

## Sexual Reproduction

Sexual reproduction introduces genetic variation into a population of fungi. In fungi, *sexual reproduction* often occurs in response to adverse environmental conditions. During sexual reproduction, two *mating types* are produced. When both mating types are present in the same mycelium, it is called **homothallic**, or self-fertile. **Heterothallic** mycelia require two different, but compatible, mycelia to reproduce sexually.

Although there are many variations in fungal sexual reproduction, all include the following three stages (Figure 24.8). First, during **plasmogamy** (literally, “marriage or union of cytoplasm”), two haploid cells fuse, leading to a dikaryotic stage where two haploid nuclei coexist in a single cell. During **karyogamy** (“nuclear marriage”), the haploid nuclei fuse to form a diploid zygote nucleus. Finally, meiosis takes place in the gametangia (singular, gametangium) organs, in which gametes of different mating types are generated. At this stage, spores are disseminated into the environment.

### LINK TO LEARNING

Review the characteristics of fungi by visiting this [interactive site \(http://openstax.org/l/fungi\\_kingdom\)](http://openstax.org/l/fungi_kingdom) from Wisconsin-online.

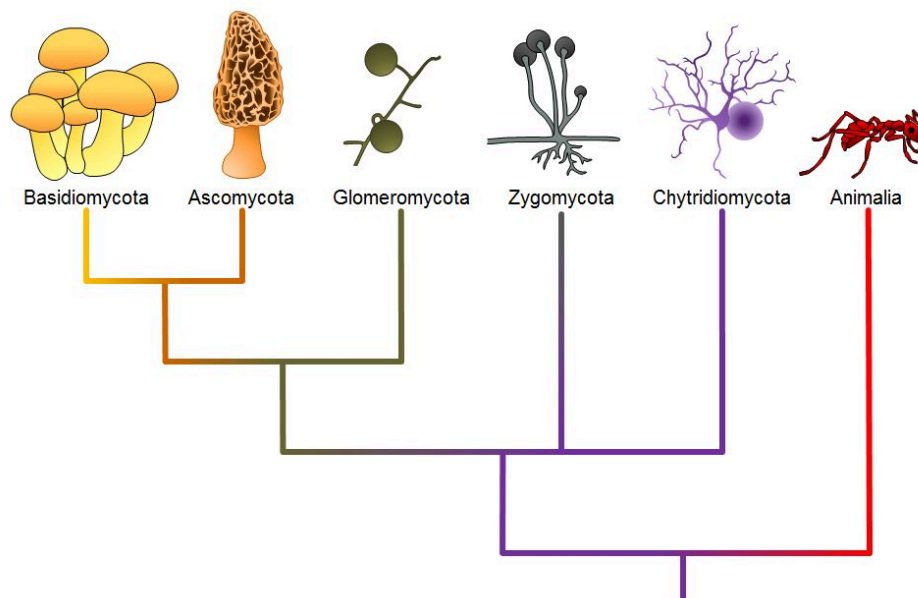
## 24.2 Classifications of Fungi

*By the end of this section, you will be able to do the following:*

- Identify fungi and place them into the five major phyla according to current classification
- Describe each phylum in terms of major representative species and patterns of reproduction

The kingdom Fungi contains five major phyla that were established according to their mode of sexual reproduction or using molecular data. Polyphyletic, unrelated fungi that reproduce without a sexual cycle, were once placed for convenience in a sixth group, the Deuteromycota, called a “form phylum,” because superficially they appeared to be similar. However, most mycologists have discontinued this practice. Rapid advances in molecular biology and the sequencing of 18S rRNA (ribosomal RNA) continue to show new and different relationships among the various categories of fungi.

The five true phyla of fungi are the Chytridiomycota (Chytrids), the Zygomycota (conjugated fungi), the Ascomycota (sac fungi), the Basidiomycota (club fungi) and the recently described Phylum Glomeromycota (Figure 24.10).



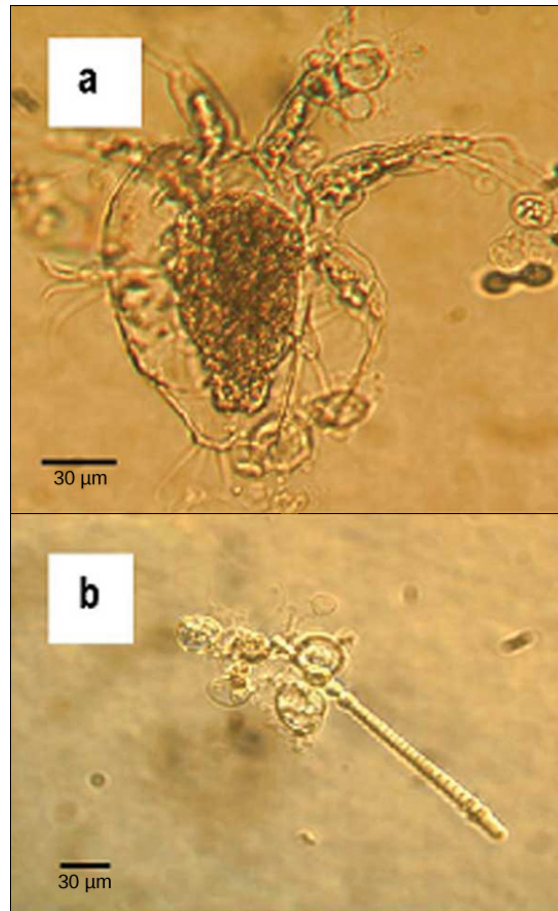
**Figure 24.10** Fungal phyla. Note: “-mycota” is used to designate a phylum while “-mycetes” formally denotes a class or is used informally to refer to all members of the phylum.

## Chytridiomycota: The Chytrids

The only class in the Phylum Chytridiomycota is the **Chytridiomycetes**. The chytrids are the simplest and most primitive

Eumycota, or true fungi. The evolutionary record shows that the first recognizable chytrids appeared during the late pre-Cambrian period, more than 500 million years ago. Like all fungi, chytrids have chitin in their cell walls, but one group of chytrids has both cellulose and chitin in the cell wall. Most chytrids are unicellular; however, a few form multicellular organisms and hyphae, which have no septa between cells (coenocytic). The Chytrids are the only fungi that have retained flagella. They produce both gametes and diploid zoospores that swim with the help of a single flagellum. An unusual feature of the chytrids is that both male and female gametes are flagellated.

The ecological habitat and cell structure of chytrids have much in common with protists. Chytrids usually live in aquatic environments, although some species live on land. Some species thrive as parasites on plants, insects, or amphibians ([Figure 24.11](#)), while others are saprobes. The chytrid species *Allomyces* is well characterized as an experimental organism. Its reproductive cycle includes both asexual and sexual phases. *Allomyces* produces diploid or haploid flagellated zoospores in a sporangium.



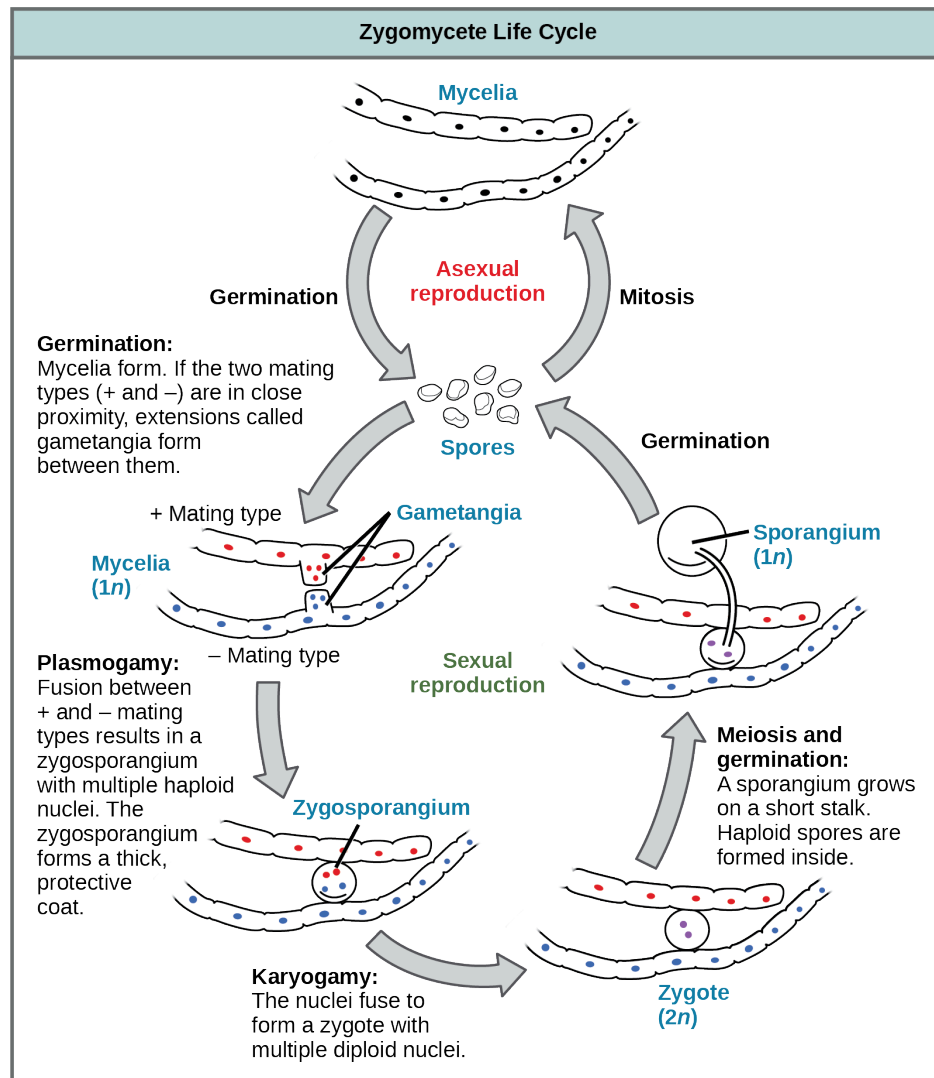
**Figure 24.11** Chytrids. The chytrid *Batrachochytrium dendrobatidis* is seen in these light micrographs as transparent spheres growing on (a) a freshwater arthropod (water mite) and (b) algae. This chytrid causes skin diseases in many species of amphibians, resulting in species decline and extinction. (credit: modification of work by Johnson ML, Speare R., CDC)

## Zygomycota: The Conjugated Fungi

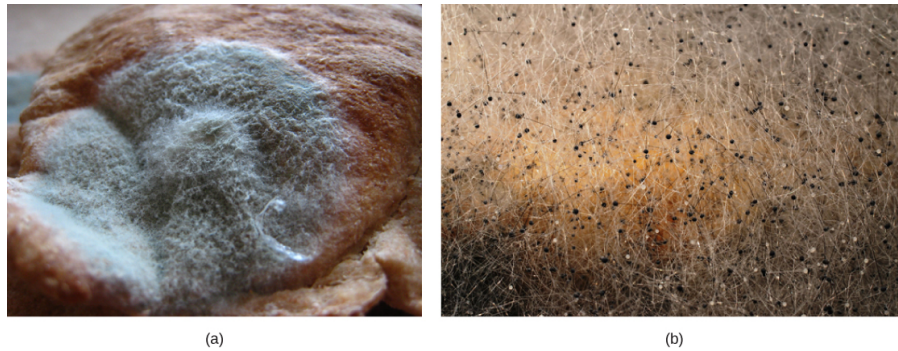
The zygomycetes are a relatively small group of fungi belonging to the Phylum **Zygomycota**. They include the familiar bread mold, *Rhizopus stolonifer*, which rapidly propagates on the surfaces of breads, fruits, and vegetables. Most species are saprobes, living off decaying organic material; a few are parasites, particularly of insects. Zygomycetes play a considerable commercial role. For example, the metabolic products of some species of *Rhizopus* are intermediates in the synthesis of semi-synthetic steroid hormones.

Zygomycetes have a thallus of coenocytic hyphae in which the nuclei are haploid when the organism is in the vegetative stage. The fungi usually reproduce asexually by producing sporangiospores ([Figure 24.12](#)). The black tips of bread mold are the swollen sporangia packed with black spores ([Figure 24.13](#)). When spores land on a suitable substrate, they germinate and produce a new

mycelium. Sexual reproduction starts when environmental conditions become unfavorable. Two opposing mating strains (type + and type –) must be in close proximity for gametangia from the hyphae to be produced and fuse, leading to karyogamy. Each zygospore can contain several diploid nuclei. The developing diploid **zygospores** have thick coats that protect them from desiccation and other hazards. They may remain dormant until environmental conditions are favorable. When the zygospore germinates, it undergoes meiosis and produces haploid spores, which will, in turn, grow into a new organism. This form of sexual reproduction in fungi is called conjugation (although it differs markedly from conjugation in bacteria and protists), giving rise to the name “conjugated fungi”.



**Figure 24.12** Zygomycete life cycle. Zygomycetes have asexual and sexual phases in their life cycles. In the asexual phase, spores are produced from haploid sporangia by mitosis (not shown). In the sexual phase, plus and minus haploid mating types conjugate to form a heterokaryotic zygosporangium. Karyogamy then produces a diploid zygote. Diploid cells in the zygote undergo meiosis and germinate to form a haploid sporangium, which releases the next generation of haploid spores.



**Figure 24.13** Rhizopus spores. Asexual sporangia grow at the end of stalks, which appear as (a) white fuzz seen on this bread mold, *Rhizopus stolonifer*. The black tips (b) of bread mold are the spore-containing sporangia. (credit b: modification of work by "polandeze"/Flickr)

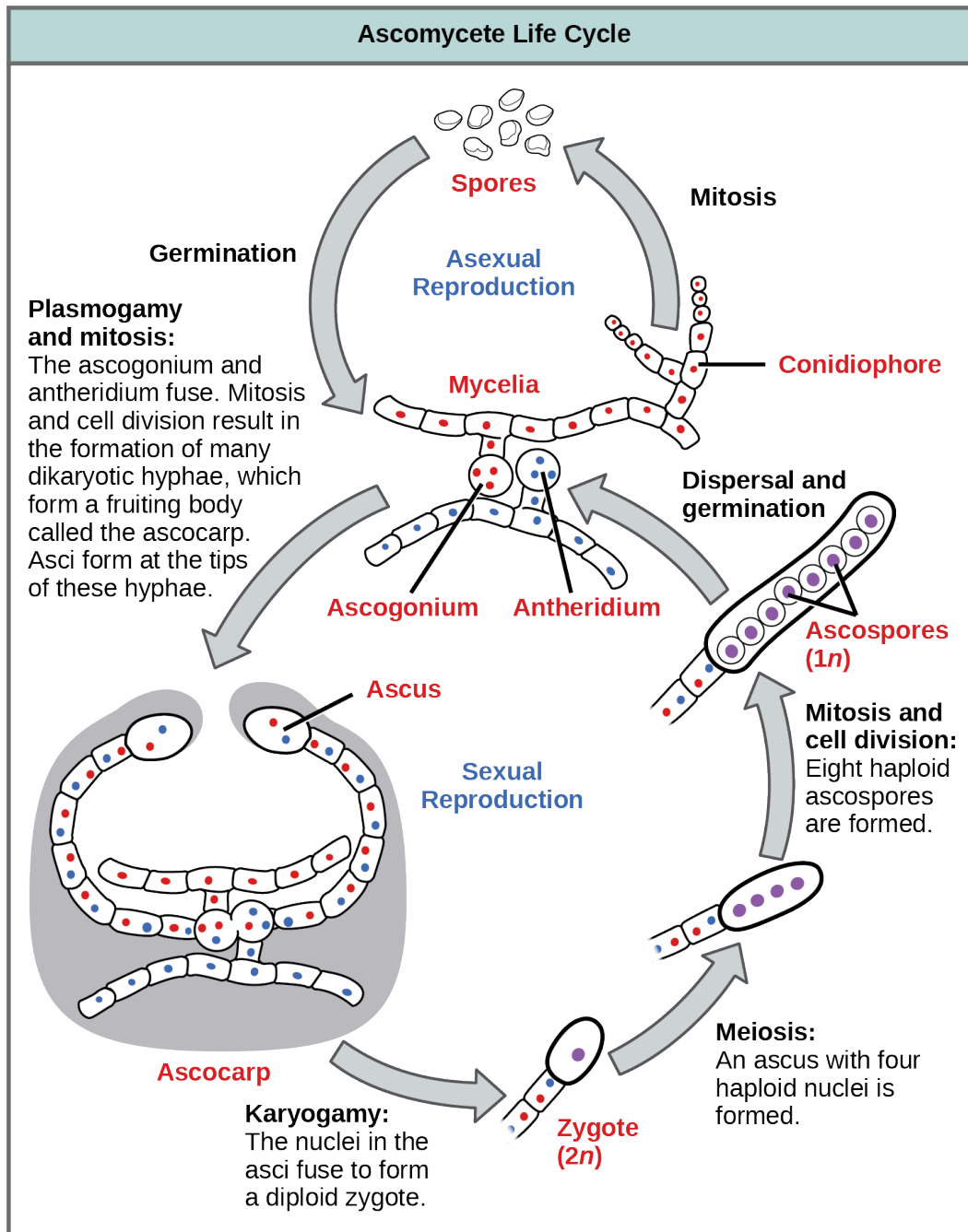
## Ascomycota: The Sac Fungi

The majority of known fungi belong to the Phylum **Ascomycota**, which is characterized by the formation of an **ascus** (plural, **asci**), a sac-like structure that contains haploid *ascospores*. Filamentous ascomycetes produce hyphae divided by perforated septa, allowing streaming of cytoplasm from one cell to another. Conidia and asci, which are used respectively for asexual and sexual reproduction, are usually separated from the vegetative hyphae by blocked (non-perforated) septa. Many ascomycetes are of commercial importance. Some play a beneficial role for humanity, such as the yeasts used in baking, brewing, and wine fermentation, and directly as food delicacies such as truffles and morels. *Aspergillus oryzae* is used in the fermentation of rice to produce sake. Other ascomycetes parasitize plants and animals, including humans. For example, fungal pneumonia poses a significant threat to AIDS patients who have a compromised immune system. Ascomycetes not only infest and destroy crops directly; they also produce poisonous secondary metabolites that make crops unfit for consumption.

Asexual reproduction is frequent and involves the production of conidiophores that release haploid *conidiospores* (Figure 24.14). Sexual reproduction starts with the development of special hyphae from either one of two types of mating strains (Figure 24.14). The “male” strain produces an antheridium and the “female” strain develops an ascogonium. At fertilization, the antheridium and the ascogonium combine in plasmogamy, without nuclear fusion. Special dikaryotic ascogenous (ascus-producing) hyphae arise from this **dikaryon**, in which each cell has pairs of nuclei: one from the “male” strain and one from the “female” strain. In each ascus, two haploid nuclei fuse in karyogamy. Thousands of asci fill a fruiting body called the **ascocarp**. The diploid nucleus in each ascus gives rise to haploid nuclei by meiosis, and spore walls form around each nucleus. The spores in each ascus contain the meiotic products of a single diploid nucleus. The ascospores are then released, germinate, and form hyphae that are disseminated in the environment and start new mycelia (Figure 24.15).



## VISUAL CONNECTION

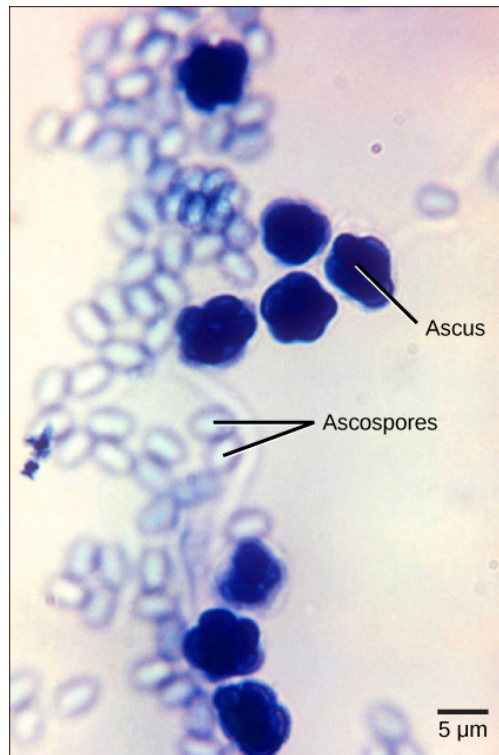


**Figure 24.14** Ascomycete life cycle. The lifecycle of an ascomycete is characterized by the production of asci during the sexual phase. In each ascus, the four nuclei produced by meiosis divide once mitotically for a total of eight haploid ascospores. The haploid phase is the predominant phase of the life cycle in Ascomycetes.

Which of the following statements is true?

- A dikaryotic ascus that forms in the ascocarp undergoes karyogamy, meiosis, and mitosis to form eight ascospores.
- A diploid ascus that forms in the ascocarp undergoes karyogamy, meiosis, and mitosis to form eight ascospores.
- A haploid zygote that forms in the ascocarp undergoes karyogamy, meiosis, and mitosis to form eight ascospores.
- A dikaryotic ascus that forms in the ascocarp undergoes plasmogamy, meiosis, and mitosis to form eight ascospores.





**Figure 24.15** Ascospores. The bright field light micrograph shows ascospores being released from asci in the fungus *Talaromyces flavus* var. *flavus*. (credit: modification of work by Dr. Lucille Georg, CDC; scale-bar data from Matt Russell)

## Basidiomycota: The Club Fungi

The fungi in the Phylum **Basidiomycota** are easily recognizable under a light microscope by their club-shaped fruiting bodies called **basidia** (singular, **basidium**), which are the swollen terminal cells of hyphae. The basidia, which are the reproductive organs of these fungi, are often contained within the familiar mushroom, commonly seen in fields after rain, on the supermarket shelves, and growing on your lawn (Figure 24.16). These mushroom-producing basidiomycetes are sometimes referred to as “*gill fungi*” because of the presence of gill-like structures on the underside of the cap. The gills are actually *compacted hyphae* on which the basidia are borne. This group also includes shelf fungi, which cling to the bark of trees like small shelves. In addition, the basidiomycota include smuts and rusts, which are important plant pathogens. Most edible fungi belong to the Phylum Basidiomycota; however, some basidiomycota are inedible and produce deadly toxins. For example, *Cryptococcus neoformans* causes severe respiratory illness. The infamous death cap mushroom (*Amanita phalloides*) is related to the fly agaric seen at the beginning of the previous section.



**Figure 24.16** Fairy ring. The fruiting bodies of a basidiomycete form a ring in a meadow, commonly called “fairy ring.” The best-known fairy ring fungus has the scientific name *Marasmius oreades*. The body of this fungus, its mycelium, is underground and grows outward in a

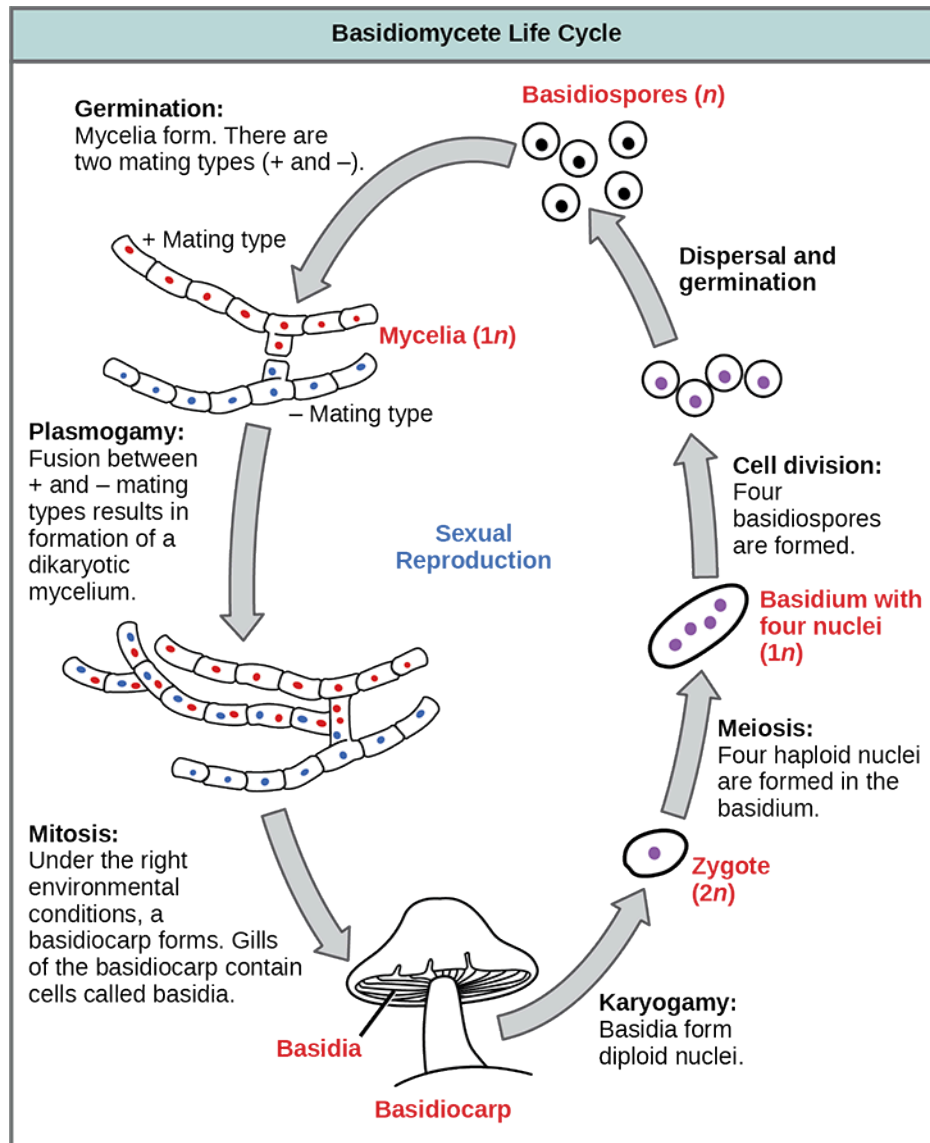
circle. As it grows, the mycelium depletes the soil of nitrogen, causing the mycelia to grow away from the center and leading to the “fairy ring” of fruiting bodies where there is adequate soil nitrogen. (Credit: “Cropcircles”/Wikipedia Commons)]

The lifecycle of basidiomycetes includes *alternation of generations* (Figure 24.17). Most fungi are haploid through most of their life cycles, but the basidiomycetes produce *both* haploid and dikaryotic mycelia, with the dikaryotic phase being dominant. (Note: The dikaryotic phase is technically not diploid, since the nuclei remain unfused until shortly before spore production.) In the basidiomycetes, sexual spores are more common than asexual spores. The sexual spores form in the club-shaped basidium and are called basidiospores. In the basidium, nuclei of two different mating strains fuse (karyogamy), giving rise to a diploid zygote that then undergoes meiosis. The haploid nuclei migrate into four different chambers appended to the basidium, and then become basidiospores.

Each basidiospore germinates and generates *monokaryotic haploid hyphae*. The mycelium that results is called a primary mycelium. Mycelia of different mating strains can combine and produce a secondary mycelium that contains haploid nuclei of two different mating strains. This is the dominant dikaryotic stage of the basidiomycete life cycle. Thus, each cell in this mycelium has two haploid nuclei, which will not fuse until formation of the basidium. Eventually, the secondary mycelium generates a **basidiocarp**, a fruiting body that protrudes from the ground—this is what we think of as a mushroom. The basidiocarp bears the developing basidia on the gills under its cap.



## VISUAL CONNECTION



**Figure 24.17** Basidiomycete life cycle. The lifecycle of a basidiomycete has alternate generations with haploid and dikaryotic mycelia. Haploid primary mycelia fuse to form a dikaryotic secondary mycelium, which is the dominant stage of the life cycle, and produces the basidiocarp.

Which of the following statements is true?

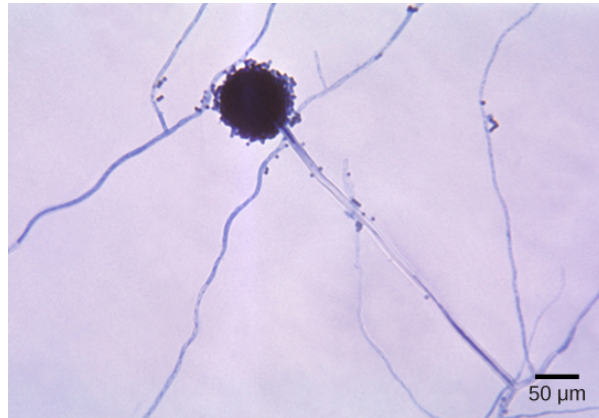
- A basidium is the fruiting body of a mushroom-producing fungus, and it forms four basidiocarps.
- The result of the plasmogamy step is four basidiospores.
- Karyogamy results directly in the formation of mycelia.
- A basidiocarp is the fruiting body of a mushroom-producing fungus.

## Asexual Ascomycota and Basidiomycota

**Imperfect fungi**—those that do not display a sexual phase—were formerly classified in the form phylum **Deuteromycota**, an invalid taxon no longer used in the present, ever-developing classification of organisms. While Deuteromycota was once a classification taxon, recent molecular analysis has shown that some of the members classified in this group belong to the Ascomycota (Figure 24.18) or the Basidiomycota. Because some members of this group have not yet been appropriately



classified, they are less well described in comparison to members of other fungal taxa. Most imperfect fungi live on land, with a few aquatic exceptions. They form visible mycelia with a fuzzy appearance and are commonly known as **mold**.



**Figure 24.18** *Aspergillus*. *Aspergillus niger* is an asexually reproducing fungus (phylum Ascomycota) commonly found as a food contaminant. The spherical structure in this light micrograph is an asexual conidiophore. Molecular studies have placed *Aspergillus* with the ascomycetes and sexual cycles have been identified in some species. (credit: modification of work by Dr. Lucille Georg, CDC; scale-bar data from Matt Russell)

The fungi in this group have a large impact on everyday human life. The food industry relies on them for ripening some cheeses. The blue veins in Roquefort cheese and the white crust on Camembert are the result of fungal growth. The antibiotic penicillin was originally discovered on an overgrown Petri plate, on which a colony of *Penicillium* fungi had killed the bacterial growth surrounding it. Other fungi in this group cause serious diseases, either directly as parasites (which infect both plants and humans), or as producers of potent toxic compounds, as seen in the aflatoxins released by fungi of the genus *Aspergillus*.

## Glomeromycota

The **Glomeromycota** is a newly established phylum that comprises about 230 species, all of which are involved in close associations with the roots of trees. Fossil records indicate that trees and their root symbionts share a long evolutionary history. It appears that nearly all members of this family form **arbuscular mycorrhizae**: the hyphae interact with the root cells forming a mutually beneficial association in which the plants supply the carbon source and energy in the form of carbohydrates to the fungus, and the fungus supplies essential minerals from the soil to the plant. The exception is *Geosiphon pyriformis*, which hosts the cyanobacterium *Nostoc* as an endosymbiont.

The glomeromycetes do not reproduce sexually and do not survive without the presence of plant roots. Although they have coenocytic hyphae like the zygomycetes, they do not form zygospores. DNA analysis shows that all glomeromycetes probably descended from a common ancestor, making them a monophyletic lineage.

## 24.3 Ecology of Fungi

*By the end of this section, you will be able to do the following:*

- Describe the role of fungi in various ecosystems
- Describe mutualistic relationships of fungi with plant roots and photosynthetic organisms
- Describe the beneficial relationship between some fungi and insects

Fungi play a crucial role in the constantly changing “balance” of ecosystems. They colonize most habitats on Earth, preferring dark, moist conditions. They can thrive in seemingly hostile environments, such as the tundra, thanks to a most successful symbiosis with photosynthetic organisms like algae to produce lichens. Within their communities, fungi are not as obvious as are large animals or tall trees. Like bacteria, they act behind the scene as major decomposers. With their versatile metabolism, fungi break down organic matter, which would otherwise not be recycled.

### Habitats

Although fungi are primarily associated with humid and cool environments that provide a supply of organic matter, they colonize a surprising diversity of habitats, from seawater to human skin and mucous membranes. Chytrids are found primarily in aquatic environments. Other fungi, such as *Coccidioides immitis*, which causes pneumonia when its spores are inhaled,