3.1 The Fungi

Figure 1 Mushrooms are the most recognizable parts of fungi.

CAREER **LINK**

Arborist

Arborists diagnose and treat diseases in trees. To learn more about a career as an arborist,

GO TO NELSON SCIENCE

Fungi (singular: fungus) are some of the most common but least visible organisms on Earth. Fungi often grow out of sight—underground or within other organisms that may be either dead or alive. We are most familiar with the reproductive structures of fungi: mushrooms (**Figure 1**), toadstools, and mould spores. Although they were once thought to be plants, fungi actually have little in common with either plants or animals.

Why Fungi Are Important

Fungi have an enormous influence on ecosystems and economies. Along with bacteria, fungi are the major decomposers on Earth. Fungi are responsible for much of the cycling of nutrients through the biosphere. Fungi also engage in important symbiotic relationships with plants. As you will learn, almost all plants rely on fungi to help them obtain nutrients from soil. Without these fungi, plant growth and productivity would be severely reduced.

Not all fungi are helpful to other organisms. Fungi are responsible for some animal diseases and many serious plant diseases. These diseases can have a dramatic impact on natural plant populations and agricultural crops (**Figure 2(a)**). Every year, a staggering 10 % to 50 % of the world's fruit harvest is destroyed by fungi! Some valuable tree species have become nearly extinct because of fungi that were accidentally introduced into a region. Fungi also rot wood and damage buildings and other structures. Wood preservatives can prevent such damage, but they are toxic compounds that have their own environmental impacts.

Humans have many uses for fungi. Every time you eat mushrooms or their very expensive relatives—truffles—you are eating tasty fungi. Fungi are also used to make bread, soy sauce, and blue cheese (**Figure 2(b)**). The most economically valuable use of fungi is in the production of alcoholic beverages. Beer and wine are both multi-billion dollar industries that depend on fungi to ferment grains and grapes to produce alcohol. Non-food products we get from fungi include some extremely valuable "miracle drugs," including the antibiotic penicillin (**Figure 2(c)**) and the antirejection drug cyclosporine, which is used by organ transplant recipients. Certain fungi are also used in genetic engineering research and applications.

Figure 2 (a) Fungi cause some diseases in plants, such as apple scab. (b) Fungi are also used in the production of foods such as blue cheese. (c) Fungi are the source of one of our most important antibiotics—penicillin.

Classification and Phylogeny

Fungi are not plants. In fact, they have almost nothing in common with plants except that they are sessile (stationary) multicellular eukaryotes and many grow in the ground. Unlike plants, fungi are not photosynthetic, and they do not produce their own food. Their cells are unlike plant cells, and they have entirely different methods of reproducing. Despite these differences, many people think that fungi are plant-like. Even Linnaeus classified them as plants in his two-kingdom system.

We know now that fungi form their own clade, sharing a common ancestor from at least 400 million years ago. Although fungi are only distantly related to animals, they are actually more closely related to animals than they are to plants! (See Figure 6, Section 2.3, page 62.)

More than 100 000 species of fungi have been described. These are classified into five major phyla (**Figure 3**). The most recognizable are the Basidiomycota, which is the phylum containing most mushrooms, and the Zygomycota, which is the phylum containing many of the moulds found on fruits and bread. The five major phyla range in size from microscopic single-celled organisms to the largest organisms on Earth. They exhibit a diversity of forms and life cycles (**Table 1**).

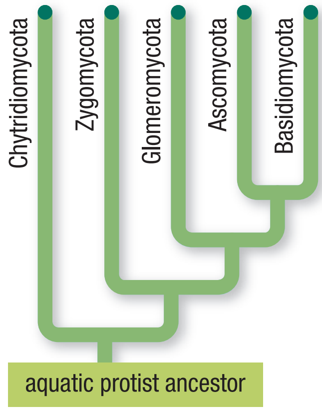

Figure 3 There are five major phyla within the Fungi kingdom. The Ascomycota and Basidiomycota phyla contain the most species.

Table 1 Summary of the Five Major Phyla of Fungi

Phylum	Key features
Chytridiomycota (chytrids)	• They are the only fungi with swimming spores. • Most are saprophytes. • They can be single-celled or multicellular.
Zygomycota (zygomycetes)	• They include some familiar bread and fruit moulds. • Most are soil fungi. • Many are used commercially. • Many are parasites of insects.
Glomeromycota (glomeromycetes)	• All form symbiotic relationships with plant roots.
Ascomycota (ascomycetes)	• Many, such as yeast, are useful to humans. • Some cause serious plant diseases.
Basidiomycota (basidiomycetes)	• They include mushrooms, puffballs, and bracket fungi. • Most are decomposers. • Some form symbiotic relationships with plants.

LEARNING **TIP**

Some Moulds Are Protists
Organisms commonly referred to as slime moulds and water moulds were once thought to be fungi. Now they are recognized as a group of protists.

Characteristics

What we think of as a fungus is usually only one small part of the organism—the reproductive structure that usually grows out into the air. Most of the fungus—its "body"—remains hidden, often below ground. Fungi display an amazing diversity of characteristics and life cycles. For example, the bird's nest fungus has reproductive structures that look like bird's nests (**Figure 4(a)**). Each "egg" contains spores. Raindrops splashing into the "nest" push the eggs out of the nest and disperse the spores.

Cordyceps have familiar reproductive structures, but amazing life cycles. They are parasitic fungi of the phylum Ascomycota. They infect an insect host and change its behaviour, forcing it to climb to a high stem. The fungus then kills the host. Its reproductive structures grow through its body and release spores (**Figure 4(b)**). Because the spores are released from a high branch, they are dispersed widely.

Figure 4 (a) This bird's nest fungus belongs to the phylum Basidiomycota. (b) This *Cordyceps* fungus is growing through its host's body.

mycelium a branched mass of hyphae

hypha a thin filament that makes up the body of a fungus

chitin a complex chemical found in the cell walls of fungi and in the external coverings of insects and crustaceans such as lobsters and crabs

The bodies of most fungi are mesh-like, composed of a branching network of filaments called a **mycelium** (**Figure 5(a)**). These filaments are called **hyphae** (singular: hypha). Hyphae are often microscopically thin, and they have a structure unlike plant or animal cells. They consist of long tubes of cytoplasm containing many nuclei. The cytoplasm is contained by a cell wall made of **chitin**. The tubes may be separated into cell-like compartments by cell walls called septa (singular: septum). These septa are usually only partially complete, however, and contain large pores (**Figure 5(b)**). A key feature of hyphae is that the cytoplasm is continuous from end to end, allowing materials to move relatively quickly through the hyphae.

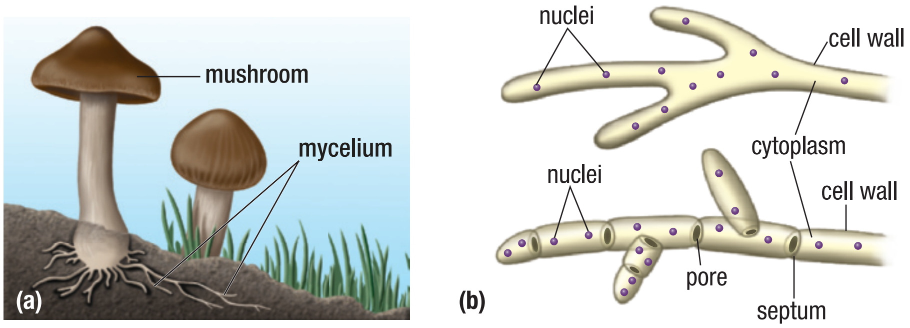

Figure 5 (a) The reproductive structure of a fungus is often the only part visible above ground. The mycelium forms the body of the fungus below ground. (b) Hyphae grow at their tips, and the nuclei multiply by mitosis as the hyphae grow.

Hyphae form the "fuzz" often associated with mould **(Figure 6(a))**. They also form the reproductive structures of many fungi. These structures take a wide variety of forms, including the puffballs shown in **Figure 6(b)**.

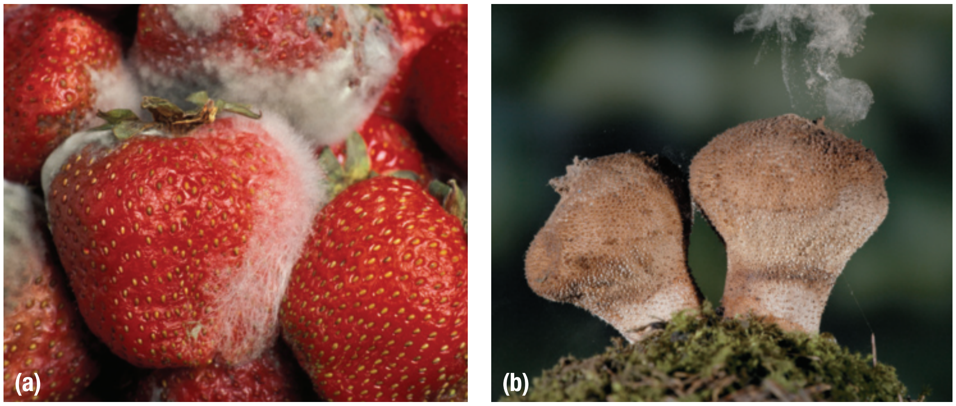

Figure 6 (a) The "fuzz" we associate with mouldy food is the hyphae of the fungus. (b) Even light contact with a mature puffball will cause the release of millions of microscopic spores.

LEARNING **TIP**

Zygote Formation

Zygotes normally form by the fusion of two different sex cells, such as a sperm and an egg. In fungi, zygotes can form from the fusion of two different nuclei within a single cell. This is still considered a form of sexual reproduction because each nucleus originated from a different individual.

Some fungi are single-celled. These fungi—called yeast—are very valuable economically because they are used in the production of many foods and alcoholic beverages.

One major difference between plants and fungi is that all fungi are heterotrophic—they get energy from other living or dead organisms. Fungi are different from most other heterotrophs, however, because they have external digestion. Rather than taking food inside their bodies, fungi grow next to—or within—their food source and release digestive enzymes into their surroundings. These enzymes digest the food, then the fungi simply absorb the nutrients through the cell membranes of the hyphae.

Life Cycles

The life cycles of many fungi are quite complicated. Some include stages of sexual as well as asexual reproduction.

The nuclei of most other eukaryotic organisms are diploid ($2n$), containing two sets of chromosomes. In fungi, most nuclei are haploid (n), containing only a single set of chromosomes.

Figure 7 shows the life cycle of a basidiomycete. Each spore (at left) contains a haploid nucleus. These spores germinate and produce hyphae with single nuclei separated by septa. When two hyphae come in contact with each other, two of their cells can fuse, forming a **dikaryotic** cell with two separate haploid nuclei. This cell then grows into a large new mycelium made of cells with two haploid nuclei. When the mycelium becomes large and mature, it may produce a mushroom cap. On the underside of the cap, spore-producing structures called basidia form on the mushroom's gills. Within the basidia, the two haploid nuclei fuse, forming a zygote. This zygote then undergoes **meiosis**, producing four haploid spores. The spores are released into the environment. When conditions are right, these spores germinate and the cycle continues.

dikaryotic containing two separate nuclei

meiosis a form of cell division in which a single cell gives rise to four haploid daughter cells

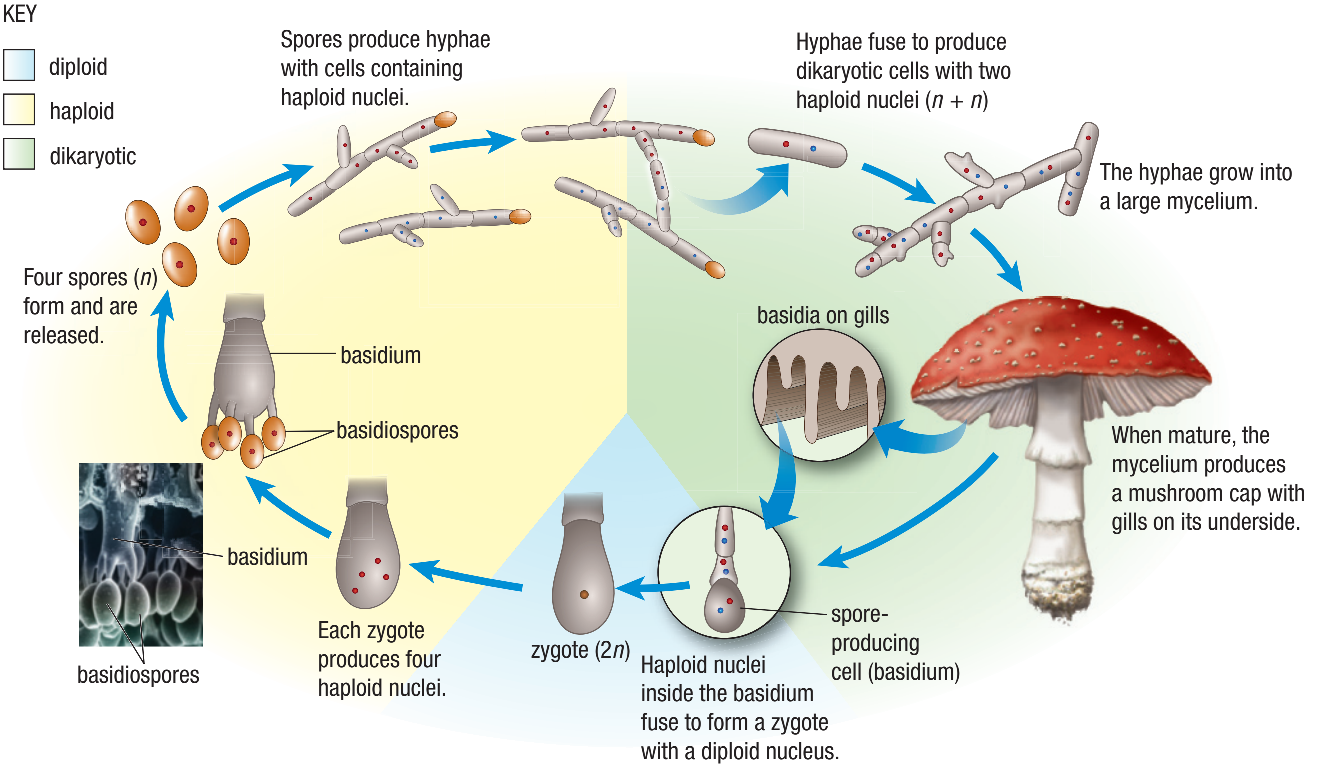

Figure 7 The life cycle of a basidiomycete

A single large mushroom can release 100 million spores in an hour! Such prolific spore production ensures that fungal spores are dispersed rapidly and widely. Any exposed surface is covered with fungal spores within seconds, and every breath you take contains many thousands of them.

Yeast are single-celled haploid fungi. They reproduce by budding. In budding, the individual yeast cell acts like a tiny hypha. The nucleus divides, and a septum forms between the two nuclei. This forms a small daughter cell on the side of the original yeast cell (**Figure 8**). As the cells continue to grow and bud, they often stay attached to each other, forming simple hypha-like arrangements. Yeast cells can also fuse and form a diploid cell that gives rise to four haploid spores, similar to the way in which multicellular fungi reproduce. Biologists consider this strong evidence that yeast evolved from multicellular fungi.

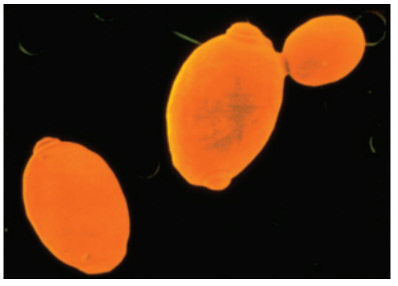

Figure 8 Yeast reproduce by budding.

Symbiotic Relationships in Ecosystems

You may have seen lichens—small crusty or pale moss-like organisms—growing on the exposed surfaces of bare rock or on the bark of trees. Lichens are symbiotic combinations of fungi and photosynthetic cyanobacteria or green algae (**Figure 9**).

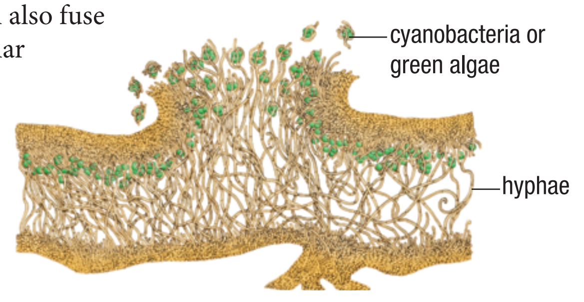

Figure 9 A cross-sectional diagram of a lichen showing the mixing of fungi (brown) and cyanobacteria or green algae (green).

Figure 10 Leaf-cutter ants were the world's first farmers. They use leaves to grow fungus in underground gardens.

mycorrhiza a symbiotic relationship between a fungus and a plant root

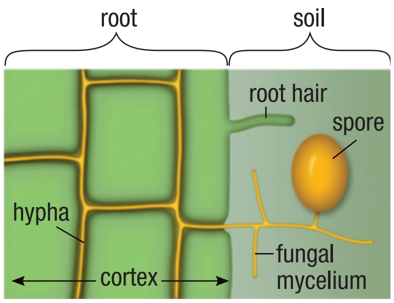

Figure 11 In mycorrhiza, a fungal mycelium grows in and around a plant's roots.

The fungi's mycelium envelops and protects the cyanobacteria or algae and supplies them with water and mineral nutrients. In return, these photosynthetic organisms supply the fungi with food. Lichens have an extraordinary ability to survive in harsh environments. They are often the first organisms to begin the process of ecological succession because they can grow on bare rock. Some lichens release chemicals that break down the rock and help form soil that can support plant growth.

Some fungi also have a fascinating symbiotic relationship with animals. Leaf-cutter ants live in tropical rain forests in large colonies, some with millions of members. These ants cut and gather pieces of leaves, then bring them back to their colony (**Figure 10**). The ants are so numerous and so good at this task that they are the largest consumers of leaves in the forest. However, the ants do not feed on the pieces of leaf. Instead, they clean and chew the leaves into a pulp and use them to feed a fungus. The ants grow and tend these fungus gardens in underground chambers and feed almost exclusively on the fungus. Scientists have recently discovered how leaf-cutter ants prevent other species of fungi from contaminating their fungus gardens: the ants have colonies of bacteria growing on their bodies. These bacteria produce chemicals that kill all other species of fungi.

Another symbiotic relationship involving soil fungi and plants has been uncovered over the past several decades. The most remarkable thing about this relationship is that more than 80 % of all plant species are involved! In this relationship, called **mycorrhiza** (plural: mycorrhizae), hyphae grow around or within the root cells of the plant. The fungi help supply the plant with needed nutrients such as phosphorus or copper (**Figure 11**). In return, the plant provides the fungi with energy-rich food molecules.

Decomposers and Disease

Fungi that feed on living organisms cause a variety of human diseases, ranging from mild athlete's foot and ringworm infections to aspergillosis, a potentially deadly lung disease. Fungal diseases also affect many plants. Some of these diseases produce toxic chemicals as well as damaging the plants. One species of fungus that infects wheat and rye produces a potent toxin similar to the one found in the drug LSD. The toxin can cause hallucinations, convulsions, and paralysis. Another fungus that feeds on peanuts produces a chemical with the potential to cause cancer.

Research This

Fungi Threaten Plants and Animals

Skills: Researching, Analyzing, Communicating — SKILLS HANDBOOK **A2.1, A5.1**

In this activity you will research several very serious threats posed by the spread of fungal diseases.

1. Chytrid fungi infect many amphibians (**Figure 12**). Research the impact these fungi are having on frog populations around the world.

Figure 12 Many frog species, including this poison dart frog, *Dendrobates auratus*, are threatened by the spread of chytrid fungi.

2. Three tree species that were once very common in northeastern North America have been almost wiped out by Dutch Elm disease, Chestnut blight, and Butternut canker. All are fungal diseases introduced by humans. Research these diseases.

A. Why are scientists concerned about the spread of chytrid fungi? T/I

B. How and when was each fungus you researched in Step 2 introduced to North America? What tree species are affected by each fungus? How is each disease spread? T/I

C. What, if anything, is being done to stop the spread of these fungal diseases and protect the affected species? T/I

D. Prepare an information piece on one fungal disease you researched in this activity. Describe the current status of the threat and what people can do to help. You may choose to present the information in the form of a news video, radio announcement, brochure, or poster. T/I C

GO TO NELSON SCIENCE

3.1 Summary

- Most fungi are multicellular heterotrophs that use external digestion.
- The bodies of fungi consist of thin hyphae containing many nuclei, surrounded by a cell wall made of chitin. Fungi also have reproductive structures that produce spores.
- The life cycles of most fungi involve haploid individuals that reproduce both sexually and asexually.
- Most plant species depend on symbiotic relationships with soil fungi.
- Fungi are important decomposers that cycle nutrients in ecosystems.
- Fungi are extremely valuable economically, particularly in the production of breads, cheeses, and alcoholic beverages.
- Fungi cause many harmful crop diseases and some human diseases.
- The introduction of non-native fungi to ecosystems by humans has had serious environmental consequences.

Investigation 3.1.1

Growing and Observing Fungi (page 110)

Now that you have had a chance to read about fungi, you can complete Investigation 3.1.1.

In this controlled experiment you will design and conduct experiments to test factors that may influence the growth of bread mould.

3.1 Questions

1. Fungi were once placed in the same kingdom as plants. What evidence suggests that fungi are very different from plants? K/U
2. Make a simple labelled diagram of a hypha. Use your diagram to explain what is unusual about the cell structure of fungi. K/U C
3. Some fungi are considered predatory—they can capture and kill nematodes and other tiny soil organisms (**Figure 13**). Conduct research to determine how they do this. How is this activity related to the availability of nitrogen? K/U

Figure 13 Nematodes are tiny worms that live in soil.

4. In the absence of oxygen, yeast ferment sugar to obtain energy. This process releases carbon dioxide gas and ethanol (an alcohol). How do humans take advantage of this process in the manufacturing of foods and beverages? K/U
5. Describe the symbiotic relationships between fungi and leaf-cutter ants, and between fungi and cyanobacteria. K/U C
6. Many fungi decay wood. Use the Internet and other resources to research how "pressure-treated" technology works to prevent fungal attack. What chemicals are used and how are they applied to the wood? T/I
7. Wild mushrooms can be valuable and delicious, but eating the wrong mushroom can be deadly. Use the Internet and other resources to research which wild mushrooms are edible and most prized, and which are most dangerous. T/I
8. Human fungal infections cause athlete's foot, vaginitis, ringworm, and aspergillosis. Use the Internet and other resources to determine the specific causes of these infections, how they are spread, and how they are treated. T/I
9. Apple scab is a widespread fungal disease that attacks the leaves and fruits of apple trees.
   (a) Research apple scab disease and find out how it is controlled in Ontario.
   (b) Given a choice, would you rather eat an organically grown apple with the occasional scab that can easily be cut off, or a spotless apple that has been grown using a fungicide? Explain your reasoning. T/I
10. Since 2006 a mysterious and deadly disease has been spreading rapidly among many species of bats in northeastern North America. Infected bats exhibit a characteristic "white-nose syndrome" caused by a white fungus. Research the current status of this serious threat. How might the decimation of bat populations influence other species in these ecosystems? T/I A
11. The phylum Glomeromycota contains approximately 160 species. All these species form mycorrhizal relationships with plants. It is also known that more than 80 % of all plant species form mycorrhizal relationships with fungi. How do you think the loss of these fungi would affect the overall biodiversity of ecosystems? Explain your reasoning. A C

GO TO NELSON SCIENCE