Euglenophyta

- In euglenophytes, a single class, Euglenophyceae, is recognized.
- It includes about 800 species, most of which are freshwater species, but some are estuarine and intertidal.
- Predominantly unicellular, flagellate.
- Only a third of the species have chloroplasts, and the rest are heterotrophic (both facultative and obligate).
- The ability of Euglena to grow heterotrophically in the absence of plastids is unique among the algae.
- Autotrophic euglenophytes contain chlorophylls a and b and, thus, have been related to Chlorophyta, but this is the only shared character.
- Carotenoids include β-carotene and diadinoxanthin, other xanthophylls less prominent.
- The energy storage product is paramylon, a polysaccharide found outside the chloroplast in the cytoplasm. Chrysolaminarin can also accumulate in a liquid form in vacuoles in the cytoplasm.

Euglenophyta and Dinophyta

Algae with one membrane of chloroplast endoplasmic reticulum

Eyespot, parafallaxial swelling, and phototaxis

- The eyespot (stigma) (E) is a collection of orange-red lipid droplets, independent of the chloroplast.
- The eyespot is in the anterior part of the cell, curving to ensheath the neck of the reservoir on the dorsal side.
- The eyespot has been reported to contain α-carotene and seven xanthophylls, mainly β-carotene, or a β-carotene derivative, echinone.
- The base of the longer flagellum bears a thickening (P), believed to be a photoreceptor, close to the stigma.
- The swimming is composed of a crystalline body next to the axoneme and inside the flagellar membrane.
- All euglenoid species with an eyespot and flagellar swelling exhibit phototaxis, usually swimming away from bright light (negative phototaxis) and away from darkness toward subdued light (positive phototaxis) to accumulate in a region of low-light intensity.

Euglenoid cells are not surrounded by cell wall, but a pellicle that containing structural protein.

- The pellicle has four main components:
  - the plasma membrane,
  - repeating proteinaceous units called strips,
  - subtending microtubules, and
  - tubular cisternae of endoplasmic reticulum.
There are two basic types of flagellar movement in the class. The first group (including the Eutreptiales and Euglenales) has the flagellum continually mobile from base to apex, resulting in cell gyration with the anterior end of the cell tracing a wide circle. The second group (including Peranema, Entosiphon, and Sphenomonas) has the flagellum held out straight in front of the cell with just the tip motile, resulting in smooth swimming or gliding locomotion in contact with the substratum or air–water interface.

Euglena gracilis changes its shape two times per day when grown under the synchronizing effect of a daily light–dark cycle.

- At the beginning of the light period, when photosynthetic capacity is low (as measured by the ability of the cells to evolve oxygen), the population of cells is largely spherical.
- The mean cell length of the population increases to a maximum in the middle of the light period when photosynthetic capacity is greatest, and then decreases for the remainder of the 24-hour period.
- The population becomes spherical by the end of the 24-hour period when the cycle reinitiates.

These changes are also observed under dim light conditions and are therefore controlled by a biological clock and represent a circadian rhythm in cell shape. Some euglenoids have a flexible pellicle that allows the cells to undergo a flowing movement known as euglenoid movement. This type of movement occurs only when the cells are not swimming and results from the movement of the pellicle strips.

Surviving unfavorable periods.

- The cell rounds off and secretes a thick sheath of mucilage that survives for months until the cell emerges by cracking the cyst.
- In conditions of partial desiccation or excessive light, the slime sheath with just the tip motile, resulting in smooth swimming or gliding locomotion in contact with the substratum or air–water interface.
- In certain genera (Euglena and Euterptia), cell division within the slime layer leads to the formation of a palmelloid colony, which may form extensive sheets of cells covering many square feet of mud surface.

Mitochondria are of typical algal type. Colorless euglenoids always have more mitochondria than do equivalent-sized green ones.

Muciferous bodies (MB) (or mucocysts) occur under the pellicle strips and contain a water-soluble mucopolysaccharide. The muciferous bodies open to the outside through pores between the strips of the pellicle. The muciferous bodies function in the formation of the stalk in Colacium, lorica formation in Trachelomonas, cyst formation and lubrication during euglenoid movement.

Nucleus and nuclear division

- The euglenoid nucleus is of the mesokaryotic type, having:
  - chromosomes that are permanently condensed during the mitotic cycle,
  - a nucleolus (endosome) that does not disperse during nuclear division,
  - no microtubules from chromosomes to pole spindles, and
  - a nuclear envelope that is intact during nuclear division.

- The chromosome number is usually high, and polyploidy probably occurs in some genera.

- Mitosis in euglenoids begins during early prophase with the nucleus migrating from the center of the cell to an anterior position.

- Microtubules appear in the nucleus, but they do not attach to the chromosomes.

- At metaphase, bundles of microtubules are among the chromosomes, and the nucleus has started to elongate along the division axis.

- In anaphase, the intact nuclear envelope elongates along the division axis, the nuclear division, and the daughter chromosomes disperse into the two daughter nuclei.
Nutrition

The Euglenophyceae have a number of modes of nutrition, depending on the species involved.

- No Euglenoid has yet been demonstrated to be fully photoautotrophic – capable of living on a medium devoid of all organic compounds (including vitamins).
- All green Euglenoid flagellates so far studied are photoautotrophic – needing at least one vitamin. Euglena gracilis has an absolute requirement for vitamin B12.

Vitamin B12-starved cells increase in cell volume, sometimes to 10 times the size of control organisms, the cells in the final stage of vitamin B12 starvation often being poly-lobed, poly-nucleate, and containing more than the normal number of chloroplasts per cell. During vitamin B12 starvation, total cellular RNA and protein increase 400% to 500% compared with controls. During vitamin B12 starvation the protein increase 400% to 500% and the total DNA increases about 180%.

Classification

Three orders of Euglenoids are presented here.

- Order 1 Heteronematales: two emergent flagella, the longer flagellum directed anteriorly and the shorter one directed posteriorly during swimming; cells have special ingestion organelle.
  - Peranema trichophorum is a Euglenoid that ingests other cells and detritus. Here the colorless cells have a special ingestion organelle, and are phagocytic, taking up food particles whole and digesting them in food vesicles.
- Order 2 Chrysophytales: three flagella, the thylakoids are grouped into bands of three, with two thylakoid bands traversing the pyrenoid.
- Order 3 Chlorophytales: the thylakoids are grouped into bands of three, with two thylakoid bands traversing the pyrenoid.

Chloroplasts and storage products

- The Euglenoid chloroplasts are surrounded by two membranes of the chloroplast envelope plus one membrane of chloroplast endoplasmic reticulum; the latter membrane is not continuous with the nuclear membrane.
- The Euglenoid chloroplasts are usually discoid or plate-like with a central pyrenoid.
- The thylakoids are grouped into bands of three, with two thylakoid bands traversing the pyrenoid.
- A sheath of paramylon granules surrounds the pyrenoid, but outside the chloroplast, in photosynthetically grown cells.
- Paramylon granules are distributed throughout the cytoplasm in heterotrophically grown cells in the dark.
- Their shape is often characteristic of the Euglena species that produces them.
• Order 3 Euglenales: two flagella, only one of which emerges from the canal; no special ingestion organelle. Common genera in the order are the green photosynthetic Euglena, Trachelomonas, and Phacus, as well as the colorless osmotrophic Astasia. Colacium libellee is a member of this order that establishes itself in the rectum of damselfly nymphs during the winter in colder lakes. During the warm summer months the damselfly nymphs and C. libellee live separately.

• Order 2 Eutreptiales: two emergent flagella, one directed anteriorly and the other laterally or posteriorly during swimming; no special ingestion organelle. Eutreptia and Eutreptiella are estuarine or marine genera, while Distigma is characteristic of acid freshwaters.

Dinophyta (Pyrrophyta)

• Dinoflagellates are unicellular, biflagellate organisms. The term "dinoflagellate" means "whirling flagella". These organisms are important members of the plankton in both fresh and marine waters, although a much greater variety of forms is found in marine members. Dinoflagellates are less important in the colder polar waters than in warmer waters.

• Dinoflagellates are surrounded by a complex covering called the amphiesma, which consists of the plasma membrane and an underlying single layer of flattened vesicles (amphiesmal vesicles = "thecal vesicles"). Based on their amphiesma, dinoflagellates are separated into two major subgroups:
  - In thecate, or "armoured" forms, the amphiesmal vesicles contain cellulosic plates (= thecal plates), resulting in a rigid and inflexible wall.
  - In athecate, or "unarmoured" (naked) dinoflagellates, the cells have empty amphiesmal vesicles (without plate-like structures) and may be fragile, easily distorted and difficult to preserve.

• The exact number and arrangement of thecal plates in armored dinoflagellates are characteristic of the particular genus, therefore they are used for taxonomic differentiation. Also, the form of the thecal plates varies from spherical forms like Peridinium to elongate horn-like forms such as Ceratium.

• In many dinoflagellates, cell division usually involves sharing of the mother cell thecal plates between the daughter cells, with the daughter cells producing the new thecal plates that they lack. However, in certain genera the theca is completely shed (ecdysis) at cell division, followed by the formation of a thickened pellicle around the cell to form an ecdysal cyst.

• In thecate, or "armoured" forms, the amphiesmal vesicles contain cellulosic plates (= thecal plates), resulting in a rigid and inflexible wall. In athecate, or "unarmoured" (naked) dinoflagellates, the cells have empty amphiesmal vesicles (without plate-like structures) and may be fragile, easily distorted and difficult to preserve.

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Representative drawings of different types of amphiesmal arrangements in the Dinophyceae. The inner plasma membrane (I), The cellulosic thecal plate (T), vesicle (V).
Dinoflagellate scales. (a) Oxyrrhis marina. (b) Heterocapsa niei. (c) Katodinium rotundatum.

In most dinophyceae, outside of the plasma membrane there is a glycocalyx composed of acidic polysaccharides.

**Scales**
- Although relatively rare, scales occur outside the plasma membrane in some Dinophyceae.

A representation of thecal plates on a typical armored dinoflagellate. Scrippsiella trochoidea. Scanning electron micrographs showing the thecal plates in ventral (a) and dorsal (b) view.

Fibrillar hairs may cover the entire longitudinal flagellum.
- The transverse flagellum is thought to be responsible for driving the cell forward and it also brings about rotation, while the longitudinal flagellum is the propelling and steering flagellum.
- The flagellum causes a direct forward movement while at the same time causing the cell to rotate.
- The flagellar beat always proceeds counterclockwise when seen from the cell apex.
- The longitudinal flagellum can also reverse the swimming direction, it stops beating, points in a different direction by bending, and then resumes beating.

The transverse flagellum is a left-handed screw; waves propagated from the attached end toward the free end.
- The flagellum causes a direct forward movement while at the same time causing the cell to rotate.
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- The longitudinal flagellum swings in a narrow orbit acting as a rudder.
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The dinoflagellates are one of the fastest swimmers among the algae.
- Marine dinoflagellates frequently move into deeper, nutrient-rich waters at night and better illuminated waters near the surface during the day.
- The diel (over a 24-hour period) migrations of dinoflagellates are 5 to 10 m in relatively quiet waters.
**Phototaxis and eyespots**
- Less than 5% of the Dinophyceae contain eyespots (e), and those that do are mostly freshwater species; yet the eyespots are among the most complex in the algae.
- An eyespot is not necessary for a phototactic response.

**Trichocysts**
- Trichocysts (T) are membrane-bound threadlike structures found in a number of species.
- In these species, the cell wall is perforated by pores (P) through which trichocysts are discharged or projected from the cell under stimulation, often hundreds per cell.
- The actual benefit of trichocysts to the cell (if any) is still obscure.
  - They could be a mechanism for quick escape as the cells move sharply in the opposite direction of discharge, or they have a protective or evasive function since they could be able to directly “spear” a naked intruder.

**Accumulation body**
- This is a large vesicle containing the remains of digested organelles.

**Chloroplasts and pigments**
- The cells can be photosynthetic or colorless and heterotrophic.
- Photosynthetic organisms have chloroplasts surrounded by one membrane, which is not continuous with the outer membrane of the nuclear envelope.
- Chlorophylls a and b are present in the chloroplasts, with peridinin and neoperidinin being the main carotenoids.
- About half of the Dinophyceae have pyrenoids in the chloroplasts.
- The storage product is starch, similar to the starch of higher plants, which is found in the cytoplasm.

**Nucleus**
- The nucleus of the dinoflagellata is unusual in that it is now thought to be a uniquely derived feature of the group.
  - The DNA does not seem to have histones (basic proteins which the DNA coils around).
  - Dinoflagellates have more DNA in their nucleus than other eukaryotes, so much so that the nucleus often fills half the volume of the cell. This implies that a large amount of the DNA is genetically inactive (structural DNA) in dinoflagellates.
  - Chromosomes in its nucleus are not scattered, but are attached to the nuclear membrane.
  - Upon division, the nuclear membrane does not break down as in plants and animals.
  - The chromosomes remain condensed during mitosis and even during interphase, though they do unwind for replication of the DNA.
  - Such permanently condensed organization of chromatin (chromosomes) is different from either prokaryotic or eukaryotic cells.
  - This unusual nuclear situation is termed dinokaryotic or dinokaryotic in the belief that it was transitional between prokaryotic and eukaryotic structures, but it is now thought to be a uniquely derived feature of the Dinoflagellata.

**Resting spores or cysts or hypnospores and fossil Dinophyceae**
- The resting spore or cyst of most dinoflagellates is morphologically distinct from the parent cell.
- The cell walls of the cysts are highly resistant to decay and contain dinosporin, a chemical similar to sporopollenin in the pollen of higher plants.
- The cysts are extremely resistant and are preserved in ancient sediments where they are of value in paleoecological studies.
- Many extant resting spores are identical to fossilized cysts.

**Calciﬁcation of cysts in some genera occurs by the deposition of calcium carbonate crystals in the narrow space between the cell wall and the plasma membrane.**

**The process of encystment or resting spore formation is regulated by a complex interaction of**
- day length,
- temperature, and
- nutrient concentration

**Melatonin levels increase by several orders of magnitude during encystment and may function in preventing oxidation of the lipids in the cyst**

**Cysts are recognizable because they lack chromatophores and have a microgranular brown cytoplasm and a red eyespot (if the organism normally has an eyespot).**

**Cyst walls are the unique derived feature of the group.**

**Examples:**
- **Glenodinium foliaceum** contains an outer silicon layer.
- **Ceratium hirundinella** has an eyespot.
- **Peridinium** has an eyespot.
- **Polykrikos schwartzii**
- **Alexandrium catenella**
- **Gonyaulax grindleyi**
- **Calciodinellum operosum**
- **Scrippsiella trochoidea**
- **Gymnodinium catenatum**
- **Gonyaulax catenella**
- **Gonyaulax polyedra**
- **Gonyaulax antiqua**
- **Gonyaulax delicatissima**
- **Gonyaulax spinifera**
- **Gonyaulax persephone**
- **Gonyaulax typica**
- **Gonyaulax tamarensis**
- **Gonyaulax baltica**
- **Gonyaulax perplexa**
- **Gonyaulax polychaeta**
- **Gonyaulax pachyderma**
- **Gonyaulax carteri**
- **Gonyaulax viridis**
- **Gonyaulax tamarensis**
- **Gonyaulax tamarensis**
- **Gonyaulax tamarensis**
Toxins have been divided into different classes based on the syndromes associated with exposure to them, such as:

1. Diarrhetic shellfish poisoning. This occurs primarily in temperate regions and is caused by species of the planktonic dinoflagellates Exuviaella, Dinophysis, and Prorocentrum.

2. Ciguatera fish poisoning. This occurs primarily in tropical regions with the common causative agent being Gambierdiscus.
   - The dinoflagellate contains gambieric acids, ciguatoxins, and maitotoxins, that are very potent Ca²⁺ channel activators that result in breakdown of the cell membrane.
   - Gambierdiscus is epiphytic on macroalgae that are eaten by herbivorous fish and shellfish, which, in turn, are eaten by humans. In French Polynesia alone, approximately 1000 cases of ciguatera fish poisoning are reported every year.
   - The term ciguatera is derived from the Spanish term “cigua” for the turban shell, which was commonly eaten before the illness developed.
   - The typical course of ciguatera fish poisoning is diarrhea for two days, followed by general weakness for one to two days.
   - Occasionally the condition is fatal.

3. Paralytic shellfish poisoning. This is caused by species of Alexandrium (A. catenella, A. acatenella, A. excavatum, A. tamarensis), Pyrodinium bahamense, and Gymnodinium catenatum.
   - These dinoflagellates produce a group of toxins that are derivatives of saxitoxin.
   - Saxitoxin is a potent neurotoxin acting upon voltage-gated Na⁺ channels, preventing influx of Na⁺, thereby preventing the generation of an action potential.

- Some Dinophyceae have the ability to produce very potent toxins which cause the death of fish and shellfish during red tides when there are dinoflagellate blooms that color the water red.
- The dinoflagellates become lodged in the gills of the shellfish, and when shellfish are eaten by humans or animals, poisoning results.
- All of the dinoflagellates that have been demonstrated to produce toxins contain chloroplasts, indicating that the ability to produce toxins may have been derived from endosymbiotic cyanobacteria.

Fig. 7.30 Scanning electron micrographs of dinoflagellates that cause diarrhetic shellfish poisoning. (a) Dinophysis acuminata. (b) Dinophysis fortii. (c) Prorocentrum lima with the arrows pointing to pores in the theca.
The amount of toxin in cells of *Alexandrium* is relatively low when nutrients are in ready supply.

The toxin concentration is highest under conditions of phosphorus deficiency, possibly because free amino acids (precursors of toxins) accumulate under conditions of phosphorus deficiency.

Cells of dinoflagellates that produce toxins are avoided by grazing copepods.

A number of factors have been suggested as the cause of red tides:

1. **High surface-water temperatures**: Dinoflagellates favor warm water, and are generally more abundant near the surface. This does not necessarily mean that they occur only in warm seas, because the surface of the sea in normally cool areas may be warmed up during periods of hot, calm weather.
2. **Wind**: A strong, offshore wind aids upwelling, whereas a gentle onshore wind concentrates the bloom near the coast. On the other hand, heavy weather and strong winds disperse the bloom. Storms also result in the death of dinoflagellates and can prevent the development of red tides.
3. **Light intensity**: There is usually a period of bright, sunny, calm weather before outbreaks.
4. **Nutrients**: Red tides usually occur after an upwelling has stopped, but the nutrients brought to the surface do not, themselves, appear to be the direct cause of these blooms. It is thought that preceding blooms of diatoms may impoverish the water and reduce one or more of the inorganic nutrients to a level favorable for the growth of dinoflagellates (but too low for the diatoms), and also allow the production of organic nutrients such as vitamin B12, which are important for their growth.

Dinoflagellates and oil and coal deposits

- Blooms of dinoflagellates have most likely been responsible for some of the oil deposits of the world, including the North Sea oil deposit.
- Petroleum deposits and ancient sediments contain 4α-methylsteroidal hydrocarbons, which probably originated from 4α-methylsterols in dinoflagellates.

Bioluminescence

- **Bioluminescence (chemiluminescence)**, in which energy from an exergonic chemical reaction is transformed into light energy
- Many marine, but no freshwater dinoflagellates are capable of bioluminescence.
- The Dinophyceae are the main contributors to marine bioluminescence, emitting a bluish-green (maximum wavelength at 474 nm) flash of light of 0.1-second duration when the cells are stimulated.
- The luminescent wake of a moving ship is usually caused primarily by *Dinophyceae.*

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- The compound responsible for bioluminescence is **luciferin**, which is oxidized with the aid of the enzyme **luciferase**, resulting in the emissions of light.

  \[
  \text{luciferin} + O_2 \xrightarrow{\text{luciferase}} (\text{P})^* \rightarrow \text{P} + h\nu
  \]

- Luciferin and luciferase are terms for a general class of compounds, and not of a specific chemical structure.
- Bioluminescence occurs in many organisms in many different phyla, ranging from bacteria to dinoflagellates to jellyfish and brittle stars to worms, fireflies, molluscs, and fish.
- In bacteria, luciferin is a reduced flavin; in insects it is a (benzo)thiazole nucleus; and in dinoflagellates it is a tetrapyrrole.

- Likewise, luciferase has different structures, although all luciferases share the feature of being **oxygenases** (enzymes that add oxygen to compounds).
- In the basic reaction of bioluminescence, a luciferin is oxidized by a luciferase, resulting in an electronically excited product (**P***) which emits a photon (hν) on decomposition.

Dinoflagellates can emit light in three modes:

1. They can flash when stimulated mechanically, chemically, or electrically;
2. They can flash spontaneously;
3. They flash at night.

- Associated with dinoflagellate luciferin is a **luciferin-binding protein (LBP)** which sequesters luciferin at alkaline pH and releases it under acidic conditions.
- It has been postulated that the flash of bioluminescent light may occur simply by a lowering of the pH from 8.0 to 6.5.
- Agitation of cells depolarizes the vacuolar membrane, allowing a flux of protons (H⁺) and acidification of the peripheral cytoplasm.
- Lowering the pH causes two pH-dependent reactions to occur:
  1. Release of luciferin from its binding protein at acidic pH, and
  2. Activation of luciferase followed by emission of a photon of blue-green light.

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**Rhythms**

Many Dinophyceae exhibit rhythmic processes, with circadian (which means literally about (circa) a day (diem)) characteristics.

1. It produces light via bioluminescence if the cells are stimulated by shaking or stirring.
   - The greatest luminescence will be produced in the middle of the dark period, whereas toward morning, flashes will gradually become smaller and a greater stimulus will be required.
   - The rhythm is circadian, as shown by the persistence of changes in brightness of luminescence when the cells are kept in the dark or in continuous light.

2. The photosynthesis, measured, either as oxygen production or carbon dioxide fixation is also found to be rhythmic and the rhythm is circadian and continues under conditions of continuous light.
   - The maximum rate of photosynthesis occurs, as one would expect, in the middle of the day.

3. A third rhythm with a circadian period is that of cell division; all cell division occurring during 30 minutes when cultures are in a light-dark cycle.
   - When the light–dark cycle is 12 : 12, then this 30 minutes spans four dark.

4. A fourth type of rhythm involves the vertical migration of dinoflagellate cells in the water column.
   - Before dawn, the cells rise to the surface, where they form dense clouds (aggregations), and before night fall, they again sink to lower depths.
   - In the marine environment, this vertical migration exposes the cells to several gradients.
     - (1) Nutrients are more concentrated at lower depths while surface waters are often practically devoid of nutrients.
     - (2) Temperatures at the surface exceed those in deeper waters.
     - (3) Variations in light intensities.
     - (4) Differences in washout by the tidal waters in shallow waters.

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**Heterotrophic dinoflagellates**

- "Burglar alarm" hypothesis. In this hypothesis dinoflagellates generate a signal identifying the location of invertebrate grazers (e.g. copepods) to individuals two levels up the food chain from the dinoflagellates. Bioluminescence generated by dinoflagellates serves to attract predators of the grazers of the dinoflagellates.
- "Startle" hypothesis. In this hypothesis, mechanical stimulation of a bioluminescent dinoflagellate by a grazer produces a flash of light that startles an invertebrate grazer, such as a copepod, and causes the copepod to swim away.
- Whichever theory is correct, experiments have shown that copepods consume only half as many dinoflagellates at night, indicating that the bioluminescence is serving as a deterrent to grazing.

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**In Lingulodinium polyedrum, there exists a control over luminescence, photosynthesis, and cell division, so that each process reaches a maximum and then declines in an orderly fashion during each 24 hours (Fig. 7.45).**

- A biological clock, may control all of these processes.
  - It appears that the part of the cell that may be the controlling agent is the plasma membrane because there is a rhythmic reorganization of the plasma membrane over a 24-hour period in synchronized cells.

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**Drawing of the ingestion of food organisms (other algae, bacteria) by Corethron hystria.**

1. The tentacle (T) is in an extended configuration. Any food organisms (FO) that collide with the mucus-covered tentacle tip, stick to the tentacle. (P) Peristome; (PO) oral pouch. (A) The tentacle bends back toward the oral pouch. (C) The cytosome opens, the tentacle tip is inserted into the cytosome, and the food organisms are swept into a food vacuole.

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**Text continued...**
Symbiotic dinoflagellates

- Symbiotic dinoflagellates (zooxanthellae) occur in almost all species of tropical and reef-building corals, jellyfish, and sea anemones (Cnidaria).
- The dinoflagellates are coccolith spheres in the symbiotic state and have been assigned to the genus Symbiodinium.
- The host exerts strong control over the translocation of metabolites from the dinoflagellate endosymbiont, resulting in 98% of the carbon fixed by the endosymbiont being released to the host.
- The host animal cells secrete the amino acid taurine which causes the dinoflagellate to release photosynthate outside the cell for absorption by the animal cells.
- In the flatworm Amphicoelos langerhansi the symbiotic dinoflagellate is Amphidinium klebsii.
- In addition to Dinophyceae living symbiotically inside other organisms, there are other organisms that live inside dinoflagellate cells.

Order 2 Dinophysiales: cell wall divided vertically into two halves, cells with elaborate extensions of the theca.
- One of the more complex organisms in this order is Ochromonas magnifica (Fig. 7.56(c), (e)).

Order 3 Peridiniales: motile cells with an epicone and hypocone separated by a girdle, relatively thick theca.
- The algae in this order have the classic dinoflagellate structure with an epicone and hypocone and two furrows, the transverse girdle and the longitudinal sulcus.
- Ceratium is a widely distributed genus.

Order 4 Gymnodiniales: motile cells with an epicone and hypocone separated by a girdle, relatively thick theca.
- The life cycle of Gymnodinium pseudopalustre is a representative of the order.

Classification

- There is a single class in the Dinophyta, the Dinophyceae.
- Four orders are considered here.
- Order 1 Prorocentrales: cell wall divided vertically into two halves; no girdle; two flagella borne at cell apex.
- Prorocentrum is an example of the order.

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