiting conditions. These algae are also chemotactic, swimming in a straight line until they reach a patch of high-nutrient concentration.

Cryptophytes are the dominant algae in the freshwater lakes of Antarctica. The lakes are fed by glacial melt streams that flow for 6–10 weeks during the brief austral (southern) summer. Cryptophytes dominate the lower stratified levels where they live heterotrophically during winter months, taking up about one bacterium per hour by phagocytosis. During the summer months, the cryptophytes are mixotrophic (combining heterotrophy and autotrophy by photosynthesis). A key to the survival of cryptophytes in this environment is maintaining the population in the vegetative state, rather than entering a resting state. The cryptophyte population can respond quickly when "good" conditions return in the short Antarctic summer.

Cryptophyte algae are mixotrophic, capable of phototrophy and phagotrophy. Phagocytic ingestion of bacteria is thought primarily to provide a source of phosphorus and nitrogen in nutrient limiting conditions. These algae are also chemotactic, swimming in a straight line until they reach a patch of high-nutrient concentration.

Cryptophytes are the dominant algae in the freshwater lakes of Antarctica. The lakes are fed by glacial melt streams that flow for 6–10 weeks during the brief austral (southern) summer. Cryptophytes dominate the lower stratified levels where they live heterotrophically during winter months, taking up about one bacterium per hour by phagocytosis. During the summer months, the cryptophytes are mixotrophic (combining heterotrophy and autotrophy by photosynthesis). A key to the survival of cryptophytes in this environment is maintaining the population in the vegetative state, rather than entering a resting state. The cryptophyte population can respond quickly when "good" conditions return in the short Antarctic summer.

Cryptophyte algae are mixotrophic, capable of phototrophy and phagotrophy. Phagocytic ingestion of bacteria is thought primarily to provide a source of phosphorus and nitrogen in nutrient limiting conditions. These algae are also chemotactic, swimming in a straight line until they reach a patch of high-nutrient concentration.

Cryptophytes are the dominant algae in the freshwater lakes of Antarctica. The lakes are fed by glacial melt streams that flow for 6–10 weeks during the brief austral (southern) summer. Cryptophytes dominate the lower stratified levels where they live heterotrophically during winter months, taking up about one bacterium per hour by phagocytosis. During the summer months, the cryptophytes are mixotrophic (combining heterotrophy and autotrophy by photosynthesis). A key to the survival of cryptophytes in this environment is maintaining the population in the vegetative state, rather than entering a resting state. The cryptophyte population can respond quickly when "good" conditions return in the short Antarctic summer.
The Prymnesiophyta are a group of uninucleate flagellates characterized by the presence of a haptonema between two smooth flagella. The Prymnesiophyta have two membranes of chloroplast endoplasmic reticulum, as do the Cryptophyta and the Heterokontophyta, but differ in having flagella without mastigonemes. Molecular data also show that the Prymnesiophyta are distinct from the Cryptophyta and Heterokontophyta. The name Haptophyta (named after the presence of the haptonema) was a descriptive name and not based on a genus in the class; thus the name was changed to Prymnesiophyceae, based on the genus Prymnesium (Fig. 22.7). The fossil record of the Prymnesiophyceae is known from the Carboniferous (approximately 300,000,000 years ago).

The Prymnesiophyceae are primarily marine organisms, although there are some freshwater representatives. They make up a major part of the marine nannoplankton and constitute about 45% of the total phytoplankton cells in the middle latitudes of the South Atlantic. They decrease in frequency toward the poles although some still occur in polar waters.

During swimming, the flagellar end of the cell can be forward with the flagella sweeping outward and backward down the sides of the body (Fig. 22.3(a)), or the flagellar end may be directed backward (Fig. 22.3(b)). Movement is usually rapid, the cells swimming only for a short distance in one direction, after which they rapidly change the position of the flagella and move off in the opposite direction. In Pavlova (Fig. 22.3(b)), the flagellar action is a little different, with the longer flagellum directed forward and the shorter flagellum trailing or directed outward.

The cells are commonly covered with scales. In many cases, the scales are calcified, thereby producing coccoliths. The chloroplasts lack girdle lamellae and most contain chlorophylls a and c1/c2, β-carotene, diadinoxanthin, and diatoxanthin. The storage product is chrysolaminarin (leucosin) in vesicles in the posterior end of the cell. The anterior end of the cell has a large Golgi apparatus and sometimes a contractile vacuole.

Cell structure
Flagella
Most of the Prymnesiophyceae have two smooth flagella of approximately the same length (Figs. 22.1, 22.3(a)). The Pavlovales is the exception, where one flagellum is longer than the other and is usually covered by small scales (Fig. 22.3(b)). There is usually no flagellar swelling associated with an eyespot.

Fig. 22.1 A light and electron microscopical drawing of a cell of a typical member of the Prymnesiophyceae, Chrysochromulina sp. A rapidly swimming individual is shown, with the arrow indicating the direction of movement. (C) Chloroplast; (CE) chloroplast envelope; (CER) chloroplast endoplasmic reticulum; (C) chrysolaminarin vesicle; (F) flagellum; (FR) flagellar root; (G) Golgi body; (H) haptonema; (M) mitochondrion; (MB) muciferous body; (N) nucleus; (S) scale.

Fig. 22.3 Pavlova mesolychnon. (a) Cell with flagella in position for swimming with flagellar pole forward. (b) Cell swimming with flagellar pole to the rear. (f) Flagellum; (h) haptonema; (l) leucosin vesicle; (m) muciferous body; (n) nucleus; (s) scale.
• The microtubules in the haptonema slide, relative to one another to produce two basic movements, coiling and bending:

1. **Coiling** is a sensory response to obstacles. The haptonema coils instantly when forward-swimming cells encounter obstacles.
2. The flagella are thrown backward and generate propulsive forces, resulting in backward swimming.

**Haptonema**
- A haptonema is a filamentous appendage arising near the flagella but thinner and with different properties and structure.
- The haptonema ranges from a reduced haptonema to a short bulbous structure to the 80-µm-long whip-like structure.
- In transverse sections the haptonema is composed of three concentric membranes surrounding a core containing seven microtubules.
- The haptonema is commonly covered with external scales of varying degree of complexity.

**Chloroplasts**
- Usually there are two elongate discoid chloroplasts in each cell.
- Each chloroplast is surrounded by four membranes: the two membranes of the chloroplast envelope, and outside of them the two membranes of the chloroplast E.R.
- The thylakoids are aggregated into bands of three.
- A pyrenoid is commonly present in the center of the chloroplast or as a bulge to one side.
- Eyespots are not common in the Prymnesiophyceae although Pavlova has an eyespot, which consists of a group of lipid droplets inside the anterior end of a chloroplast.

**Phaeocystis globosa** has vesicles that contain tightly-wound filaments of chitin. Each vesicle contains five chitin filaments that attach near the base of another chitin filament (Fig. 22.9). The chitin filaments produce a five-sided star at their base when they are released from their vesicles.

**Muciferous bodies**
- Two types of membrane-bounded vesicles are in the cytoplasm, the first containing lipids and the second the storage product.
- The storage product is usually stated as being chrysolaminarin (leucosin), although in a study of Pavlova mesolychnon it was found that one of the storage products present in the cells was a β-1,3 linked glucan similar to paramylon in the Euglenophyceae.

**Other cytoplasmic structures**
- Two types of membrane-bound vesicles are in the cytoplasm, the first containing lipids and the second the storage product.
- The function of muciferous bodies is not known.
Like many of the other algal groups, the Prymnesiophyceae participate in symbiotic events. Radiolarians can harbor prymnesiophyte algal symbionts. The symbionts are held in the rhizopodial network surrounding the central capsule of the radiolarian.

The algal symbionts fix carbon dioxide, and some of the photosynthetic process passes to the radiolarian.

There is a diurnal rhythm in the production of scales. The greatest production of scales is in the late afternoon with the least in the early morning hours. The time of nuclear division is the reverse, with the most mitotic figures appearing in the early morning.

Even in the non-motile filamentous stages of the Prymnesiophyceae, the cell wall is composed of scales embedded in a gelatinous matrix.

There is a diurnal rhythm in the production of scales. The greatest production of scales is in the late afternoon with the least in the early morning hours. The time of nuclear division is the reverse, with the most mitotic figures appearing in the early morning.

Even in the non-motile filamentous stages of the Prymnesiophyceae, the cell wall is composed of scales embedded in a gelatinous matrix.

Coccoliths are calcified scales of the Prymnesiophyceae. The coccoliths have been suggested to serve as a grazing deterrent, to help maintain buoyancy and to act as an ultra-violet radiation filter. Coccoliths are basically organic scales that have calcium carbonate (CaCO₃) deposited on one surface in a characteristic pattern depending on the species of the alga. In coccoliths the form of CaCO₃ is usually calcite (rhombohedral), not of aragonite type (orthorhombic).

The coccoliths of *Emiliania huxleyi* are composed of a number of hollow crystals of calcite arranged around the periphery of a plate scale. Each coccolith consists of an upper and lower shield joined by a tube. The tube and the shields are composed of subunits.
There are two very different types of coccoliths are formed by these algae: heterococcoliths and holococcoliths. In Heterococcoliths, coccolith are formed of morphologically complex and diverse CaCO$_3$ elements of variable shape and size. Crystal units typically arranged in cycles with radial symmetry (Figs. 22.12, 22.14, 22.16). In Holococcoliths, coccolith are formed of numerous minute (<0.1 µm) calcite crystals (Fig. 22.15) all of similar shape and size (often rhombohedral). Crystal units typically arranged in continuous arrays. The two coccolith types were originally thought to be produced by different families of coccolithophores. Now, however, it is known that the two coccolith types are produced by the same species but at different life cycle phases. Heterococcoliths are produced in the diploid life-cycle phase and holococcoliths in the haploid phase. The base plates of heterococcoliths are produced in Golgi cisternae followed by calcification in the same cisternae. These base plates are discharged outside the cell where calcification occurs within an outer vestment. In Holococcoliths, coccolith are formed of numerous minute (<0.1 µm) calcite crystals, but other crystalline units are also in an outer vestment. These base plates are discharged outside the cell where calcification occurs within an outer vestment.

The abundance of coccolithophorids in these chalks can be demonstrated by taking a piece of ordinary blackboard chalk, pulverizing it, mixing it with distilled water in a test tube, and letting it stand for 20 minutes. Draw some of the solution into a pipette, dispose of the first four to five drops, and place the next few drops on a slide. Place a cover slip on the slide, and view it at a magnification of 400 to 500. Many coccoliths and other remains will be seen. Although coccolithophorids constitute a minor part of recent calcareous ooze (bottom sediments composed of calcified remains of organisms) in the ocean, in the Cretaceous they dominated the calcareous nanoplankton. This domination paralleled an increase in Ca$^{2+}$ in seawater at the time. Coccolithophorids provided the major constituent of Mesozoic (Jurassic and Cretaceous) and Tertiary chalks and marls. The abundance of coccolithophores in these chalks can be demonstrated by taking a piece of ordinary blackboard chalk, pulverizing it, mixing it with distilled water in a test tube, and letting it stand for 20 minutes. Draw some of the solution into a pipette, dispose of the first four to five drops, and place the next few drops on a slide. Place a cover slip on the slide, and view it at a magnification of 400 to 500. Many coccoliths and other remains will be seen.

The calcification reaction is:

\[ 2\text{HCO}_3^- + \text{Ca}^{2+} \rightarrow \text{CaCO}_3 + \text{CO}_2 + \text{H}_2\text{O} \]

Carbon dioxide is released in calcification, and this may make coccolithophorids more competitive by increasing the amount of CO$_2$ available for photosynthesis inside the cell. The membrane of the coccolith vesicle contains an H$_2$-ATPase that pumps H$^+$ out of the coccolith vesicle, removing protons produced during dehydration of bicarbonate and increasing the rate of calcification. The membrane of the coccolith vesicle contains an H$_2$-ATPase that pumps H$^+$ out of the coccolith vesicle, removing protons produced during dehydration of bicarbonate and increasing the rate of calcification.

The coccolithophorids (algae with coccoliths) are common in tropical waters because these warm waters have - a low partial pressure of carbon dioxide and - are usually saturated or supersaturated with calcium carbonate, the concentrations being especially high in the upper layers. Supersaturation of calcium carbonate is favorable for the formation of coccoliths, and the distribution of coccolithophorids shows a close correlation with the degree of saturation of seawater by calcium carbonate. In the seas of polar regions, the degree of saturation does not even reach 90%.

The external coccoliths can be removed by lowering the pH of the culture medium. Decalcified cells may acquire a complete coccolith envelope (i.e. recalcified) when transferred back to a normal medium in the light. A photochemical process is directly associated with coccolith production. In some species there is a sharp drop in coccolith production when light is turned off. Throughout a 16-hour light : 8-hour dark cycle, Pleurochrysis carterae form coccoliths in the light as well as in the dark at a similar rate. The cells divide during the dark periods with a concomitant decrease in cell size during the dark period followed by an increase in cell size during the light period.

The coccolithophorids are detached from cells in layers at the same time as other coccoliths are produced. During logarithmic growth, about the same number of coccoliths are detached as are produced. In stationary growth, however, the rate of coccolith detachment increases about threefold, while coccolith production drops off. Coccolithophorids have greater rates of calcification when nitrogen and phosphorus are limiting in the seawater.

Two to seven coccoliths are produced per day by E. huxleyi. Coccoliths are detached from cells in layers at the same time as other coccoliths are produced. During logarithmic growth, about the same number of coccoliths are detached as are produced. In stationary growth, however, the rate of coccolith detachment increases about threefold, while coccolith production drops off. Coccolithophorids have greater rates of calcification when nitrogen and phosphorus are limiting in the seawater.

The coccolithophorids are detached from cells in layers at the same time as other coccoliths are produced. During logarithmic growth, about the same number of coccoliths are detached as are produced. In stationary growth, however, the rate of coccolith detachment increases about threefold, while coccolith production drops off. Coccolithophorids have greater rates of calcification when nitrogen and phosphorus are limiting in the seawater.

The coccolithophorids are detached from cells in layers at the same time as other coccoliths are produced. During logarithmic growth, about the same number of coccoliths are detached as are produced. In stationary growth, however, the rate of coccolith detachment increases about threefold, while coccolith production drops off. Coccolithophorids have greater rates of calcification when nitrogen and phosphorus are limiting in the seawater.

The coccolithophorids are detached from cells in layers at the same time as other coccoliths are produced. During logarithmic growth, about the same number of coccoliths are detached as are produced. In stationary growth, however, the rate of coccolith detachment increases about threefold, while coccolith production drops off. Coccolithophorids have greater rates of calcification when nitrogen and phosphorus are limiting in the seawater.
Coccoliths in sedimentary rocks can be used as markers in the discovery and mode of deposition of oil deposits.

For example, the oil shales of the Kimmeridge Clays in England are sandwiched between limestone bands that are composed mostly of coccoliths of one species, *Ellipsagelosphaera britannica*.

Other oil-bearing rocks have similar characteristic coccoliths.

Therefore petroleum geologists know that when a drill core shows certain coccoliths that are associated with petroleum, there is a good chance of finding oil in that stratum of rock.

---

The prymnesiophycean alga *Prymnesium parvum* (golden algae) secretes the potent exotoxin *prymnesin*.

The toxin causes fish mortalities by increasing cell membrane permeability of gills of fish and molluscs, disturbing cellular ion balance in gill-breathing animals.

Experiments have shown that the toxin affect the permeability of the gill, resulting in the increased sensitivity of the fish.

If fish removed promptly from such toxin solutions, the gill damage is repaired within hours.

It is possible to control *P. parvum* in fish ponds by adding small amounts of ammonium salt, which causes the algal cells to lyse.

---

Some species of *Chrysochromulina* produce toxins that kill fish, mussels, and ascidians.

The large blooms of *Chrysochromulina* causing the fish kills have been associated with a lack of predation by the normal ciliate grazers of *Chrysochromulina*.

It appears that the long spines on the surface of the *Chrysochromulina* cells make them too large to be taken up by the ciliates.

---

In the North Sea of Europe, and in the seas off Antarctica, blooms of the prymnesiophyte *Phaeocystis* occur as macroscopic lobed colonies or "bladders" in the spring and fall.

*Phaeocystis* colonies are hollow, balloonlike structures with individual cells lying beneath a thin mucous skin.

Cells in colonies are round, lacking flagella, haptonema and scales.

Grazing by invertebrates results in colonies of larger size, the larger size induced by chemicals released into the water by the grazing.

Colonization formation and enlargement is a defense mechanism that results in clogging of the filtration apparatus of the grazers.

---

*Phaeocystis* produces large amounts of acrylic acid which has a strong bactericidal action capable of inhibiting the microbially mediated digestion in the guts of consumers (e.g. marine birds) and could induce future avoidance of the alga.

*Phaeocystis* secretes 16% to 64% of the carbon assimilated in photosynthesis as polysaccharides of varying molecular weight.

*Phaeocystis* produces about 10% of global DMS (dimethylsulfide).

During dense blooms, foam accumulates on the beaches because wave action destroys the cells and wipes the cells' proteins to foam.

Toxicity is not reported from such blooms, but fish avoids blooms, probably by detection of the DMS in the water.

In the North Sea, herring avoid the ocean areas where there are *Phaeocystis*'s blooms because of its unpalatability to the fish.

Fisheries are affected by net clogging.
**Classification**
The Prymnesiophyceae can be divided into two orders:
- Order 1 Prymnesiales: cells with two equal smooth flagella, no eyespot, scales commonly covering the cell body.
- Order 2 Pavlovales: cells with two unequal flagella often covered with hairs and deposits, eyespots may be present.

---

**Prymnesiales**
- *Emiliania huxleyi* is typical of the order with motile cells that have two flagella.
- The life cycle of *E. huxleyi* probably involves a diploid, non-motile phase with coccoliths, which alternates with a haploid phase that has scales but no coccoliths.

---

**Classification**
The Prymnesiophyceae can be divided into two orders:
- Order 1 Prymnesiales: cells with two equal smooth flagella, no eyespot, scales commonly covering the cell body.
- Order 2 Pavlovales: cells with two unequal flagella often covered with hairs and deposits, eyespots may be present.

---

**Prymnesiales**
- *Emiliania huxleyi* is typical of the order with motile cells that have two flagella.
- The life cycle of *E. huxleyi* probably involves a diploid, non-motile phase with coccoliths, which alternates with a haploid phase that has scales but no coccoliths.

---

**Classification**
The Prymnesiophyceae can be divided into two orders:
- Order 1 Prymnesiales: cells with two equal smooth flagella, no eyespot, scales commonly covering the cell body.
- Order 2 Pavlovales: cells with two unequal flagella often covered with hairs and deposits, eyespots may be present.

---

**Prymnesiales**
- *Emiliania huxleyi* is typical of the order with motile cells that have two flagella.
- The life cycle of *E. huxleyi* probably involves a diploid, non-motile phase with coccoliths, which alternates with a haploid phase that has scales but no coccoliths.

---

**Classification**
The Prymnesiophyceae can be divided into two orders:
- Order 1 Prymnesiales: cells with two equal smooth flagella, no eyespot, scales commonly covering the cell body.
- Order 2 Pavlovales: cells with two unequal flagella often covered with hairs and deposits, eyespots may be present.

---

**Prymnesiales**
- *Emiliania huxleyi* is typical of the order with motile cells that have two flagella.
- The life cycle of *E. huxleyi* probably involves a diploid, non-motile phase with coccoliths, which alternates with a haploid phase that has scales but no coccoliths.

---

**Classification**
The Prymnesiophyceae can be divided into two orders:
- Order 1 Prymnesiales: cells with two equal smooth flagella, no eyespot, scales commonly covering the cell body.
- Order 2 Pavlovales: cells with two unequal flagella often covered with hairs and deposits, eyespots may be present.

---

**Prymnesiales**
- *Emiliania huxleyi* is typical of the order with motile cells that have two flagella.
- The life cycle of *E. huxleyi* probably involves a diploid, non-motile phase with coccoliths, which alternates with a haploid phase that has scales but no coccoliths.

---

**Classification**
The Prymnesiophyceae can be divided into two orders:
- Order 1 Prymnesiales: cells with two equal smooth flagella, no eyespot, scales commonly covering the cell body.
- Order 2 Pavlovales: cells with two unequal flagella often covered with hairs and deposits, eyespots may be present.

---

**Prymnesiales**
- *Emiliania huxleyi* is typical of the order with motile cells that have two flagella.
- The life cycle of *E. huxleyi* probably involves a diploid, non-motile phase with coccoliths, which alternates with a haploid phase that has scales but no coccoliths.

---

**Classification**
The Prymnesiophyceae can be divided into two orders:
- Order 1 Prymnesiales: cells with two equal smooth flagella, no eyespot, scales commonly covering the cell body.
- Order 2 Pavlovales: cells with two unequal flagella often covered with hairs and deposits, eyespots may be present.

---

**Prymnesiales**
- *Emiliania huxleyi* is typical of the order with motile cells that have two flagella.
- The life cycle of *E. huxleyi* probably involves a diploid, non-motile phase with coccoliths, which alternates with a haploid phase that has scales but no coccoliths.

---

**Classification**
The Prymnesiophyceae can be divided into two orders:
- Order 1 Prymnesiales: cells with two equal smooth flagella, no eyespot, scales commonly covering the cell body.
- Order 2 Pavlovales: cells with two unequal flagella often covered with hairs and deposits, eyespots may be present.

---

**Prymnesiales**
- *Emiliania huxleyi* is typical of the order with motile cells that have two flagella.
- The life cycle of *E. huxleyi* probably involves a diploid, non-motile phase with coccoliths, which alternates with a haploid phase that has scales but no coccoliths.

---

**Classification**
The Prymnesiophyceae can be divided into two orders:
- Order 1 Prymnesiales: cells with two equal smooth flagella, no eyespot, scales commonly covering the cell body.
- Order 2 Pavlovales: cells with two unequal flagella often covered with hairs and deposits, eyespots may be present.

---

**Prymnesiales**
- *Emiliania huxleyi* is typical of the order with motile cells that have two flagella.
- The life cycle of *E. huxleyi* probably involves a diploid, non-motile phase with coccoliths, which alternates with a haploid phase that has scales but no coccoliths.

---

**Classification**
The Prymnesiophyceae can be divided into two orders:
- Order 1 Prymnesiales: cells with two equal smooth flagella, no eyespot, scales commonly covering the cell body.
- Order 2 Pavlovales: cells with two unequal flagella often covered with hairs and deposits, eyespots may be present.

---

**Prymnesiales**
- *Emiliania huxleyi* is typical of the order with motile cells that have two flagella.
- The life cycle of *E. huxleyi* probably involves a diploid, non-motile phase with coccoliths, which alternates with a haploid phase that has scales but no coccoliths.

---

**Classification**
The Prymnesiophyceae can be divided into two orders:
- Order 1 Prymnesiales: cells with two equal smooth flagella, no eyespot, scales commonly covering the cell body.
- Order 2 Pavlovales: cells with two unequal flagella often covered with hairs and deposits, eyespots may be present.

---

**Prymnesiales**
- *Emiliania huxleyi* is typical of the order with motile cells that have two flagella.
- The life cycle of *E. huxleyi* probably involves a diploid, non-motile phase with coccoliths, which alternates with a haploid phase that has scales but no coccoliths.

---

**Classification**
The Prymnesiophyceae can be divided into two orders:
- Order 1 Prymnesiales: cells with two equal smooth flagella, no eyespot, scales commonly covering the cell body.
- Order 2 Pavlovales: cells with two unequal flagella often covered with hairs and deposits, eyespots may be present.

---

**Prymnesiales**
- *Emiliania huxleyi* is typical of the order with motile cells that have two flagella.
- The life cycle of *E. huxleyi* probably involves a diploid, non-motile phase with coccoliths, which alternates with a haploid phase that has scales but no coccoliths.

---

**Classification**
The Prymnesiophyceae can be divided into two orders:
- Order 1 Prymnesiales: cells with two equal smooth flagella, no eyespot, scales commonly covering the cell body.
- Order 2 Pavlovales: cells with two unequal flagella often covered with hairs and deposits, eyespots may be present.

---

**Prymnesiales**
- *Emiliania huxleyi* is typical of the order with motile cells that have two flagella.
- The life cycle of *E. huxleyi* probably involves a diploid, non-motile phase with coccoliths, which alternates with a haploid phase that has scales but no coccoliths.

---

**Classification**
The Prymnesiophyceae can be divided into two orders:
- Order 1 Prymnesiales: cells with two equal smooth flagella, no eyespot, scales commonly covering the cell body.
- Order 2 Pavlovales: cells with two unequal flagella often covered with hairs and deposits, eyespots may be present.

---

**Prymnesiales**
- *Emiliania huxleyi* is typical of the order with motile cells that have two flagella.
- The life cycle of *E. huxleyi* probably involves a diploid, non-motile phase with coccoliths, which alternates with a haploid phase that has scales but no coccoliths.

---

**Classification**
The Prymnesiophyceae can be divided into two orders:
- Order 1 Prymnesiales: cells with two equal smooth flagella, no eyespot, scales commonly covering the cell body.
- Order 2 Pavlovales: cells with two unequal flagella often covered with hairs and deposits, eyespots may be present.

---

**Prymnesiales**
- *Emiliania huxleyi* is typical of the order with motile cells that have two flagella.
- The life cycle of *E. huxleyi* probably involves a diploid, non-motile phase with coccoliths, which alternates with a haploid phase that has scales but no coccoliths.

---

**Classification**
The Prymnesiophyceae can be divided into two orders:
- Order 1 Prymnesiales: cells with two equal smooth flagella, no eyespot, scales commonly covering the cell body.
- Order 2 Pavlovales: cells with two unequal flagella often covered with hairs and deposits, eyespots may be present.

---

**Prymnesiales**
- *Emiliania huxleyi* is typical of the order with motile cells that have two flagella.
- The life cycle of *E. huxleyi* probably involves a diploid, non-motile phase with coccoliths, which alternates with a haploid phase that has scales but no coccoliths.

---

**Classification**
The Prymnesiophyceae can be divided into two orders:
- Order 1 Prymnesiales: cells with two equal smooth flagella, no eyespot, scales commonly covering the cell body.
- Order 2 Pavlovales: cells with two unequal flagella often covered with hairs and deposits, eyespots may be present.
Pavlovales

- The Pavlovales have cells with two unequal flagella with the haptonema arising between the flagella.
- In Pavlova, the two unequal flagella are attached some distance below the cell apex (Fig. 23.3(b)).
- The longer flagellum is directed forward during swimming and is covered with fine hairs and dense bodies, whereas the short flagellum projects outward and can have fibrillar hairs on it.
- The flagella and haptonema are attached at the bottom of a depression.
- A pit (P) or canal passes from the bottom of the depression, under the base of the long flagellum, and terminates at the inner face of the eyespot (E).
- The shape of the cells is variable, and there is a single two-lobed chloroplast with a pyrenoid.
- No sexual reproduction is known, and the cells propagate by longitudinal division.
- The algae in the Pavlovales have unusual sterols with two hydroxyl groups called pavlovals.

<table>
<thead>
<tr>
<th>Economic importance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Haptophytes are economically important as Pavlova lutheri and Isochrysis sp. are widely used in the aquaculture industries.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 4: Commercial dinoflagellates and its applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Species</td>
</tr>
<tr>
<td>-----------------</td>
</tr>
<tr>
<td>Pavlova</td>
</tr>
<tr>
<td>Pavlova mesoephyta</td>
</tr>
<tr>
<td>Pavlova granifera</td>
</tr>
</tbody>
</table>

- (DHA) Docosahexaenoic acid
- (EPA) Eicosapentaenoic acid

**Economic importance**

- Haptophytes are economically important as Pavlova lutheri and Isochrysis sp. are widely used in the aquaculture industries.

**Table 4: Commercial dinoflagellates and its applications**

<table>
<thead>
<tr>
<th>Species</th>
<th>Morphology</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pavlova</td>
<td>Small prostrate flagellate, with unequal flagella</td>
<td>Swimming and feeding</td>
</tr>
<tr>
<td>Pavlova mesoephyta</td>
<td>Large green flagellate</td>
<td>Photosynthesis</td>
</tr>
<tr>
<td>Pavlova granifera</td>
<td>Small green flagellate</td>
<td>Photosynthesis</td>
</tr>
</tbody>
</table>

- (DHA) Docosahexaenoic acid
- (EPA) Eicosapentaenoic acid