Chapter Outline

From boiling thermal hot springs to deep beneath the Antarctic ice, microorganisms can be found almost everywhere on earth in great quantities. Microorganisms (or microbes, as they are also called) are small organisms. Most are so small that they cannot be seen without a microscope.

Most microorganisms are harmless to humans and, in fact, many are helpful. They play fundamental roles in ecosystems everywhere on earth, forming the backbone of many food webs. People use them to make biofuels, medicines, and even foods. Without microbes, there would be no bread, cheese, or beer. Our bodies are filled with microbes, and our skin alone is home to trillions of them.[1] Some of them we can't live without; others cause diseases that can make us sick or even kill us.

Although much more is known today about microbial life than ever before, the vast majority of this invisible world remains unexplored. Microbiologists continue to identify new ways that microbes benefit and threaten humans.

LEARNING OBJECTIVES

By the end of this section, you will be able to:
- Describe how our ancestors improved food with the use of invisible microbes
- Describe how the causes of sickness and disease were explained in ancient times, prior to the invention of the microscope
- Describe key historical events associated with the birth of microbiology

Cora's doctor orders a lumbar puncture (spinal tap) to take three samples of cerebrospinal fluid (CSF) from around the spinal cord. The samples will be sent to laboratories in three different departments for testing: clinical chemistry, microbiology, and hematology. The samples will first be visually examined to determine whether the CSF is abnormally colored or cloudy; then the CSF will be examined under a microscope to see if it contains a normal number of red and white blood cells and to check for any abnormal cell types. In the microbiology lab, the specimen will be centrifuged to concentrate any cells in a sediment; this sediment will be smeared on a slide and stained with a Gram stain. Gram staining is a procedure used to differentiate between two different types of bacteria (gram-positive and gram-negative).

About 80% of patients with bacterial meningitis will show bacteria in their CSF with a Gram stain. Cora's Gram stain did not show any bacteria, but her doctor decides to prescribe her antibiotics just in case. Part of the CSF sample will be cultured—put in special dishes to see if bacteria or fungi will grow. It takes some time for most microorganisms to reproduce in sufficient quantities to be detected and analyzed.

CLINICAL FOCUS

Part 1

Cora, a 41-year-old lawyer and mother of two, has recently been experiencing severe headaches, a high fever, and a stiff neck. Her husband, who has accompanied Cora to see a doctor, reports that Cora also seems confused at times and unusually drowsy. Based on these symptoms, the doctor suspects that Cora may have meningitis, a potentially life-threatening infection of the tissue that surrounds the brain and spinal cord.

Meningitis has several potential causes. It can be brought on by bacteria, fungi, viruses, or even a reaction to medication or exposure to heavy metals. Although people with viral meningitis usually heal on their own, bacterial and fungal meningitis are quite serious and require treatment.

What types of microorganisms would be
killed by antibiotic treatment?

(a) (b)

(a) A lumbar puncture is used to take a sample of a patient’s cerebrospinal fluid (CSF) for testing. A needle is inserted between two vertebrae of the lower back, called the lumbar region. (b) CSF should be clear, as in this sample. Abnormally cloudy CSF may indicate an infection but must be tested further to confirm the presence of microorganisms. (credit a: modification of work by Centers for Disease Control and Prevention; credit b: modification of work by James Heilman)

Most people today, even those who know very little about microbiology, are familiar with the concept of microbes, or “germs,” and their role in human health. Schoolchildren learn about bacteria, viruses, and other microorganisms, and many even view specimens under a microscope. But a few hundred years ago, before the invention of the microscope, the existence of many types of microbes was impossible to prove. By definition, microorganisms, or microbes, are very small organisms; many types of microbes are too small to see without a microscope, although some parasites and fungi are visible to the naked eye.

Humans have been living with—and using—microorganisms for much longer than they have been able to see them. Historical evidence suggests that humans have had some notion of microbial life since prehistoric times and have used that knowledge to develop foods as well as prevent and treat disease. In this section, we will explore some of the historical applications of microbiology as well as the early beginnings of microbiology as a science.

Fermented Foods and Beverages

People across the world have enjoyed fermented foods and beverages like beer, wine, bread, yogurt, cheese, and pickled vegetables for all of recorded history. Discoveries from several archeological sites suggest that even prehistoric people took advantage of fermentation to preserve and enhance the taste of food. Archaeologists studying pottery jars from a Neolithic village in China found that people were making a fermented beverage from rice, honey, and fruit as early as 7000 BC.

Production of these foods and beverages requires microbial fermentation, a process that uses bacteria, mold, or yeast to convert sugars (carbohydrates) to alcohol, gases, and organic acids. While it is likely that people first learned about fermentation by accident—perhaps by drinking old milk that had curdled or old grape juice that had fermented —they later learned to harness the power of fermentation to make products like bread, cheese, and wine.

Figure 1.3 A microscopic view of Saccharomyces cerevisiae, the yeast responsible for making bread rise (left). Yeast is a microorganism. Its cells metabolize the carbohydrates in flour (middle) and produce carbon dioxide, which causes the bread to rise (right). (credit middle: modification of work by Janus Sandsgaard; credit right: modification of work by "MDreibelbis"/Flickr)

The Iceman and Evidence of Early Treatments

Prehistoric humans had a very limited understanding of the causes of disease, and various cultures developed different beliefs and explanations. While many believed that illness was punishment for angering the gods or was simply the result of fate, archaeological evidence suggests that prehistoric people attempted to treat illnesses and infections. One example of this is Otzi the Iceman, a 5300-year-old mummy found frozen in the ice of the Otzal Alps on the Austrian-ltalian border in 1991. Because Otzi was so well preserved by the ice, researchers discovered that he was infected with the eggs of the parasite Trichuris trichiura, which may have caused him to have abdominal pain and anemia. Researchers also found evidence of Borrelia burgdorferi, a bacterium that causes Lyme disease. Some researchers think Otzi may have been trying to treat his infections with the woody fruit of the Fomitopsis betulinus fungus, which was discovered tied to his belongings. This fungus has both laxative and antibiotic properties. Otzi was also covered in tattoos that were made by cutting incisions into his skin, filling them with herbs, and then burning the herbs. There is speculation that this may have been another attempt to treat his health ailments.

Early Notions of Disease, Contagion, and Containment

Several ancient civilizations appear to have had some understanding that disease could be transmitted by things they could not see. This is especially evident in historical attempts to contain the spread of disease. For example, the Bible refers to the practice of quarantining people with leprosy and other diseases, suggesting that people understood that diseases could be communicable. Ironically, while leprosy is communicable, it is also a disease that progresses slowly. This means that people were likely quarantined after they had already spread the disease to others.

Clean water and sanitation are among the most important elements of healthy societies. The earliest examples of urban sanitation systems are from the ancient Indus Valley Civilization cities of Mohenjo-daro and Harappa, located in current-day Pakistan. Constructed in 2500 BCE (about 4,500 years ago), the cities had complex networks of wells, baths, and drainage systems that stored fresh water and carried waste away. About two thousand years later, people in the ancient Greek civilization attributed disease to bad air, mal'aria, which they called "miasmatic odors." They developed hygiene practices that built on this idea. In Rome, they built aqueducts, which brought fresh water into the city, and a giant sewer, the Cloaca Maxima, which carried waste away and into the river Tiber. Some researchers believe that this infrestructure helped protect the Romans from epidedmics of waterborne illnesses.

Even before the invention of the microscope, some doctors, philosophers, and scientists made great strides in understanding the invisible forces—what we now know as microbes—that can cause infection, disease, and death.

The Greek physician Hippocrates (460-370 BC) is considered the "father of Western medicine". Unlike many of his ancestors and contemporaries,
he dismissed the idea that disease was caused by supernatural forces. Instead, he posited that diseases had natural causes from within patients or their environments. Hippocrates and his heirs are believed to have written the Hippocratic Corpus, a collection of texts that make up some of the oldest surviving medical books. Hippocrates is also often credited as the author of the Hippocratic Oath, taken by new physicians to pledge their dedication to diagnosing and treating patients without causing harm.

While Hippocrates is considered the father of Western medicine, the Greek philosopher and historian Thucydides (460-395 BC) is considered the father of scientific history because he advocated for evidence-based analysis of cause-and-effect reasoning. Among his most important contributions are his observations regarding the Athenian plague that killed one-third of the population of Athens between 430 and 410 BC. Having survived the epidemic himself, Thucydides made the important observation that survivors did not get re-infected with the disease, even when taking care of actively sick people. This observation shows an early understanding of the concept of immunity.

Marcus Terentius Varro (116-27 BC) was a prolific Roman writer who was one of the first people to propose the concept that things we cannot see (what we now call microorganisms) can cause disease. In Res Rusticae (On Farming), published in 36 BC,
he said that “precautions must also be taken in neighborhood swamps

. .. because certain minute creatures [animalia minuta] grow there which cannot be seen by the eye, which float in the air and enter the body through the mouth and nose and there cause serious diseases.

Centuries later, Islamic scholars, mainly in Persia, built on the knowledge from Hippocrates as well as from Chinese and Indian medicine. Foremost among them was Abu Bakr al-Razi, usually refered to as al-Razi or by his Latinized name, Rhazes. He developed a range of experimental methods to test various aspects of medicine. For example, to select a location for a hospital, al-Razi hung raw meat around the city, and located the facility in the place where the meat took the longest to rot. He also was the first to distinguish measles and smallbox, and undertook experiments to determine which available treatments were most effective for each. While al-Razi did not have the technology to understand the role of microbes, his efforts to identify the causes of illnesses, rather than solely focusing on the symptoms, were highly influential.

Islamic physicians created one of the most important medical texts in history, the Canon of Medicine (Arabic:

al-Qanun fi al-Tibb). Compiled in 1025 by physician and philosopher Ibn Sina (often referred to as Avicenna), the encyclopedia included detailed descriptions of the parts of the body, a detailed account of over 800 medicinal substances, and pathologies of several illnesses organized by body part or health event. In the work, Ibn Sina described mechanisms of contagion, indicated that organisms could be infected by foreign substances, and that illness could be transmitted by breath. He is also credited with advancing the practice of isolating people who are sick, laying the foundation for historical and contemporary quarantine methods. The Canon was translated into many languages, and was a primary resource for teaching medicine around the world, through the Renaissance and beyond.

Hippocrates, the “father of Western medicine,” believed that diseases had natural, not supernatural, causes. (b) The historian Thucydides observed that survivors of the Athenian plague were subsequently immune to the infection. (c) Marcus Terentius Varro proposed that disease could be caused by “certain minute creatures... which cannot be seen by the eye.” (credit c: modification of work by Alessandro Antonelli)

The Birth of Microbiology

While the ancients may have suspected the existence of invisible “minute creatures,” it wasn’t until the invention of the microscope that their existence was definitively confirmed. While it is unclear who exactly invented the microscope, a Dutch cloth merchant named Antonie van Leeuwenhoek (1632-1723) was the first to develop a lens powerful enough to view microbes. In 1675, using a simple but powerful microscope, Leeuwenhoek was able to observe single-celled organisms, which he described as “animalcules” or “wee little beasties,” swimming in a drop of rain water. From his drawings of these little organisms, we now know he was looking at bacteria and protists. (We will explore Leeuwenhoek's contributions to microscopy further in How We See the Invisible World.)

Nearly 200 years after van Leeuwenhoek got his first glimpse of microbes, the "Golden Age of Microbiology" spawned a host of new discoveries between 1857 and 1914. Two famous microbiologists, Louis Pasteur and Robert Koch, were especially active in advancing our understanding of the unseen world of microbes. Pasteur, a French chemist, showed that individual microbial strains had unique properties and demonstrated that fermentation is caused by microorganisms. He also invented pasteurization, a process used to kill microorganisms responsible for spoilage, and developed vaccines for the treatment of diseases, including rabies, in animals and humans. Koch, a German physician, was the first to demonstrate the connection between a single, isolated microbe and a known human disease. For example, he discovered the bacteria that cause anthrax (Bacillus anthracis), cholera (Vibrio cholera), and tuberculosis (Mycobacterium tuberculosis). We will discuss these famous microbiologists, and others, in later chapters.

MICRO CONNECTIONS

Microbiology Toolbox

Because individual microbes are generally too small to be seen with the naked eye, the science of microbiology is dependent on technology that can artificially enhance the capacity of our natural senses of perception. Early microbiologists like Pasteur and Koch had fewer tools at their disposal than are found in modern laboratories, making their discoveries and innovations that much more impressive. Later chapters of this text will explore many applications of technology in depth, but for now, here is a brief overview of some of the fundamental tools of the microbiology lab.

Microscopes produce magnified images of microorganisms, human cells and tissues, and many other types of specimens too small to be observed with the naked eye.

Stains and dyes are used to add color to microbes so they can be better observed under a microscope. Some dyes can be used on living microbes, whereas others require that the specimens be fixed with chemicals or heat before staining. Some stains only work on certain types of microbes because of differences in their cellular chemical composition.

Growth media are used to grow microorganisms in a lab setting. Some media are liquids; others are more solid or gel-like. A growth medium provides nutrients, including water, various salts, a source of carbon (like glucose), and a source of nitrogen and amino acids (like yeast extract) so microorganisms can grow and reproduce. Ingredients in a growth medium can be modified to grow unique types of microorganisms.

A Petri dish is a flat-lidded dish that is typically 10-11 centimeters (cm) in diameter and 1-1.5 cm high. Petri dishes made out of either plastic or glass are used to hold growth media.

Test tubes are cylindrical plastic or glass tubes with rounded bottoms and open tops. They can be used to grow microbes in broth, or semisolid or solid growth media.

A Bunsen burner is a metal apparatus that creates a flame that can be used to sterilize pieces of equipment. A rubber tube carries gas (fuel) to the burner. In many labs, Bunsen burners are being phased out in favor of infrared microincinerators, which serve a similar purpose without the safety risks of an open flame.

An inoculation loop is a handheld tool that ends in a small wire loop. The loop can be used to streak microorganisms on agar in a Petri dish or to transfer them from one test tube to another. Before each use, the inoculation loop must be sterilized so cultures do not become contaminated.

Footnotes

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Taxonomy is the classification, description, identification, and naming of living organisms. Classification is the practice of organizing organisms into different groups based on their shared characteristics. The most famous early taxonomist was a Swedish botanist, zoologist, and physician named Carolus Linnaeus (1701-1778). In 1735, Linnaeus published Systema Naturae, an 11-page booklet in which he proposed the Linnaean taxonomy, a system of categorizing and naming organisms using a standard format so scientists could discuss organisms using consistent terminology. He continued to revise and add to the book, which grew into multiple volumes.
In his taxonomy, Linnaeus divided the natural world into three kingdoms: animal, plant, and mineral (the mineral kingdom was later abandoned). Within the animal and plant kingdoms, he grouped organisms using a hierarchy of increasingly specific levels and sublevels based on their similarities. The names of the levels in Linnaeus's original taxonomy were kingdom, class, order, family, genus (plural: genera), and species. Species was, and continues to be, the most specific and basic taxonomic unit.

Evolving Trees of Life (Phylogenies)

With advances in technology, other scientists gradually made refinements to the Linnaean system and eventually created new systems for classifying organisms. In the 1800s, there was a growing interest in developing taxonomies that took into account the evolutionary relationships, or phylogenies, of all different species of organisms on earth. One way to depict these relationships is via a diagram called a phylogenetic tree (or tree of life). In these diagrams, groups of organisms are arranged by how closely related they are thought to be. In early phylogenetic trees, the relatedness of organisms was inferred by their visible similarities, such as the presence or absence of hair or the number of limbs. Now, the analysis is more complicated. Today, phylogenic analyses include genetic, biochemical, and embryological comparisons, as will be discussed later in this chapter.

Linnaeus's tree of life contained just two main branches for all living things: the animal and plant kingdoms. In 1866, Ernst Haeckel, a German biologist, philosopher, and physician, proposed another kingdom, Protista, for unicellular organisms. He later proposed a fourth kingdom, Monera, for unicellular organisms whose Cells lack nuclei, like bacteria.
Nearly 100 years later, in 1969, American ecologist Robert Whittaker (1920-1980) proposed adding another kingdom—Fungi—in his tree of life. Whittaker's tree also contained a level of categorization above the kingdom level—the empire or superkingdom level—to distinguish between organisms that have membrane-bound nuclei in their cells (eukaryotes) and those that do not (prokaryotes). Empire Prokaryota contained just the Kingdom Monera. The Empire Eukaryota contained the other four kingdoms: Fungi, Protista, Plantae, and Animalia. Whittaker's five-kingdom tree was considered the standard phylogeny for many years.

Figure 1.10 shows how the tree of life has changed over time. Note that viruses are not found in any of these trees. That is because they are not made up of cells and thus it is difficult to determine where they would fit into a tree of life.

CLINICAL FOCUS

Part 2

Antibiotic drugs are specifically designed to kill or inhibit the growth of bacteria. But after a couple of days on antibiotics, Cora shows no signs of improvement. Also, her CSF cultures came back from the lab negative. Since bacteria or fungi were not isolated from Cora's CSF sample, her doctor rules out bacterial and fungal meningitis. Viral meningitis is still a possibility.

However, Cora now reports some troubling new symptoms. She is starting to have difficulty walking. Her muscle stiffness has spread from her neck to the rest of her body, and her limbs sometimes jerk involuntarily. In addition, Cora's cognitive symptoms are worsening. At this point, Cora's doctor becomes very concerned and orders more tests on the CSF samples.

The Role of Genetics in Modern Taxonomy

Haeckel's and Whittaker's trees presented hypotheses about the phylogeny of different organisms based on readily observable characteristics. But the advent of molecular genetics in the late 20th century revealed other ways to organize phylogenetic trees. Genetic methods allow for a standardized way to compare all living organisms without relying on observable characteristics that can often be subjective. Modern taxonomy relies heavily on comparing the nucleic acids (deoxyribonucleic acid [DNA] or ribonucleic acid [RNA]) or proteins from different organisms. The more similar the nucleic acids and proteins are between two organisms, the more closely related they are considered to be. In the 1970s, American microbiologist Carl Woese discovered what appeared to be a "living record" of the evolution of organisms. He and his collaborator George

Fox created a genetics-based tree of life based on similarities and differences they observed in the gene sequences coding for small subunit ribosomal RNA (rRNA) of different organisms. In the process, they discovered that a certain type of bacteria, called archaebacteria (now known simply as archaea), were significantly different from other bacteria and eukaryotes in terms of their small subunit rRNA gene sequences. To accommodate this difference, they created a tree with three Domains above the level of Kingdom: Archaea, Bacteria, and Eukarya.
Analysis of small subunit rRNA gene sequences suggests archaea, bacteria, and eukaryotes all evolved from a common ancestral cell type. The tree is skewed to show a closer evolutionary relationship between Archaea and Eukarya than they have to Bacteria.
Scientists continue to use analysis of RNA, DNA, and proteins to determine how organisms are related. One interesting, and complicating, discovery is that of horizontal gene transfer—when a gene of one species is absorbed into another organism's genome.
Horizontal gene transfer is especially common in microorganisms and can make it difficult to determine how organisms are evolutionarily related. Consequently, some scientists now think in terms of "webs of life" rather than "trees of life."

Microbiology as a Field of Study

Microbiology is a broad term that encompasses the study of all different types of microorganisms. But in practice, microbiologists tend to specialize in one of several subfields. For example, bacteriology is the study of bacteria; mycology is the study of fungi; protozoology is the study of protozoa; parasitology is the study of helminths and other parasites; and virology is the study of viruses.
Immunology, the study of the immune system, is often

included in the study of microbiology because host-pathogen interactions are central to our understanding of infectious disease processes. Microbiologists can also specialize in certain areas of microbiology, such as clinical microbiology, environmental microbiology, applied microbiology, or food microbiology.

In this textbook, we are primarily concerned with clinical applications of microbiology, but since the various subfields of microbiology are highly interrelated, we will often discuss applications that are not strictly clinical.

Naming Microbes

In developing his taxonomy, Linnaeus used a system of binomial nomenclature, a two-word naming system for identifying organisms by genus and specific epithet. For example, modern humans are in the genus Homo and have the specific epithet name sapiens, so their scientific name in binomial nomenclature is Homo sapiens. In binomial nomenclature, the genus part of the name is always capitalized; it is followed by the specific epithet name, which is not capitalized. Both names are italicized. When referring to the species of humans, the binomial nomenclature would be Homo sapiens. Taxonomic names in the 18th through 20th centuries were typically derived from Latin, since that was the common language used by scientists when taxonomic systems were first created. Today, newly discovered organisms can be given names derived from Latin, Greek, or English. Sometimes these names reflect some distinctive trait of the organism; in other cases, microorganisms are named after the scientists who discovered them. The archaeon Haloquadratum walsbyi is an example of both of these naming schemes. The genus, Haloquadratum, describes the microorganism’s saltwater habitat (halo is derived from the Greek word for “salt”) as well as the arrangement of its square cells, which are arranged in square clusters of four cells (quadratum is Latin for “foursquare”). The species, walsbyi, is named after Anthony Edward Walsby, the microbiologist who discovered Haloquadratum walsbyi in 1980. While it might seem easier to give an organism a common descriptive name—like a red-headed woodpecker—we can imagine how that could become problematic. What happens when another species of woodpecker with red head coloring is discovered? The systematic nomenclature scientists use eliminates this potential problem by assigning each organism a single, unique two-word name that is recognized by scientists all over the world.

MICRO CONNECTIONS

Same Name, Different Strain

Within one species of microorganism, there can be several subtypes called strains. While different strains may be nearly identical genetically, they can have very different attributes. The bacterium Escherichia coli is infamous for causing food poisoning and traveler's diarrhea. However, there are actually many different strains of E. coli, and they vary in their ability to cause disease.

One pathogenic (disease-causing) E. coli strain that you may have heard of is E. coli 0157:H7. In humans, infection from E. coli 0157:H7 can cause abdominal cramps and diarrhea. Infection usually originates from contaminated water or food, particularly raw vegetables and undercooked meat. In the 1990s, there were several large outbreaks of E. coli 0157:H7 thought to have originated in undercooked hamburgers.

While E. coli 0157:H7 and some other strains have given E. coli a bad name, most E. coli strains do not cause disease. In fact, some can be helpful. Different strains of E. coli found naturally in our gut help us digest our food, provide us with some needed chemicals, and fight against pathogenic microbes.
Microorganisms differ from each other not only in size, but also in structure, habitat, metabolism, and many other characteristics. While we typically think of microorganisms as being unicellular, there are also many multicellular organisms that are too small to be seen without a microscope. Some microbes, such as viruses, are even acellular (not composed of cells).

Microorganisms are found in each of the three domains of life: Archaea, Bacteria, and Eukarya. Microbes within the domains Bacteria and Archaea are all prokaryotes (their cells lack a nucleus), whereas microbes in the domain Eukarya are eukaryotes (their cells have a nucleus). Some microorganisms, such as viruses, do not fall within any of the three domains of life. In this section, we will briefly introduce each of the broad groups of microbes. Later chapters will go into greater depth about the diverse species within each group.

Prokaryotic Microorganisms

Bacteria are found in nearly every habitat on earth, including within and on humans. Most bacteria are harmless or helpful, but some are pathogens, causing disease in humans and other animals. Bacteria are prokaryotic because their genetic material (DNA) is not housed within a true nucleus. Most bacteria have cell walls that contain peptidoglycan. They have a wide range of metabolic capabilities and can grow in a variety of environments, using different combinations of nutrients. Some bacteria are photosynthetic, such as oxygenic cyanobacteria and anoxygenic green sulfur and green nonsulfur bacteria; these bacteria use energy derived from sunlight, and fix carbon dioxide for growth. Other types of bacteria are nonphotosynthetic, obtaining their energy from organic or inorganic compounds in their environment.

Archaea are also unicellular prokaryotic organisms. Archaea and bacteria have different evolutionary histories, as well as significant differences in genetics, metabolic pathways, and the composition of their cell walls and membranes. Unlike most bacteria, archaeal cell walls do not contain peptidoglycan, but their cell walls are often composed of a similar substance called pseudopeptidoglycan. Like bacteria, archaea are found in nearly every habitat on earth, even extreme environments that are very cold, very hot, very basic, or very acidic. Some archaea live in the human body, but none have been shown to be human pathogens.

Eukaryotic Microorganisms

The domain Eukarya contains all eukaryotes, including uni- or multicellular eukaryotes such as protists, fungi, plants, and animals. The major defining characteristic of eukaryotes is that their cells contain a nucleus.

Protists

Protists are an informal grouping of eukaryotes that are not plants, animals, or fungi. Some algae are protists and others are bacteria; all protozoa are examples of protists.

Algae (singular: alga) are mostly made up of protists that can be either unicellular or multicellular and vary widely in size, appearance, and habitat.

Algal protists are surrounded by cell walls made of cellulose, a type of carbohydrate. Algae are photosynthetic organisms that extract energy from the sun and release oxygen and carbohydrates into their environment. Cyanobacteria, a type of bacteria, is also considered an algae, but these organisms are bacterial prokaryotes and therefore have a peptidoglycan-based cell wall, unlike the cellulose-based cell wall of the algal protists. Because other organisms can use the waste products of all algae for energy, algae are important parts of many ecosystems. Many consumer products contain ingredients derived from algae, such as carrageenan or alginic acid, which are found in some brands of ice cream, salad dressing, beverages, lipstick, and toothpaste. A derivative of algae also plays a prominent role in the microbiology laboratory. Agar, a gel derived from algae, can be mixed with various nutrients and used to grow microorganisms in a Petri dish. Algae are also being developed as a possible source for biofuels.

Protozoa (singular: protozoan) are protists that make up the backbone of many food webs by providing nutrients for other organisms. Protozoa are very diverse. Some protozoa move with help from hair-like structures called cilia or whip-like structures called flagella. Others extend part of their cell membrane and cytoplasm to propel themselves forward. These cytoplasmic extensions are called pseudopods ("false feet"). Some protozoa are photosynthetic; others feed on organic material. Some are free-living, whereas others are parasitic, only able to survive by extracting nutrients from a host organism. Most protozoa are harmless, but some are pathogens that can cause disease in animals or humans.

Fungi

Fungi (singular: fungus) are also eukaryotes. Some multicellular fungi, such as mushrooms, resemble plants, but they are actually quite different. Fungi are not photosynthetic, and their cell walls are usually made out of chitin rather than cellulose.

Unicellular fungi—yeasts—are included within the study of microbiology. There are more than 1000 known species. Yeasts are found in many different environments, from the deep sea to the human navel. Some yeasts have beneficial uses, such as causing bread to rise and beverages to ferment; but yeasts can also cause food to spoil. Some even cause diseases, such as vaginal yeast infections and oral thrush.