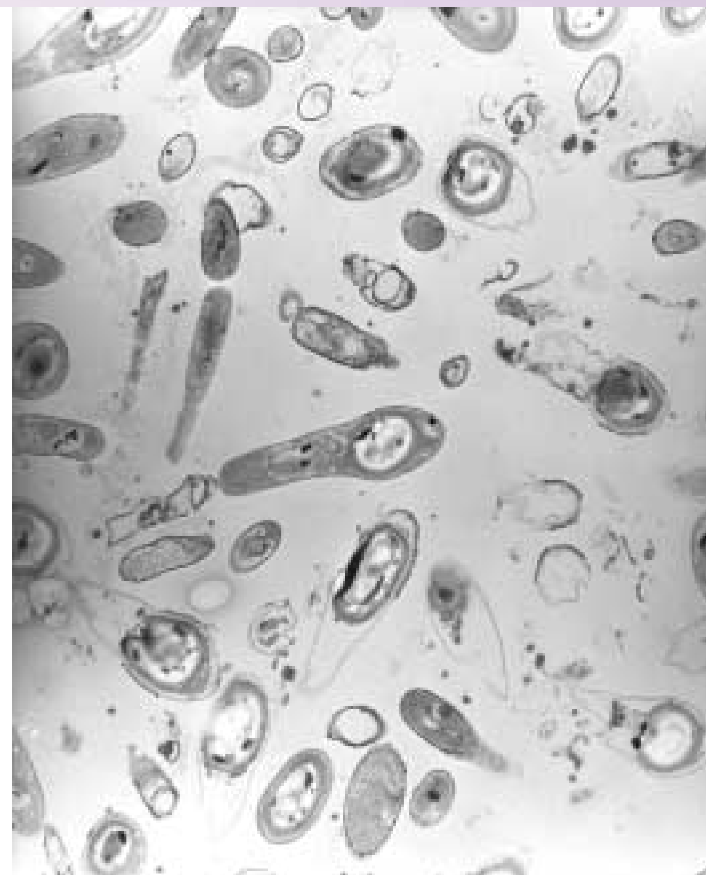
The Main Themes of Microbiology

CHAPTER 1



An ancient bacterium that has been awakened from a quarter of a billion years' sleep. What secrets does it have to share?

The earth is an amazingly nurturing environment for microorganisms. Altshough it has been fancifully nicknamed the "blue planet" or the "water planet," the earth is truly the "planet of the microbes." They are the dominant organisms living in most natural environments, and they are woven tightly through the cycles of all living things. Because of this fact, microbiologists are accustomed to finding extraordinary microbes in unusual places. In the fall of 2000, scientists from Pennsylvania unearthed a microbe that made even the most seasoned microbiologists take notice. They were able to isolate and grow a living bacterium that had been lying dormant and protected in a salt crystal for about 250 million years. This creature was alive even before the time of the dinosaurs, during the Permian period of geologic time. Its source was deep in an underground cavern near Carlsbad, New Mexico. The microbiologists on the project dated it by nearby fossils, and are now taking a close look at its characteristics and genetics. One secret to its longevity is that this bacterium, like its modern relatives, forms very resistant endospores. This finding has prompted a dramatic revision in our ideas about the nature of life and longevity.

Clearly, microorganisms pervade our lives in both an everyday, mundane sense and in a far wider view. We wash our clothes with detergents containing microbe-produced enzymes, eat food that derives flavor from microbial action, and, in many cases, even eat microorganisms themselves. We are vaccinated with altered microbes to prevent diseases that are caused by those very same microbes. We treat various medical conditions with drugs produced by microbes; we dust our plants with insecticides of microbial origin; and we use microorganisms as tiny factories to churn out various industrial chemicals and plastics. We depend upon microbes for many facets of life—one might say even for life itself.

No one can emerge from a microbiology course without a changed view of the world and of themselves.

Chapter Overview

- Microorganisms, also called microbes, are organisms that require a microscope to be readily observed.
- In terms of numbers and range of distribution, microbes are the dominant organisms on earth.
- Major groups of microorganisms include bacteria, algae, protozoa, fungi, parasitic worms, and viruses.
- Microbiology involves study in numerous areas involving cell structure, function, genetics, immunology, biochemistry, epidemiology, and ecology.
- Microorganisms have developed complex interactions with other organisms and the environment.
- Microorganisms are essential to the operation of the earth's ecosystems, as photosynthesizers, decomposers, and recyclers.
- Humans use the versatility of microbes to make improvements in industrial production, agriculture, medicine, and environmental protection.
- The beneficial qualities of microbes are in contrast to the many infectious diseases they cause.
- Microbiologists use the scientific method to develop theories and explanations for microbial phenomena.
- The history of microbiology is marked by numerous significant discoveries and events in microscopy, culture techniques, and other methods of handling or controlling microbes.
- Microorganisms are the oldest organisms, having evolved over the 4 billion years of earth's history to the modern varieties we now observe.
- Microbes are classified into groups according to evolutionary relationships, provided with standard scientific names, and identified by specific characteristics.
- Microorganisms can be classified by means of general categories called domains and cell types (procaryotes and eucaryotes).

The Scope of Microbiology

Microbiology is a specialized area of **biology*** that deals with living things ordinarily too small to be seen without magnification. Such **microscopic*** organisms are collectively referred to as **microorganisms,* microbes,*** or several other terms, depending upon the purpose. Some people call them germs or bugs in reference to their role in infection and disease, but those terms have other biological meanings and perhaps place undue emphasis on the disagreeable reputation of microorganisms. Other terms that are encountered in our study are **bacteria, viruses, fungi, protozoa, algae,** and **helminths;** these microorganisms are the major biological groups that microbiologists study. The very nature of microorganisms makes them ideal subjects for study. They often are more accessible than **macroscopic*** organisms because of their relative simplicity, rapid reproduction, and adaptability, which is the capacity of a living thing to change its structure or function in order to adjust to its environment.

Microbiology is one of the largest and most complex of the biological sciences because it deals with many diverse biological disciplines. In addition to studying the natural history of microbes, it also deals with every aspect of microbe-human and microbe-environmental interactions. These interactions include genetics, metabolism, infection, disease, drug therapy, immunology, genetic engineering, industry, agriculture, and ecology. The subordinate branches that come under the large and expanding umbrella of microbiology are presented in table 1.1.

Microbiology has numerous practical uses in industry and medicine. Some prominent areas that are heavily based on applications in microbiology are as follows:

Immunology studies the system of body defenses that protects against infection. It includes *serology*, a discipline that looks for the products of immune reactions in the blood and tissues and aids in diagnosis of infectious diseases by that means, and *allergy*, the study of hypersensitive responses to ordinary, harmless materials (see chapters 14, 15, 16, and 17).

Public health microbiology and **epidemiology** aim to monitor and control the spread of diseases in communities. The principal U.S. and global institutions involved in this concern are the United States Public Health Service (USPHS) with its main agency, the Centers for Disease Control and Prevention (CDC) located in Atlanta, Georgia, and the World Health Organization (WHO), the medical limb of the United Nations (see chapter 13). The CDC collects information on disease from around the United States and publishes it in a weekly newsletter called the *Morbidity and Mortality Weekly Report*. (Visit www.cdc.gov/mmwr/ for the most current report.)

Food microbiology, dairy microbiology, and **aquatic microbiology** examine the ecological and practical roles of microbes in food and water (see chapter 26).

Agricultural microbiology is concerned with the relationships between microbes and crops, with an emphasis on improving yields and combating plant diseases.

Biotechnology includes any process in which humans use the metabolism of living things to arrive at a desired product, ranging from bread making to gene therapy (see chapters 10 and 26).

Industrial microbiology is concerned with the uses of microbes to produce or harvest large quantities of substances such as beer, vitamins, amino acids, drugs, and enzymes (see chapters 7 and 26).

Genetic engineering and **recombinant DNA technology** involve techniques that deliberately alter the genetic makeup of organisms to mass-produce human hormones and other drugs, create totally novel substances, and develop organisms with unique methods of synthesis and adaptation. This is the most powerful and rapidly growing area in modern microbiology (see chapter 10).

Each of the major disciplines in microbiology contains numerous subdivisions or specialties that in turn deal with a specific subject area or field. In fact, many areas of this science have become so specialized that it is not uncommon for a microbiologist to spend his or her whole life concentrating on a single group or type of microbe, biochemical process, or disease. On the other hand, rarely is one person a single type of microbiologist, and most can be classified in several ways. There are, for instance, bacterial physiologists who study industrial processes, molecular biologists who focus on the genetics of viruses, mycologists doing research on agricultural pests, epidemiologists who are also nurses, and dentists who specialize in the microbiology of gum disease.

Studies in microbiology have led to greater understanding of many theoretical biological principles. For example, the study of microorganisms established universal concepts concerning the chemistry of life (see chapters 2 and 8), systems of inheritance (see chapter 9), and the global cycles of nutrients, minerals, and gases (see chapter 26).

The Impact of Microbes on Earth: Small Organisms with a Giant Effect

The most important knowledge that should emerge from a microbiology course is the profound influence microorganisms have on all aspects of the earth and its residents (figure 1.1). For billions of years, microbes have extensively shaped the development of the earth's habitats and the evolution of other life forms. It is understandable that scientists searching for life on other planets first look for signs of microorganisms.

Microbes can be found nearly everywhere, from deep in the earth's crust, to the polar ice caps and oceans, to the bodies of plants and animals. Being mostly invisible, the actions of microorganisms are usually not as obvious or familiar as those of larger

*biology Gr. *bios*, life, and *logos*, to study. The study of organisms.

*microscopic (my″-kroh-skaw′-pik) Gr. *mikros*, small, and *scopein*, to see.

*microorganism (my-kroh″-or′-gun-izm)

*microbe (my′-krohb) Gr. *mikros*, small, and *bios*, life.

*macroscopic (mak″-roh-skaw′-pik) Gr. *macros*, large, and *scopein*, to see. Visible with the naked eye.

TABLE 1.1
Branches of Microbiology

Science	Area of Study	Chapter Reference
Bacteriology	The bacteria—the smallest, simplest single-celled organisms	4
Mycology	The fungi, a group of organisms that includes both microscopic forms (molds and yeasts) and larger forms (mushrooms, puffballs)	5, 22
Protozoology	The protozoa—animal-like and mostly single-celled organisms	5, 23
Virology	Viruses—minute, noncellular particles that parasitize cells	6, 24, 25
Parasitology	Parasitism and parasitic organisms—traditionally including pathogenic protozoa, helminth worms, and certain insects	5, 23
Phycology or Algology	Simple aquatic organisms called algae, ranging from single-celled forms to large seaweeds	5
Microbial Morphology	The detailed structure of microorganisms	4, 5, 6
Microbial Physiology	Microbial function (metabolism) at the cellular and molecular levels	7, 8
Microbial Taxonomy	Classification, naming, and identification of microorganisms	1, 4, 5
Microbial Genetics, Molecular Biology	The function of genetic material and the biochemical reactions of cells involved in metabolism and growth	9, 10
Microbial Ecology	Interrelationships between microbes and the environment; the roles of microorganisms in the nutrient cycles of soil, water, and other natural communities	7, 26

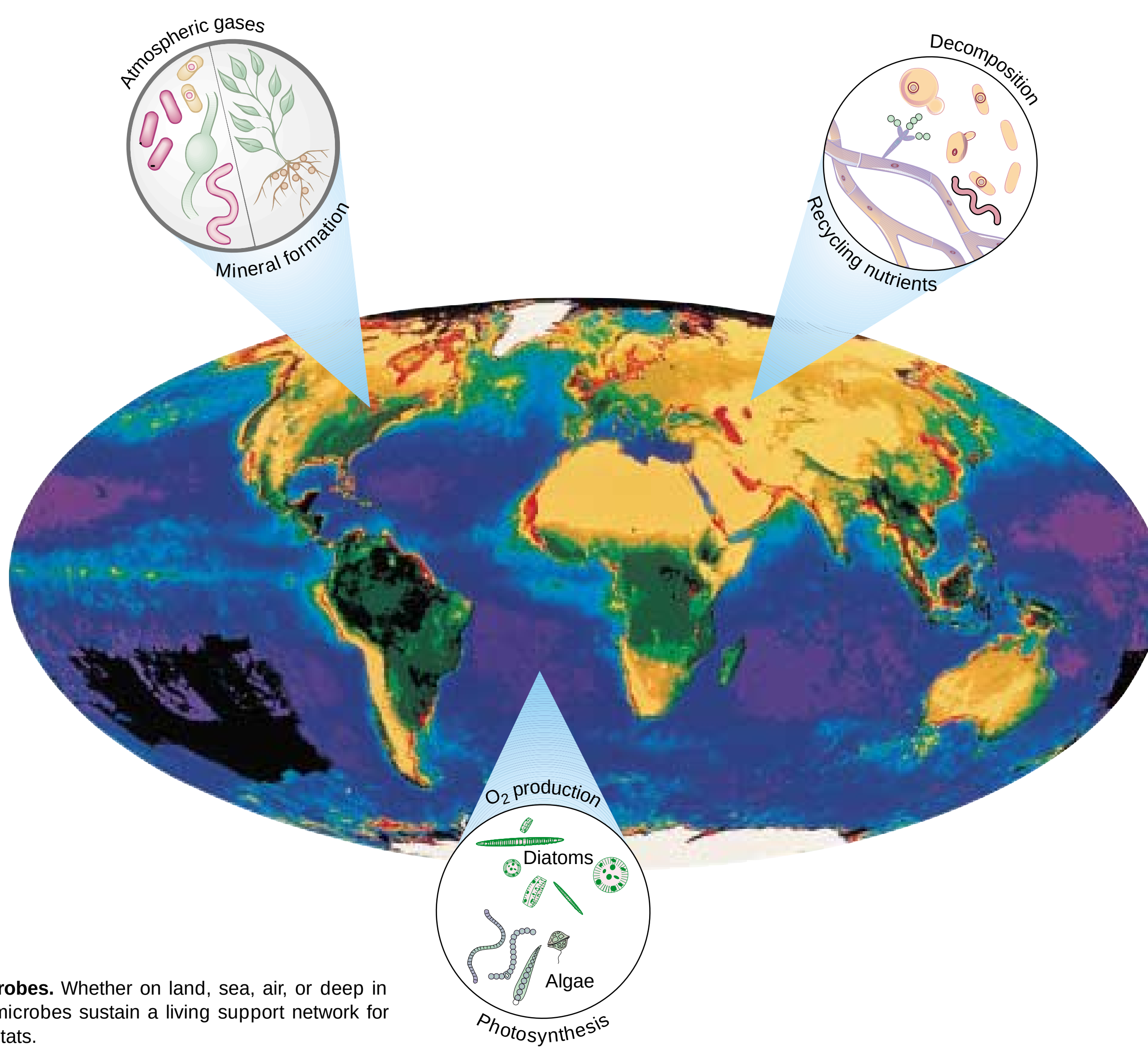


FIGURE 1.1
The world of microbes. Whether on land, sea, air, or deep in the earth's crust, microbes sustain a living support network for all the earth's habitats.

plants and animals. They make up for their small size by occurring in large numbers and living in places that many other organisms cannot survive. Above all, they play central roles in the earth's landscape that are essential to life.

MICROBIAL INVOLVEMENT IN ENERGY AND NUTRIENT FLOW

Microbes are deeply involved in the flow of energy and food through the earth's ecosystems.[1] At the producer end of this range is **photosynthesis,** the formation of food using energy derived from the sun. Photosynthetic microorganisms, including algae and cyanobacteria, account for more than 50% of the earth's photosynthesis (figure 1.2*a*). In addition to serving as the basis for the food chains in the ocean and fresh water, these microorganisms also contribute the majority of oxygen to the atmosphere.

Another process that helps keep the earth in balance is the process of biological **decomposition** and nutrient recycling. Decomposition involves the breakdown of dead matter and wastes into simple compounds that can be directed back into the natural cycles of living things (figure 1.2*b*). If it were not for multitudes of bacteria and fungi, many chemical elements would become locked up and unavailable to organisms. In the long-term scheme of things, microorganisms are the main forces that drive the structure and content of the soil, water, and atmosphere.

- Decomposers play strategic and often very specific roles in the cycling of elements such as nitrogen, sulfur, phosphorus, and carbon between the living and nonliving environment. The very temperature of the earth is regulated by "greenhouse gases," such as carbon dioxide and methane, that create an insulation layer in the atmosphere and help retain heat. Much of this gas is produced by microbes living in the environment and the digestive tracts of animals.
- Recent estimates propose that, based on weight and numbers, up to 50% of all organisms exist within and beneath the earth's crust in sediments, rocks, and even volcanoes. These are mostly primitive microbes that can survive high temperatures and nutrient extremes. It is increasingly evident that this enormous underground community of microbes is a significant influence on weathering, mineral extraction, and soil formation (figure 1.2*c*).
- Microbes have also developed symbiotic[2] associations with other organisms that are highly beneficial to the participating members. Bacteria and fungi live in complex associations with plants that assist the plants in obtaining nutrients and water and may protect them against disease (figure 1.2*d*). Microbes form similar interrelationships with animals, notably represented by the stomach of cattle, which harbor a rich assortment of bacteria to digest the complex carbohydrates of the animals' diets. Other microbes become normal flora[3] that serve as barriers to infectious agents.

(a) Summer pond with a thick mat of algae—a rich photosynthetic community.

(b) A fruit being decomposed by a common soil fungus.

(c) Hydrothermal vents deep in the ocean present a hostile habitat that teems with unusual microorganisms.

(d) A high-magnification view of plant roots reveals a clinging growth of fungi and bacteria.

FIGURE 1.2
Microbial habitats.

1. Ecosystems are any interactions that occur between living organisms and their environment.
2. Symbiosis is a partnership between organisms that benefits at least one of them.
3. Flora are microbes that normally inhabit the bodies of animals.

APPLICATIONS USING MICROORGANISMS: VERSATILE CHEMICAL MACHINES

It is clear that microorganisms have monumental importance to the earth's operation. It is this very same diversity and versatility that also makes them excellent candidates for solving human problems. By accident or choice, humans have been using microorganisms for thousands of years to improve life and even to mold civilizations. The use of microbes to create products is the science of biotechnology. For the most part, this technology relies on the chemical reactions of microorganisms[4] to produce many types of foods and manufactured materials through a process called fermentation[5] (figure 1.3*a*). Yeasts, a type of microscopic fungi, supply the necessary reactions to make bread, alcoholic beverages, and vitamins. Some specialized bacteria have unique capacities to ferment milk products, pickle foods, and even to mine precious metals from raw minerals (figure 1.3*b*). Microbes are also employed to synthesize drugs (antibiotics and hormones) and to mass-produce enzymes for industry and amino acids for health supplements (figure 1.3*a*).

Genetic engineering is a newer area of biotechnology that manipulates the genetics of microbes, plants, and animals for the purpose of creating new products and genetically modified organisms (figure 1.3*c*). One powerful technique for designing new organisms is termed **recombinant DNA.** This technology makes it possible to deliberately alter DNA[6] and to switch genetic material from one organism to another. Bacteria and fungi were some of the first microorganisms to be genetically engineered, because they are so adaptable to changes in their genetic makeup. Recombinant DNA technology has unlimited potential in terms of medical, industrial, and agricultural uses. Microbes can be engineered to synthesize desirable proteins such as drugs, hormones, enzymes, and physiological substances.

Among the genetically unique organisms that have been designed by bioengineers are bacteria that contain a natural pesticide, viruses that serve as vaccines, pigs that produce human hemoglobin, and plants that do not ripen too rapidly (figure 1.3*d*). The techniques also extend to the characterization of human genetic material and diseases.

Another way of tapping into the unlimited potential of microorganisms is the relatively new science of **bioremediation.*** This process involves the introduction of microbes into the environment to restore stability or to clean up toxic pollutants. Bioremediation is required to control the massive levels of pollution from industry and modern living. Microbes have a surprising capacity to break down chemicals that would be harmful to other organisms. Agencies and companies have developed microbes to handle oil spills and detoxify sites contaminated with heavy metals, pesticides, and other chemical wastes (figure 1.3*e*). The solid waste disposal industry is interested in developing methods for degrading the tons of garbage in landfills, especially human-made plastics and paper products. One form of bioremediation that has been in use for some

4. These chemical reactions are also called metabolism.
5. Large-scale processes in industry, using microbes as tiny factories.
6. DNA, or deoxyribonucleic acid, the chemical substance that comprises the genetic material of organisms.

* **bioremediation** (by′-oh-ree-mee-dee-ay″-shun) *bios,* life; *re,* again; *mederi,* to heal. The use of biological agents to remedy environmental problems.

(a) Microbes as synthesizers. A large complex fermentor manufactures drugs and enzymes using microbial metabolism.

(b) An aerial view of a copper mine looks like a giant quilt pattern. The colored patches are various stages of bacteria extracting metals from the ore.

(c) Workers in a clean biotechnology lab isolate genes for possible testing.

(d) Genetically engineered tomatoes have genes manipulated to slow ripening and increase flavor and nutritional content.

(e) A bioremediation platform placed in a river for the purpose of detoxifying the water containing industrial pollutants.

FIGURE 1.3
Microbes at work.

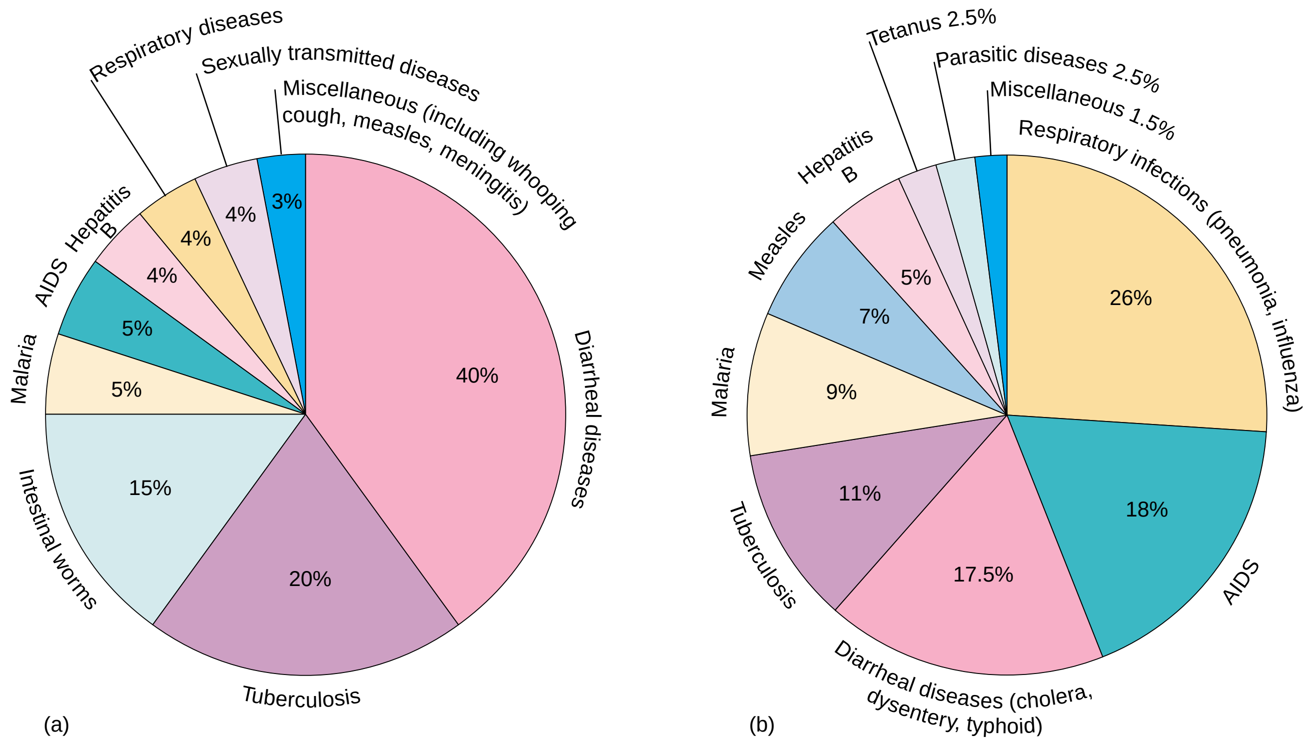


FIGURE 1.4

Global infectious disease statistics. Infectious disease statistics rank the major causes of **(a)** morbidity (rate of disease) and **(b)** mortality (deaths). A large number of diseases can be treated with drugs or prevented altogether with vaccination and improvements in health care and sanitation.

Source: World Health Organization, 1999; most recent data available.

time is the treatment of water and sewage. Since clean freshwater supplies are rapidly dwindling worldwide, it will become even more important to find ways to reclaim polluted water.

INFECTIOUS DISEASES AND THE HUMAN CONDITION

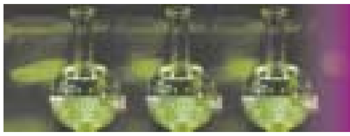
One of the most fascinating aspects of the microorganisms with which we share the earth is that, despite all of the benefits they provide, they also contribute significantly to human misery as **pathogens.*** Humanity is plagued by nearly 2,000 different microbes that can infect the human body and cause various types of disease. Infectious diseases still devastate human populations worldwide, despite significant strides in understanding and treating them. The most recent estimates from the World Health Organization (WHO) point to a total of 10 billion new infections across the world every year (figure 1.4*a*). There are more infections than people because many people acquire more than one infection. Infectious diseases are also the most common cause of death in much of humanity, and they still kill about one-third of the U.S. population. The worldwide death toll is about 13 million people, and many of these diseases are preventable by drugs and vaccines (figure 1.4*b*). Those hardest hit are residents in countries where access to adequate medical care is lacking. One-third of the earth's inhabitants live on less than $1 per day, are malnourished, and are not fully immunized.

Adding to the overload of infectious diseases, we are also witnessing an increase in the number of new (emerging) and older (reemerging) diseases (Spotlight on Microbiology 1.1). AIDS, hepatitis C, and viral encephalitis are examples of recently identified diseases that cause severe mortality and morbidity and are currently on the rise. To somewhat balance this trend, there have also been some advances in eradication of diseases such as polio, measles, leprosy, and certain parasitic worms. The WHO is currently on a global push to vaccinate children against the most common childhood diseases.

It is significant that, in addition to known infectious diseases, many other diseases are suspected of having a microbial origin. A connection has been established between certain cancers and viruses, between diabetes and the Coxsackie virus, and between schizophrenia and a virus called the borna agent. Diseases as disparate as multiple sclerosis, obsessive compulsive disorder, and coronary artery disease have been linked to chronic infections with microorganisms.

A further health complication from infectious diseases is the increasing number of patients with weakened defenses that are kept alive for extended periods. They are subject to infections by common microbes that are not pathogenic to healthy people. There is also an increase in microbes that are resistant to drugs. It appears that even with the most modern technology available to us, microbes still have the "last word," as the great French microbiologist Louis Pasteur observed.

*pathogens (path′-oh-jenz) Gr. *pathos*, disease, and *gennan*, to produce. Disease-causing agents.



SPOTLIGHT ON MICROBIOLOGY 1.1

Infectious Diseases in the Global Village

Eradicating infectious diseases and arresting their spread have long been goals of medical science. There is no doubt that advances in detection, treatment, and prevention have gradually reduced the numbers of such diseases, but most of these decreases have occurred in more developed countries. In less developed countries, however, infections still account for over 40% of deaths.

From the standpoint of infectious diseases, the earth's inhabitants serve as a collective incubator for old and new diseases. Newly identified diseases that are becoming more prominent are termed **emerging.** Table 1.A lists 20 of the most common emerging diseases that have been diagnosed over a span of 30 years. Some of them were associated with a specific geographic site (Ebola fever), whereas others were spread across all continents (AIDS). Older diseases that have been known for hundreds of years and are increasing in occurrence are termed **reemerging.** Among the diseases currently experiencing a resurgence are tuberculosis, influenza, malaria, cholera, and hepatitis B. Many factors play a part in emergence, but fundamental to all emerging diseases is the formidable capacity of microorganisms to respond and adapt to alterations in the individual, community, and environment.

What events in the world cause emerging diseases? Dr. David Satcher, director of the Centers for Disease Control and Prevention (CDC), states simply that "organisms changed and people changed." Among the most profound influences are disruptions in the human population, such as crowding or immigration. For an excellent example of this effect, we have only to look at AIDS, which began as a focus of infection in remote African villages and was transported out of the region through immigration and tourism. These factors caused the disease to spread rapidly, so that by 2001, it had become the second most common cause of death worldwide (see figure 1.4). Another population factor is an increase in the number of people who are susceptible to infections. Some countries have a high percentage of young people at risk. These children lack immunization or are malnourished, both of which increase their susceptibility to common childhood and diarrheal diseases.

A number of prominent emerging diseases are associated with changing methods in agriculture and technology. The mass production and packing of food increases the opportunity for large outbreaks, especially if foods are grown in fecally contaminated soils or are eaten raw or poorly cooked. In the past several years, dozens of food-borne outbreaks caused by emerging pathogens have occurred. Epidemics have been associated with the bacterium *Escherichia coli* 0157:H7 in fresh vegetables, fruits, and meats; hundreds of thousands of people are exposed to the cholera bacteria in seafood and to *Salmonella* bacteria in eggs and milk. Even municipal water supplies have spread water-borne protozoa such as *Cryptosporidium* and *Giardia* that slipped past the usual water treatment systems. An unusual protein-infectious agent (prion) was spread to consumers of beef in some parts of Europe, where it was associated with a disease known as *spongiform encephalopathy*.

Other influences on emergent diseases are fluctuations in ecology, climate, animal migration, and human travel. Warming in some regions has increased the spread of mosquitoes that carry dengue fever or encephalitis viruses. There is considerable concern about the migration of tropical diseases such as malaria and West Nile fever into northern climates.

The encroachment of humans into wild habitats has opened the way to *zoonotic** pathogens. A zoonosis is an infection indigenous to animals that can be transmitted to humans. It is important to realize that many microbes are not specific to their host, and many of them have mutated to become more virulent. A recent study found that 79% of emerging human pathogens originate from animals. Examples of host switching are the African outbreaks of monkeypox and Ebola fever (ostensibly from contact with wild monkeys), a Malaysian outbreak of the Nipah virus that is harbored in fruit bats, and hantavirus disease from exposure to rodents.

Increased personal freedom and opportunities for travel favor the rapid dispersal of microbes. A person may become infected and be home for several days before symptoms appear. Pathogens can literally be transmitted around the globe in a short time. Because of this potential, we can no longer separate the world into "them" and "us." Health authorities from every country must be constantly vigilant to prevent another crisis like AIDS and to keep common diseases in check through vaccination and medication.

TABLE 1.A
Prominent Emerging Diseases over a Span of 30 Years

Microbe	Source	Disease	Year of Emergence
Lassa fever virus	Rodents	Lassa fever	1969
Monkeypox virus	Monkeys, rodents	Monkeypox	1970
Marburg virus	Monkeys?	Hemorrhagic fever	1975
Ebola virus	Monkeys?	Hemorrhagic fever	1977
Legionella bacteria	Water	Legionnaire's disease	1977
Human T-cell virus	Humans	Lymphoma, leukemia	1980
Staphylococcus bacteria	Humans	Toxic shock syndrome	1981
Human immuno-deficiency virus	Humans	AIDS	1981
Escherichia coli bacteria	Cattle	Hemolytic uremic syndrome	1982
Borrelia bacteria	Ticks	Lyme disease	1982
Helicobacter bacteria	Humans	Peptic ulcers	1983
Hepatitis C virus	Humans	Hepatitis, liver diseases	1989
Hantavirus	Mice	Respiratory distress syndrome	1993
Hendra virus	Bats	Encephalitis	1994
Cryptosporidium protozoa	Water	Diarrhea, enteric disease	1994
Ehrlichia bacteria	Ticks	Arthritis, muscle pain	1995
New variant CJD prion	Cattle	Creutzfeldt-Jakob disease	1996
Nipah virus	Bats	Encephalitis, pneumonia	1998
Arenavirus	Woodrats	Respiratory distress	1999
West Nile virus	Mosquitoes	Encephalitis	1999

*zoonotic (zoh-naw′-tik) Gr. *zoion*, animal, and *nosis*, disease.

CHAPTER CHECKPOINTS

Microorganisms are defined as "living organisms too small to be seen with the naked eye." Among the members of this huge group of organisms are bacteria, fungi, protozoa, algae, viruses, and parasitic worms.

Microorganisms live nearly everywhere and have impact on many biological and physical activities on earth.

There are many kinds of relationships between microorganisms and humans; most are beneficial, but some are harmful.

The scope of microbiology is incredibly diverse. It includes basic microbial research, research on infectious diseases, study of prevention and treatment of disease, environmental functions of microorganisms, and industrial use of microorganisms for commercial, agricultural, and medical purposes.

In the last 120 years, microbiologists have identified the causative agents for most of the infectious diseases. In addition, they have discovered distinct connections between microorganisms and diseases whose causes were previously unknown.

Microorganisms: We have to learn to live with them because we cannot live without them.

The General Characteristics of Microorganisms

CELLULAR ORGANIZATION

Two basic cell lines have appeared during evolutionary history. These lines, termed **procaryotic*** **cells** and **eucaryotic*** **cells,** differ primarily in the complexity of their cell structure (figure 1.5*a*).

In general, procaryotic cells are smaller than eucaryotic cells, and they lack special structures such as a nucleus and **organelles.*** Organelles are small membrane-bound cell structures that perform specific functions in eucaryotic cells. These two cell types and the organisms that possess them (called procaryotes and eucaryotes) are covered in more detail in chapters 2, 4, and 5.

All procaryotes are microorganisms, but only some eucaryotes are microorganisms. The bodies of most microorganisms consist of either a single cell or just a few cells (figure 1.5*c, d*). Because of their role in disease, certain animals such as helminth worms and insects, many of which can be seen with the naked eye, are also considered in the study of microorganisms. Even in its seeming simplicity, the microscopic world is every bit as complex and diverse as the macroscopic one. There is no doubt that microorganisms also outnumber macroscopic organisms by a factor of several million.

*__procaryotic__ (proh″-kar-ee-ah′-tik) Gr. *pro,* before, and *karyon,* nucleus.

*__eucaryotic__ (yoo″-kar-ee-ah′-tik) Gr. *eu,* true or good, and *karyon,* nucleus. Sometimes spelled prokaryotic and eukaryotic.

*__organelle__ (or′-gan-el″) L., little organ.

A NOTE ON VIRUSES

Viruses are subject to intense study by microbiologists. They are small particles that exist at a level of complexity somewhere between large molecules and cells (figure 1.5*b*). Viruses are much simpler than cells; they are composed essentially of a small amount of hereditary material wrapped up in a protein covering. Some biologists refer to viruses as parasitic particles; others consider them to be very primitive organisms. One thing is certain—they are highly dependent on a host cell's machinery for their activities.

MICROBIAL DIMENSIONS: HOW SMALL IS SMALL?

When we say that microbes are too small to be seen with the unaided eye, what sorts of dimensions are we talking about? This concept is best visualized by comparing microbial groups with the larger organisms of the macroscopic world and also with the molecules and atoms of the molecular world (figure 1.6). Whereas the dimensions of macroscopic organisms are usually given in centimeters (cm) and meters (m), those of most microorganisms fall within the range of micrometers (μm) and to a lesser extent, nanometers (nm) and millimeters (mm). The size range of most microbes extends from the smallest viruses, measuring around 20 nm and actually not much bigger than a large molecule, to protozoans measuring 3 to 4 mm and visible with the naked eye.

LIFE-STYLES OF MICROORGANISMS

The majority of microorganisms live a free existence in habitats such as soil and water, where they are relatively harmless and often beneficial. A free-living organism can derive all required foods and other factors directly from the nonliving environment. Some microorganisms require interactions with other organisms. One such group, termed **parasites,** are harbored and nourished by other living organisms, called **hosts.** A parasite's actions cause damage to its host through infection and disease. Most microbial parasites are some type of bacterium, fungus, protozoan, worm, or virus. Although parasites cause important diseases, they make up only a small proportion of microbes. As we shall see later in the chapter, a few microorganisms can exist on either free-living or parasitic levels.

CHAPTER CHECKPOINTS

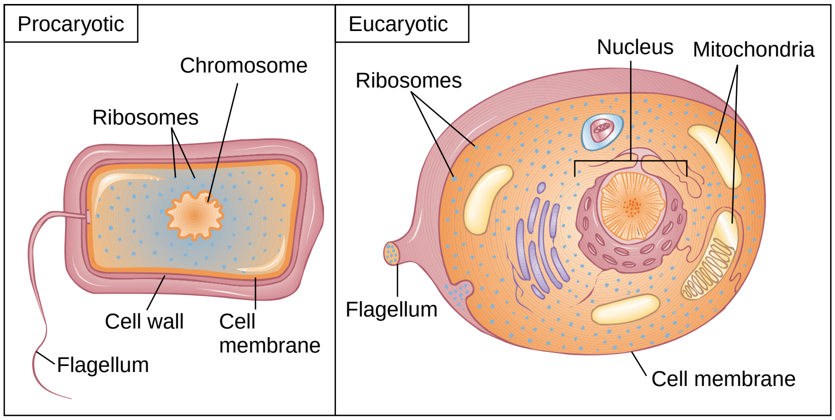
Excluding the viruses, there are two types of microorganisms: procaryotes, which are small and lack a nucleus and organelles, and eucaryotes, which are larger and have both a nucleus and organelles.

Viruses are not cellular and are therefore called particles rather than organisms. They are included in microbiology because of their small size and close relationship with cells.

Most microorganisms are measured in micrometers, with two exceptions. The helminths are measured in millimeters, and the viruses are measured in nanometers.

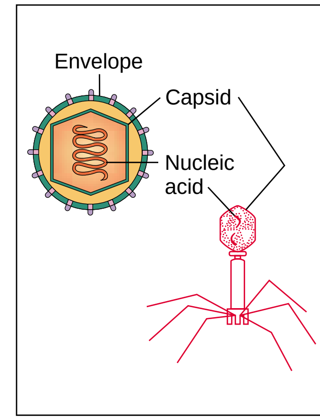
Contrary to popular belief, most microorganisms are harmless, free-living species that perform vital functions in both the environment and larger organisms. Comparatively few species are agents of disease.

(a) Cell Types



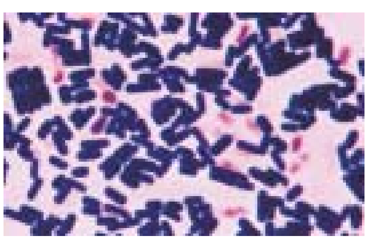
Microbial cells are of the small, relatively simple procaryotic variety (left) or the larger, more complex eucaryotic type (right).

(b) Virus Types

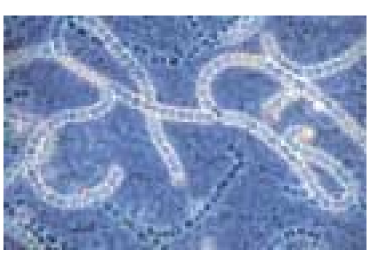


Viruses are tiny particles, not cells, that consist of genetic material surrounded by a protective covering. Shown here are a human virus (top) and bacterial virus (bottom).

(c) Examples of procaryotic organisms



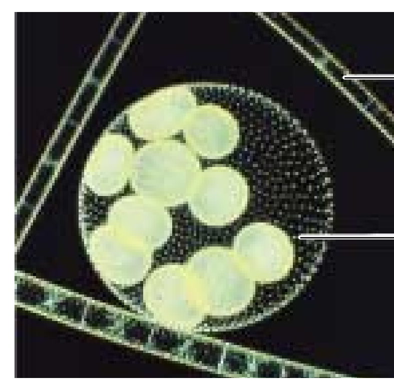
Rod-shaped bacteria, *Clostridium,* found in soil



Nostoc, a cyanobacterium that lives in fresh water

(d) Examples of eucaryotic organisms

The stalked protozoan *Vorticella* is shown in feeding mode. These free-living eucaryotes are common in pond water.



Representatives of algae. *Volvox* is a large, complex colony composed of smaller colonies (spheres) and cells (dots). *Spirogyra* is a filamentous alga composed of elongate cells joined end to end.

Example of a fungus; shown here is the mold *Thamnidium* displaying its sac-like reproductive vessels.

FIGURE 1.5

The organization of living things and viruses.

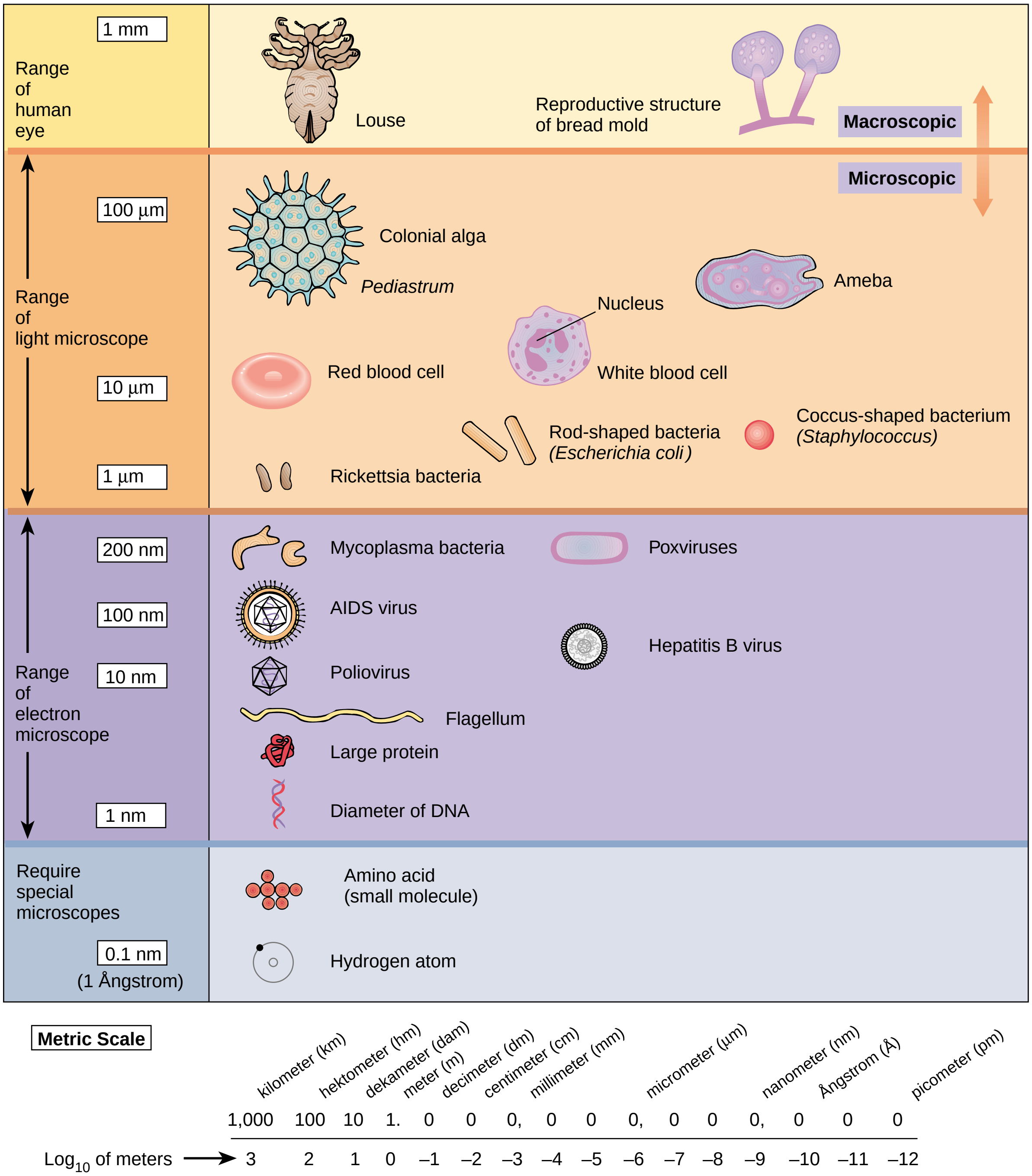


FIGURE 1.6

The size of things. Common measurements encountered in microbiology and a scale of comparison from the macroscopic to the microscopic, molecular, and atomic. Most microbes encountered in our studies will fall between 100 µm and 10 nm in overall dimensions. The microbes shown are more or less to scale within size zone but not between size zones.

The Historical Foundations of Microbiology

If not for the extensive interest, curiosity, and devotion of thousands of microbiologists over the last 300 years, we would know little about the microscopic realm that surrounds us. Many of the discoveries in this science have resulted from the prior work of men and women who toiled long hours in dimly lit laboratories with the crudest of tools. Each additional insight, whether large or small, has added to our current knowledge of living things and processes. This treatment of the early history of microbiology will summarize the prominent discoveries made in the past 300 years: microscopy, the rise of the scientific method, and the development of medical microbiology, including the germ theory and the origins of modern microbiological techniques. See table B.1 in appendix B, which summarizes some of the pivotal events in microbiology, from its earliest beginnings to the present. Additional historical vignettes are integrated throughout this text to emphasize the developmental stages of modern microbiology.

FIGURE 1.7

An oil painting of Antonie van Leeuwenhoek (1632–1723) sitting in his laboratory. J.R. Porter and C. Dobell have commented on the unique qualities Leeuwenhoek brought to his craft: "He was one of the most original and curious men who ever lived. It is difficult to compare him with anybody because he belonged to a genus of which he was the type and only species, and when he died his line became extinct."

THE DEVELOPMENT OF THE MICROSCOPE: "SEEING IS BELIEVING"

It is likely that from the very earliest history, humans noticed that when certain foods spoiled they became inedible or caused illness, and yet other spoiled foods did no harm and even had enhanced flavor. Indeed, several centuries ago, there was already a sense that diseases such as the black plague and smallpox were caused by some sort of transmissible matter. But the causes of such phenomena were vague and obscure because the technology to study them was lacking. Consequently, they remained cloaked in mystery and regarded with superstition—a trend that led even well-educated scientists to believe in spontaneous generation (Historical Highlights 1.2). True awareness of the widespread distribution of microorganisms and some of their characteristics was finally made possible by the development of the first microscopes. These devices revealed microbes as discrete entities sharing many of the characteristics of larger, visible plants and animals. Several early scientists fashioned magnifying lenses, but their microscopes lacked the optical clarity needed for examining bacteria and other small, single-celled organisms. The first careful and exacting observations awaited the clever single-lens microscope hand-fashioned by Antonie van Leeuwenhoek, a Dutch linen merchant and self-made microbiologist (figure 1.7). The original purpose of the microscopes was to examine cloth for flaws, but Leeuwenhoek turned them to other uses as well.

Leeuwenhoek's wide-ranging investigations included observations of tiny organisms he called *animalcules* (little animals), blood, and other human tissues (including his own tooth scrapings), insects, minerals, and plant materials. He constructed more than 250 small, powerful microscopes that could magnify up to 300 times (figure 1.8). Considering that he had no formal training in science and that he was the first person ever to faithfully record this strange new world, his descriptions of bacteria and protozoa were astute and precise. Because of Leeuwenhoek's extraordinary contributions to microbiology, he is known as the father of bacteriology and protozoology.

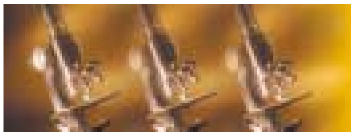
From the time of Leeuwenhoek, microscopes evolved into more complex and improved instruments with the addition of refined lenses, a condenser, finer focusing devices, and built-in light sources. The prototype of the modern compound microscope, in use from about the mid-1800s, was capable of magnifications of 1,000 times or more. Even our modern laboratory microscopes are not greatly different in basic structure and function from those early microscopes. The technical characteristics of microscopes and microscopy are the major focus of chapter 3.

THE ESTABLISHMENT OF THE SCIENTIFIC METHOD

A serious impediment to the development of true scientific reasoning and testing was the tendency of early scientists to explain natural phenomena by a mixture of belief, superstition, and argument. The development of an experimental system that answered questions objectively and was not based on prejudice marked the beginning of true scientific thinking. These ideas gradually crept into the consciousness of the scientific community during the 1600s. The general approach taken by scientists to explain a certain natural phenomenon is called the **scientific method.** A primary aim of this method is to formulate a **hypothesis,** a tentative explanation to account for what has been observed or measured. A good hypothesis must be capable of being either supported or discredited by careful, systematic observation or experimentation. For example, the statement that "microorganisms cause diseases" can be experimentally determined by the tools of science, but the statement that "diseases are caused by evil spirits" cannot.

The two types of reasoning that are commonly applied separately or in combination to develop and support hypotheses are **induction** and **deduction.** In the **inductive approach,** a scientist first accumulates specific data or facts and then formulates a general hypothesis that accounts for those facts (figure 1.9). The inductive approach asks, "Are various observed events best explained by this hypothesis or by another one?" In the **deductive approach,** a scientist constructs a hypothesis, tests its validity by outlining particular events that are predicted by the hypothesis, and then performs experiments to test for those events (figure 1.10). The deductive process states: "If the hypothesis is valid, then certain specific events can be expected to occur."

Natural processes have numerous physical, chemical, and biological factors, or *variables,* that can hypothetically affect their outcome. To account for these variables, scientists design experiments: (1) to thoroughly test for or measure the consequences of each possible variable and (2) to accompany each variable with one or more *control groups*. A control group is designed exactly as the test group but omits only that variable being tested; thus, it may serve as a basis of comparison for the test group. The reasoning is that, if a certain experimental finding occurs only in the test group and not in the control group, the finding must be due to the variable being tested and not to some uncontrolled, untested factor that is not part of the hypothesis (figure 1.11).

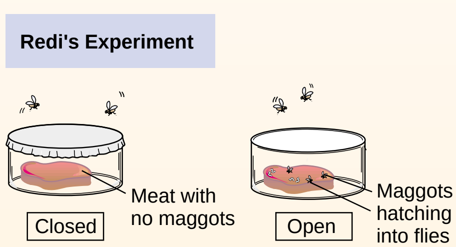


HISTORICAL HIGHLIGHTS 1.2

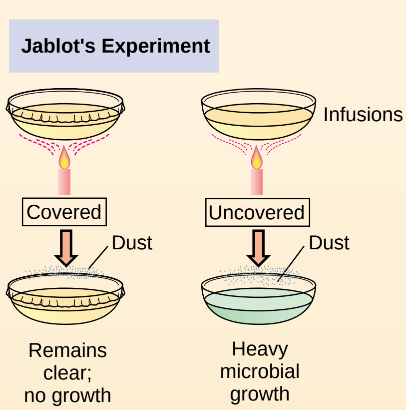
The Fall of Mysticism and the Rise of Microbiology

For thousands of years, people believed that certain living things arose from vital forces present in nonliving or decomposing matter. This ancient belief, known as **spontaneous generation,** was continually reinforced as people observed that meat left out in the open soon "produced" maggots, that mushrooms appeared on rotting wood, that rats and mice emerged from piles of litter, and other similar phenomena. Though some of these early ideas seem quaint and ridiculous in light of modern knowledge, we must remember that, at the time, mysteries in life were accepted, and the scientific method was not widely practiced.

Even after single-celled organisms were discovered during the mid-1600s, the idea of spontaneous generation continued to exist. Some scientists assumed that microscopic beings were an early stage in the development of more complex ones.



Over the subsequent 200 years, scientists waged an experimental battle over the two hypotheses that could explain the origin of simple life forms. Some tenaciously clung to the idea of **abiogenesis,*** which embraced spontaneous generation. On the other side were advocates of **biogenesis** saying that living things arise only from others of their same kind. There were serious proponents on both sides, and each side put forth what appeared on the surface to be plausible explanations of why their evidence was more correct. Gradually, the abiogenesis hypothesis was abandoned, as convincing evidence for biogenesis continued to mount. The following series of experiments were among the most important in finally tipping the balance. Among the important variables to be considered in challenging the hypotheses were the effects of nutrients, air, and heat and the presence of preexisting life forms in the environment. One of the first people to test the spontaneous generation theory was Francesco Redi of Italy. He conducted a simple experiment in which he placed meat in a jar and covered it with fine gauze. Flies gathering at the jar were blocked from entering and thus laid their eggs on the outside of the gauze. The maggots subsequently developed without access to the meat, indicating that maggots were the offspring of flies and did not arise from some "vital force" in the meat. This and related experiments laid to rest the idea that more complex animals such as insects and mice developed through abiogenesis, but it did not convince many scientists of the day that simpler organisms could not arise in that way.



Frenchman Louis Jablot reasoned that even microscopic organisms must have parents, and his experiments with infusions (dried hay steeped in water) supported that hypothesis. He divided an infusion that had been boiled to destroy any living things into two containers: a heated container that was closed to the air and a heated container that was freely open to the air. Only the open vessel developed microorganisms, which he presumed had entered in air laden with dust. Regrettably, the validation of biogenesis was temporarily set back by John Needham, an Englishman who did similar experiments using mutton gravy. His results were in conflict with Jablot's because both his heated and unheated test containers teemed with microbes. Unfortunately, his experiments were done before the concepts of heat-resistant endospores and true methods of sterilization were understood and widely known.

*abiogenesis (ah-bee″-oh-jen-uh-sis) Gr. *a*, not, *bios*, living, and *gennan*, to produce.

A lengthy process of experimentation, analysis, and testing eventually leads to conclusions that either support or refute the hypothesis. If experiments do not uphold the hypothesis—that is, if it is found to be flawed—the hypothesis or some part of it is rejected; it is either discarded or modified to fit the results of the experiment. If the hypothesis is supported by the results from the experiment, it is not (or should not be) immediately accepted as fact. It then must be tested and retested. Indeed, this is an important guideline in the acceptance of a hypothesis. The results of the experiment must be published and then repeated by other investigators.

In time, as each hypothesis is supported by a growing body of data and survives rigorous scrutiny, it moves to the next level of acceptance—the **theory.** A theory is a collection of statements, propositions, or concepts that explains or accounts for a natural event. A theory is not the result of a single experiment repeated over and over again, but is an entire body of ideas that expresses or explains many aspects of a phenomenon. It is not a fuzzy or weak speculation, as is

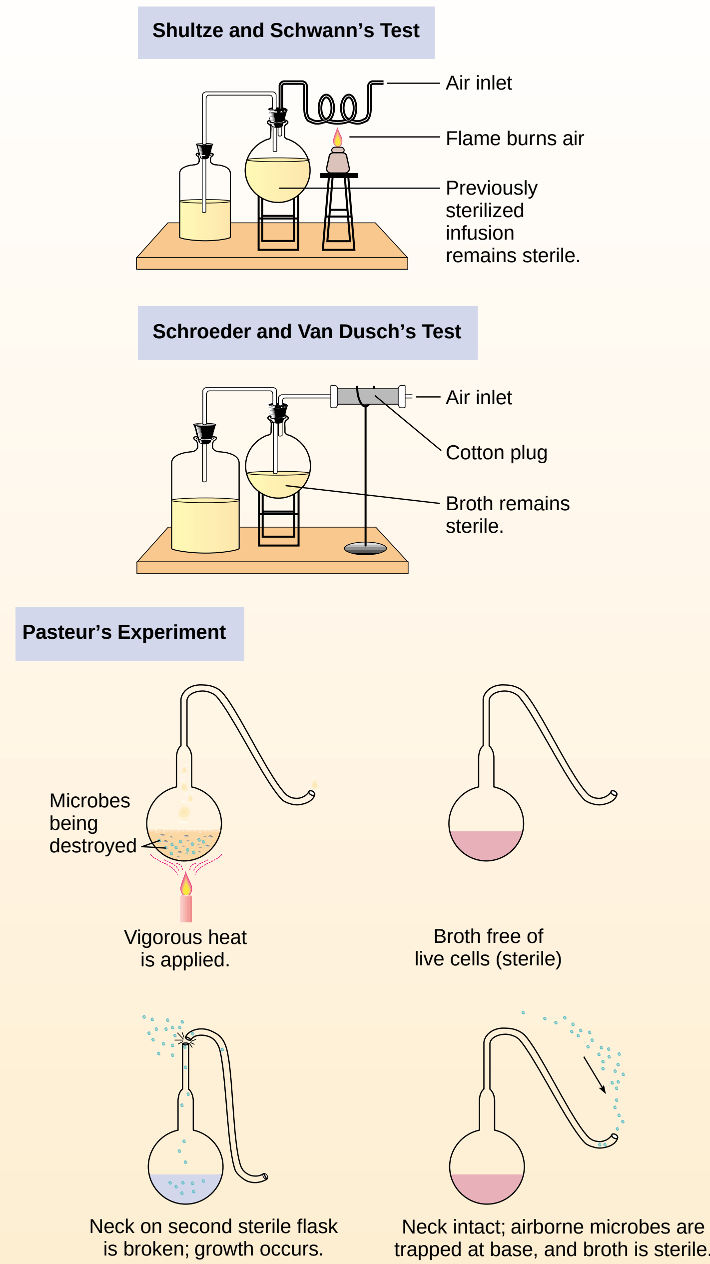
Additional experiments further defended biogenesis. Franz Shultze and Theodor Schwann of Germany felt sure that air was the source of microbes and sought to prove this by passing air through strong chemicals or hot glass tubes into heat-treated infusions in flasks. When the infusions again remained devoid of living things, the supporters of abiogenesis claimed that the treatment of the air had made it harmful to the spontaneous development of life.

Georg Schroeder and Theodor Van Dusch followed up these studies. They did not treat the air with heat or chemicals but passed it through cotton wool to filter out microscopic organisms. Again, no microbes grew in the infusions. Although all these experiments should have finally laid to rest the arguments for spontaneous generation, they did not.

Then, in the mid-1800s, the acclaimed microbiologist Louis Pasteur entered the arena. He had recently been studying the roles of microorganisms in the fermentation of beer and wine, and it was clear to him that these processes were brought about by the activities of microbes introduced into the beverage from air, fruits, and grains. The methods he used to discount abiogenesis were simple yet brilliant.

Pasteur repeated the experiments using cotton filters to trap dust from air and observed tiny objects (probably spores) in the filters. He also observed that these same filters would initiate growth in previously sterile broths. To further clarify that air and dust were the source of microbes, he filled flasks with broth and fashioned their openings into elongate, swan-neck–shaped tubes. The flasks' openings were freely open to the air but were curved so that gravity would cause any airborne dust particles to deposit in the lower part of the necks. He heated the flasks to sterilize the broth and then incubated them. As long as the flask remained intact, the broth remained sterile, but if the neck was broken off so that dust fell directly down into the container, microbial growth immediately commenced.

Pasteur summed up his findings, "For I have kept from them, and am still keeping from them, that one thing which is above the power of man to make; I have kept from them the germs that float in the air, I have kept from them life."



sometimes the popular notion, but a viable declaration that has stood the test of time and has yet to be disproved by serious scientific endeavors. Often, theories develop and progress through decades of research and are added to and modified by new findings. At some point, evidence of the accuracy and predictability of a theory is so compelling that the next level of confidence is reached and the theory becomes a **law,** or principle. For example, although we still refer to the germ *theory* of disease, so little question remains that microbes can cause disease that it has clearly passed into the realm of law.

Science and its hypotheses and theories must progress along with technology. As advances in instrumentation allow new, more detailed views of living phenomena, old theories may be reexamined and altered and new ones proposed. But scientists do not take the stance that theories are ever absolutely proved. The characteristics that make scientists most effective in their work are curiosity, open-mindedness, skepticism, creativity, cooperation, and readiness to revise their views of natural processes as new discoveries are made (Medical Microfile 1.3).

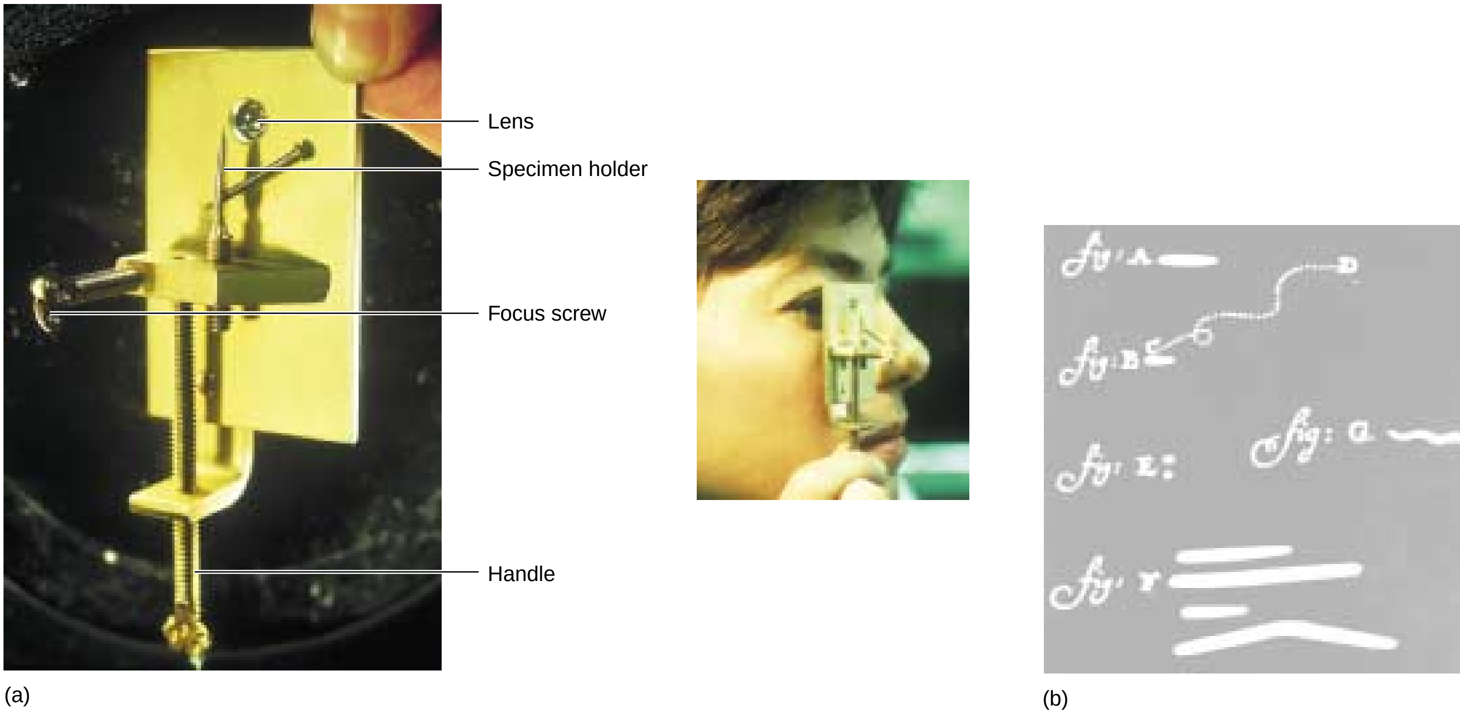


FIGURE 1.8

Leeuwenhoek's microscope. (a) A brass replica of a Leeuwenhoek microscope and how it is held. **(b)** Examples of bacteria drawn by Leeuwenhoek. He keenly observed, "I discovered living creatures in rain water which had stood but a few days in a new earthen pot. This invited me to view this water with great attention, especially those little animals appearing to me ten thousand times less than those which may be perceived in the water with the naked eye." This is probably the first observation of bacteria.

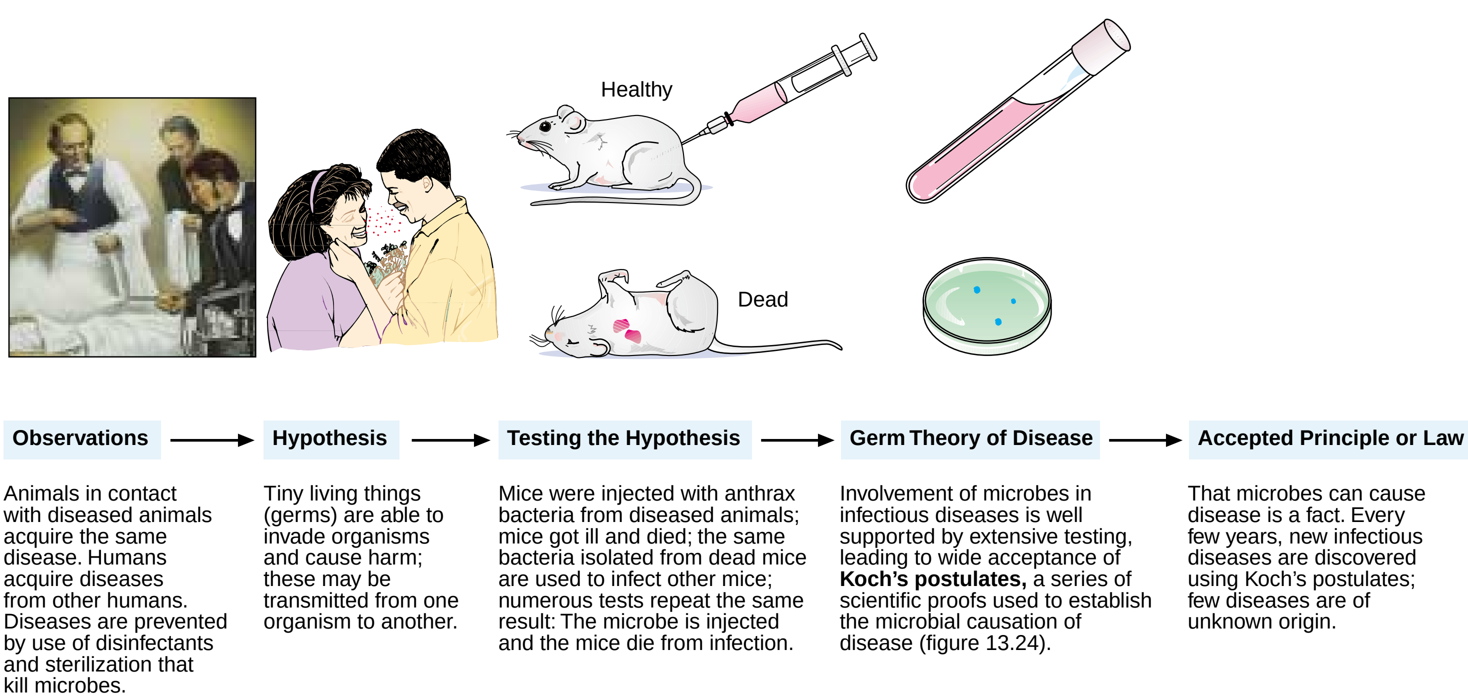


FIGURE 1.9

Induction and the germ theory. The inductive process proceeds from specific observations to a general hypothesis. This example presents the classic events in developing the germ theory of disease.

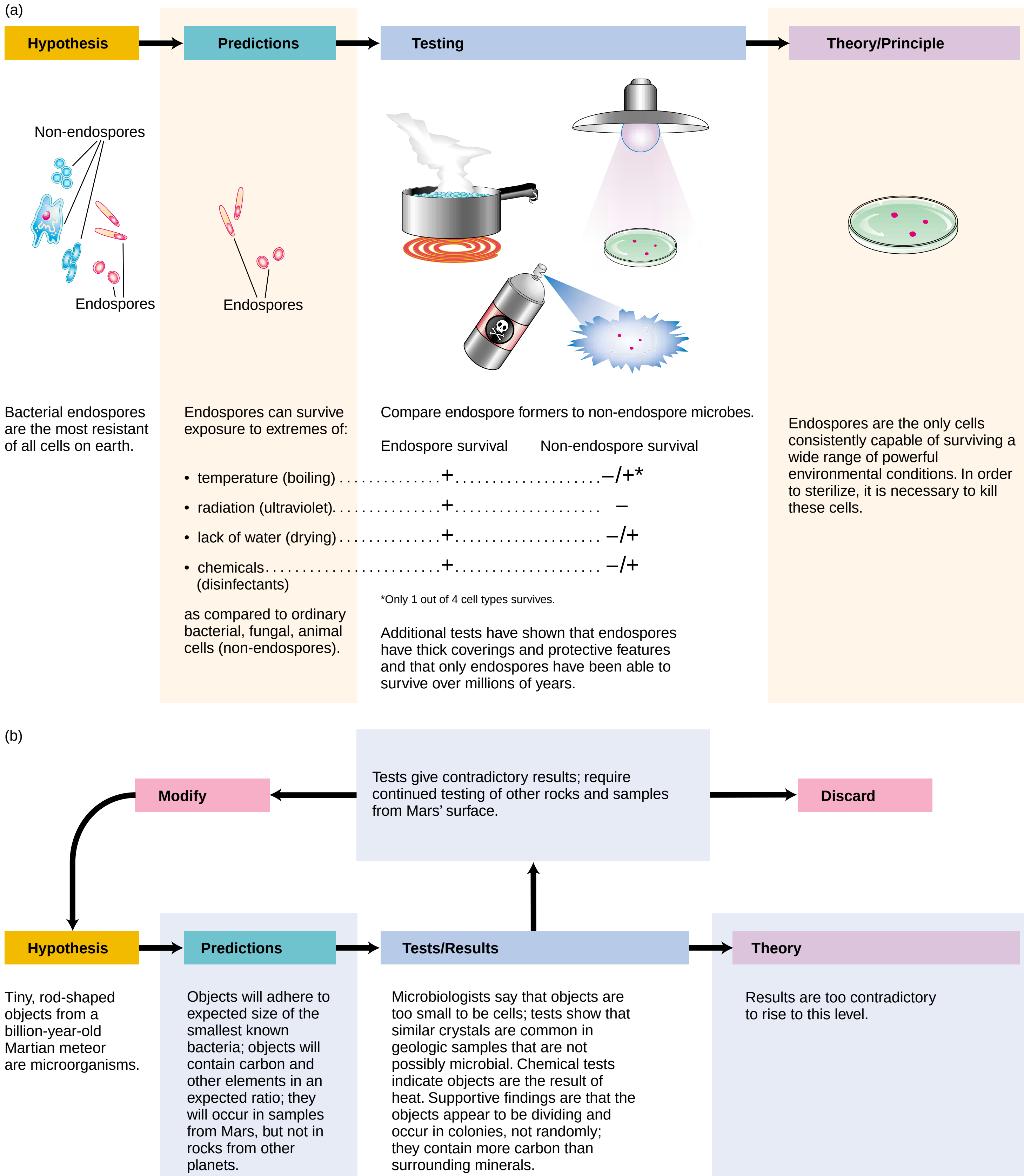


FIGURE 1.10

The pattern of deductive reasoning. The deductive process starts with a general hypothesis that predicts specific expectations. **(a)** This example is based on a well-established principle. **(b)** This example is based on a new hypothesis that has not stood up to critical testing.

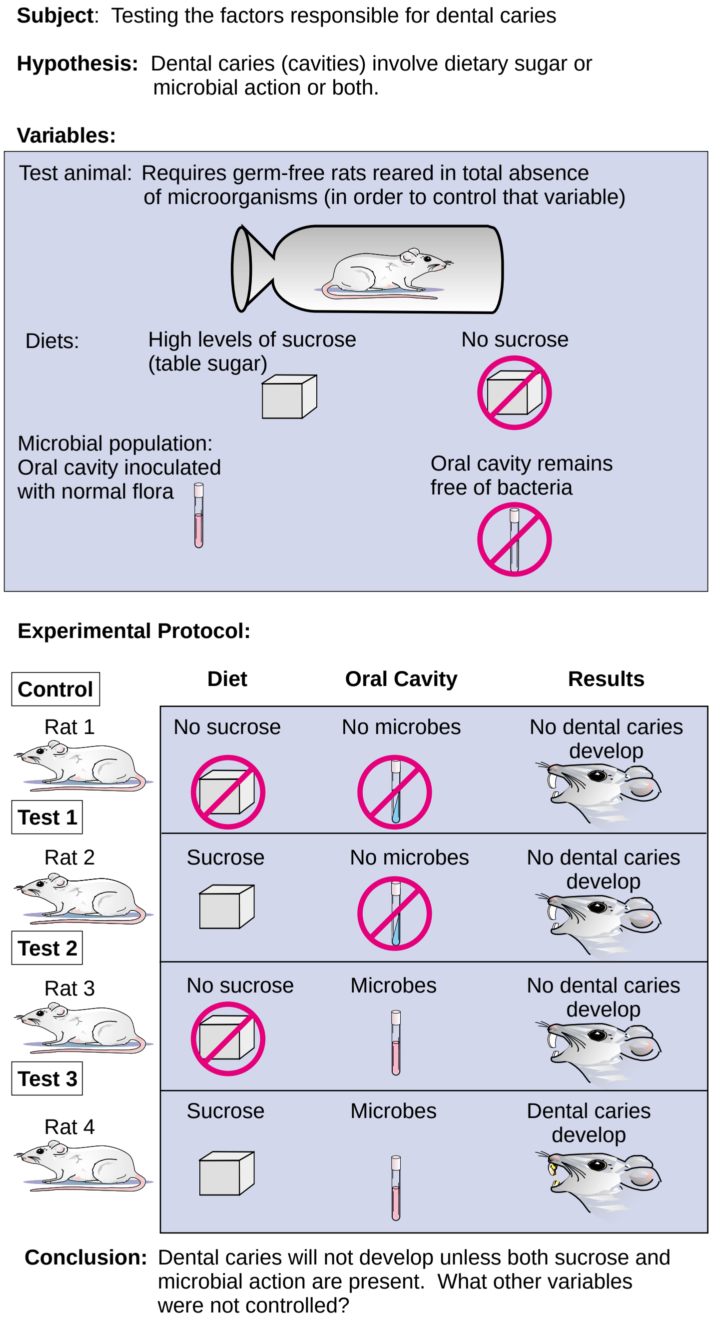


FIGURE 1.11

Variables. Any factor that can affect the experimental outcome is called a variable, and each combination of variables must be controlled while the hypothesis is being tested.

THE DEVELOPMENT OF MEDICAL MICROBIOLOGY

Early experiments on the sources of microorganisms led to the profound realization that microbes are everywhere: Not only are air and dust full of them, but the entire surface of the earth, its waters, and all objects are exposed to them. This discovery led to immediate applications in medicine, thus the seeds of medical microbiology were sown in the mid to latter half of the nineteenth century with the introduction of the germ theory of disease and the resulting use of sterile, aseptic, and pure culture techniques.

The Discovery of Spores and Sterilization

Following Pasteur's inventive work with infusions (see Historical Highlights 1.2), it was not long before English physicist John Tyndall demonstrated that heated broths would not spoil if stored in chambers completely free of dust. His studies provided the initial evidence that some of the microbes in dust and air have very high heat resistance and that particularly vigorous treatment is required to destroy them. Later, the discovery and detailed description of heat-resistant bacterial endospores by Ferdinand Cohn, a German botanist, clarified the reason that heat would sometimes fail to completely eliminate all microorganisms. The modern sense of the word **sterile,*** meaning completely free of all life forms including spores and viruses, was established from that point on (see chapter 11). The capacity to sterilize objects and materials is an absolutely essential part of microbiology, medicine, dentistry, and industry.

The Development of Aseptic Techniques

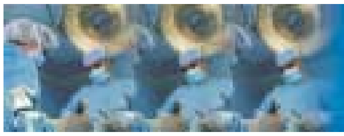
From earliest history, humans experienced a vague sense that "unseen forces" or "poisonous vapors" emanating from decomposing matter could cause disease. As the study of microbiology became more scientific and the invisible was made visible, the fear of such mysterious vapors was replaced by the knowledge and sometimes even the fear of "germs." About 120 years ago, the first studies by Robert Koch clearly linked a microscopic organism with a specific disease. Since that time, microbiologists have conducted a continuous search for disease-causing agents.

At the same time that abiogenesis was being hotly debated, a few budding microbiologists began to suspect that microorganisms could cause not only spoilage and decay but also infectious diseases. It occurred to these rugged individualists that even the human body itself was a source of infection. Dr. Oliver Wendell Holmes, an American physician, observed that mothers who gave birth at home experienced fewer infections than did mothers who gave birth in the hospital, and the Hungarian Dr. Ignaz Semmelweis showed quite clearly that women became infected in the maternity ward after examinations by physicians coming directly from the autopsy room. The English surgeon Joseph Lister took notice of these observations and was the first to introduce **aseptic*** **techniques** aimed at reducing microbes in a medical setting and preventing wound infections. Lister's concept of asepsis was much more limited than our modern precautions. It mainly involved disinfecting the hands and the air with strong antiseptic chemicals, such as phenol, prior to surgery. These techniques and the application of heat for sterilization became the bases for microbial control by physical and chemical methods, which are still in use today.

---

*__sterile__ (stair′-il) Gr. *steira,* barren.

*__aseptic__ (ay-sep′-tik) Gr. *a,* no, and *sepsis,* decay or infection. These techniques are aimed at reducing pathogens and do not necessarily sterilize.

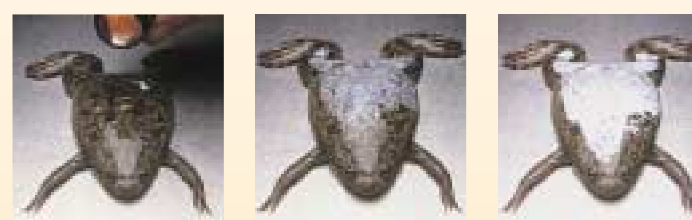


MEDICAL MICROFILE 1.3
The Serendipity of the Scientific Method: Discovering Drugs

The discoveries in science are not always determined by the strict formulation and testing of a formal hypothesis. Quite often, they involve serendipity* and the luck of being in the right place and time, followed by a curiosity and willingness to change the direction of an experiment. This is especially true in the field of drug discoveries. The first antibiotic, penicillin, was discovered in the late 1920s by Dr. Alexander Fleming, who found a mold colony growing on a culture of bacteria that was wiping out the bacteria. He isolated the active ingredient that eventually launched the era of antibiotics. The search for new drugs to treat infections and cancer has been a continuous focus since that time. Even though the detailed science of testing a drug and working out its chemical structure and action require sophisticated scientific technology, the first and most important part of discovery often lies in a keen eye and an open mind.

In 1987, Dr. Michael Zasloff, a physician and molecular biologist, was doing research in gene expression, using African clawed frogs as a source of eggs. After performing surgery on the frogs and routinely placing them back in a nonsterile aquarium, he was surprised to notice that most of the time the frogs did not get infected or die. If the animal had been a mammal such as a mouse, it would probably not have survived the nonsterile surgery. This led him to conclude that the frog's skin must provide some form of natural protection. He observed that when the skin was stimulated by injury or irritants, it formed a thick white coating in a few moments that reminded him of a self-made "bandage" over the wound. He took a section of skin and extracted the components that were responsible for killing the microbes. His tests showed that they were small proteins called peptides, which he named *magainins,* after the Hebrew word for shield. Within 6 months of these findings, Dr. Zasloff made the decision to completely change the subject of his research and started up a new biotechnology company (Magainin Pharmaceuticals) to explore the therapeutic potential for magainins as well as other frog peptides.

The initial tests on this new class of drugs would indicate that they do indeed destroy a variety of bacteria as well as fungi, protozoa, and viruses. Although they are toxic to human cells too, this makes them a possible candidate for cancer treatment. Currently the drugs are being synthesized and tested in the lab for effectiveness and safety. Dr. Zasloff's intriguing observation and subsequent experiments had the impact of opening up a whole new area of biology: isolating antimicrobic peptides from multicellular organisms. Additional studies have shown that these compounds are widespread among amphibians, fish, birds, mammals, and plants. A number of companies are involved in developing applications for animal peptides. This discovery has been well timed, since resistance among microorganisms to traditional drugs is a continuing problem.



An African clawed frog responding to an irritant on its back first forms spots and then a thick opaque blotch of protective chemicals.

*__serendipity__ Making useful discoveries by accident.

The Discovery of Pathogens and the Germ Theory of Disease

Two ingenious founders of microbiology, Louis Pasteur of France (figure 1.12) and Robert Koch of Germany (figure 1.13), introduced techniques that are still used today. Pasteur made enormous contributions to our understanding of the microbial role in wine and beer formation. He invented pasteurization and completed some of the first studies showing that diseases could arise from infection. These studies, supported by the work of other scientists, became known as the **germ theory of disease.** Pasteur's contemporary, Koch, established *Koch's postulates,* a series of proofs that verified the germ theory and could establish whether an organism was pathogenic and which disease it caused (see figure 1.9). About 1875, Koch used this experimental system to show that anthrax was caused by a bacterium called *Bacillus anthracis*. So useful were his postulates that the causative agents of 20 other diseases were discovered between 1875 and 1900, and even today, they are the standard for identifying pathogens.

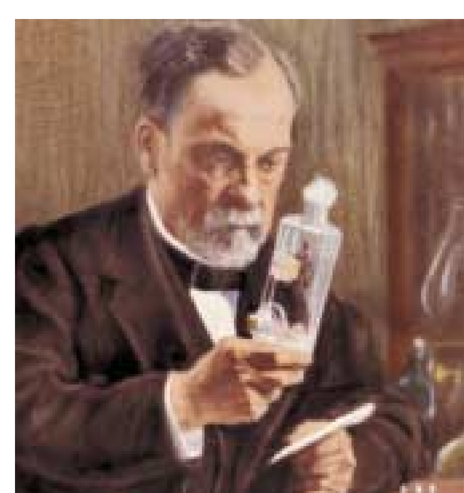


FIGURE 1.12

Louis Pasteur (1822–1895), one of the founders of microbiology, viewing a sample. Few microbiologists can match the scope and impact of his contributions to the science of microbiology.

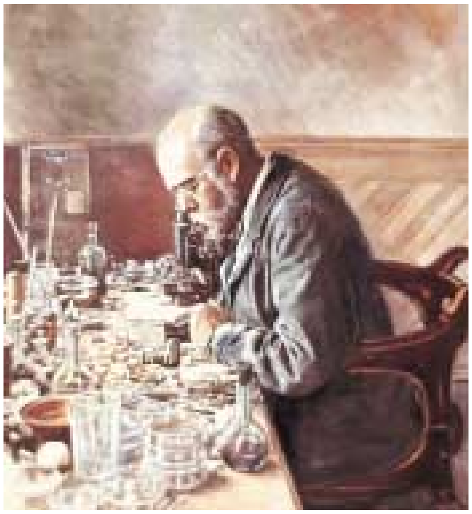


FIGURE 1.13

Robert Koch (1843–1910), intent at his laboratory workbench and surrounded by the new implements of his trade: Petri plates, tubes, and flasks filled with media; smears of bacteria; and bottles of stains.

Numerous exciting technologies emerged from Koch's prolific and probing laboratory work. During this golden age of the 1880s, he realized that study of the microbial world would require separating microbes from each other and growing them in culture. It is not an overstatement to say that he and his colleagues invented most of the techniques that are described in chapter 3: inoculation, isolation, media, maintenance of pure cultures, and preparation of specimens for microscopic examination. Other highlights in this era of discovery are presented in later chapters on microbial control (see chapter 11) and vaccination (see chapter 16).

Taxonomy: Organizing, Classifying, and Naming Microorganisms

Students just beginning their microbiology studies are often dismayed by the seemingly endless array of new, unusual, and sometimes confusing names for groups and specific types of microorganisms. Learning microbial **nomenclature*** is very much like learning a new language, and occasionally its demands may be a bit overwhelming. But paying attention to proper microbial names is just like following a baseball game or a movie plot: You cannot tell the players apart without a program! Your understanding and appreciation of microorganisms will be greatly improved by learning a few general rules about how they are named.

The formal system for organizing, classifying, and naming living things is **taxonomy.*** This science originated more than 250 years ago when Carl von Linné (Linnaeus; 1701–1778), a Swedish botanist, laid down the basic rules for taxonomic categories, or **taxa.*** Von Linné realized early on that a system for recognizing and defining the properties of living things would prevent chaos in scientific studies by providing each organism with a unique name and an exact "slot" in which to catalogue it. This classification would then serve as a means for future identification of that same organism and permit workers in many biological fields to know if they were indeed discussing the same organism. The von Linné system has served well in categorizing the 2 million or more different types of organisms that have been discovered since that time.

The primary concerns of taxonomy are classification, nomenclature, and identification. These three areas are interrelated and

*nomenclature (noh′-men-klay″-chur) L. *nomen*, name, and *clare*, to call. A system of naming.

*taxonomy (tacks-on″-uh-mee) Gr. *taxis*, arrangement, and *nomos*, name.

*taxa (tacks′-uh) sing. taxon.

CHAPTER CHECKPOINTS

- Our current understanding of microbiology is the cumulative work of thousands of microbiologists, many of whom literally gave their lives to advance knowledge in this field.
- The microscope made it possible to see microorganisms and thus to identify their widespread presence, particularly as agents of disease.
- Antonie van Leeuwenhoek is considered the father of bacteriology and protozoology because he was the first person to produce precise, correct descriptions of these organisms using microscopes he made himself.
- The theory of spontaneous generation of living organisms from "vital forces" in the air was disproved once and for all by Louis Pasteur.
- The scientific method is a process by which scientists seek to explain natural phenomena. It is characterized by specific procedures that either support or discredit an initial hypothesis.
- Knowledge acquired through the scientific method is rigorously tested by repeated experiments by many scientists to verify its validity. A collection of valid hypotheses is called a theory. A theory supported by much data collected over time is called a law.
- Scientific truth changes through time as new research brings new information. Scientists must be able and willing to change theory in response to new data.
- Medical microbiologists developed the germ theory of disease and introduced the critically important concept of aseptic technique to control the spread of disease agents.
- Koch's postulates are the cornerstone of the germ theory of disease. They are still used today to pinpoint the causative agent of a specific disease.
- Louis Pasteur and Robert Koch were the leading microbiologists during the golden age of microbiology (1875–1900). Each had his own research institute.

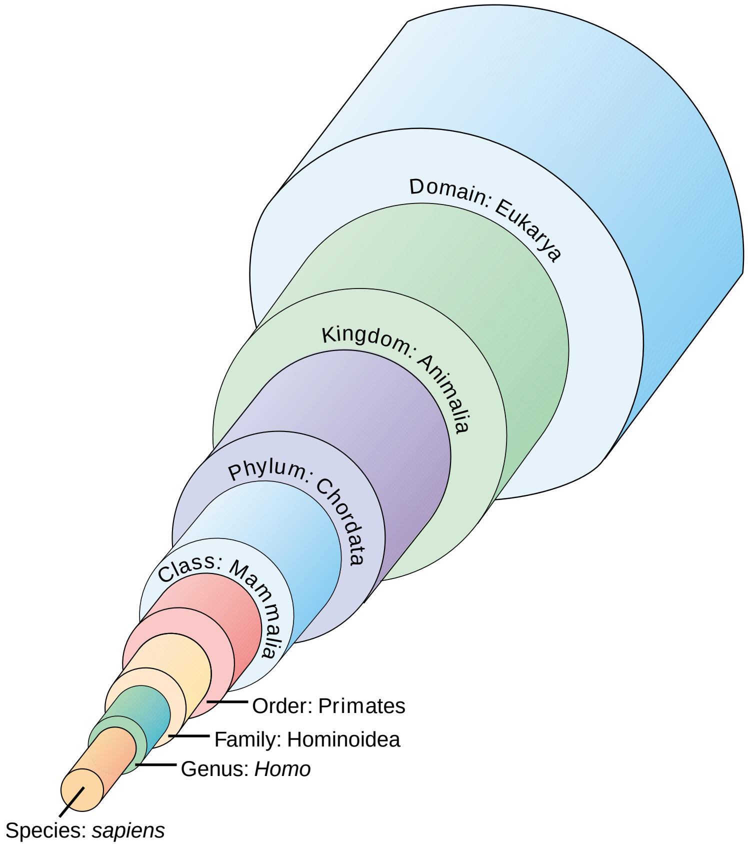


FIGURE 1.14

Classification scheme. The levels in classification from domain to species operate like a set of nesting boxes. Humans are the example here.

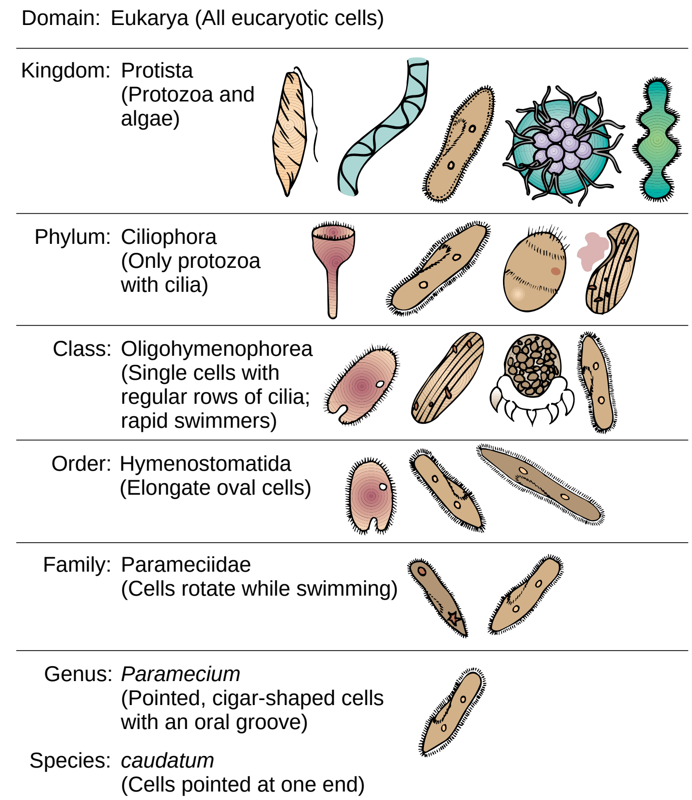


FIGURE 1.15

Sample taxonomy. A common species of protozoan, *Paramecium caudatum*, traced through its taxonomic series. Note the gradual narrowing of the members, proceeding from general to specific levels.

play a vital role in keeping a dynamic inventory of the extensive array of living things. *Classification* is the orderly arrangement of organisms into groups, preferably in a format that shows evolutionary relationships. *Nomenclature* is the process of assigning names to the various taxonomic rankings of each microbial species. *Identification* is the process of discovering and recording the traits of organisms so that they may be placed in an overall taxonomic scheme. A survey of some general methods of identification appears in chapter 3.

THE LEVELS OF CLASSIFICATION

The main taxa, or groups, in a classification scheme are organized into several descending ranks, beginning with **domain,** which is a giant, all-inclusive category based on a unique cell type, and ending with a **species,*** the smallest and most specific taxon. All the members of a domain share only one or few general characteristics, whereas members of a species are essentially the same kind of organism—that is, they share the majority of their characteristics. The taxa between the top and bottom levels are, in descending order: **kingdom, phylum*** or **division,**[7] **class, order, family,** and **genus.*** Thus, each domain can be subdivided into a series of kingdoms, each kingdom is made up of several phyla, each phylum contains several classes, and so on. Because taxonomic schemes are to some extent artificial, certain groups of organisms do not exactly fit into the eight taxa. In that case, additional levels can be imposed immediately above (super) or below (sub) a taxon, giving us such categories as superphylum and subclass.

To illustrate the fine points of this system, we compare the taxonomic breakdowns of a human (figure 1.14) and a protozoan (figure 1.15). Humans and protozoa belong to the same domain (Eukarya) but are placed in different kingdoms. To emphasize just how broad the category kingdom is, ponder the fact that we belong to the same kingdom as sponges. Of the several phyla within this kingdom, humans belong to the Phylum Chordata (notochord-bearing animals), but even a phylum is rather all-inclusive, considering that humans share it with other vertebrates as well as creatures called sea squirts. The next level, Class Mammalia, narrows

*species (spee′-sheez) L. *specere*, kind. In biology, this term is always in the plural form.

7. The term *phylum* is used for protozoa and animals; the term *division* is used for bacteria, algae, plants, and fungi.

*phylum (fy′-lum) pl. phyla (fye′-luh) Gr. *phylon*, race.

*genus (jee′-nus) pl. genera (jen′-er-uh) L. birth, kind.

the field considerably by grouping only those vertebrates that have hair and suckle their young. Humans belong to the Order Primates, a group that also includes apes, monkeys, and lemurs. Next comes the Family Hominoidea, containing only humans and apes. The final levels are our genus, *Homo* (all races of modern and ancient humans), and our species, *sapiens* (meaning wise). Notice that for both the human and the protozoan, the categories become less inclusive and the individual members more closely related. Other examples of classification schemes are provided in sections of chapters 4 and 5 and in several later chapters.

It would be well to remember that all taxonomic **hierarchies*** are based on the judgment of scientists with certain expertise in a particular group of organisms and that not all other experts may agree with the system being used. Consequently, no taxa are permanent to any degree; they are constantly being revised and refined as new information becomes available or new viewpoints become prevalent. Because this text does not aim to emphasize details of taxonomy, we will usually be concerned with only the most general (kingdom, phylum) and specific (genus, species) levels.

ASSIGNING SPECIFIC NAMES

Many larger organisms are known by a common name suggested by certain dominant features. For example, a bird species might be called a red-headed blackbird or a flowering species a black-eyed Susan. Some species of microorganisms (especially pathogens) are also called by informal names, such as the gonococcus (*Neisseria gonorrhoeae*) or the tubercle bacillus (*Mycobacterium tuberculosis*), but this is not the usual practice. If we were to adopt common names such as the "little yellow coccus"* or the "club-shaped diphtheria bacterium,"* the terminology would become even more cumbersome and challenging than scientific names. Even worse, common names are notorious for varying from region to region, even within the same country. A decided advantage of standardized nomenclature is that it provides a universal language, thereby enabling scientists from all countries on the earth to freely exchange information.

The method of assigning the **scientific,** or **specific name** is called the **binomial (two-name) system of nomenclature.** The scientific name is always a combination of the generic (genus) name followed by the species name. The generic part of the scientific name is capitalized, and the species part begins with a lowercase letter. Both should be italicized (or underlined if italics are not available), as follows:

Saccharomyces cerevisiae

Because other taxonomic levels are not italicized and consist of only one word, one can always recognize a scientific name. An organism's scientific name is sometimes abbreviated to save space, as in *S. cerevisiae,* but only if the genus name has already been stated. The source for nomenclature is usually Latin or Greek. If other languages such as English or French are used, the endings of these words are revised to have Latin endings. In general, the name first applied to a species will be the one that takes precedence over all others. An international group oversees the naming of every new organism discovered, making sure that standard procedures have been followed and that there is not already an earlier name for the organism or another organism with that same name. The inspiration for names is extremely varied and often rather imaginative. Some species have been named in honor of a microbiologist who originally discovered the microbe or who has made outstanding contributions to the field. Other names may designate a characteristic of the microbe (shape, color), a location where it was found, or a disease it causes. Some examples of specific names, their pronunciations, and their origins are:

- *Saccharomyces cerevisiae* (sak′-air-oh″-my-seez sair′-uh-vis″-ee-ee) Gr. *sakcharon,* sugar, *mykes,* fungus, and L. *cerevisia,* beer. The common yeast used in making beer, wine, and bread.
- *Haemophilus aegypticus* (hee′-mah-fil-us ee-jip′-tih-kus) Gr. *haema,* blood, *philos,* to love, and Egypt, the country. The causative agent of pinkeye.
- *Pseudomonas tomato* (soo′-doh-mon′-us toh-may′-toh) Gr. *pseudo,* false, *monas,* unit, and *tomato,* the fruit. A bacterium that infects the common garden tomato.
- *Campylobacter jejuni* (cam-pee′-loh-bak-ter jee-joo′-neye) Gr. *kampylos,* curved, *bakterion,* little rod, and *jejunum,* a section of intestine. One of the most important causes of intestinal infection worldwide.
- *Lactobacillus sanfrancisco* (lak″-toh-bass-ill′-us san-fran-siss′-koh) L. *lacto,* milk, and *bacillus,* little rod. A bacterial species used to make sourdough bread.
- *Vampirovibrio chlorellavorus* (vam-py′-roh-vib-ree-oh klor-ell-ah′-vor-us) F. *vampire;* L. *vibrio,* curved cell; *Chlorella,* a genus of green algae; and *vorus,* to devour. A small, curved bacterium that sucks out the cell juices of *Chlorella*.
- *Giardia lamblia* (jee-ar′-dee-uh lam′-blee-uh) for Alfred Giard, a French microbiologist, and Vilem Lambl, a Bohemian physician, both of whom worked on the organism, a protozoan that causes a severe intestinal infection.

THE ORIGIN AND EVOLUTION OF MICROORGANISMS

Earlier we indicated that taxonomists prefer to use a system of classification that shows the degree of relatedness of organisms, one that places closely related organisms into the same categories. This pattern of organization, called a *natural* or *phylogenetic system,* often uses selected observable traits to form the categories.

A phylogenetic system is based on the concept of evolutionary relationships among types of organisms. **Evolution*** is an important theme that underlies all of biology, including microbiology. From its simplest standpoint, evolution states that living things

*__hierarchy__ (hy′-ur-ar-kee) L. *hierarchia,* levels of power. Things arranged in the order of rank.

*__Micrococcus luteus__ (my″-kroh-kok′-us loo′-tee-us) Gr. *micros,* small, and *kokkus,* berry; L. *luteus,* yellow.

****Corynebacterium diphtheriae*** (kor-eye″-nee-bak-ter′-ee-yum dif′-theer-ee-eye) Gr. *coryne,* club, *bacterion,* little rod, and *diphtheriae,* the causative agent of the disease diphtheria.

*__evolution__ (ev-oh-loo′-shun) L. *evolutio,* to roll out.

change gradually through hundreds of millions of years and that these evolvements are expressed in various types of structural and functional changes through many generations. The process of evolution is selective: Those changes that most favor the survival of a particular organism or group of organisms tend to be retained, and those that are less beneficial to survival tend to be lost. Space does not permit a detailed analysis of evolutionary theories, but the occurrence of evolution is supported by a tremendous amount of evidence from the fossil record and from the study of **morphology,*** **physiology,*** and **genetics** (inheritance). Evolution accounts for the millions of different species on the earth and their adaptation to its many and diverse habitats.

Evolution is founded on two preconceptions: (1) that all new species originate from preexisting species and (2) that closely related organisms have similar features because they evolved from common ancestral forms. Usually, evolution progresses toward greater complexity, and evolutionary stages range from simple, primitive forms that are close to an ancestral organism to more complex, advanced forms. Although we use the terms *primitive* and *advanced* to denote the degree of change from the original set of ancestral traits, it is very important to realize that all species presently residing on the earth are modern, but some have arisen more recently in evolutionary history than others.

The evolutionary patterns of organisms are often drawn as a family tree, with the trunk representing the main ancestral lines and the branches showing offshoots into specialized groups of organisms. This sort of arrangement places the more ancient groups at the bottom and the more recent ones at the top. The branches may also indicate origins, how closely related various organisms are, and an approximate timescale for evolutionary history (figures 1.16 and 1.17).

SYSTEMS OF PRESENTING A UNIVERSAL TREE OF LIFE

The first phylogenetic trees of life were constructed on the basis of just two kingdoms (plants and animals). In time, it became clear that certain organisms did not truly fit either of those categories, so a third kingdom for simpler organisms that lacked tissue differentiation (protists) was recognized. Eventually, when significant differences became evident even among the protists, Robert Whittaker proposed a fourth kingdom for the bacteria and a fifth one for the fungi.

Although biologists have found the system of five kingdoms and two basic cell types to be a valuable method of classification, recent studies in molecular biology have provided a more accurate view of the relationships and origins of cells. It has been determined that certain types of molecules in cells, called small ribosomal ribonucleic acid (rRNA), provide a "living record" of the evolutionary history of an organism. Analysis of this molecule in procaryotic and eucaryotic cells indicates that certain unusual cells called archaea (originally archaebacteria) are so different from the other two groups that they should be included in a separate superkingdom. Those same studies have also revealed that the cells of archaea, though procaryotic in nature, are actually more closely related to eucaryotic cells than to bacterial cells (see table 4.7). To reflect these relationships, Carl Woese and George Fox have proposed a system that assigns all organisms to one of three domains, each described by a different type of cell (figure 1.16). The procaryotic cell types are placed in the Domains **Archaea** and **Bacteria.** Eucaryotes are all placed in the Domain **Eukarya.** It is believed that these three superkingdoms arose from an ancestor most similar to the archaea. This new system is still undergoing analysis and somewhat complicates the presentation of organisms in that it disposes of some traditional groups, although many of the traditional kingdoms still work within this framework (animals, plants, and fungi). The original Kingdom Protista is now a collection of protozoa and algae that exist in several separate kingdoms (see chapter 5). This new scheme will not greatly affect our presentation of most microbes, because we will be discussing them at the genus or species level. It is also an important truism that our methods of classification reflect our current understanding and are constantly changing as new information is uncovered.

In the interest of balance, we will also present the traditional Whittaker system of classification (figure 1.17). This system places all living things in one of five basic kingdoms: (1) the Procaryotae or Monera, (2) the Protista, (3) the Myceteae or Fungi, (4) the Plantae, and (5) the Animalia. The simple, single-celled organisms at the base of the family tree are in the **Kingdom Procaryotae** (also called **Monera**). Because only those organisms with procaryotic

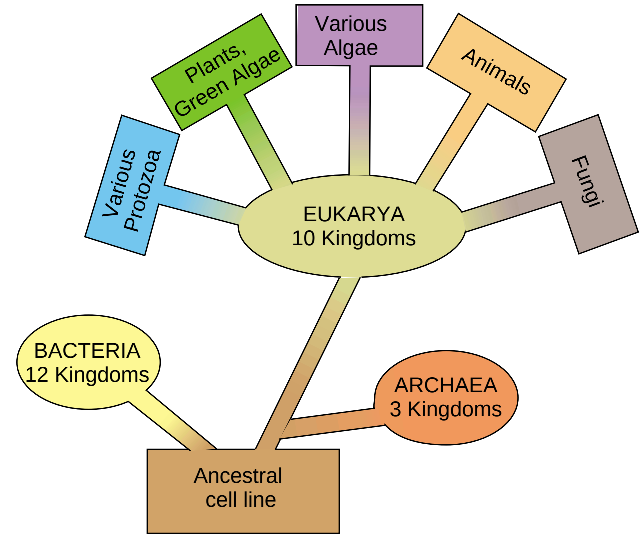


FIGURE 1.16

Woese system. A system for representing the origins of cell lines and major taxonomic groups as proposed by Carl Woese and colleagues. They propose three distinct cell lines placed in superkingdoms called domains. The first primitive cells, called progenotes, were ancestors of both lines of procaryotes (Domains Bacteria and Archaea), and the Archaea emerged from the same cell line as eucaryotes (Domain Eukarya). Some of the traditional kingdoms are still present with this system (see figure 1.17). Protozoa and some algal groups (called various algae here) are lumped into general categories.

*__morphology__ (mor-fol′-oh-jee) Gr. *morphos*, form, and *logos*, to study. The study of organismic structure.

*__physiology__ (fiz″-ee-ol′-oh-jee) Gr. *physis*, nature. The study of the function of organisms.

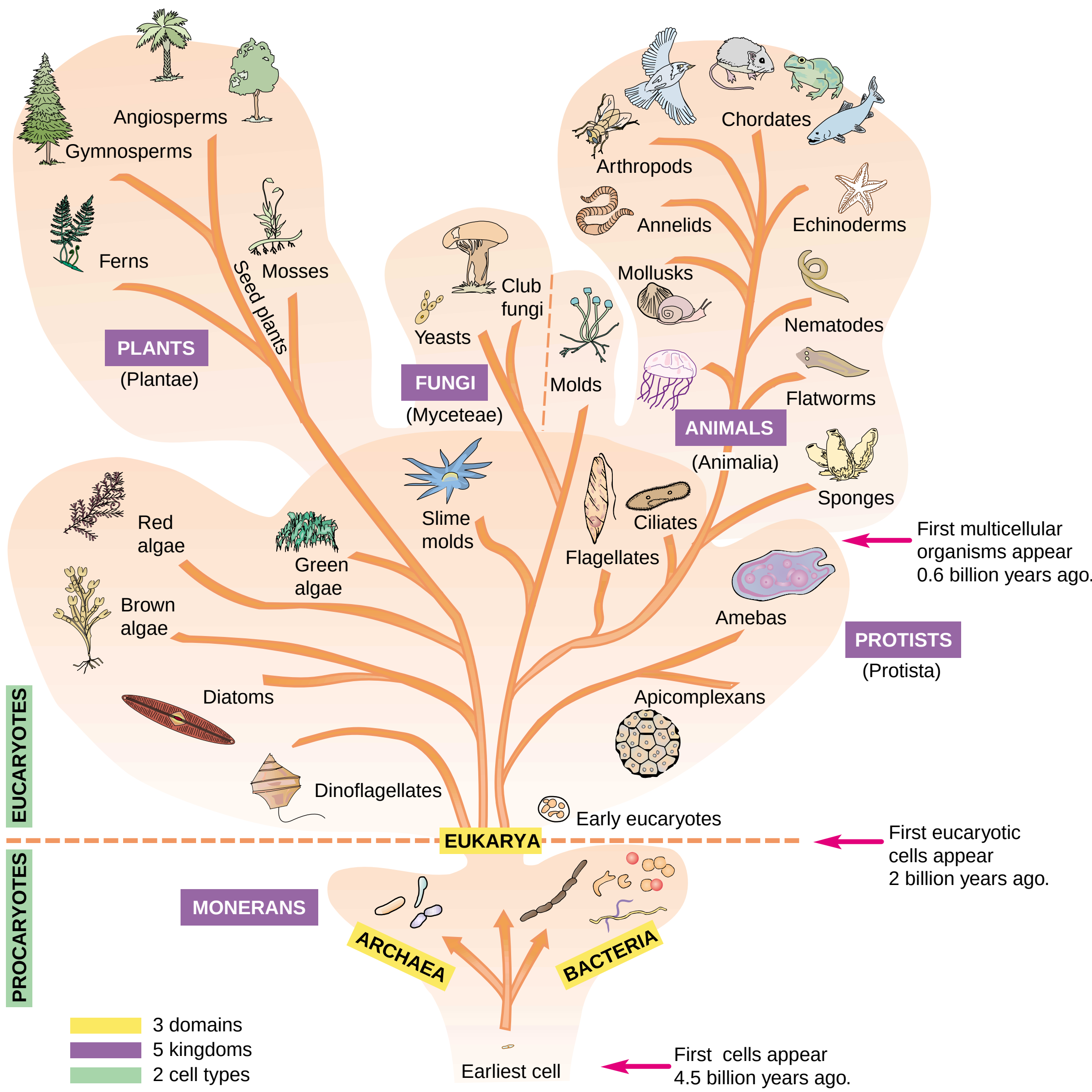


FIGURE 1.17

Traditional Whittaker system of classification. Kingdoms are based on cell structure and type, the nature of body organization, and nutritional type. Bacteria and Archaea (monerans) have procaryotic cells and are unicellular. Protists have eucaryotic cells and are mostly unicellular. They can be photosynthetic (algae), or they can feed on other organisms (protozoa). Fungi have eucaryotic cells and are unicellular or multicellular; they have cell walls and are not photosynthetic. Plants have eucaryotic cells, are multicellular, have cell walls, and are photosynthetic. Animals have eucaryotic cells, are multicellular, do not have cell walls, and derive nutrients from other organisms.

After Dolphin, Biology Lab Manual, *4th ed., Fig. 14.1, p. 177, McGraw-Hill Companies.*

cells are placed in it, the nature of cell structure is the main defining characteristic for this kingdom. It includes all of the microorganisms commonly known as **eubacteria,*** cells with typical procaryotic cell structure, and the **archaebacteria,*** cells with atypical cell structure that live in extreme environments (high salt and temperatures). Primitive procaryotes were the earliest cells to appear on the earth (see figure 4.30) and were the original ancestors of both more advanced bacteria and eucaryotic organisms. The Kingdom Procaryotae is a large and complex group that is surveyed in more detail in chapter 4.

The other four kingdoms contain organisms composed of eucaryotic cells. Their probable origin from procaryotic cells is discussed in Spotlight on Microbiology 5.1. The **Kingdom Protista*** contains mostly single-celled microbes that lack more complex levels of organization, such as tissues. Its members include both the

*eubacteria (yoo″-bak-ter′-ee-uh) Gr. *eu,* true, and *bakterion,* little rod. All bacteria besides the archaebacteria.

*archaebacteria (ark″-ee-uh-bak-ter′-ee-uh) Gr. *archaios,* ancient. The same name as archaea.

*Protista (pro-tiss′-tah) Gr. *protos,* the first.

microscopic algae, defined as independent photosynthetic cells with rigid walls, and the protozoans, animal-like creatures that feed upon other live or dead organisms and lack cell walls. More information on this group's taxonomy is given in chapter 5. The **Kingdom Myceteae*** contains the fungi, single- or multi-celled eucaryotes that are encased in cell walls and absorb nutrients from other organisms (see chapter 5). With the exception of certain infectious worms and arthropods, the final two kingdoms, **Animalia** and **Plantae,** are generally not included in the realm of microbiology because most are large, multicellular organisms with tissues, organs, and organ systems. In general, animals move freely and feed on other organisms, whereas plants grow in an attached state and exhibit a nutritional scheme based on photosynthesis. It is possible to integrate the two systems as shown in figure 1.17.

Please note that viruses are *not* included in any of the classification or evolutionary schemes, because they are not cells and their position cannot be given with any confidence. Their special taxonomy is discussed in chapter 6.

*__Myceteae__ (my-cee′-tee-eye) Gr. *mycos*, the fungi.

CHAPTER CHECKPOINTS

- Taxonomy is the formal filing system scientists use to classify living organisms. It puts every organism in its place and makes a place for every living organism.
- The taxonomic system has three primary functions: classification, nomenclature, and identification of species.
- The eight major taxa, or groups, in the taxonomic system are (in descending order): domain, kingdom, phylum or division, class, order, family, genus, and species.
- The binomial system of nomenclature describes each living organism by two names: genus and species.
- Taxonomy groups organisms by phylogenetic similarity, which in turn is based on evolutionary similarities in morphology, physiology, and genetics.
- Evolutionary patterns show a treelike branching from simple, primitive life forms to complex, advanced life forms.
- The Woese-Fox classification system places all eucaryotes in the Domain (Superkingdom) Eukarya and subdivides the procaryotes into the two Domains Archaea and Bacteria.
- The Whittaker five-kingdom classification system places all bacteria in the Kingdom Procaryotae and subdivides the eucaryotes into Kingdoms Protista, Myceteae, Animalia, and Plantae.

CHAPTER CAPSULE WITH KEY TERMS

I. **Microbiology** is the study of **bacteria, viruses, fungi, protozoa,** and **algae,** which are collectively called **microorganisms,** or **microbes.** In general, microorganisms are **microscopic** and, unlike **macroscopic** organisms, which are readily visible, they require magnification to be adequately observed or studied.

II. Microbes live in most of the world's habitats and are indispensable for normal, balanced life on earth. They play many roles in the functioning of the earth's ecosystems. Most organisms are free-living, but a few are **parasites.**
   A. Microbes are involved in nutrient production and energy flow. Algae and certain bacteria trap the sun's energy to produce food through **photosynthesis.**
   B. Other microbes are responsible for the breakdown and recycling of nutrients through **decomposition.** Microbes are essential to the maintenance of the air, soil, and water.

III. Microbes have been called upon to solve environmental, agricultural, and medical problems.
   A. **Biotechnology** applies the power of microbes toward the manufacture of industrial products, foods, and drugs.
   B. Microbes form the basis of **genetic engineering** and **recombinant DNA** technology, which alter genetic material to produce new products and modified life forms.
   C. With **bioremediation,** microbes are used to clean up pollutants and wastes in natural environments.

IV. Nearly 2,000 microbes are **pathogens** that cause **infectious diseases.** Infectious diseases result in high levels of mortality and morbidity. Many infections are **emerging,** meaning that they are newly identified pathogens gaining greater prominence. Many older diseases are also increasing.

V. The simplicity, growth rate, and adaptability of microbes are some of the reasons that microbiology is so diverse and has branched out into many subsciences and applications. Important subsciences include **immunology, epidemiology, public health, food, dairy, aquatic,** and **industrial** microbiology.

VI. **Important Historical Events**
   A. Microbiology as a science is about 200 years old. Hundreds of contributors have provided discoveries and knowledge to enrich our understanding.
   B. With his simple microscope, Leeuwenhoek discovered organisms he called animalcules. As a consequence of his findings and the rise of the **scientific method,** the notion of **spontaneous generation,** or **abiogenesis,** was eventually abandoned for **biogenesis.** The scientific method applies **inductive** and **deductive** reasoning to develop rational **hypotheses** and **theories** that can be tested. Principles that withstand repeated scrutiny become **law** in time.
   C. Early microbiology blossomed with the conceptual developments of **sterilization, aseptic techniques,** and the **germ theory of disease.**

VII. **Characteristics and Classification of Microorganisms**
   A. Organisms can be described according to their **morphology** and **physiology.** The **genetics** of organisms reveals an ancestral **evolutionary** relationship among these kingdoms.
   B. Cells of **eucaryotic** organisms contain a nucleus, but those of **procaryotic** organisms do not.
   C. **Taxonomy** is a hierarchy scheme for the **classification, identification,** and **nomenclature** of organisms, which are grouped in categories called **taxa,** based on features ranging from general to specific.

1. Starting with the broadest category, the taxa are **domain, kingdom, phylum** (or **division**), **class, order, family, genus,** and **species.** Organisms are assigned **binomial scientific names** consisting of their genus and species names.
2. The latest classification scheme for living things is based on the genetic structure of their ribosomes. The Woese-Fox system recognizes three domains: **Archaea,** simple procaryotes that live in extremes; **Bacteria,** typical procaryotes; and **Eukarya,** all types of eucaryotic organisms.
3. An alternative classification scheme uses a simpler five-kingdom organization: **Kingdom Procaryotae (Monera),** containing the **eubacteria** and the **archaebacteria; Kingdom Protista,** containing primitive unicellular microbes such as algae and protozoa; **Kingdom Myceteae,** containing the fungi; **Kingdom Animalia,** containing animals; and **Kingdom Plantae,** containing plants.

MULTIPLE-CHOICE QUESTIONS

Select the correct answer from the answers provided. For questions with blanks, choose the combination of answers that most accurately completes the statement.

1. Which of the following is not considered a microorganism?
   a. alga c. protozoan
   b. bacterium d. mushroom
2. Which microorganism(s) is/are responsible for photosynthesis in the aqueous environment?
   a. bacteria c. cyanobacteria
   b. algae d. both b and c
3. Which process involves the deliberate alteration in an organism's genetic material?
   a. bioremediation
   b. biotechnology
   c. decomposition
   d. recombinant DNA
4. A prominent difference between procaryotic and eucaryotic cells is the
   a. larger size of procaryotes
   b. lack of pigmentation in eucaryotes
   c. presence of a nucleus in eucaryotes
   d. presence of a cell wall in procaryotes
5. Which of the following parts was absent from Leeuwenhoek's microscopes?
   a. focusing screw
   b. lens
   c. specimen holder
   d. condenser
6. Abiogenesis refers to the
   a. spontaneous generation of organisms from nonliving matter
   b. development of life forms from preexisting life forms
   c. development of aseptic technique
   d. germ theory of disease
7. A hypothesis can be defined as
   a. a belief based on knowledge
   b. knowledge based on belief
   c. a scientific explanation that is subject to testing
   d. a theory that has been thoroughly tested
8. Which early microbiologist was most responsible for developing sterile laboratory techniques?
   a. Louis Pasteur c. Carl von Linné
   b. Robert Koch d. John Tyndall
9. Which scientist is most responsible for finally laying the theory of spontaneous generation to rest?
   a. Joseph Lister c. Francesco Redi
   b. Robert Koch d. Louis Pasteur
10. The process of observing an event and then constructing a hypothesis to explain it involves
    a. inductive reasoning
    b. deductive reasoning
    c. a controlled experiment
    d. guesswork
11. When a hypothesis has been thoroughly supported by long-term study and data, it is considered
    a. a law c. a theory
    b. a speculation d. proved
12. Which is the correct order of the taxonomic categories, going from most specific to most general?
    a. domain, kingdom, phylum, class, order, family, genus, species
    b. division, domain, kingdom, class, family, genus, species
    c. species, genus, family, order, class, phylum, kingdom, domain
    d. species, family, class, order, phylum, kingdom
13. By definition, organisms in the same ____ are more closely related than are those in the same ____ .
    a. order, family c. family, genius
    b. class, phylum d. phylum, division
14. Which of the following are procaryotic?
    a. bacteria c. protists
    b. archaea d. both a and b
15. Order the following items by size, using numbers: 1 = smallest and 8 = largest.
    ____ AIDS virus ____ worm
    ____ ameba ____ coccus bacterium
    ____ rickettsia ____ white blood cell
    ____ protein ____ atom

CONCEPT QUESTIONS

These questions are suggested as a *writing-to-learn* experience. For each question, compose a one- or two-paragraph answer that includes the factual information needed to completely address the question. Discuss the concepts in a sequence that allows you to present the subject using clear logic and correct terminology

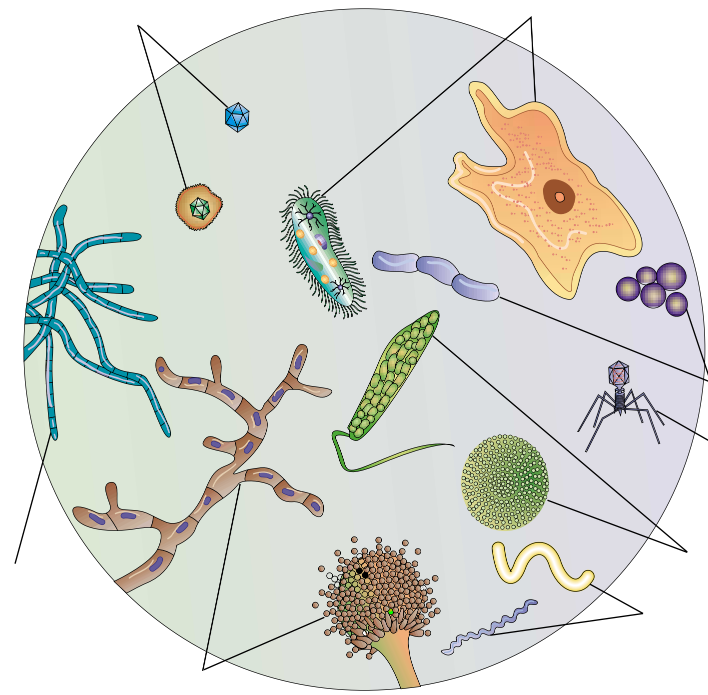
1. Explain the important contributions microorganisms make in the earth's ecosystems.
2. Describe five different ways in which humans exploit microorganisms for our benefit.

3. Identify the groups of microorganisms included in the scope of microbiology, and explain the criteria for including these groups in the field.
4. Briefly identify the subdivisions of microbiology and tell what is studied in each. What do the following microbiologists study: algologist, epidemiologist, biotechnologist, ecologist, virologist, and immunologist?
5. Why was the abandonment of the spontaneous generation theory so significant? Using the scientific method, describe the steps you would take to test the theory of spontaneous generation.
6. a. Explain how inductive reasoning and deductive reasoning are similar and different.
   b. What are variables and controls?
   c. Look at figure 1.11 and answer the question at the bottom of the figure.
7. a. Differentiate between a hypothesis and a theory.
   b. Is the germ theory of disease really a law, and why?
8. a. Differentiate between taxonomy, classification, and nomenclature.
   b. What is the basis for a phylogenetic system of classification?
   c. What is a binomial system of nomenclature, and why is it used?
   d. Give the correct order of taxa, going from most general to most specific. A mnemonic (memory) device for recalling the order is *D*arling *K*ing *P*hillip *C*ame *O*ver *F*or *G*ood *S*paghetti.
9. a. Construct a table that compares cell types and places them into domains and kingdoms. In which kingdoms do we find microorganisms?
   b. Compare the new domain system with the five-kingdom system. Does the newer system change the basic idea of procaryotes and eucaryotes? What is the third cell type?

CRITICAL-THINKING QUESTIONS

Critical thinking is the ability to reason and solve problems using facts and concepts. It requires you to apply information to new or different circumstances, to integrate several ideas to arrive at a solution, and to perform practical demonstrations as part of your analysis. These questions can be approached from a number of angles, and in most cases, they do not have a single correct answer.

1. What do you suppose the world would be like if there were cures for all infectious diseases and a means to destroy all microbes? What characteristics of microbes will prevent this from ever happening?
2. a. Where do you suppose the "new" infectious diseases come from?
   b. Name some factors that could cause older diseases to show an increase in the number of cases.
   c. Comment on the sensational ways that some tabloid media portray infectious diseases to the public.
3. Add up the numbers of deaths worldwide from infectious diseases (figure 1.4). Look up each disease in the index and see which ones could be prevented by vaccines or treated with drugs. How many do you think could have been prevented by modern medicine?
4. Correctly label the types of microorganisms in the drawing at right, using basic characteristics featured in the chapter.



5. What events, discoveries, or inventions were probably the most significant in the development of microbiology and why?
6. List the major variables in abiogenesis outlined in Historical Highlights 1.2 and explain how each was tested and controlled by the scientific method.
7. Can you develop a scientific hypothesis and means of testing the cause of stomach ulcers? (Is it caused by an infection? By too much acid? By a genetic disorder?)
8. Construct the scientific name of a newly discovered species of bacterium, using your name, a pet's name, a place, or a unique characteristic. Be sure to use proper notation and endings.
9. Archaea are found in hot, sulfuric, acidic, salty habitats, much like the early earth's conditions. Postulate on the origins of life, especially as it relates to the archaea.

INTERNET SEARCH TOPICS

1. Access a search engine on the World Wide Web under the heading *emerging diseases*. Adding terms like WHO and CDC will refine your search and take you to several appropriate websites. List the top 10 emerging diseases in the United States and worldwide.
2. Locate websites that discuss the ancient sporeformer isolated from a cavern in New Mexico. Determine the exact methods used in its isolation and what characteristics allowed it to survive.