

Chapter 5

The Eukaryotes of Microbiology

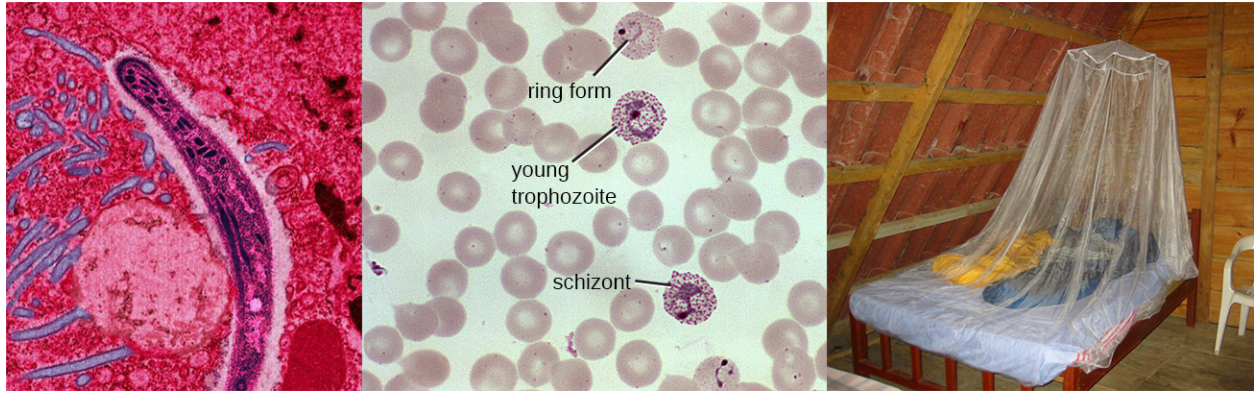


Figure 5.1 Malaria is a disease caused by a eukaryotic parasite transmitted to humans by mosquitos. Micrographs (left and center) show a sporozoite life stage, trophozoites, and a schizont in a blood smear. On the right is depicted a primary defense against mosquito-borne illnesses like malaria—mosquito netting. (credit left: modification of work by Ute Frevert; credit middle: modification of work by Centers for Disease Control and Prevention; credit right: modification of work by Tjeerd Wiersma)

Chapter Outline

- 5.1 Unicellular Eukaryotic Parasites
- 5.2 Parasitic Helminths
- 5.3 Fungi
- 5.4 Algae
- 5.5 Lichens

Introduction

Although bacteria and viruses account for a large number of the infectious diseases that afflict humans, many serious illnesses are caused by eukaryotic organisms. One example is malaria, which is caused by *Plasmodium*, a eukaryotic organism transmitted through mosquito bites. Malaria is a major cause of morbidity (illness) and mortality (death) that threatens 3.4 billion people worldwide.^[1] In severe cases, organ failure and blood or metabolic abnormalities contribute to medical emergencies and sometimes death. Even after initial recovery, relapses may occur years later. In countries where malaria is endemic, the disease represents a major public health challenge that can place a tremendous strain on developing economies.

Worldwide, major efforts are underway to reduce malaria infections. Efforts include the distribution of insecticide-treated bed nets and the spraying of pesticides. Researchers are also making progress in their efforts to develop effective vaccines.^[2] The President's Malaria Initiative, started in 2005, supports prevention and treatment. The Bill and Melinda Gates Foundation has a large initiative to eliminate malaria. Despite these efforts, malaria continues to cause long-term morbidity (such as intellectual disabilities in children) and mortality (especially in children younger than 5 years), so we still have far to go.

1. Centers for Disease Control and Prevention. "Impact of Malaria." September 22, 2015. http://www.cdc.gov/malaria/malaria_worldwide/impact.html. Accessed January 18, 2016.

2. RTS, S Clinical Trials Partnership. "Efficacy and safety of RTS,S/AS01 malaria vaccine with or without a booster dose in infants and children in Africa: final results of a phase 3, individually randomised, controlled trial." *The Lancet* 23 April 2015. DOI: [http://dx.doi.org/10.1016/S0140-6736\(15\)60721-8](http://dx.doi.org/10.1016/S0140-6736(15)60721-8).

5.1 Unicellular Eukaryotic Parasites

Learning Objectives

- Summarize the general characteristics of unicellular eukaryotic parasites
- Describe the general life cycles and modes of reproduction in unicellular eukaryotic parasites
- Identify challenges associated with classifying unicellular eukaryotes
- Explain the taxonomic scheme used for unicellular eukaryotes
- Give examples of infections caused by unicellular eukaryotes

Eukaryotic microbes are an extraordinarily diverse group, including species with a wide range of life cycles, morphological specializations, and nutritional needs. Although more diseases are caused by viruses and bacteria than by microscopic eukaryotes, these eukaryotes are responsible for some diseases of great public health importance. For example, the protozoal disease malaria was responsible for 584,000 deaths worldwide (primarily children in Africa) in 2013, according to the World Health Organization (WHO). The protist parasite *Giardia* causes a diarrheal illness (giardiasis) that is easily transmitted through contaminated water supplies. In the United States, *Giardia* is the most common human intestinal parasite (**Figure 5.3**). Although it may seem surprising, parasitic worms are included within the study of microbiology because identification depends on observation of microscopic adult worms or eggs. Even in developed countries, these worms are important parasites of humans and of domestic animals. There are fewer fungal pathogens, but these are important causes of illness, as well. On the other hand, fungi have been

Clinical Focus

Part 1

Upon arriving home from school, 7-year-old Sarah complains that a large spot on her arm will not stop itching. She keeps scratching at it, drawing the attention of her parents. Looking more closely, they see that it is a red circular spot with a raised red edge (**Figure 5.2**). The next day, Sarah's parents take her to their doctor, who examines the spot using a Wood's lamp. A Wood's lamp produces ultraviolet light that causes the spot on Sarah's arm to fluoresce, which confirms what the doctor already suspected: Sarah has a case of ringworm.

Sarah's mother is mortified to hear that her daughter has a "worm." How could this happen?

- What are some likely ways that Sarah might have contracted ringworm?



Figure 5.2 Ringworm presents as a raised, red ring on the skin. (credit: Centers for Disease Control and Prevention)

Jump to the **next** Clinical Focus box.

important in producing antimicrobial substances such as penicillin. In this chapter, we will examine characteristics of protists, worms, and fungi while considering their roles in causing disease.

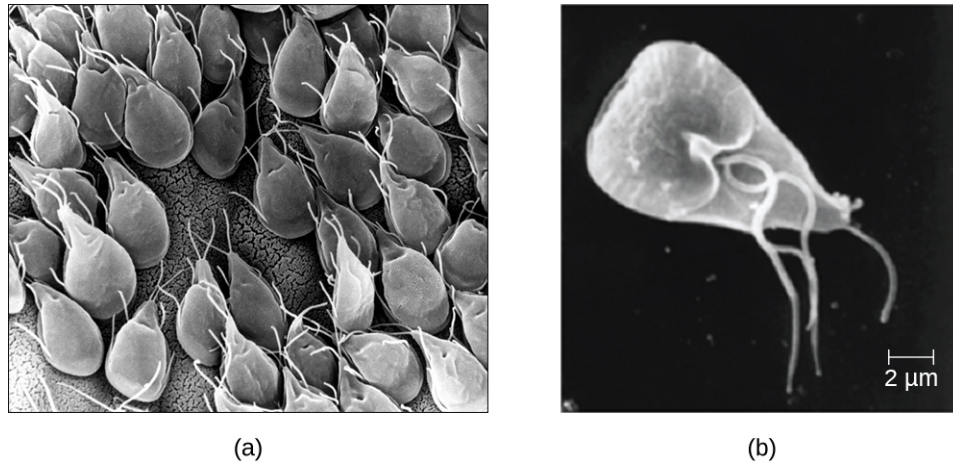


Figure 5.3 (a) A scanning electron micrograph shows many *Giardia* parasites in the trophozoite, or feeding stage, in a gerbil intestine. (b) An individual trophozoite of *G. lamblia*, visualized here in a scanning electron micrograph. This waterborne protist causes severe diarrhea when ingested. (credit a, b: modification of work by Centers for Disease Control and Prevention)

Characteristics of Protists

The word *protist* is a historical term that is now used informally to refer to a diverse group of microscopic eukaryotic organisms. It is not considered a formal taxonomic term because the organisms it describes do not have a shared evolutionary origin. Historically, the protists were informally grouped into the “animal-like” protozoans, the “plant-like” algae, and the “fungus-like” protists such as water molds. These three groups of protists differ greatly in terms of their basic characteristics. For example, algae are photosynthetic organisms that can be unicellular or multicellular. Protozoa, on the other hand, are nonphotosynthetic, motile organisms that are always unicellular. Other informal terms may also be used to describe various groups of protists. For example, microorganisms that drift or float in water, moved by currents, are referred to as **plankton**. Types of plankton include **zooplankton**, which are motile and nonphotosynthetic, and **phytoplankton**, which are photosynthetic.

Protozoans inhabit a wide variety of habitats, both aquatic and terrestrial. Many are free-living, while others are parasitic, carrying out a life cycle within a host or hosts and potentially causing illness. There are also beneficial symbionts that provide metabolic services to their hosts. During the feeding and growth part of their life cycle, they are called **trophozoites**; these feed on small particulate food sources such as bacteria. While some types of protozoa exist exclusively in the trophozoite form, others can develop from trophozoite to an encapsulated cyst stage when environmental conditions are too harsh for the trophozoite. A **cyst** is a cell with a protective wall, and the process by which a trophozoite becomes a cyst is called **encystment**. When conditions become more favorable, these cysts are triggered by environmental cues to become active again through **excystment**.

One protozoan genus capable of encystment is *Eimeria*, which includes some human and animal pathogens. **Figure 5.4** illustrates the life cycle of *Eimeria*.

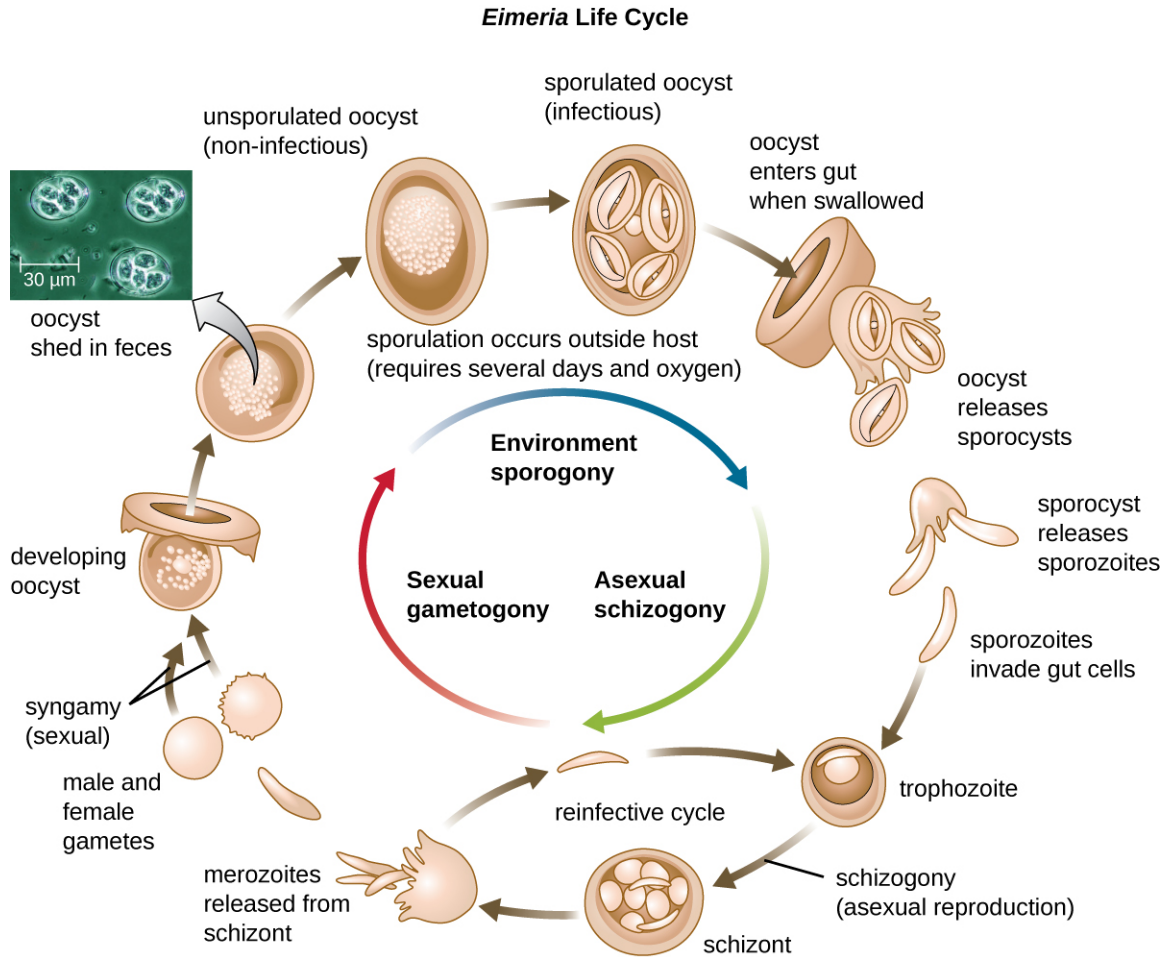


Figure 5.4 In the sexual/asexual life cycle of *Eimeria*, oocysts (inset) are shed in feces and may cause disease when ingested by a new host. (credit "life cycle," "micrograph": modification of work by USDA)

Protozoans have a variety of reproductive mechanisms. Some protozoans reproduce asexually and others reproduce sexually; still others are capable of both sexual and asexual reproduction. In protozoans, asexual reproduction occurs by binary fission, budding, or schizogony. In **schizogony**, the nucleus of a cell divides multiple times before the cell divides into many smaller cells. The products of schizogony are called merozoites and they are stored in structures known as schizonts. Protozoans may also reproduce sexually, which increases genetic diversity and can lead to complex life cycles. Protozoans can produce haploid gametes that fuse through **syngamy**. However, they can also exchange genetic material by joining to exchange DNA in a process called conjugation. This is a different process than the conjugation that occurs in bacteria. The term protist conjugation refers to a true form of eukaryotic sexual reproduction between two cells of different mating types. It is found in **ciliates**, a group of protozoans, and is described later in this subsection.

All protozoans have a plasma membrane, or **plasmalemma**, and some have bands of protein just inside the membrane that add rigidity, forming a structure called the **pellicle**. Some protists, including protozoans, have distinct layers of cytoplasm under the membrane. In these protists, the outer gel layer (with microfilaments of actin) is called the **ectoplasm**. Inside this layer is a sol (fluid) region of cytoplasm called the **endoplasm**. These structures contribute to complex cell shapes in some protozoans, whereas others (such as amoebas) have more flexible shapes (**Figure 5.5**).

Different groups of protozoans have specialized feeding structures. They may have a specialized structure for taking in food through phagocytosis, called a **cytostome**, and a specialized structure for the exocytosis of wastes called a **cytoproct**. Oral grooves leading to cytostomes are lined with hair-like cilia to sweep in food particles. Protozoans are heterotrophic. Protozoans that are **holozoic** ingest whole food particles through phagocytosis. Forms that are

saprozoic ingest small, soluble food molecules.

Many protists have whip-like flagella or hair-like cilia made of microtubules that can be used for locomotion (**Figure 5.5**). Other protists use cytoplasmic extensions known as pseudopodia (“false feet”) to attach the cell to a surface; they then allow cytoplasm to flow into the extension, thus moving themselves forward.

Protozoans have a variety of unique organelles and sometimes lack organelles found in other cells. Some have **contractile vacuoles**, organelles that can be used to move water out of the cell for osmotic regulation (salt and water balance) (**Figure 5.5**). Mitochondria may be absent in parasites or altered to kinetoplasts (modified mitochondria) or hydrogenosomes (see **Unique Characteristics of Prokaryotic Cells** for more discussion of these structures).

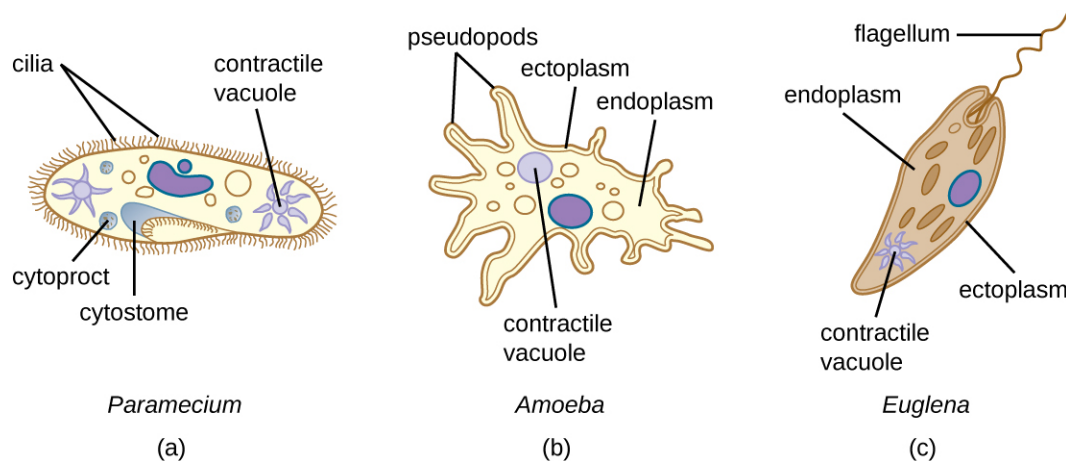


Figure 5.5 (a) *Paramecium* spp. have hair-like appendages called cilia for locomotion. (b) *Amoeba* spp. use lobe-like pseudopodia to anchor the cell to a solid surface and pull forward. (c) *Euglena* spp. use a whip-like structure called a flagellum to propel the cell.



Check Your Understanding

- What is the sequence of events in reproduction by schizogony and what are the cells produced called?

Taxonomy of Protists

The protists are a **polyphyletic** group, meaning they lack a shared evolutionary origin. Since the current taxonomy is based on evolutionary history (as determined by biochemistry, morphology, and genetics), protists are scattered across many different taxonomic groups within the domain Eukarya. Eukarya is currently divided into six supergroups that are further divided into subgroups, as illustrated in (**Figure 5.6**). In this section, we will primarily be concerned with the supergroups Amoebozoa, Excavata, and Chromalveolata; these supergroups include many protozoans of clinical significance. The supergroups Opisthokonta and Rhizaria also include some protozoans, but few of clinical significance. In addition to protozoans, Opisthokonta also includes animals and fungi, some of which we will discuss in **Parasitic Helminths** and **Fungi**. Some examples of the Archaeplastida will be discussed in **Algae**. **Figure 5.7** and **Figure 5.8** summarize the characteristics of each supergroup and subgroup and list representatives of each.

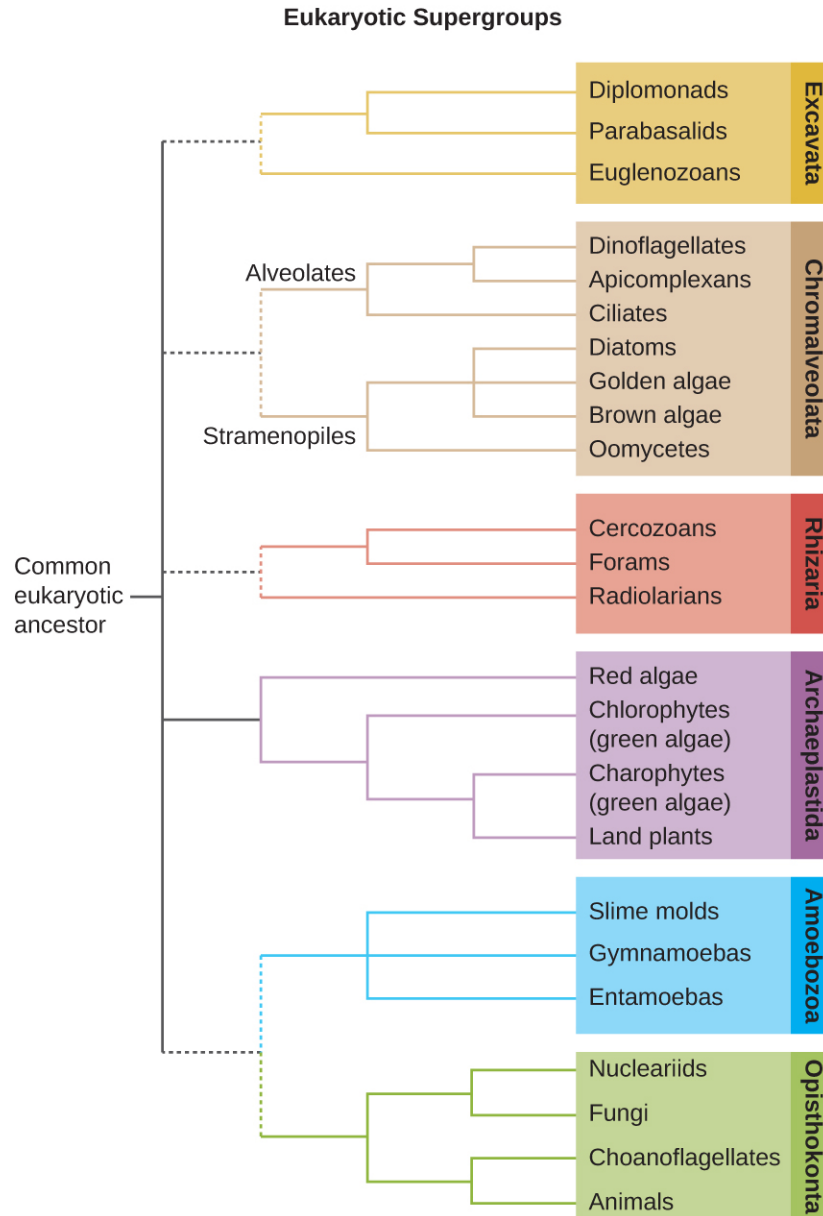


Figure 5.6 This tree shows a proposed classification of the domain Eukarya based on evolutionary relationships. Currently, the domain Eukarya is divided into six supergroups. Within each supergroup are multiple kingdoms. Dotted lines indicate suggested evolutionary relationships that remain under debate.

The Eukaryote Supergroups and Some Examples				
Supergroup	Subgroups	Distinguishing Features	Examples	Clinical Notes
Excavata	Fornicata	Form cysts Pair of equal nuclei No mitochondria Often parasitic Four free flagella	<i>Giardia lamblia</i>	Giardiasis
	Parabasalids	No mitochondria Four free flagella One attached flagellum No cysts Parasitic or symbiotic Basal bodies Kinetoplastids	<i>Trichomonas</i>	Trichomoniasis
	Euglenozoans	Photosynthetic or heterotrophic Flagella	<i>Euglena</i>	N/a
			<i>Trypanosoma</i>	African sleeping sickness, Chagas disease
			<i>Leishmania</i>	Leishmaniasis
	Chromalveolata	Dinoflagellates	Cellulose theca Two dissimilar flagella	<i>Gonyaulax</i>
<i>Alexandrium</i>				Paralytic shellfish poisoning
<i>Pfiesteria</i>				Harmful algal blooms
Apicomplexans		Intracellular parasite Apical organelles	<i>Plasmodium</i>	Malaria
			<i>Cryptosporidium</i>	Cryptosporidiosis
			<i>Theileria (Babesia)</i>	Babesiosis
			<i>Toxoplasma</i>	Toxoplasmosis
Ciliates		Cilia	<i>Balantidium</i>	Balantidiasis
			<i>Paramecium</i>	N/a
			<i>Stentor</i>	N/a
Öomycetes/ peronosporomy- cetes		“Water molds” Generally diploid Cellulose cell walls	<i>Phytophthora</i>	Diseases in crops

Figure 5.7

The Eukaryote Supergroups and Some Examples (continued)				
Supergroup	Subgroups	Distinguishing Features	Examples	Clinical Notes
Rhizaria	Foraminifera	Amoeboid Threadlike pseudopodia Calcium carbonate shells	<i>Astrodonche</i>	N/a
	Radiolaria	Amoeboid Threadlike pseudopodia Silica shells	<i>Actinomma</i>	N/a
	Cercospora	Amoeboid Threadlike pseudopodia Complex shells Parasitic forms	<i>Spongospora subterranea</i>	Powdery scab (potato disease)
			<i>Plasmodiophora brassicae</i>	Cabbage clubroot
Archaeplastida	Red algae	Chlorophyll <i>a</i> Phycocyanin Phycocyanin Floridean starch Agar in cell walls	<i>Gelidium</i>	Source of agar
			<i>Gracilaria</i>	Source of agar
	Chlorophytes	Chlorophyll <i>a</i> Chlorophyll <i>b</i> Cellulose cell walls Starch storage	<i>Acetabularia</i>	N/a
			<i>Ulva</i>	N/a
Amoebozoa	Slime molds	Plasmodial and cellular forms	<i>Dictyostelium</i>	N/a
	Entamoebas	Trophozoites Form cysts	<i>Entamoeba</i>	Amoebiasis
			<i>Naegleria</i>	Primary amoebic meningoencephalitis
			<i>Acanthamoeba</i>	Keratitis, granulomatous amoebic encephalitis
Opisthokonta	Fungi	Chitin cell walls Unicellular or multicellular Often hyphae	Zygomycetes	Zygomycosis
			Ascomycetes	Candidiasis
			Basidiomycetes	Cryptococcosis
			Microsporidia	Microsporidiosis
	Animals	Multicellular heterotrophs No cell walls	Nematoda	Trichinosis; hookworm and pinworm infections
			Trematoda	Schistosomiasis
			Cestoda	Tapeworm infections

Figure 5.8



Check Your Understanding

- Which supergroups contain the clinically significant protists?

Amoebozoa

The supergroup Amoebozoa includes protozoans that use amoeboid movement. Actin microfilaments produce pseudopodia, into which the remainder of the protoplasm flows, thereby moving the organism. The genus *Entamoeba* includes commensal or parasitic species, including the medically important *E. histolytica*, which is transmitted by cysts in feces and is the primary cause of amoebic dysentery. The notorious “brain-eating amoeba,” *Naegleria fowleri*, is also classified within the Amoebozoa. This deadly parasite is found in warm, fresh water and causes primary amoebic meningoencephalitis (PAM). Another member of this group is *Acanthamoeba*, which can cause keratitis (corneal inflammation) and blindness.

The Eumycetozoa are an unusual group of organisms called slime molds, which have previously been classified as animals, fungi, and plants (**Figure 5.9**). Slime molds can be divided into two types: cellular slime molds and plasmodial slime molds. The cellular slime molds exist as individual amoeboid cells that periodically aggregate into a mobile slug. The aggregate then forms a fruiting body that produces haploid spores. Plasmodial slime molds exist as large, multinucleate amoeboid cells that form reproductive stalks to produce spores that divide into gametes. One cellular slime mold, *Dictyostelium discoideum*, has been an important study organism for understanding cell differentiation, because it has both single-celled and multicelled life stages, with the cells showing some degree of differentiation in the multicelled form. **Figure 5.10** and **Figure 5.11** illustrate the life cycles of cellular and plasmodial slime molds, respectively.



(a)



(b)

Figure 5.9 (a) The cellular slime mold *Dictyostelium discoideum* can be grown on agar in a Petri dish. In this image, individual amoeboid cells (visible as small spheres) are streaming together to form an aggregation that is beginning to rise in the upper right corner of the image. The primitively multicellular aggregation consists of individual cells that each have their own nucleus. (b) *Fuligo septica* is a plasmodial slime mold. This brightly colored organism consists of a large cell with many nuclei.

Haploid and Asexual Reproduction

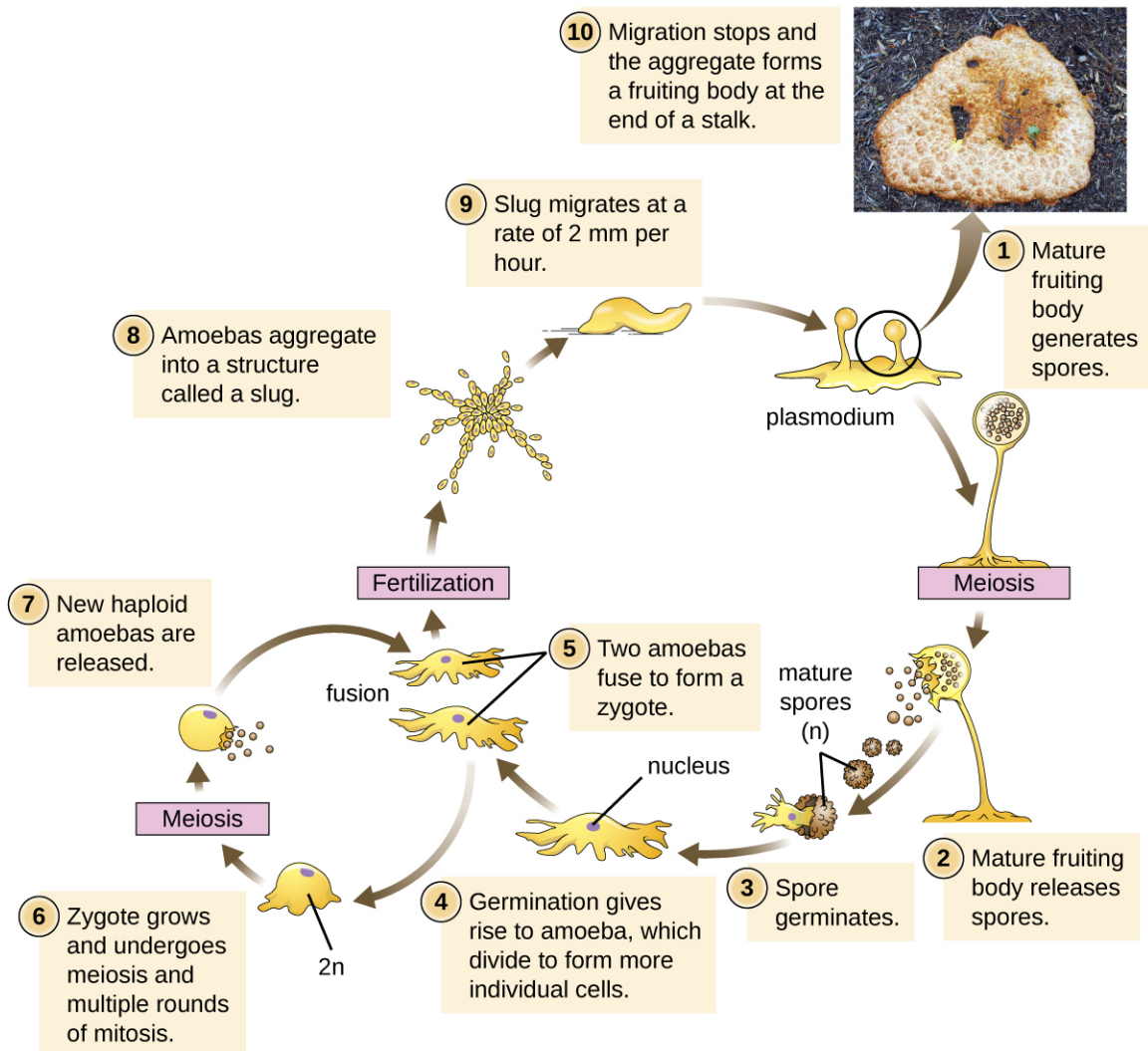


Figure 5.10 The life cycle of the cellular slime mold *Dictyostelium discoideum* primarily involves individual amoebas but includes the formation of a multinucleate plasmodium formed from a uninucleate zygote (the result of the fusion of two individual amoeboid cells). The plasmodium is able to move and forms a fruiting body that generates haploid spores. (credit "photo": modification of work by "thatredhead4"/Flickr)

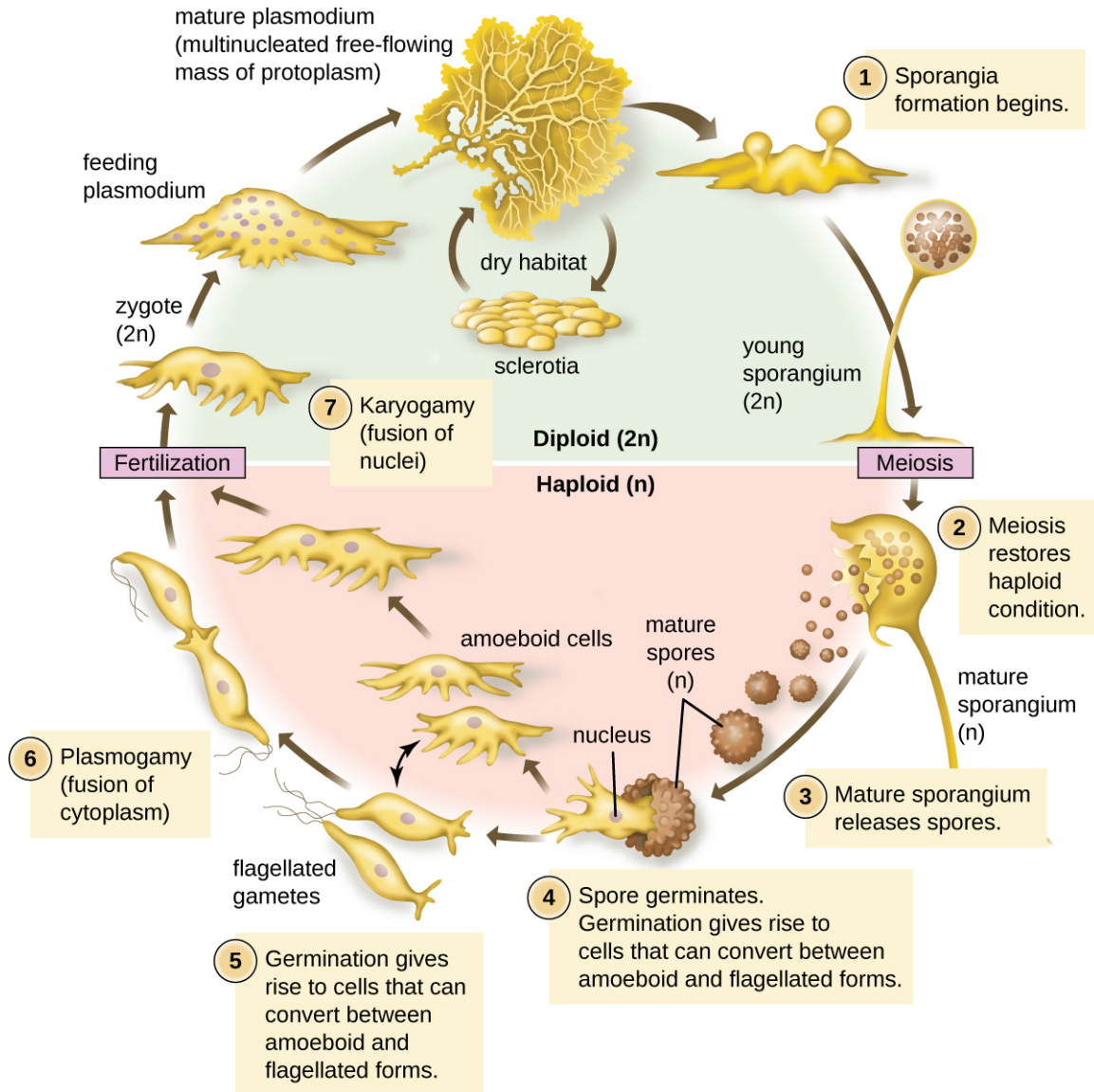


Figure 5.11 Plasmodial slime molds exist as large multinucleate amoeboid cells that form reproductive stalks to produce spores that divide into gametes.

Chromalveolata

The supergroup Chromalveolata is united by similar origins of its members' plastids and includes the apicomplexans, ciliates, diatoms, and dinoflagellates, among other groups (we will cover the diatoms and dinoflagellates in **Algae**). The apicomplexans are intra- or extracellular parasites that have an apical complex at one end of the cell. The apical complex is a concentration of organelles, vacuoles, and microtubules that allows the parasite to enter host cells (**Figure 5.12**). Apicomplexans have complex life cycles that include an infective sporozoite that undergoes schizogony to make many merozoites (see the example in **Figure 5.4**). Many are capable of infecting a variety of animal cells, from insects to livestock to humans, and their life cycles often depend on transmission between multiple hosts. The genus *Plasmodium* is an example of this group.

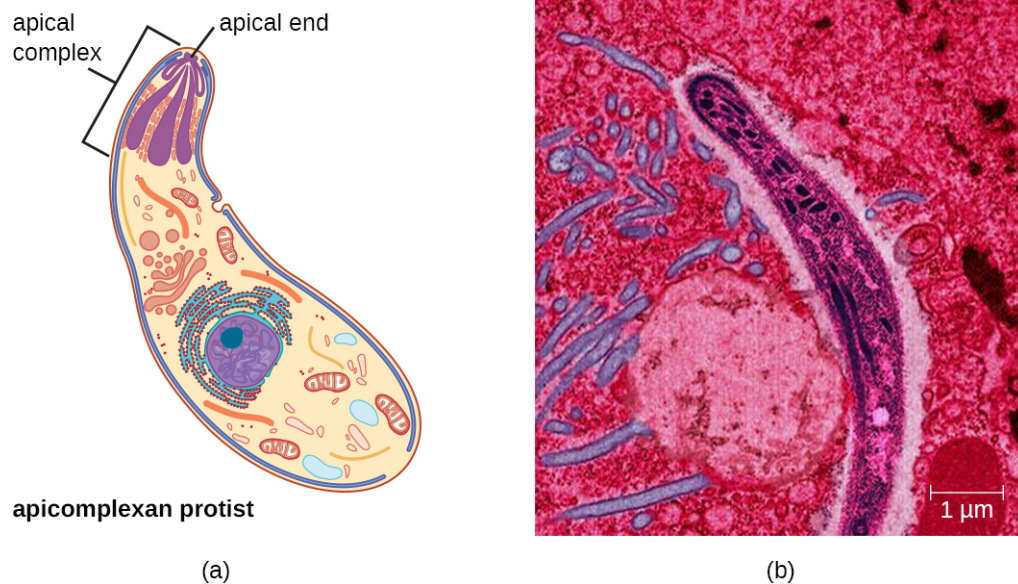


Figure 5.12 (a) Apicomplexans are parasitic protists. They have a characteristic apical complex that enables them to infect host cells. (b) A colorized electron microscope image of a *Plasmodium* sporozoite. (credit b: modification of work by Ute Frevert)

Other apicomplexans are also medically important. *Cryptosporidium parvum* causes intestinal symptoms and can cause epidemic diarrhea when the cysts contaminate drinking water. *Theileria (Babesia) microti*, transmitted by the tick *Ixodes scapularis*, causes recurring fever that can be fatal and is becoming a common transfusion-transmitted pathogen in the United States (*Theileria* and *Babesia* are closely related genera and there is some debate about the best classification). Finally, *Toxoplasma gondii* causes toxoplasmosis and can be transmitted from cat feces, unwashed fruit and vegetables, or from undercooked meat. Because toxoplasmosis can be associated with serious birth defects, pregnant women need to be aware of this risk and use caution if they are exposed to the feces of potentially infected cats. A national survey found the frequency of individuals with antibodies for toxoplasmosis (and thus who presumably have a current latent infection) in the United States to be 11%. Rates are much higher in other countries, including some developed countries.^[3] There is also evidence and a good deal of theorizing that the parasite may be responsible for altering infected humans' behavior and personality traits.^[4]

The ciliates (Ciliophora), also within the Chromalveolata, are a large, very diverse group characterized by the presence of cilia on their cell surface. Although the cilia may be used for locomotion, they are often used for feeding, as well, and some forms are nonmotile. *Balantidium coli* (Figure 5.13) is the only parasitic ciliate that affects humans by causing intestinal illness, although it rarely causes serious medical issues except in the immunocompromised (those having a weakened immune system). Perhaps the most familiar ciliate is *Paramecium*, a motile organism with a clearly visible cytostome and cytoproct that is often studied in biology laboratories (Figure 5.14). Another ciliate, *Stentor*, is sessile and uses its cilia for feeding (Figure 5.15). Generally, these organisms have a **micronucleus** that is diploid, somatic, and used for sexual reproduction by conjugation. They also have a **macronucleus** that is derived from the micronucleus; the macronucleus becomes polyploid (multiple sets of duplicate chromosomes), and has a reduced set of metabolic genes.

Ciliates are able to reproduce through conjugation, in which two cells attach to each other. In each cell, the diploid micronuclei undergo meiosis, producing eight haploid nuclei each. Then, all but one of the haploid micronuclei and the macronucleus disintegrate; the remaining (haploid) micronucleus undergoes mitosis. The two cells then exchange one micronucleus each, which fuses with the remaining micronucleus present to form a new, genetically different,

3. J. Flegr et al. "Toxoplasmosis—A Global Threat. Correlation of Latent Toxoplasmosis With Specific Disease Burden in a Set of 88 Countries." *PloS ONE* 9 no. 3 (2014):e90203.

4. J. Flegr. "Effects of Toxoplasma on Human Behavior." *Schizophrenia Bull* 33, no. 3 (2007):757–760.

diploid micronucleus. The diploid micronucleus undergoes two mitotic divisions, so each cell has four micronuclei, and two of the four combine to form a new macronucleus. The chromosomes in the macronucleus then replicate repeatedly, the macronucleus reaches its polyploid state, and the two cells separate. The two cells are now genetically different from each other and from their previous versions.



Figure 5.13 This specimen of the ciliate *Balantidium coli* is a trophozoite form isolated from the gut of a primate. *B. coli* is the only ciliate capable of parasitizing humans. (credit: modification of work by Kouassi RYW, McGraw SW, Yao PK, Abou-Bacar A, Brunet J, Pesson B, Bonfoh B, N'goran EK & Candolfi E)

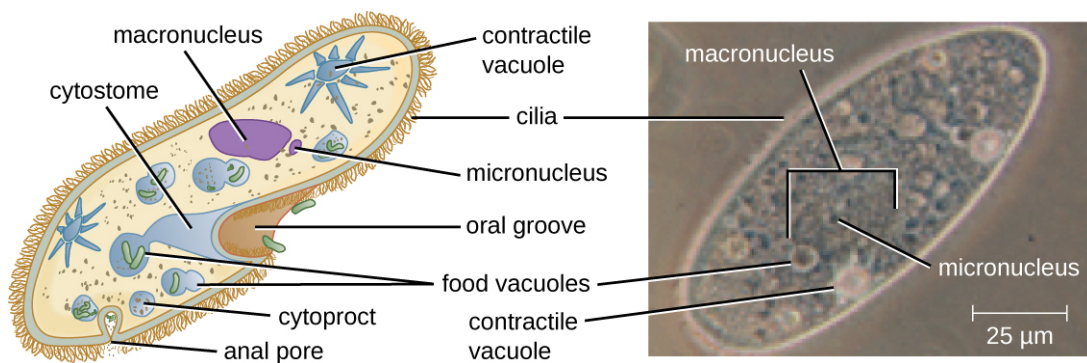


Figure 5.14 *Paramecium* has a primitive mouth (called an oral groove) to ingest food, and an anal pore to excrete it. Contractile vacuoles allow the organism to excrete excess water. Cilia enable the organism to move.

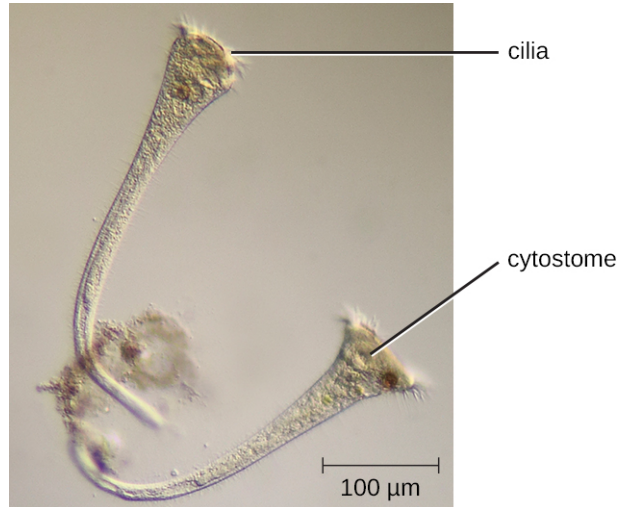


Figure 5.15 This differential interference contrast micrograph (magnification: $\times 65$) of *Stentor roeselie* shows cilia present on the margins of the structure surrounding the cytostome; the cilia move food particles. (credit: modification of work by "picturepest"/Flickr)

Öomycetes have similarities to fungi and were once classified with them. They are also called water molds. However, they differ from fungi in several important ways. Öomycetes have cell walls of cellulose (unlike the chitinous cell walls of fungi) and they are generally diploid, whereas the dominant life forms of fungi are typically haploid. *Phytophthora*, the plant pathogen found in the soil that caused the Irish potato famine, is classified within this group (**Figure 5.16**).



Figure 5.16 A saprobic oomycete, or water mold, engulfs a dead insect. (credit: modification of work by Thomas Bresson)

Link to Learning



Explore the procedures for detecting the presence of an apicomplexan in a public water supply, at [this \(https://openstax.org/l/22detpreapicom\)](https://openstax.org/l/22detpreapicom) website.

This [video \(https://openstax.org/l/22feedstentor\)](https://openstax.org/l/22feedstentor) shows the feeding of *Stentor*.

Excavata

The third and final supergroup to be considered in this section is the Excavata, which includes primitive eukaryotes and many parasites with limited metabolic abilities. These organisms have complex cell shapes and structures, often including a depression on the surface of the cell called an excavate. The group Excavata includes the subgroups Fornicata, Parabasalia, and Euglenozoa. The Fornicata lack mitochondria but have flagella. This group includes *Giardia lamblia* (also known as *G. intestinalis* or *G. duodenalis*), a widespread pathogen that causes diarrheal illness and can be spread through cysts from feces that contaminate water supplies (**Figure 5.3**). Parabasalia are frequent animal endosymbionts; they live in the guts of animals like termites and cockroaches. They have basal bodies and modified mitochondria (kinetoplasts). They also have a large, complex cell structure with an undulating membrane and often have many flagella. The trichomonads (a subgroup of the Parabasalia) include pathogens such as *Trichomonas vaginalis*, which causes the human sexually transmitted disease trichomoniasis. Trichomoniasis often does not cause symptoms in men, but men are able to transmit the infection. In women, it causes vaginal discomfort and discharge and may cause complications in pregnancy if left untreated.

The Euglenozoa are common in the environment and include photosynthetic and nonphotosynthetic species. Members of the genus *Euglena* are typically not pathogenic. Their cells have two flagella, a pellicle, a **stigma** (eyespot) to sense light, and chloroplasts for photosynthesis (**Figure 5.17**). The pellicle of *Euglena* is made of a series of protein bands surrounding the cell; it supports the cell membrane and gives the cell shape.

The Euglenozoa also include the trypanosomes, which are parasitic pathogens. The genus *Trypanosoma* includes *T. brucei*, which causes African trypanosomiasis (African sleeping sickness) and *T. cruzi*, which causes American trypanosomiasis (Chagas disease). These tropical diseases are spread by insect bites. In African sleeping sickness, *T. brucei* colonizes the blood and the brain after being transmitted via the bite of a tsetse fly (*Glossina* spp.) (**Figure 5.18**). The early symptoms include confusion, difficulty sleeping, and lack of coordination. Left untreated, it is fatal.

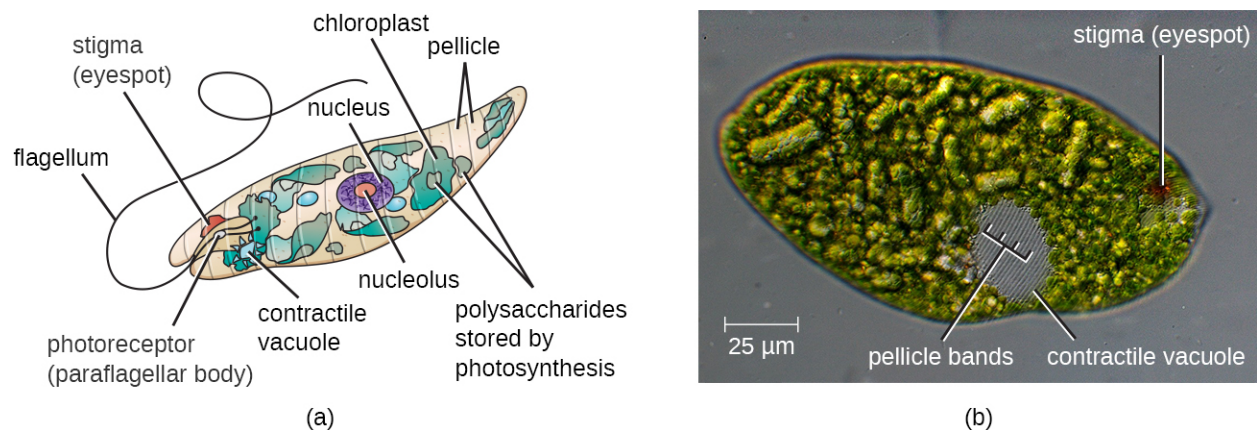


Figure 5.17 (a) This illustration of a *Euglena* shows the characteristic structures, such as the stigma and flagellum. (b) The pellicle, under the cell membrane, gives the cell its distinctive shape and is visible in this image as delicate parallel striations over the surface of the entire cell (especially visible over the grey contractile vacuole). (credit a: modification of work by Claudio Miklos; credit b: modification of work by David Shykind)

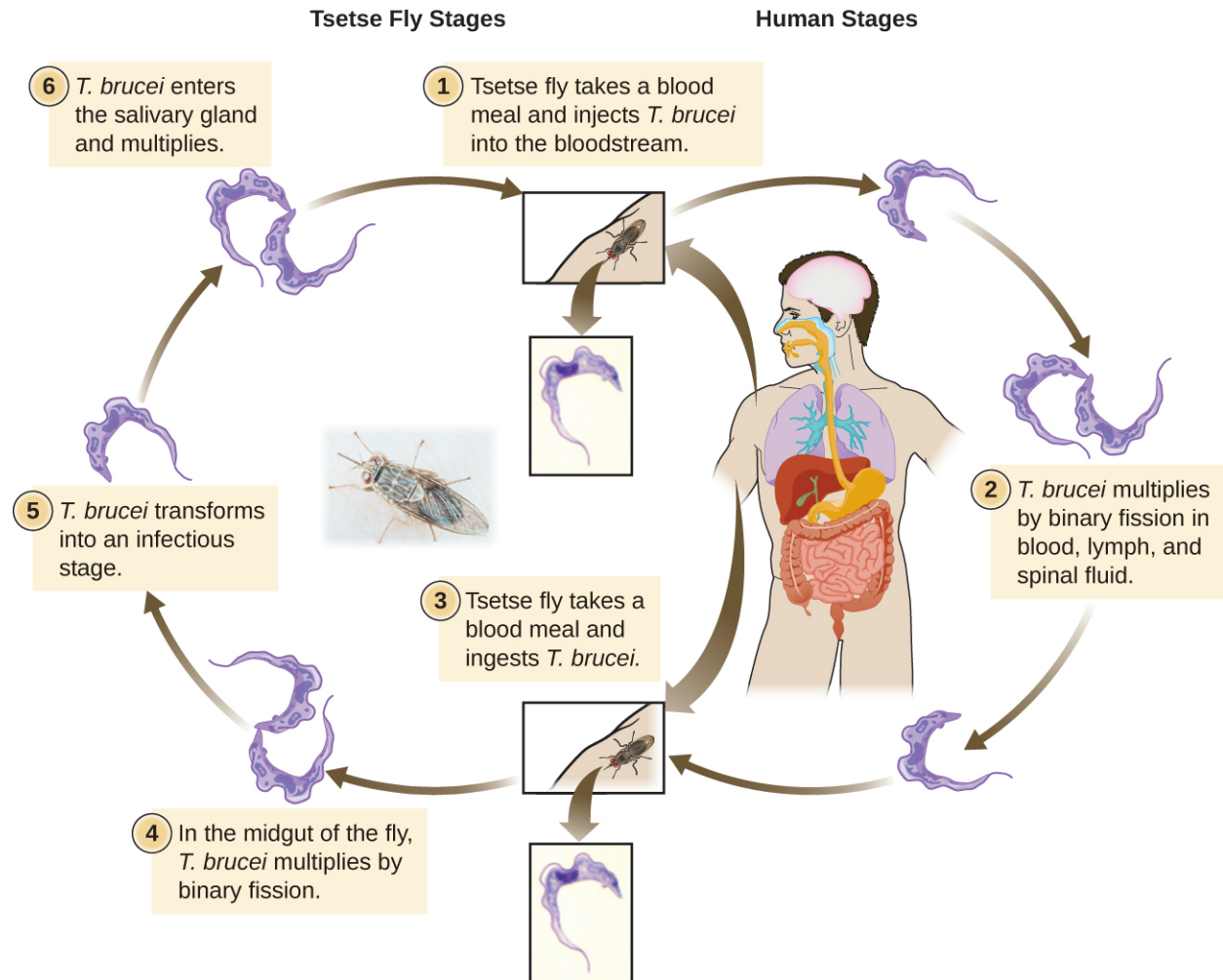


Figure 5.18 *Trypanosoma brucei*, the causative agent of African trypanosomiasis, spends part of its life cycle in the tsetse fly and part in humans. (credit “illustration”: modification of work by Centers for Disease Control and Prevention; credit “photo”: DPDx/Centers for Disease Control and Prevention)

Chagas’ disease originated and is most common in Latin America. The disease is transmitted by *Triatoma* spp., insects often called “kissing bugs,” and affects either the heart tissue or tissues of the digestive system. Untreated cases can eventually lead to heart failure or significant digestive or neurological disorders.

The genus *Leishmania* includes trypanosomes that cause disfiguring skin disease and sometimes systemic illness as well.

Eye on Ethics



Neglected Parasites

The Centers for Disease Control and Prevention (CDC) is responsible for identifying public health priorities in the United States and developing strategies to address areas of concern. As part of this mandate, the

CDC has officially identified five parasitic diseases it considers to have been neglected (i.e., not adequately studied). These neglected parasitic infections (NPIs) include toxoplasmosis, Chagas disease, toxocariasis (a nematode infection transmitted primarily by infected dogs), cysticercosis (a disease caused by a tissue infection of the tapeworm *Taenia solium*), and trichomoniasis (a sexually transmitted disease caused by the parabasalid *Trichomonas vaginalis*).

The decision to name these specific diseases as NPIs means that the CDC will devote resources toward improving awareness and developing better diagnostic testing and treatment through studies of available data. The CDC may also advise on treatment of these diseases and assist in the distribution of medications that might otherwise be difficult to obtain.^[5]

Of course, the CDC does not have unlimited resources, so by prioritizing these five diseases, it is effectively deprioritizing others. Given that many Americans have never heard of many of these NPIs, it is fair to ask what criteria the CDC used in prioritizing diseases. According to the CDC, the factors considered were the number of people infected, the severity of the illness, and whether the illness can be treated or prevented. Although several of these NPIs may seem to be more common outside the United States, the CDC argues that many cases in the United States likely go undiagnosed and untreated because so little is known about these diseases.^[6]

What criteria should be considered when prioritizing diseases for purposes of funding or research? Are those identified by the CDC reasonable? What other factors could be considered? Should government agencies like the CDC have the same criteria as private pharmaceutical research labs? What are the ethical implications of deprioritizing other potentially neglected parasitic diseases such as leishmaniasis?

5.2 Parasitic Helminths

Learning Objectives

- Explain why we include the study of parasitic worms within the discipline of microbiology
- Compare the basic morphology of the major groups of parasitic helminths
- Describe the characteristics of parasitic nematodes, and give an example of infective eggs and infective larvae
- Describe the characteristics of parasitic trematodes and cestodes, and give examples of each
- Identify examples of the primary causes of infections due to nematodes, trematodes, and cestodes
- Classify parasitic worms according to major groups

Parasitic helminths are animals that are often included within the study of microbiology because many species of these worms are identified by their microscopic eggs and larvae. There are two major groups of parasitic helminths: the roundworms (Nematoda) and flatworms (Platyhelminthes). Of the many species that exist in these groups, about half are parasitic and some are important human pathogens. As animals, they are multicellular and have organ systems. However, the parasitic species often have limited digestive tracts, nervous systems, and locomotor abilities. Parasitic forms may have complex reproductive cycles with several different life stages and more than one type of host. Some are **monoecious**, having both male and female reproductive organs in a single individual, while others are **dioecious**, each having either male or female reproductive organs.

5. Centers for Disease Control and Prevention. "Neglected Parasitic Infections (NPIs) in the United States." <http://www.cdc.gov/parasites/npi/>. Last updated July 10, 2014.

6. Centers for Disease Control and Prevention. "Fact Sheet: Neglected Parasitic Infections in the United States." http://www.cdc.gov/parasites/resources/pdf/npi_factsheet.pdf

Nematoda (Roundworms)

Phylum **Nematoda** (the roundworms) is a diverse group containing more than 15,000 species, of which several are important human parasites (**Figure 5.19**). These unsegmented worms have a full digestive system even when parasitic. Some are common intestinal parasites, and their eggs can sometimes be identified in feces or around the anus of infected individuals. *Ascaris lumbricoides* is the largest nematode intestinal parasite found in humans; females may reach lengths greater than 1 meter. *A. lumbricoides* is also very widespread, even in developed nations, although it is now a relatively uncommon problem in the United States. It may cause symptoms ranging from relatively mild (such as a cough and mild abdominal pain) to severe (such as intestinal blockage and impaired growth).

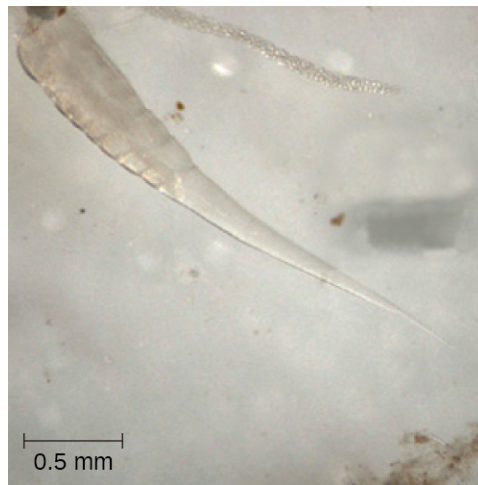


Figure 5.19 A micrograph of the nematode *Enterobius vermicularis*, also known as the pinworm. (credit: modification of work by Centers for Disease Control and Prevention)

Of all nematode infections in the United States, pinworm (caused by *Enterobius vermicularis*) is the most common. Pinworm causes sleeplessness and itching around the anus, where the female worms lay their eggs during the night. *Toxocara canis* and *T. cati* are nematodes found in dogs and cats, respectively, that can be transmitted to humans, causing toxocariasis. Antibodies to these parasites have been found in approximately 13.9% of the U.S. population, suggesting that exposure is common.^[7] Infection can cause larval migrans, which can result in vision loss and eye inflammation, or fever, fatigue, coughing, and abdominal pain, depending on whether the organism infects the eye or the viscera. Another common nematode infection is hookworm, which is caused by *Necator americanus* (the New World or North American hookworm) and *Ancylostoma duodenale* (the Old World hookworm). Symptoms of hookworm infection can include abdominal pain, diarrhea, loss of appetite, weight loss, fatigue, and anemia.

Trichinellosis, also called trichinosis, caused by *Trichinella spiralis*, is contracted by consuming undercooked meat, which releases the larvae and allows them to encyst in muscles. Infection can cause fever, muscle pains, and digestive system problems; severe infections can lead to lack of coordination, breathing and heart problems, and even death. Finally, heartworm in dogs and other animals is caused by the nematode *Dirofilaria immitis*, which is transmitted by mosquitoes. Symptoms include fatigue and cough; when left untreated, death may result.

Clinical Focus

Part 2

The physician explains to Sarah's mother that ringworm can be transferred between people through touch.

7. Won K, Kruszon-Moran D, Schantz P, Jones J. "National seroprevalence and risk factors for zoonotic *Toxocara* spp. infection." In: Abstracts of the 56th American Society of Tropical Medicine and Hygiene; Philadelphia, Pennsylvania; 2007 Nov 4-8.

"It's common in school children, because they often come in close contact with each other, but anyone can become infected," he adds. "Because you can transfer it through objects, locker rooms and public pools are also a potential source of infection. It's very common among wrestlers and athletes in other contact sports."

Looking very uncomfortable, Sarah says to her mother "I want this worm out of me."

The doctor laughs and says, "Sarah, you're in luck because ringworm is just a name; it is not an actual worm. You have nothing wriggling around under your skin."

"Then what is it?" asks Sarah.

- What type of pathogen causes ringworm?

Jump to the **next** Clinical Focus box. Go back to the **previous** Clinical Focus box.



Check Your Understanding

- What is the most common nematode infection in the United States?

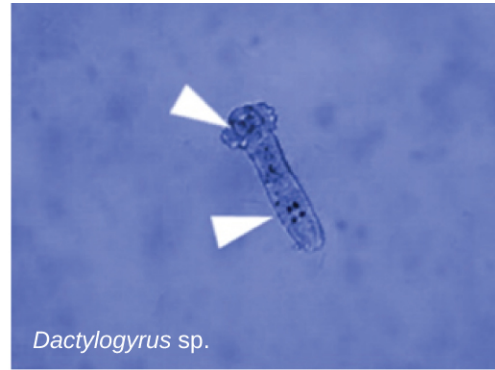
Platyhelminths (Flatworms)

Phylum **Platyhelminthes** (the platyhelminths) are flatworms. This group includes the flukes, tapeworms, and the turbellarians, which include planarians. The flukes and tapeworms are medically important parasites (**Figure 5.20**).

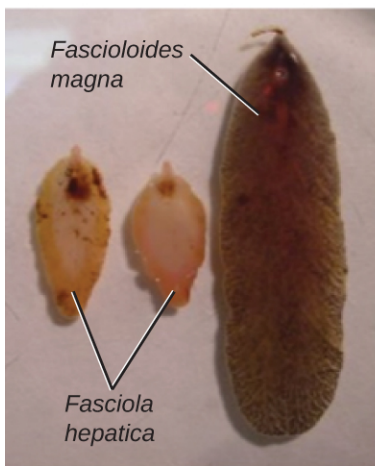
The **flukes** (trematodes) are nonsegmented flatworms that have an oral sucker (**Figure 5.21**) (and sometimes a second ventral sucker) and attach to the inner walls of intestines, lungs, large blood vessels, or the liver. Trematodes have complex life cycles, often with multiple hosts. Several important examples are the liver flukes (*Clonorchis* and *Opisthorchis*), the intestinal fluke (*Fasciolopsis buski*), and the oriental lung fluke (*Paragonimus westermani*). Schistosomiasis is a serious parasitic disease, considered second in the scale of its impact on human populations only to malaria. The parasites *Schistosoma mansoni*, *S. haematobium*, and *S. japonicum*, which are found in freshwater snails, are responsible for schistosomiasis (**Figure 5.22**). Immature forms burrow through the skin into the blood. They migrate to the lungs, then to the liver and, later, other organs. Symptoms include anemia, malnutrition, fever, abdominal pain, fluid buildup, and sometimes death.



(a) Class Turbellaria



(b) Class Monogenea



(c) Class Trematoda



(d) Class Cestoda

Figure 5.20 Phylum Platyhelminthes is divided into four classes. (a) Class Turbellaria includes the Bedford's flatworm (*Pseudobiceros bedfordi*), which is about 8–10 cm long. (b) The parasitic class Monogenea includes *Dactylogyrus* spp. Worms in this genus are commonly called gill flukes. The specimen pictured here is about 0.2 mm long and has two anchors, indicated by arrows, that it uses to latch onto the gills of host fish. (c) The Trematoda class includes the common liver fluke *Fasciola hepatica* and the giant liver fluke *Fascioloides magna* (right). The *F. magna* specimen shown here is about 7 cm long. (d) Class Cestoda includes tapeworms such as *Taenia saginata*, which infects both cattle and humans and can reach lengths of 4–10 meters; the specimen shown here is about 4 meters long. (credit c: modification of work by "Flukeman"/Wikimedia Commons)

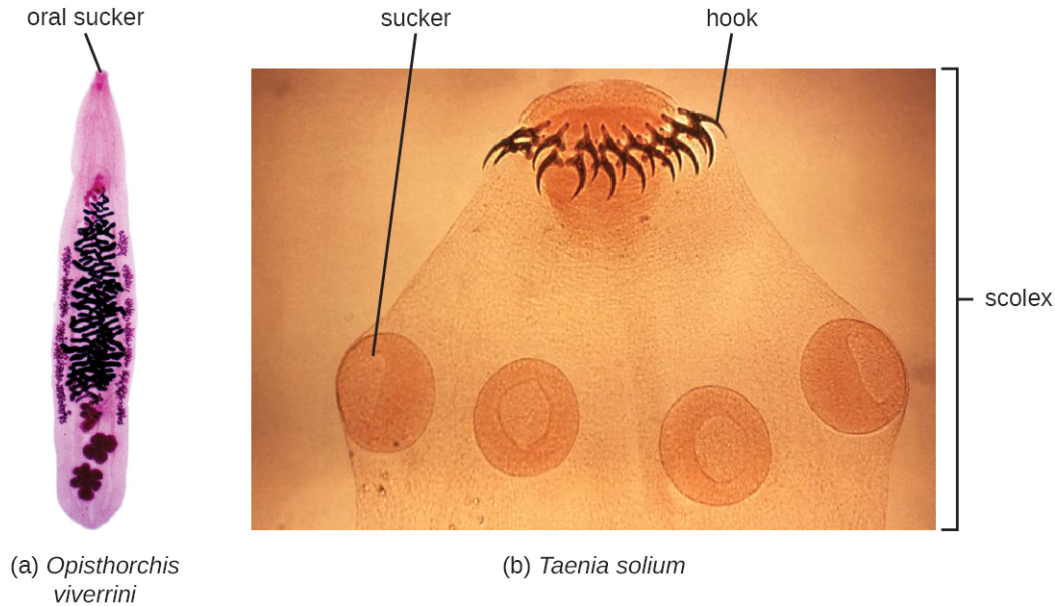


Figure 5.21 (a) The oral sucker is visible on the anterior end of this liver fluke, *Opisthorchis viverrini*. (b) This micrograph shows the scolex of the cestode *Taenia solium*, also known as the pork tapeworm. The visible suckers and hooks allow the worm to attach itself to the inner wall of the intestine. (credit a: modification of work by Sripa B, Kaewkes S, Sithithaworn P, Mairiang E, Laha T, and Smout M; credit b: modification of work by Centers for Disease Control and Prevention)

The other medically important group of platyhelminths are commonly known as **tapeworms** (cestodes) and are segmented flatworms that may have suckers or hooks at the **scolex** (head region) (**Figure 5.21**). Tapeworms use these suckers or hooks to attach to the wall of the small intestine. The body of the worm is made up of segments called **proglottids** that contain reproductive structures; these detach when the gametes are fertilized, releasing gravid proglottids with eggs. Tapeworms often have an intermediate host that consumes the eggs, which then hatch into a larval form called an oncosphere. The oncosphere migrates to a particular tissue or organ in the intermediate host, where it forms cysticerci. After being eaten by the definitive host, the cysticerci develop into adult tapeworms in the host's digestive system (**Figure 5.23**). *Taenia saginata* (the beef tapeworm) and *T. solium* (the pork tapeworm) enter humans through ingestion of undercooked, contaminated meat. The adult worms develop and reside in the intestine, but the larval stage may migrate and be found in other body locations such as skeletal and smooth muscle. The beef tapeworm is relatively benign, although it can cause digestive problems and, occasionally, allergic reactions. The pork tapeworm can cause more serious problems when the larvae leave the intestine and colonize other tissues, including those of the central nervous system. *Diphyllobothrium latum* is the largest human tapeworm and can be ingested in undercooked fish. It can grow to a length of 15 meters. *Echinococcus granulosus*, the dog tapeworm, can parasitize humans and uses dogs as an important host.

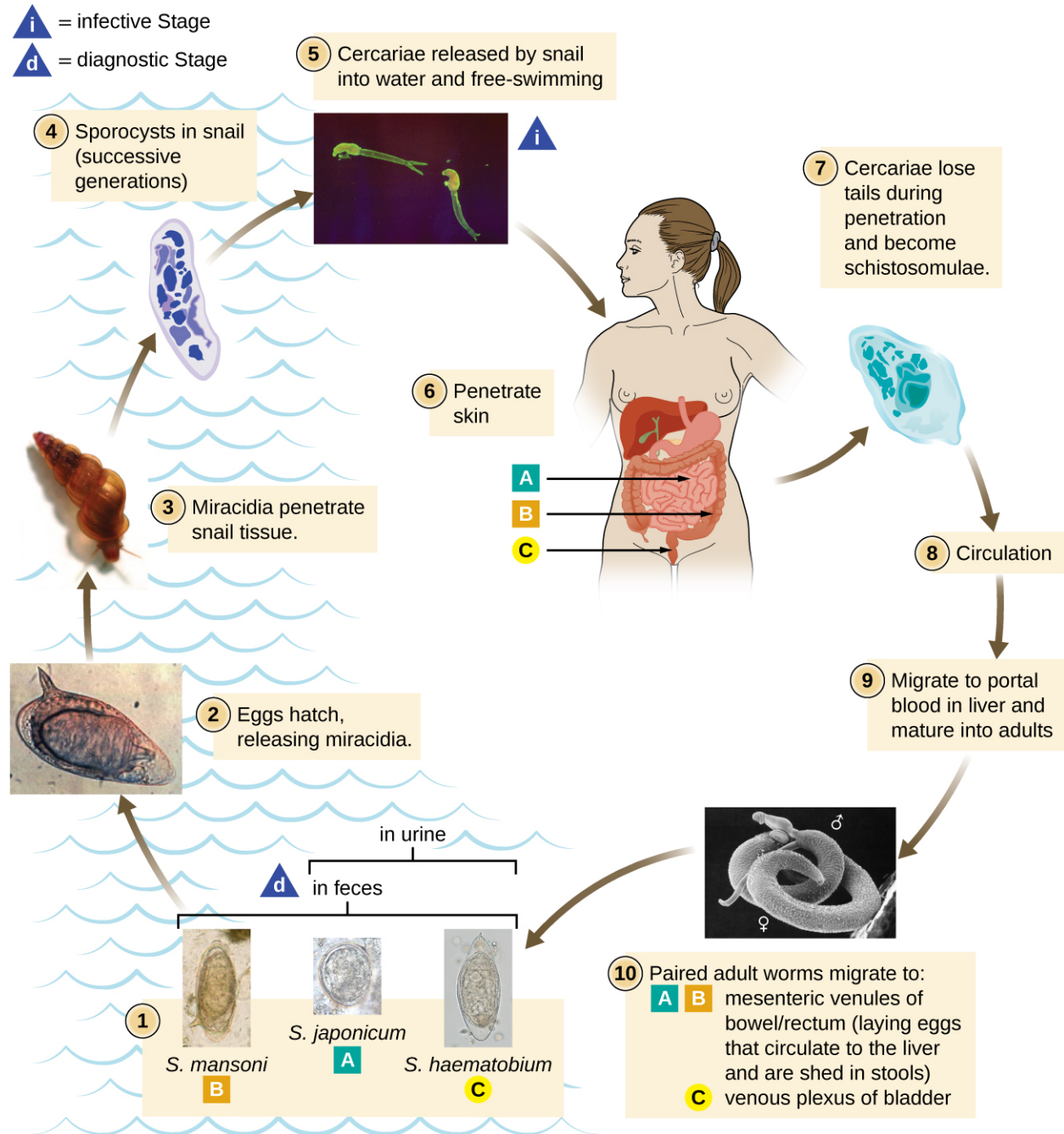


Figure 5.22 The life cycle of *Schistosoma* spp. includes several species of water snails, which serve as secondary hosts. The parasite is transmitted to humans through contact with contaminated water and takes up residence in the veins of the digestive system. Eggs escape the host in the urine or feces and infect a snail to complete the life cycle. (credit “illustration”: modification of work by Centers for Disease Control and Prevention; credit “step 3 photo”: modification of work by Fred A. Lewis, Yung-san Liang, Nithya Raghavan & Matty Knight)

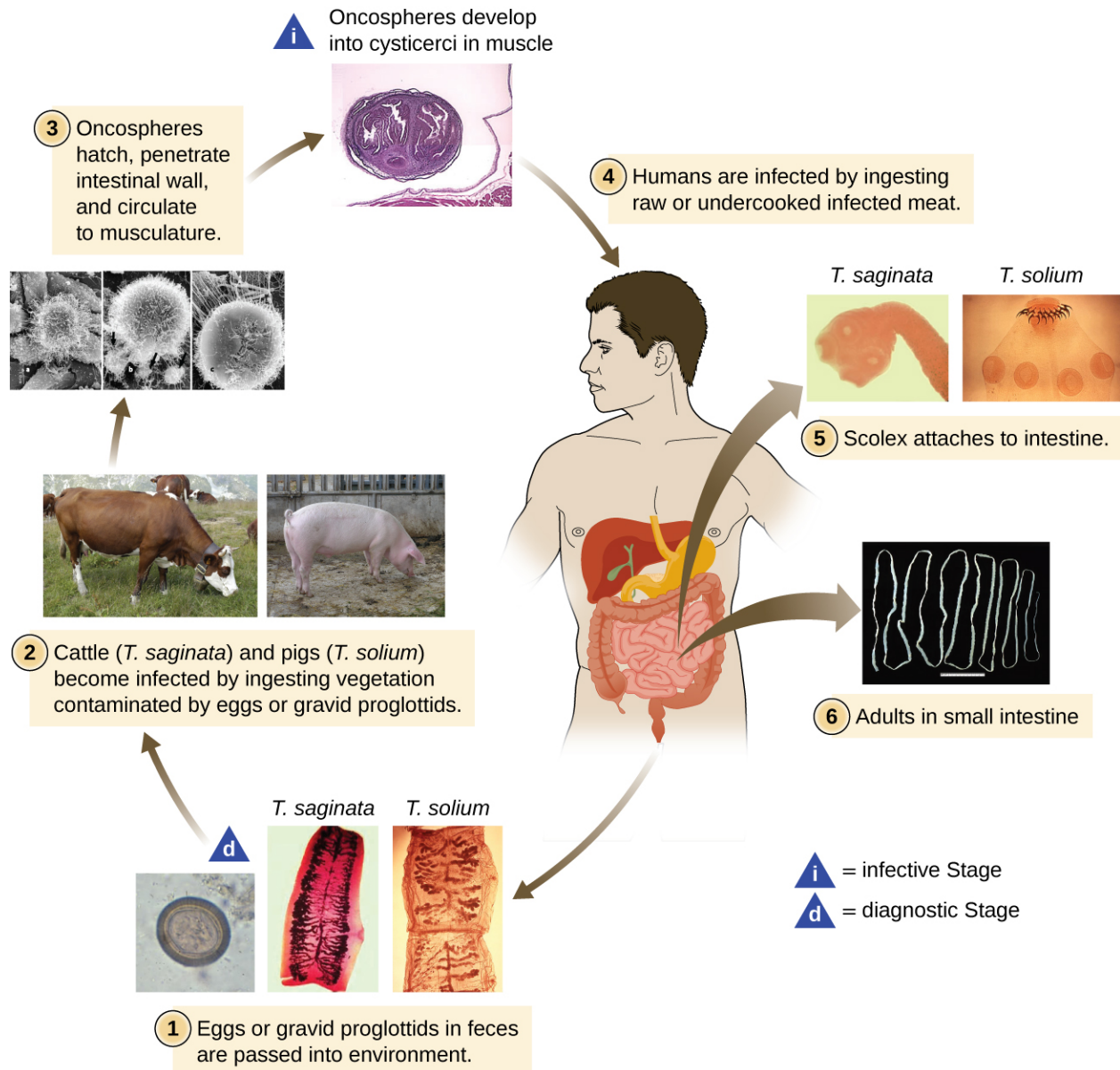


Figure 5.23 Life cycle of a tapeworm. (credit "illustration": modification of work by Centers for Disease Control and Prevention; credit "step 3 micrographs": modification of work by American Society for Microbiology)



Check Your Understanding

- What group of medically important flatworms is segmented and what group is unsegmented?

Micro Connections

Food for Worms?

For residents of temperate, developed countries, it may be difficult to imagine just how common helminth infections are in the human population. In fact, they are quite common and even occur frequently in the United States. Worldwide, approximately 807–1,221 million people are infected with *Ascaris lumbricoides* (perhaps one-sixth of the human population) and far more are infected if all nematode species are considered.^[8] Rates of infection are relatively high even in industrialized nations. Approximately 604–795 million people are infected with whipworm (*Trichuris*) worldwide (*Trichuris* can also infect dogs), and 576–740 million people are infected with hookworm (*Necator americanus* and *Ancylostoma duodenale*).^[9] *Toxocara*, a nematode parasite of dogs and cats, is also able to infect humans. It is widespread in the United States, with about 10,000 symptomatic cases annually. However, one study found 14% of the population (more than 40 million Americans) was seropositive, meaning they had been exposed to the parasite at one time. More than 200 million people have schistosomiasis worldwide. Most of the World Health Organization (WHO) neglected tropical diseases are helminths. In some cases, helminths may cause subclinical illnesses, meaning the symptoms are so mild that they go unnoticed. In other cases, the effects may be more severe or chronic, leading to fluid accumulation and organ damage. With so many people affected, these parasites constitute a major global public health concern.

Micro Connections

Eradicating the Guinea Worm

Dracunculiasis, or Guinea worm disease, is caused by a nematode called *Dracunculus medinensis*. When people consume contaminated water, water fleas (small crustaceans) containing the nematode larvae may be ingested. These larvae migrate out of the intestine, mate, and move through the body until females eventually emerge (generally through the feet). While Guinea worm disease is rarely fatal, it is extremely painful and can be accompanied by secondary infections and edema (Figure 5.24).



Figure 5.24 The Guinea worm can be removed from a leg vein of an infected person by gradually winding it around a stick, like this matchstick. (credit: Centers for Disease Control and Prevention)

An eradication campaign led by WHO, the CDC, the United Nations Children's Fund (UNICEF), and the Carter Center (founded by former U.S. president Jimmy Carter) has been extremely successful in reducing cases of dracunculiasis. This has been possible because diagnosis is straightforward, there is an inexpensive method of control, there is no animal reservoir, the water fleas are not airborne (they are restricted to still water),

8. Fenwick, A. "The global burden of neglected tropical diseases." *Public health* 126 no.3 (Mar 2012): 233–6.

9. de Silva, N., et. al. (2003). "Soil-transmitted helminth infections: updating the global picture". *Trends in Parasitology* 19 (December 2003): 547–51.

the disease is geographically limited, and there has been a commitment from the governments involved. Additionally, no vaccines or medication are required for treatment and prevention. In 1986, 3.5 million people were estimated to be affected. After the eradication campaign, which included helping people in affected areas learn to filter water with cloth, only four countries continue to report the disease (Chad, Mali, South Sudan, and Ethiopia) with a total of 126 cases reported to WHO in 2014.^[10]

5.3 Fungi

Learning Objectives

- Explain why the study of fungi such as yeast and molds is within the discipline of microbiology
- Describe the unique characteristics of fungi
- Describe examples of asexual and sexual reproduction of fungi
- Compare the major groups of fungi in this chapter, and give examples of each
- Identify examples of the primary causes of infections due to yeasts and molds
- Identify examples of toxin-producing fungi
- Classify fungal organisms according to major groups

The fungi comprise a diverse group of organisms that are heterotrophic and typically saprozoic. In addition to the well-known macroscopic fungi (such as mushrooms and molds), many unicellular yeasts and spores of macroscopic fungi are microscopic. For this reason, fungi are included within the field of microbiology.

Fungi are important to humans in a variety of ways. Both microscopic and macroscopic fungi have medical relevance, with some pathogenic species that can cause **mycoses** (illnesses caused by fungi). Some pathogenic fungi are opportunistic, meaning that they mainly cause infections when the host's immune defenses are compromised and do not normally cause illness in healthy individuals. Fungi are important in other ways. They act as decomposers in the environment, and they are critical for the production of certain foods such as cheeses. Fungi are also major sources of antibiotics, such as penicillin from the fungus *Penicillium*.

Characteristics of Fungi

Fungi have well-defined characteristics that set them apart from other organisms. Most multicellular fungal bodies, commonly called molds, are made up of filaments called **hyphae**. Hyphae can form a tangled network called a **mycelium** and form the **thallus** (body) of fleshy fungi. Hyphae that have walls between the cells are called **septate hyphae**; hyphae that lack walls and cell membranes between the cells are called nonseptate or **coenocytic hyphae**. (Figure 5.25).

10. World Health Organization. "South Sudan Reports Zero Cases of Guinea-Worm Disease for Seventh Consecutive Month." 2016. http://www.who.int/dracunculiasis/no_new_case_for_seventh_consecutive_months/en/. Accessed May 2, 2016.

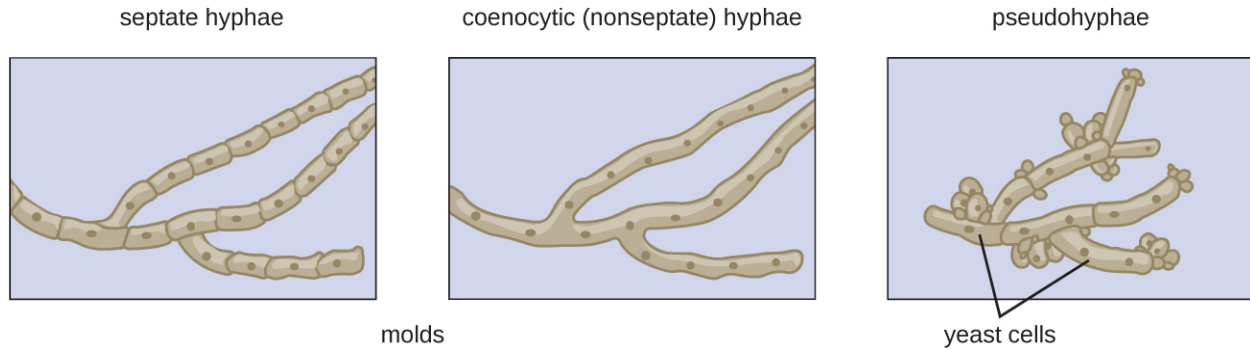


Figure 5.25 Multicellular fungi (molds) form hyphae, which may be septate or nonseptate. Unicellular fungi (yeasts) cells form pseudohyphae from individual yeast cells.

In contrast to molds, yeasts are unicellular fungi. The **budding yeasts** reproduce asexually by budding off a smaller daughter cell; the resulting cells may sometimes stick together as a short chain or **pseudohypha** (**Figure 5.25**). *Candida albicans* is a common yeast that forms pseudohyphae; it is associated with various infections in humans, including vaginal yeast infections, oral thrush, and candidiasis of the skin.

Some fungi are dimorphic, having more than one appearance during their life cycle. These **dimorphic fungi** may be able to appear as yeasts or molds, which can be important for infectivity. They are capable of changing their appearance in response to environmental changes such as nutrient availability or fluctuations in temperature, growing as a mold, for example, at 25 °C (77 °F), and as yeast cells at 37 °C (98.6 °F). This ability helps dimorphic fungi to survive in diverse environments. *Histoplasma capsulatum*, the pathogen that causes histoplasmosis, a lung infection, is an example of a dimorphic fungus (**Figure 5.26**).

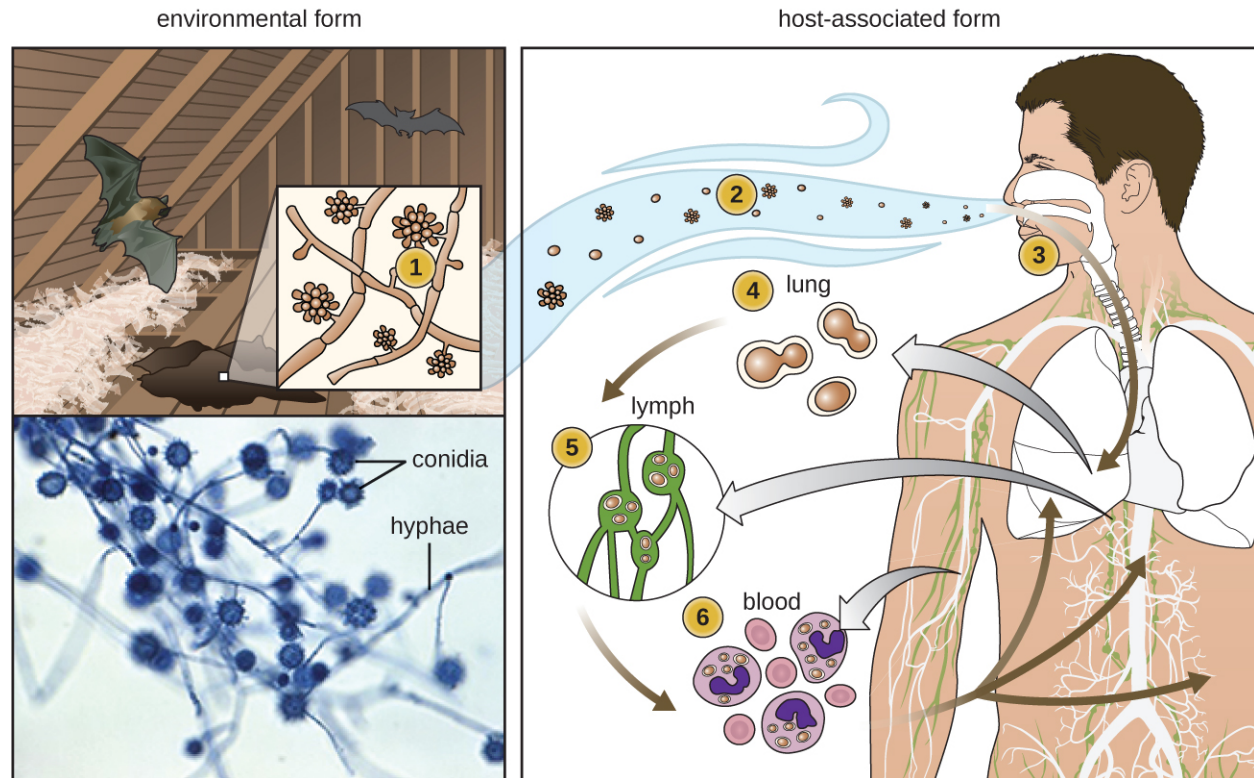


Figure 5.26 *Histoplasma capsulatum* is a dimorphic fungus that grows in soil exposed to bird feces or bat feces (guano) (top left). It can change forms to survive at different temperatures. In the outdoors, it typically grows as a mycelium (as shown in the micrograph, bottom left), but when the spores are inhaled (right), it responds to the high internal temperature of the body (37 °C [98.6 °F]) by turning into a yeast that can multiply in the lungs, causing the chronic lung disease histoplasmosis. (credit: modification of work by Centers for Disease Control and Prevention)

There are notable unique features in fungal cell walls and membranes. Fungal cell walls contain **chitin**, as opposed to the cellulose found in the cell walls of plants and many protists. Additionally, whereas animals have cholesterol in their cell membranes, fungal cell membranes have different sterols called ergosterols. Ergosterols are often exploited as targets for antifungal drugs.

Fungal life cycles are unique and complex. Fungi reproduce sexually either through cross- or self-fertilization. Haploid fungi form hyphae that have gametes at the tips. Two different mating types (represented as “+ type” and “– type”) are involved. The cytoplasm of the + and – type gametes fuse (in an event called plasmogamy), producing a cell with two distinct nuclei (a **dikaryotic** cell). Later, the nuclei fuse (in an event called karyogamy) to create a diploid zygote. The zygote undergoes meiosis to form **spores** that germinate to start the haploid stage, which eventually creates more haploid mycelia (**Figure 5.27**). Depending on the taxonomic group, these sexually produced spores are known as zygospores (in Zygomycota), ascospores (in Ascomycota), or basidiospores (in Basidiomycota) (**Figure 5.28**).

Fungi may also exhibit asexual reproduction by mitosis, mitosis with budding, fragmentation of hyphae, and formation of asexual spores by mitosis. These spores are specialized cells that, depending on the organism, may have unique characteristics for survival, reproduction, and dispersal. Fungi exhibit several types of asexual spores and these can be important in classification.

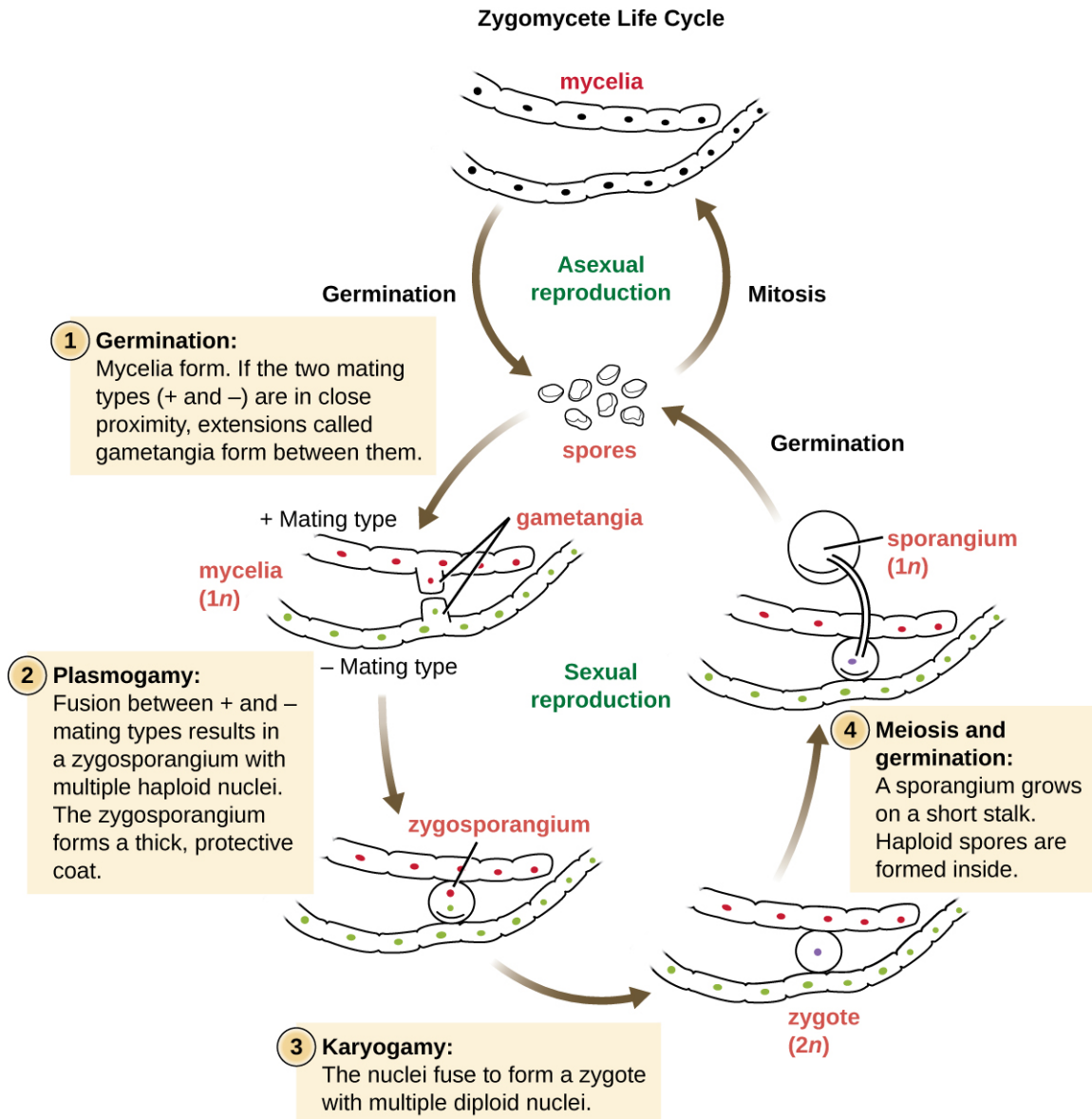


Figure 5.27 Zygomycetes have sexual and asexual life cycles. In the sexual life cycle, + and - mating types conjugate to form a zygosporangium.



Figure 5.28 These images show asexually produced spores. (a) This brightfield micrograph shows the release of spores from a sporangium at the end of a hypha called a sporangiophore. The organism is a *Mucor* sp. fungus, a mold often found indoors. (b) Sporangia grow at the ends of stalks, which appear as the white fuzz seen on this bread mold, *Rhizopus stolonifer*. The tips of bread mold are the dark, spore-containing sporangia. (credit a: modification of work by Centers for Disease Control and Prevention; credit b right: modification of work by “Andrew”/Flickr)



Check Your Understanding

- Is a dimorphic fungus a yeast or a mold? Explain.

Fungal Diversity

The fungi are very diverse, comprising seven major groups. Not all of the seven groups contain pathogens. Some of these groups are generally associated with plants and include plant pathogens. For example, Urediniomycetes and Ustilagomycetes include the plant rusts and smuts, respectively. These form reddish or dark masses, respectively, on plants as rusts (red) or smuts (dark). Some species have substantial economic impact because of their ability to reduce crop yields. Glomeromycota includes the mycorrhizal fungi, important symbionts with plant roots that can promote plant growth by acting like an extended root system. The Glomeromycota are obligate symbionts, meaning that they can only survive when associated with plant roots; the fungi receive carbohydrates from the plant and the plant benefits from the increased ability to take up nutrients and minerals from the soil. The Chytridiomycetes (chytrids) are small fungi, but are extremely ecologically important. Chytrids are generally aquatic and have flagellated, motile gametes; specific types are implicated in amphibian declines around the world. Because of their medical importance, we will focus on Zygomycota, Ascomycota, Basidiomycota, and Microsporidia. **Figure 5.33** summarizes the characteristics of these medically important groups of fungi.

The Zygomycota (zygomycetes) are mainly saprophytes with coenocytic hyphae and haploid nuclei. They use sporangiospores for asexual reproduction. The group name comes from the **zygospores** that they use for sexual reproduction (**Figure 5.27**), which have hard walls formed from the fusion of reproductive cells from two individuals. Zygomycetes are important for food science and as crop pathogens. One example is *Rhizopus stolonifer* (**Figure 5.28**), an important bread mold that also causes rice seedling blight. *Mucor* is a genus of fungi that can potentially cause necrotizing infections in humans, although most species are intolerant of temperatures found in mammalian bodies (**Figure 5.28**).

The Ascomycota include fungi that are used as food (edible mushrooms, morels, and truffles), others that are common causes of food spoilage (bread molds and plant pathogens), and still others that are human pathogens. Ascomycota may have septate hyphae and cup-shaped fruiting bodies called **ascocarps**. Some genera of Ascomycota use sexually produced **ascospores** as well as asexual spores called **conidia**, but sexual phases have not been discovered or described for others. Some produce an **ascus** containing ascospores within an ascocarp (**Figure 5.29**).

Examples of the Ascomycota include several bread molds and minor pathogens, as well as species capable of causing

more serious mycoses. Species in the genus *Aspergillus* are important causes of allergy and infection, and are useful in research and in the production of certain fermented alcoholic beverages such as Japanese *sake*. The fungus *Aspergillus flavus*, a contaminant of nuts and stored grains, produces an **aflatoxin** that is both a toxin and the most potent known natural carcinogen. *Neurospora crassa* is of particular use in genetics research because the spores produced by meiosis are kept inside the ascus in a row that reflects the cell divisions that produced them, giving a direct view of segregation and assortment of genes (**Figure 5.30**). *Penicillium* produces the antibiotic penicillin (**Figure 5.29**).

Many species of ascomycetes are medically important. A large number of species in the genera *Trichophyton*, *Microsporum*, and *Epidermophyton* are dermatophytes, pathogenic fungi capable of causing skin infections such as athlete's foot, jock itch, and ringworm. *Blastomyces dermatitidis* is a dimorphic fungus that can cause blastomycosis, a respiratory infection that, if left untreated, can become disseminated to other body sites, sometimes leading to death. Another important respiratory pathogen is the dimorphic fungus *Histoplasma capsulatum* (**Figure 5.26**), which is associated with birds and bats in the Ohio and Mississippi river valleys. *Coccidioides immitis* causes the serious lung disease Valley fever. *Candida albicans*, the most common cause of vaginal and other yeast infections, is also an ascomycete fungus; it is a part of the normal microbiota of the skin, intestine, genital tract, and ear (**Figure 5.29**). Ascomycetes also cause plant diseases, including ergot infections, Dutch elm disease, and powdery mildews.

Saccharomyces yeasts, including the baker's yeast *S. cerevisiae*, are unicellular ascomycetes with haploid and diploid stages (**Figure 5.31**). This and other *Saccharomyces* species are used for brewing beer.

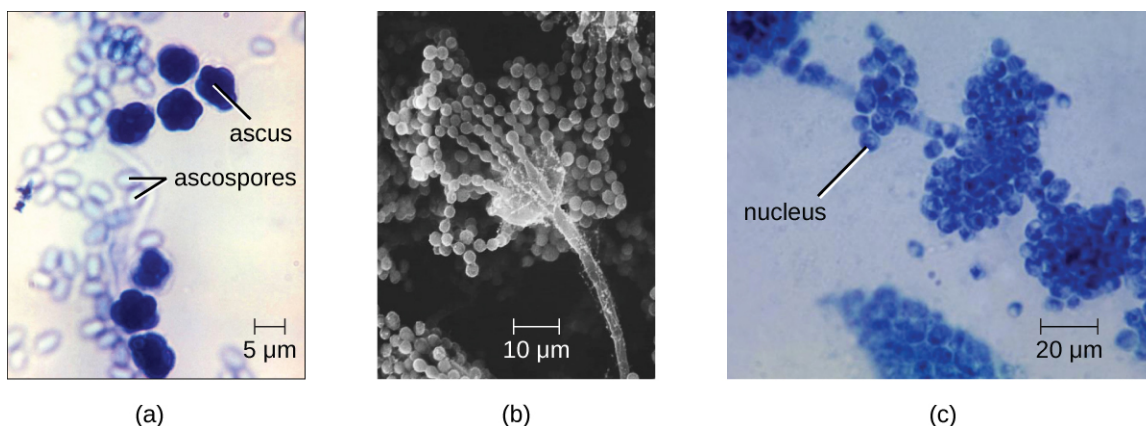


Figure 5.29 (a) This brightfield micrograph shows ascospores being released from asci in the fungus *Talaromyces flavus* var. *flavus*. (b) This electron micrograph shows the conidia (spores) borne on the conidiophore of *Aspergillus*, a type of toxic fungus found mostly in soil and plants. (c) This brightfield micrograph shows the yeast *Candida albicans*, the causative agent of candidiasis and thrush. (credit a, b, c: modification of work by Centers for Disease Control and Prevention)

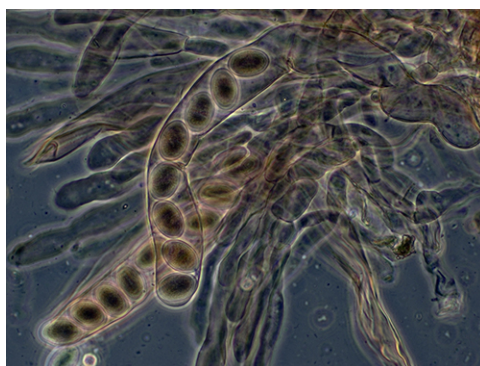


Figure 5.30 These ascospores, lined up within an ascus, are produced sexually. (credit: Peter G. Werner)

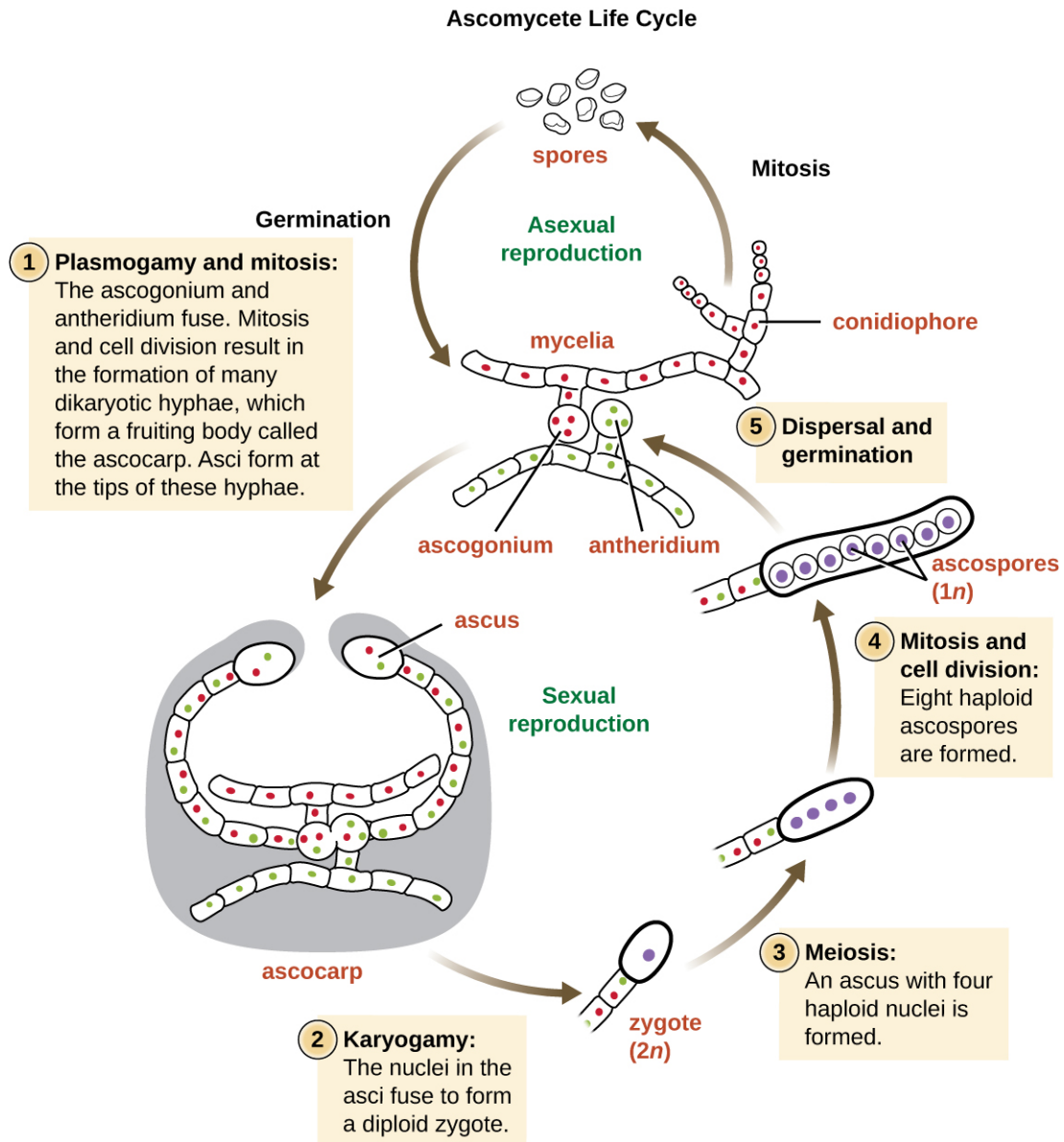


Figure 5.31 The life cycle of an ascomycete is characterized by the production of asci during the sexual phase. The haploid phase is the predominant phase of the life cycle.

The Basidiomycota (basidiomycetes) are fungi that have **basidia** (club-shaped structures) that produce **basidiospores** (spores produced through budding) within fruiting bodies called **basidiocarps** (Figure 5.32). They are important as decomposers and as food. This group includes rusts, stinkhorns, puffballs, and mushrooms. Several species are of particular importance. *Cryptococcus neoformans*, a fungus commonly found as a yeast in the environment, can cause serious lung infections when inhaled by individuals with weakened immune systems. The edible meadow mushroom, *Agaricus campestris*, is a basidiomycete, as is the poisonous mushroom *Amanita phalloides*, known as the death cap. The deadly toxins produced by *A. phalloides* have been used to study transcription.

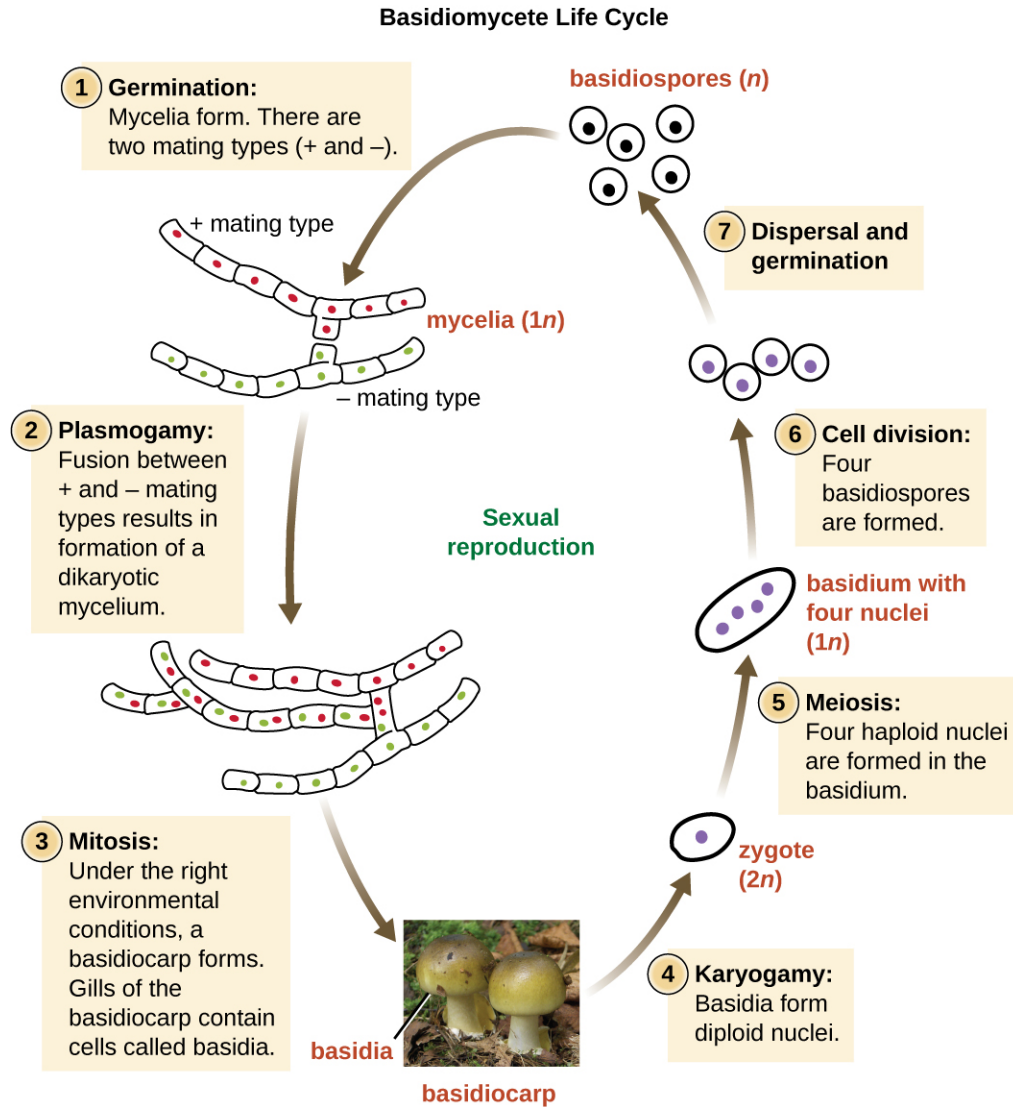


Figure 5.32 The life cycle of a basidiomycete alternates a haploid generation with a prolonged stage in which two nuclei (dikaryon) are present in the hyphae.

Finally, the **Microsporidia** are unicellular fungi that are obligate intracellular parasites. They lack mitochondria, peroxisomes, and centrioles, but their spores release a unique **polar tubule** that pierces the host cell membrane to allow the fungus to gain entry into the cell. A number of microsporidia are human pathogens, and infections with microsporidia are called microsporidiosis. One pathogenic species is *Enterocystozoan bienewsi*, which can cause symptoms such as diarrhea, cholecystitis (inflammation of the gall bladder), and in rare cases, respiratory illness.

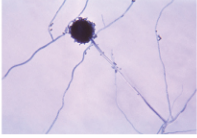

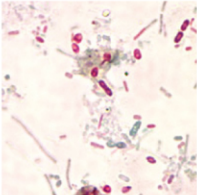
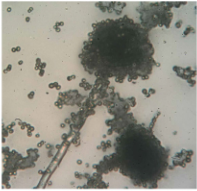
Select Groups of Fungi				
Group	Characteristics	Examples	Medically Important Species	Image
Ascomycota	Septate hyphae Ascus with ascospores in ascocarp Conidiospores	Cup fungi Edible mushrooms Morels Truffles <i>Neurospora</i> <i>Penicillium</i>	<i>Aspergillus</i> spp. <i>Trichophyton</i> spp. <i>Microsporum</i> spp. <i>Epidermophyton</i> spp. <i>Blastomyces dermatitidis</i> <i>Histoplasma capsulatum</i>	 <i>Aspergillus niger</i>
Basidiomycota	Basidia produce basidiospores in a basidiocarp	Club fungi Rusts Stinkhorns Puffballs Mushrooms <i>Cryptococcus neoformans</i> <i>Amanita phalloides</i>	<i>Cryptococcus neoformans</i>	 <i>Amanita phalloides</i>
Microsporidia	Lack mitochondria, peroxisomes, centrioles Spores produce a polar tube	<i>Enterocystozoan bienewisi</i>	<i>Enterocystozoan bienewisi</i>	 Microsporidia (unidentified)
Zygomycota	Mainly saprophytes Coenocytic hyphae Haploid nuclei Zygospores	<i>Rhizopus stolonifera</i>	<i>Mucor</i> spp.	 <i>Rhizopus</i> sp.

Figure 5.33 (credit "Ascomycota": modification of work by Dr. Lucille Georg, Centers for Disease Control and Prevention; credit "Microsporidia": modification of work by Centers for Disease Control and Prevention)



Check Your Understanding

- Which group of fungi appears to be associated with the greatest number of human diseases?

Micro Connections

Eukaryotic Pathogens in Eukaryotic Hosts

When we think about antimicrobial medications, antibiotics such as penicillin often come to mind. Penicillin and related antibiotics interfere with the synthesis of peptidoglycan cell walls, which effectively targets bacterial cells. These antibiotics are useful because humans (like all eukaryotes) do not have peptidoglycan cell walls.

Developing medications that are effective against eukaryotic cells but not harmful to human cells is more difficult. Despite huge morphological differences, the cells of humans, fungi, and protists are similar in terms of their ribosomes, cytoskeletons, and cell membranes. As a result, it is more challenging to develop medications that target protozoans and fungi in the same way that antibiotics target prokaryotes.

Fungicides have relatively limited modes of action. Because fungi have ergosterols (instead of cholesterol) in their cell membranes, the different enzymes involved in sterol production can be a target of some medications. The azole and morpholine fungicides interfere with the synthesis of membrane sterols. These are used widely in agriculture (fenpropimorph) and clinically (e.g., miconazole). Some antifungal medications target the chitin cell walls of fungi. Despite the success of these compounds in targeting fungi, antifungal medications for systemic infections still tend to have more toxic side effects than antibiotics for bacteria.

Clinical Focus

Part 3

Sarah is relieved the ringworm is not an actual worm, but wants to know what it really is. The physician explains that ringworm is a fungus. He tells her that she will not see mushrooms popping out of her skin, because this fungus is more like the invisible part of a mushroom that hides in the soil. He reassures her that they are going to get the fungus out of her too.

The doctor cleans and then carefully scrapes the lesion to place a specimen on a slide. By looking at it under a microscope, the physician is able to confirm that a fungal infection is responsible for Sarah's lesion. In **Figure 5.34**, it is possible to see macro- and microconidia in *Trichophyton rubrum*. Cell walls are also visible. Even if the pathogen resembled a helminth under the microscope, the presence of cell walls would rule out the possibility because animal cells lack cell walls.

The doctor prescribes an antifungal cream for Sarah's mother to apply to the ringworm. Sarah's mother asks, "What should we do if it doesn't go away?"

- Can all forms of ringworm be treated with the same antifungal medication?

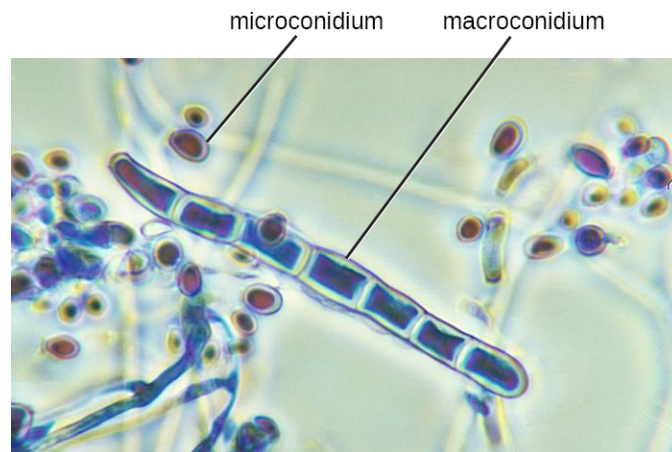


Figure 5.34 This micrograph shows hyphae (macroconidium) and microconidia of *Trichophyton rubrum*, a dermatophyte responsible for fungal infections of the skin. (credit: modification of work by Centers for Disease Control and Prevention)

Jump to the **next** Clinical Focus box. Go back to the **previous** Clinical Focus box.

5.4 Algae

Learning Objectives

- Explain why algae are included within the discipline of microbiology
- Describe the unique characteristics of algae
- Identify examples of toxin-producing algae
- Compare the major groups of algae in this chapter, and give examples of each
- Classify algal organisms according to major groups

The **algae** are autotrophic protists that can be unicellular or multicellular. These organisms are found in the supergroups Chromalveolata (dinoflagellates, diatoms, golden algae, and brown algae) and Archaeplastida (red algae and green algae). They are important ecologically and environmentally because they are responsible for the production of approximately 70% of the oxygen and organic matter in aquatic environments. Some types of algae, even those that are microscopic, are regularly eaten by humans and other animals. Additionally, algae are the source for **agar**, agarose, and **carrageenan**, solidifying agents used in laboratories and in food production. Although algae are typically not pathogenic, some produce toxins. Harmful **algal blooms**, which occur when algae grow quickly and produce dense populations, can produce high concentrations of toxins that impair liver and nervous-system function in aquatic animals and humans.

Like protozoans, algae often have complex cell structures. For instance, algal cells can have one or more chloroplasts that contain structures called **pyrenoids** to synthesize and store starch. The chloroplasts themselves differ in their number of membranes, indicative of secondary or rare tertiary endosymbiotic events. Primary chloroplasts have two membranes—one from the original cyanobacteria that the ancestral eukaryotic cell engulfed, and one from the plasma membrane of the engulfing cell. Chloroplasts in some lineages appear to have resulted from secondary endosymbiosis, in which another cell engulfed a green or red algal cell that already had a primary chloroplast within it. The engulfing cell destroyed everything except the chloroplast and possibly the cell membrane of its original cell, leaving three or four membranes around the chloroplast. Different algal groups have different pigments, which are

reflected in common names such as red algae, brown algae, and green algae.

Some algae, the seaweeds, are macroscopic and may be confused with plants. Seaweeds can be red, brown, or green, depending on their photosynthetic pigments. Green algae, in particular, share some important similarities with land plants; however, there are also important distinctions. For example, seaweeds do not have true tissues or organs like plants do. Additionally, seaweeds do not have a waxy cuticle to prevent desiccation. Algae can also be confused with cyanobacteria, photosynthetic bacteria that bear a resemblance to algae; however, cyanobacteria are prokaryotes (see **Nonproteobacteria Gram-negative Bacteria and Phototrophic Bacteria**).

Algae have a variety of life cycles. Reproduction may be asexual by mitosis or sexual using gametes.

Algal Diversity

Although the algae and protozoa were formerly separated taxonomically, they are now mixed into supergroups. The algae are classified within the Chromalveolata and the Archaeplastida. Although the Euglenozoa (within the supergroup Excavata) include photosynthetic organisms, these are not considered algae because they feed and are motile.

The dinoflagellates and stramenopiles fall within the Chromalveolata. The **dinoflagellates** are mostly marine organisms and are an important component of plankton. They have a variety of nutritional types and may be phototrophic, heterotrophic, or mixotrophic. Those that are photosynthetic use chlorophyll *a*, chlorophyll *c*₂, and other photosynthetic pigments (**Figure 5.35**). They generally have two flagella, causing them to whirl (in fact, the name dinoflagellate comes from the Greek word for “whirl”: *dini*). Some have cellulose plates forming a hard outer covering, or **theca**, as armor. Additionally, some dinoflagellates produce neurotoxins that can cause paralysis in humans or fish. Exposure can occur through contact with water containing the dinoflagellate toxins or by feeding on organisms that have eaten dinoflagellates.

When a population of dinoflagellates becomes particularly dense, a **red tide** (a type of harmful algal bloom) can occur. Red tides cause harm to marine life and to humans who consume contaminated marine life. Major toxin producers include *Gonyaulax* and *Alexandrium*, both of which cause paralytic shellfish poisoning. Another species, *Pfiesteria piscicida*, is known as a fish killer because, at certain parts of its life cycle, it can produce toxins harmful to fish and it appears to be responsible for a suite of symptoms, including memory loss and confusion, in humans exposed to water containing the species.

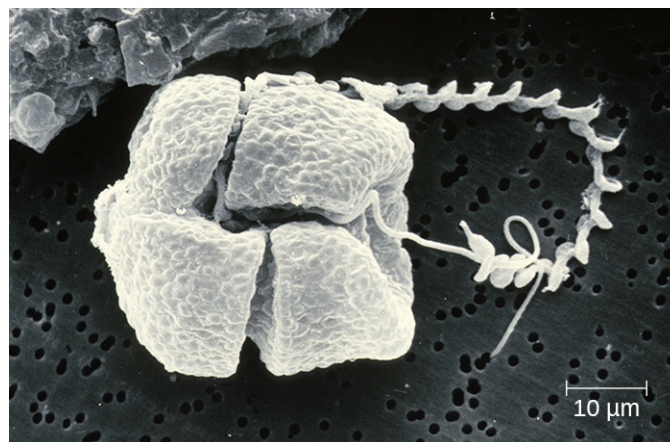


Figure 5.35 The dinoflagellates exhibit great diversity in shape. Many are encased in cellulose armor and have two flagella that fit in grooves between the plates. Movement of these two perpendicular flagella causes a spinning motion. (credit: modification of work by CSIRO)

The **stramenopiles** include the golden algae (Chrysophyta), the brown algae (Phaeophyta), and the **diatoms** (Bacillariophyta). Stramenopiles have chlorophyll *a*, chlorophyll *c*_{1/c}₂, and fucoxanthin as photosynthetic pigments. Their storage carbohydrate is chrysolaminarin. While some lack cell walls, others have scales. Diatoms have

flagella and **frustules**, which are outer cell walls of crystallized silica; their fossilized remains are used to produce diatomaceous earth, which has a range of uses such as filtration and insulation. Additionally, diatoms can reproduce sexually or asexually. One diatom genus, *Pseudo-nitzschia*, is known to be associated with harmful algal blooms.

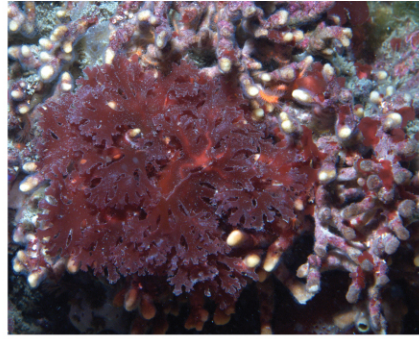
Brown algae (Phaeophyta) are multicellular marine seaweeds. Some can be extremely large, such as the giant kelp (*Laminaria*). They have leaf-like blades, stalks, and structures called holdfasts that are used to attach to substrate. However, these are not true leaves, stems, or roots (**Figure 5.36**). Their photosynthetic pigments are chlorophyll *a*, chlorophyll *c*, β -carotene, and fucoxanthine. They use laminarin as a storage carbohydrate.

The Archaeplastids include the green algae (Chlorophyta), the red algae (Rhodophyta), another group of green algae (Charophyta), and the land plants. The Charophyta are the most similar to land plants because they share a mechanism of cell division and an important biochemical pathway, among other traits that the other groups do not have. Like land plants, the Charophyta and Chlorophyta have chlorophyll *a* and chlorophyll *b* as photosynthetic pigments, cellulose cell walls, and starch as a carbohydrate storage molecule. *Chlamydomonas* is a green alga that has a single large chloroplast, two flagella, and a stigma (eyespot); it is important in molecular biology research (**Figure 5.37**).

Chlorella is a nonmotile, large, unicellular alga, and *Acetabularia* is an even larger unicellular green alga. The size of these organisms challenges the idea that all cells are small, and they have been used in genetics research since Joachim Hämmerring (1901–1980) began to work with them in 1943. *Volvox* is a colonial, unicellular alga (**Figure 5.37**). A larger, multicellular green alga is *Ulva*, also known as the sea lettuce because of its large, edible, green blades. The range of life forms within the Chlorophyta—from unicellular to various levels of coloniality to multicellular forms—has been a useful research model for understanding the evolution of multicellularity. The red algae are mainly multicellular but include some unicellular forms. They have rigid cell walls containing agar or carrageenan, which are useful as food solidifying agents and as a solidifier added to growth media for microbes.



(a)



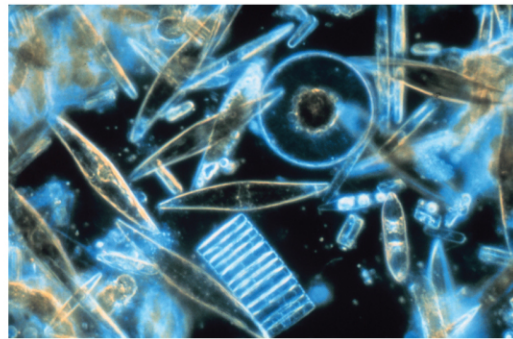
(b)



(c)



(d)



(e)



(f)

Figure 5.36 (a) These large multicellular kelps are members of the brown algae. Note the “leaves” and “stems” that make them appear similar to green plants. (b) This is a species of red algae that is also multicellular. (c) The green alga *Halimeda incrassata*, shown here growing on the sea floor in shallow water, appears to have plant-like structures, but is not a true plant. (d) Bioluminescence, visible in the cresting wave in this picture, is a phenomenon of certain dinoflagellates. (e) Diatoms (pictured in this micrograph) produce siliceous tests (skeletons) that form diatomaceous earths. (f) Colonial green algae, like volvox in these three micrographs, exhibit simple cooperative associations of cells. (credit a, e: modification of work by NOAA; credit b: modification of work by Ed Bierman; credit c: modification of work by James St. John; credit d: modification of work by “catalano82”/Flickr; credit f: modification of work by Dr. Ralf Wagner)

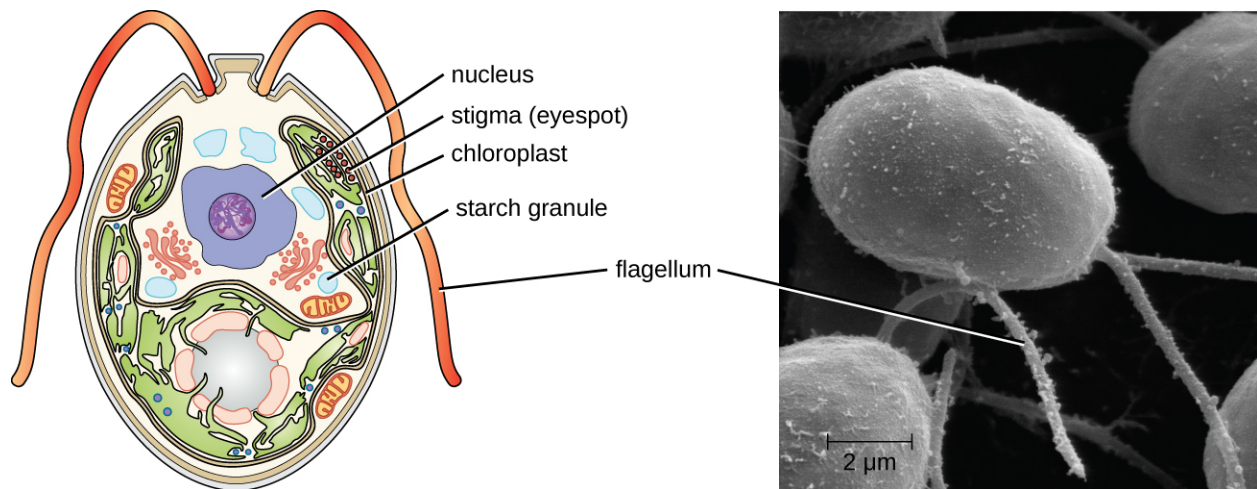


Figure 5.37 *Chlamydomonas* is a unicellular green alga.



Check Your Understanding

- Which groups of algae are associated with harmful algal blooms?

5.5 Lichens

Learning Objectives

- Explain why lichens are included in the study of microbiology
- Describe the unique characteristics of a lichen and the role of each partner in the symbiotic relationship of a lichen
- Describe ways in which lichens are beneficial to the environment

No one has to worry about getting sick from a lichen infection, but lichens are interesting from a microbiological perspective and they are an important component of most terrestrial ecosystems. Lichens provide opportunities for study of close relationships between unrelated microorganisms. Lichens contribute to soil production by breaking down rock, and they are early colonizers in soilless environments such as lava flows. The cyanobacteria in some lichens can fix nitrogen and act as a nitrogen source in some environments. Lichens are also important soil stabilizers in some desert environments and they are an important winter food source for caribou and reindeer. Finally, lichens produce compounds that have antibacterial effects, and further research may discover compounds that are medically useful to humans.

Characteristics

A **lichen** is a combination of two organisms, a green alga or cyanobacterium and an ascomycete fungus, living in a symbiotic relationship. Whereas algae normally grow only in aquatic or extremely moist environments, lichens can potentially be found on almost any surface (especially rocks) or as **epiphytes** (meaning that they grow on other plants).

In some ways, the symbiotic relationship between lichens and algae seems like a mutualism (a relationship in which both organisms benefit). The fungus can obtain photosynthates from the algae or cyanobacterium and the algae or

cyanobacterium can grow in a drier environment than it could otherwise tolerate. However, most scientists consider this symbiotic relationship to be a controlled parasitism (a relationship in which one organism benefits and the other is harmed) because the photosynthetic organism grows less well than it would without the fungus. It is important to note that such symbiotic interactions fall along a continuum between conflict and cooperation.

Lichens are slow growing and can live for centuries. They have been used in foods and to extract chemicals as dyes or antimicrobial substances. Some are very sensitive to pollution and have been used as environmental indicators.

Lichens have a body called a thallus, an outer, tightly packed fungal layer called a **cortex**, and an inner, loosely packed fungal layer called a **medulla** (Figure 5.38). Lichens use hyphal bundles called **rhizines** to attach to the substrate.

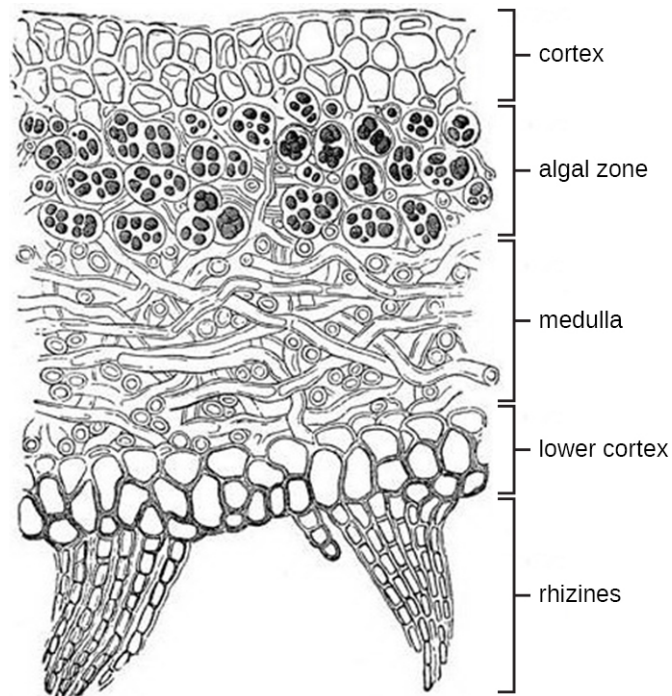


Figure 5.38 This cross-section of a lichen thallus shows its various components. The upper cortex of fungal hyphae provides protection. Photosynthesis occurs in the algal zone. The medulla consists of fungal hyphae. The lower cortex also provides protection. The rhizines anchor the thallus to the substrate.

Lichen Diversity

Lichens are classified as fungi and the fungal partners belong to the Ascomycota and Basidiomycota. Lichens can also be grouped into types based on their morphology. There are three major types of lichens, although other types exist as well. Lichens that are tightly attached to the substrate, giving them a crusty appearance, are called **crustose lichens**. Those that have leaf-like lobes are **foliose lichens**; they may only be attached at one point in the growth form, and they also have a second cortex below the medulla. Finally, **fruticose lichens** have rounded structures and an overall branched appearance. Figure 5.39 shows an example of each of the forms of lichens.

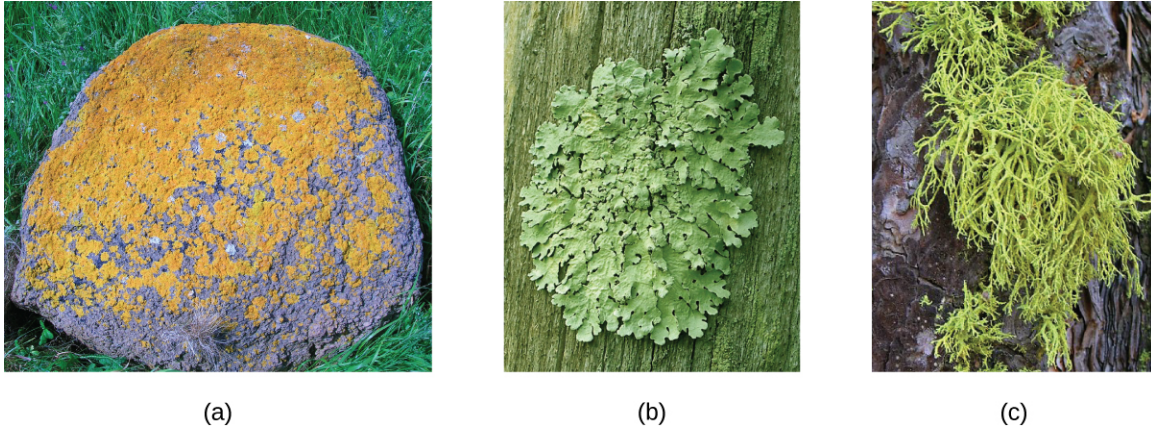


Figure 5.39 Examples of the three types of lichens are shown here. (a) This is a crustose lichen found mostly on marine rocks, *Caloplaca marina*. (b) This is a foliose lichen, *Flavoparmelia caperata*. (c) This is a fruticose lichen, *Letharia vulpina*, which is sufficiently poisonous that it was once used to make arrowheads. (credit b, c: modification of work by Jason Hollinger)



Check Your Understanding

- What types of organisms are found in lichens?
- What are the three growth forms of lichens?

Clinical Focus

Resolution

Sarah's mother asks the doctor what she should do if the cream prescribed for Sarah's ringworm does not work. The doctor explains that ringworm is a general term for a condition caused by multiple species. The first step is to take a scraping for examination under the microscope, which the doctor has already done. He explains that he has identified the infection as a fungus, and that the antifungal cream works against the most common fungi associated with ringworm. However, the cream may not work against some species of fungus. If the cream is not working after a couple of weeks, Sarah should come in for another visit, at which time the doctor will take steps to identify the species of the fungus.

Positive identification of dermatophytes requires culturing. For this purpose, Sabouraud's agar may be used. In the case of Sarah's infection, which cleared up within 2 weeks of treatment, the culture would have a granular texture and would appear pale pink on top and red underneath. These features suggest that the fungus is *Trichophyton rubrum*, a common cause of ringworm.

Go back to the [previous](#) Clinical Focus box.

Summary

5.1 Unicellular Eukaryotic Parasites

- **Protists** are a diverse, **polyphyletic** group of eukaryotic organisms.
- Protists may be unicellular or multicellular. They vary in how they get their nutrition, morphology, method of locomotion, and mode of reproduction.

- Important structures of protists include **contractile vacuoles**, cilia, flagella, **pellicles**, and pseudopodia; some lack organelles such as mitochondria.
- Taxonomy of protists is changing rapidly as relationships are reassessed using newer techniques.
- The protists include important pathogens and parasites.

5.2 Parasitic Helminths

- Helminth parasites are included within the study of microbiology because they are often identified by looking for microscopic eggs and larvae.
- The two major groups of helminth parasites are the roundworms (Nematoda) and the flatworms (Platyhelminthes).
- Nematodes are common intestinal parasites often transmitted through undercooked foods, although they are also found in other environments.
- Platyhelminths include **tapeworms** and **flukes**, which are often transmitted through undercooked meat.

5.3 Fungi

- The fungi include diverse saprotrophic eukaryotic organisms with chitin cell walls
- Fungi can be unicellular or multicellular; some (like yeast) and fungal spores are microscopic, whereas some are large and conspicuous
- Reproductive types are important in distinguishing fungal groups
- Medically important species exist in the four fungal groups Zygomycota, Ascomycota, Basidiomycota, and Microsporidia
- Members of Zygomycota, Ascomycota, and Basidiomycota produce deadly toxins
- Important differences in fungal cells, such as ergosterols in fungal membranes, can be targets for antifungal medications, but similarities between human and fungal cells make it difficult to find targets for medications and these medications often have toxic adverse effects

5.4 Algae

- Algae are a diverse group of photosynthetic eukaryotic protists
- Algae may be unicellular or multicellular
- Large, multicellular algae are called seaweeds but are not plants and lack plant-like tissues and organs
- Although algae have little pathogenicity, they may be associated with toxic **algal blooms** that can and aquatic wildlife and contaminate seafood with toxins that cause paralysis
- Algae are important for producing **agar**, which is used as a solidifying agent in microbiological media, and **carrageenan**, which is used as a solidifying agent

5.5 Lichens

- **Lichens** are a symbiotic association between a fungus and an algae or a cyanobacterium
- The symbiotic association found in lichens is currently considered to be a controlled **parasitism**, in which the fungus benefits and the algae or cyanobacterium is harmed
- Lichens are slow growing and can live for centuries in a variety of habitats
- Lichens are environmentally important, helping to create soil, providing food, and acting as indicators of air pollution

Review Questions

Multiple Choice

- Which genus includes the causative agent for malaria?
 - Euglena*
 - Paramecium*
 - Plasmodium*
 - Trypanosoma*
- Which protist is a concern because of its ability to contaminate water supplies and cause diarrheal illness?
 - Plasmodium vivax*
 - Toxoplasma gondii*
 - Giardia lamblia*
 - Trichomonas vaginalis*
- A fluke is classified within which of the following?
 - Nematoda
 - Rotifera
 - Platyhelminthes
 - Annelida
- A nonsegmented worm is found during a routine colonoscopy of an individual who reported having abdominal cramps, nausea, and vomiting. This worm is likely which of the following?
 - nematode
 - fluke
 - trematode
 - annelid
- A segmented worm has male and female reproductive organs in each segment. Some use hooks to attach to the intestinal wall. Which type of worm is this?
 - fluke
 - nematode
 - cestode
 - annelid
- Mushrooms are a type of which of the following?
 - conidia
 - ascus
 - polar tubule
 - basidiocarp
- Which of the following is the most common cause of human yeast infections?
 - Candida albicans*
 - Blastomyces dermatitidis*
 - Cryptococcus neoformans*
 - Aspergillus fumigatus*
- Which of the following is an ascomycete fungus associated with bat droppings that can cause a respiratory infection if inhaled?
 - Candida albicans*
 - Histoplasma capsulatum*
 - Rhizopus stolonifera*
 - Trichophyton rubrum*
- Which polysaccharide found in red algal cell walls is a useful solidifying agent?
 - chitin
 - cellulose
 - phycoerythrin
 - agar
- Which is the term for the hard outer covering of some dinoflagellates?
 - theca
 - thallus
 - mycelium
 - shell
- Which protists are associated with red tides?
 - red algae
 - brown algae
 - dinoflagellates
 - green algae
- You encounter a lichen with leafy structures. Which term describes this lichen?
 - crustose
 - foliose
 - fruticose
 - agarose
- Which of the following is the term for the outer layer of a lichen?
 - the cortex
 - the medulla
 - the thallus
 - the theca

14. The fungus in a lichen is which of the following?

- a. a basidiomycete
- b. an ascomycete
- c. a zygomycete
- d. an apicomplexan

Fill in the Blank

15. The plasma membrane of a protist is called the _____.
16. Animals belong to the same supergroup as the kingdom _____.
17. Flukes are in class _____.
18. A species of worm in which there are distinct male and female individuals is described as _____.
19. Nonseptate hyphae are also called _____.
20. Unicellular fungi are called _____.
21. Some fungi have proven medically useful because they can be used to produce _____.
22. Structures in chloroplasts used to synthesize and store starch are called _____.
23. Algae with chloroplasts with three or four membranes are a result of _____.

Short Answer

24. What are kinetoplastids?
25. Aside from a risk of birth defects, what other effect might a toxoplasmosis infection have?
26. What is the function of the ciliate macronucleus?
27. What is the best defense against tapeworm infection?
28. Which genera of fungi are common dermatophytes (fungi that cause skin infections)?
29. What is a dikaryotic cell?
30. What is a distinctive feature of diatoms?
31. Why are algae not considered parasitic?
32. Which groups contain the multicellular algae?
33. What are three ways that lichens are environmentally valuable?

Critical Thinking

34. The protist shown has which of the following?

- a. pseudopodia
- b. flagella
- c. a shell
- d. cilia

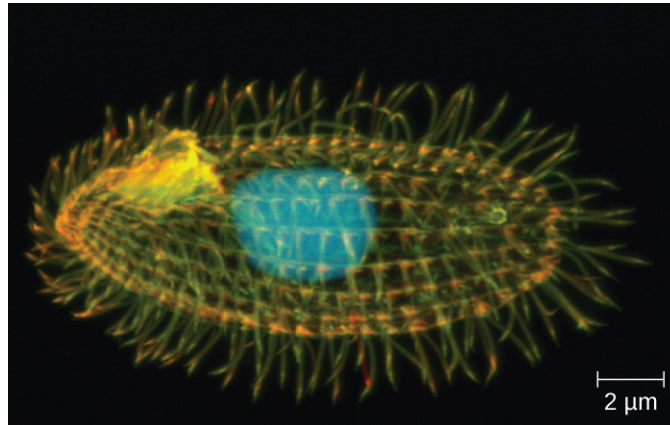


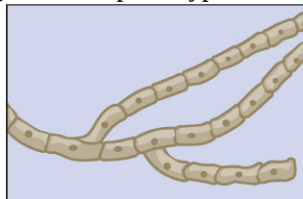
Figure 5.40 (credit: modification of work by Richard Robinson)

35. Protist taxonomy has changed greatly in recent years as relationships have been re-examined using newer approaches. How do newer approaches differ from older approaches?

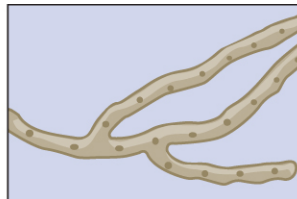
36. What characteristics might make you think a protist could be pathogenic? Are certain nutritional characteristics, methods of locomotion, or morphological differences likely to be associated with the ability to cause disease?

37. Given the life cycle of the *Schistosoma* parasite, suggest a method of prevention of the disease.

38. Which of the drawings shows septate hyphae?



A



B

39. Explain the benefit of research into the pathways involved in the synthesis of chitin in fungi.

