CAROLUS LINNAEUS AND THE KINGDOMS OF LIVING THINGS

We live in a world of classified things. Every aisle in the grocery store is classified by a different sort of food, such as meats and vegetable, or type of household item, such as mops and mushrooms. Whenever you download music from the Internet, you choose from classifications such as rock, pop, classical, hip hop, jazz, electronic, and many other kinds of music. Sometimes these big categories are made up of even smaller categories; for example, rock music might also be broken down into alternative, heavy metal, southern rock, or rock legends. People definitely like to classify things and bring order to the choices in our lives. Classification allows us to understand the world around us by examining the traits that make up different things. The ability to categorize also provides a common vocabulary and point of reference for those who want to share their interest in a common group of things. Without classification, imagine how difficult it would be to describe the kind of music you like or compare one kind of mushroom with another.

Classification is important to the study of living things. By providing rules for categorizing different kinds of plants and animals by their characteristics, classification provides clues to the ways in which different kinds of living things are related to each other. Observing the similarities and differences in living things provided Darwin with some of the clues that he needed for his explanation of evolution.

Much classification work had been done by other natural scientists before Darwin. The Greek philosopher Aristotle (384 B.C.–322 B.C.) was perhaps the first scientific thinker to attempt to classify life. He divided organisms into the two kingdoms of plants and animals. Aristotle's two kingdoms stood the test of time for several centuries. British naturalist John Ray (1627–1705) was a botanist who used observation to classify plants and animals according to similarities in their structures. He was the first scientist to use the terms **genus** and **species** to classify different plants and animals. A genus is a major subcategory of a larger group, or family of related organisms. A genus consists of one or more species, which are the most basic biological unit of living organisms. All members of a species can interbreed and produce fertile offspring.

Ray was followed by the great Swedish botanist Carolus Linnaeus (1707–1778), who introduced an intricate new method for grouping and naming organisms. Linnaeus began by placing all living things into one of two overall categories: plants or animals. Linnaeus then suggested that living things could be further organized into a grand hierarchy of groups within groups. He recognized a species as the most basic biological unit of life, and grouped species within ever-widening categories of organisms based on the similarities of their visible structures. Dogs, for example, are part of a group, the Carnivora, or carnivorous (meat-eating) animals, which also includes such animals as cats, bears, pandas, weasels, sea lions, and walruses. The Carnivora, in turn, are part of a larger group, the Mammalia, or mammals. Mammals, in their turn, are grouped in yet a larger group with other animals with backbones: the Chordata, or vertebrates. The vertebrates include fish, amphibians, reptiles, mammals, and birds. The vertebrates are then grouped with all animals without backbones to form the kingdom of animals. The Linnaean classification method was widely accepted and refined for more than 200 years until genetic studies provided a more accurate method of determining the evolutionary relationships of organisms by looking at their DNA.

In choosing the species as his basic building block for classification, Linnaeus was the first scientist to establish a rule that affected the way that evolution works: traits are passed along from one generation to the next through genetic material. Although Linnaeus and other scientists of his time had no direct evidence of genes, DNA, or the way in which traits are passed from one generation to the next, these scientists were able to establish rules behind evolution that were observable in living organisms.

Using the Linnaeus method, all life could be classified using seven categories: kingdom, phylum, class, order, family, genus, and species. A diagram of a human being made by using the Linnaean system is shown in the accompanying table (Table 2.1).

Linnaean Classification of Humans

The following table shows where humans fit within the Linnaean classification of organisms.

Table 2.1		
Linnaean Category	Name of Category in the Classification of Humans	What the Category Includes
KINGDOM	Animalia	All living and extinct animals
PHYLUM	Chordata	Animals having a backbone (vertebrates)
CLASS	Mammalia	Warm-blooded vertebrates, the females of which have mammary glands
ORDER	Primates	Living and fossil monkeys, apes, and prosimians, including humans
FAMILY	Hominoidea	Living and fossil apes and humans
GENUS	Homo	Living and extinct members of the Family Hominoidea
SPECIES	Homo sapiens	Modern humans, the only surviving humans

MODERN CLASSIFICATION: THE DOMAINS OF LIFE

Even though all organisms share the five essential traits explained above, organisms can still be extraordinarily different from one another. Linnaeus provided the first widely accepted rules for classifying life. His system for dividing living things into two kingdoms was based on what could be seen with the naked eye. The next breakthrough in the classification of life would take scientists beyond the world that can be seen with the unaided eye.

By the late nineteenth century, biologists discovered through the use of microscopes that organisms were composed of tiny cells. The first microscopes were not powerful enough to reveal the internal structure of a cell. Because they were unable to see inside the cell, most biologists assumed that each cell was a kind of grab bag of molecules. This assumption changed entirely in 1945, when Albert Claude (1899–1983) and his colleagues at the Rockefeller Institute in New York City published the first electron micrograph of an intact cell. Magnified 1,600 times, the image revealed that cells

Figure 2.2 Carolus Linnaeus is thought to be the first person to place humans in a biological classification system. He listed humans under *Homo sapiens* among primates in the first edition of his book *Systema Naturae* (1735).

contained many small functional structures. With the door now open to the world of the cell, many biologists turned their attention to deciphering these minute structures. As a result, some startling changes took place in the definitions of life-forms and our understanding of evolution.

The first great departure from the Linnaean two-kingdom system came in 1959 with the work of ecologist Robert H. Whittaker (1920–1980). Whittaker refined the definition of plant and animal kingdoms by considering their cellular structure. His system recognized two basic kinds of cells: those with nuclei, the **eukaryotes**, and those without nuclei, the **prokaryotes**. Whittaker then established five kingdoms of life based on the structure and function of cells. The Monera included prokaryotes, represented only by bacteria. All other organisms, the eukaryotes, were divided into four additional kingdoms based on their method of processing nutrition: Plants, which use **photosynthesis**; Animals, which use ingestion; and Fungi and Protists, which use absorption.

Genetic molecules, including DNA, can also be used to decipher the evolutionary links between living things and extinct organisms from the past. This is done by studying fragments of genetic molecules that are sometimes found preserved in fossils. DNA contains the best clues yet for accurately categorizing organisms within proper groups. This is because DNA can reveal inherited traits that link different organisms with common ancestors.

Another breakthrough in the classification of living things came in 1977 when molecular biologists Carl Woese (b. 1928) and George Fox (b. 1945) were studying the genetic makeup of bacteria. While studying samples of "bacteria," Woese and Fox stumbled upon a form that was different from other bacteria. This form became known as an anaerobic organism, which means that it does not require oxygen to live. Instead, it creates energy by converting carbon dioxide and hydrogen to methane. This microbe was so unlike any form of life that had been previously known that Woese and Fox considered it to be a form that was yet to be defined. The two men classified this microorganism within a new group that they called Archaebacteria ("ancient bacteria") because they felt that it represented an ancient form of life.

At the same time, Woese and Fox argued for a change in the five-kingdom system of classification. Instead of five kingdoms, they proposed a system of classification that uses three **domains**—the Archaea, Bacteria, and Eukarya—to occupy a level of classification higher than the kingdom. The domain Archaea includes the archaebacteria, the domain Bacteria includes organisms that have prokaryote cells other than Archaea, and the domain Eukarya includes all life with eukaryote cells. Within these three domains, Woese and Fox defined six kingdoms: Archaebacteria, their newly defined form of life within Archaea; Bacteria, the only member of the domain Bacteria; and the Protista, Fungi, Plantae, and Animalia kingdoms, all of which are within the domain Eukarya.

The three-domain classification system was not widely accepted by other scientists for several years. The most convincing evidence for it was discovered in 1996 when the full genetic DNA sequences of archaebacteria and bacteria were completed, showing how fundamentally different they were from each other.

Types of Organisms

The three-domain system is widely accepted today because of evidence found at the base level of all organisms: the chemistry of their cells. This system provides a common reference point for any scientist who studies the evolution of different kinds of organisms.

The three domains of life are:

- ***Bacteria***: The earliest known fossils of life-forms are those of blue-green algae, which are bacteria that date from about 3.5 billion years ago. Bacteria are single-celled organisms whose cell structure is less complex than those found in plants and animals. A bacterial cell does not have a nucleus. Instead, the cell's DNA floats freely in the cell's cytoplasm—the gelatinous fluid that fills most cells—as a tangled strand called a nucleoid. Even though bacteria consist only of a single cell, they are far from being simple organisms. They are one of the heartiest and most adaptable life-forms on the planet. Some bacteria can live in freezing temperatures. Others can live in liquid that is hotter than boiling water. Bacteria consume a wide variety of substances for food, including mere sunlight, sugar, starch, and even sulfur or iron. One species of bacteria can withstand a blast of atomic radiation 1,000 times greater than would be needed to kill a human. Bacteria usually get a bad rap because some forms can cause disease in animals and plants. But bacteria are all around us and serve many useful functions. Blue-green algae aid in the production of nitrogen, an element in the air

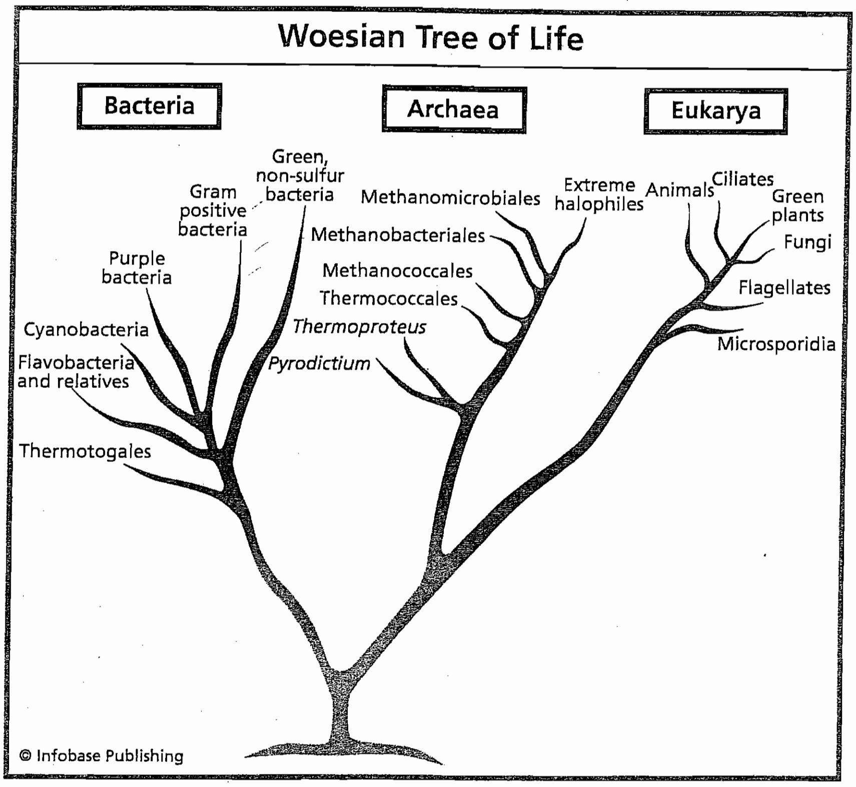

Figure 2.3 Carl Woese created the tree of life as a three-domain system based on genetic relationships.

that is essential for plant and animal growth. Bacteria live in the guts of living animals, helping to digest food and keep the animal healthy. Bacteria break down decaying leaves and other organic matter, thereby returning nutrients to the soil. They also add that little tart taste to yogurt and sourdough bread.

- ***Archaea***: This group of unusual organisms probably includes the first kinds of creatures that inhabited Earth. Archaebacteria live in environments that would be the harshest imaginable for other kinds of life. These prokaryotic microbes are composed of single cells and resemble bacteria, but their ability to survive without oxygen makes them unique among organisms. Their

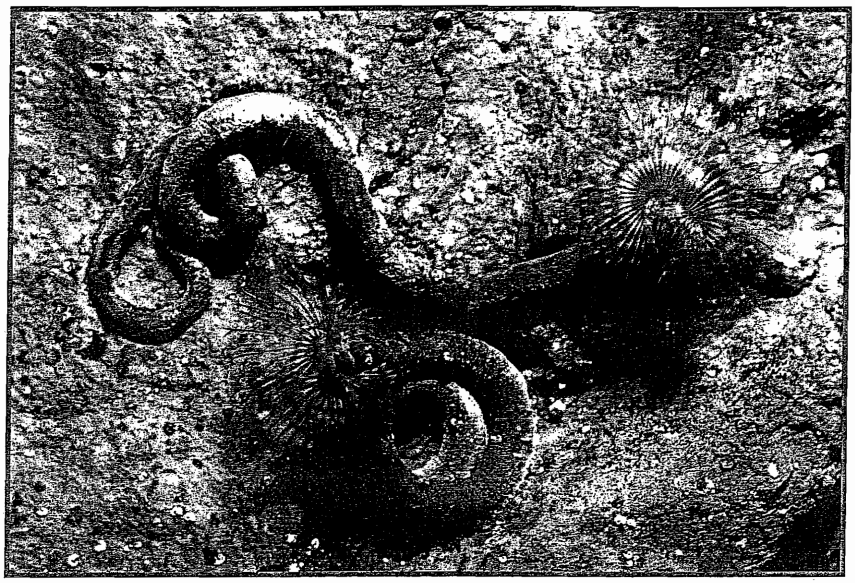

Figure 2.4 Red tube worms belong to the domain Archaea. They live a mile or more below the surface of the Pacific Ocean and can tolerate extremely high temperatures and sulfur levels.

tolerance for extreme temperatures is also unusual, with some being able to live near deep ocean volcanic vents where temperatures reach 250°F (121°C). Archaebacteria thrive in some of the planet's more inhospitable places, such as hydrothermal volcanic sea vents where superheated water squirts out through cracks in the ocean floor, salt pools, and even hot springs where no other life can survive. In the absence of sunlight, archaebacteria use a process called chemosynthesis to convert inorganic compounds such as hydrogen sulfide and carbon dioxide into energy. Archaebacteria often live inside a host organism. Around hydrothermal sea vents, archaebacteria provide food for animals such as tube worms, clams, and mussels, which depend on them for the absorption of nutrients from the chemically harsh sea water in which they live. These archaebacteria convert inorganic matter from vent water into food for their animal hosts.

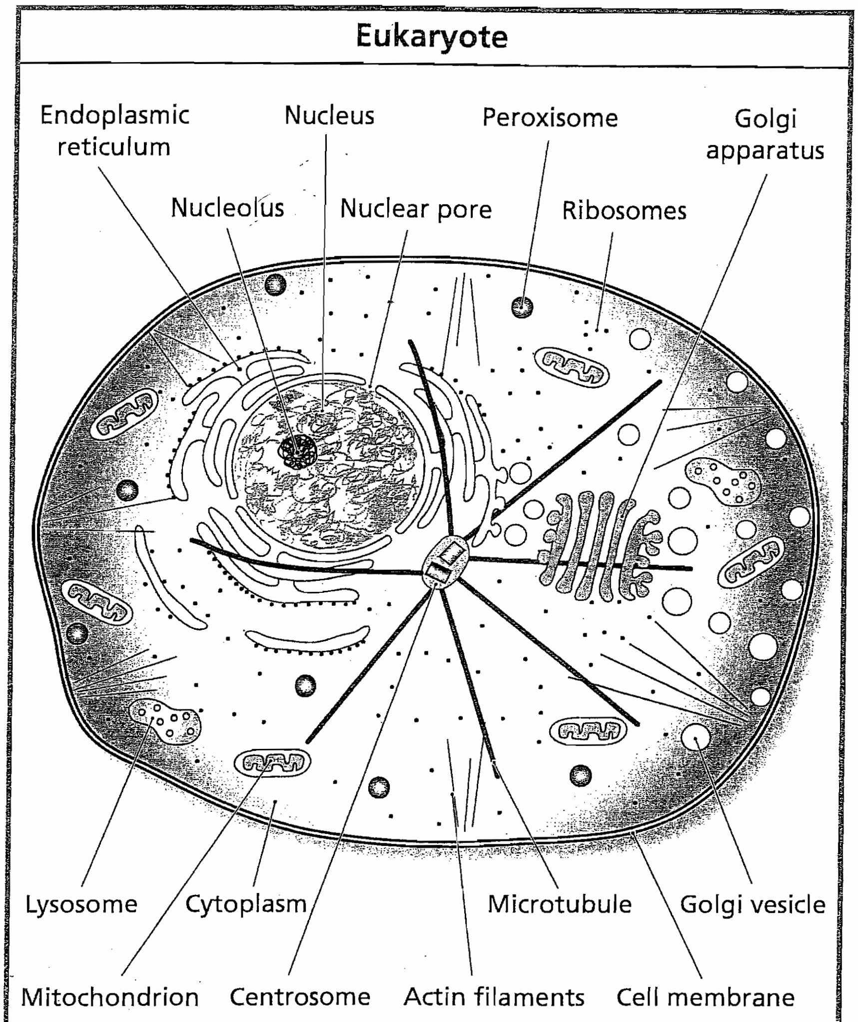

Figure 2.5 The domain Eukarya features living things that have eukaryotic cells. Each cell includes a nucleus with a DNA genome.

- *Eukarya*: This group includes plants, animals, fungi, and protists, all of which have a eukaryote cell type. Considered to be more complex than single-celled Bacteria and Archaea, the multicellular Eukarya possess cells that can work together and take on special functions for the good

> of the organism. The eukaryote cell structure allows multicellular organisms to build larger, more complicated bodies. This is the reason why this life-form was able to rise above its microscopic origins and build creatures that are as different from each other as ants, azaleas, anteaters, and the dinosaur *Apatosaurus.*

Yet as different as they may be, all three domains of organisms are subject to the natural laws of evolution.

CLASSIFICATION LEADS TO GREATER UNDERSTANDING

In the two hundred and fifty years since Linnaeus introduced his classification system, science has broadened its knowledge of living things by leaps and bounds. By 1758, Linnaeus had succeeded in classifying about 12,100 plant and animal species, a stupendous feat for one individual. Today, with the inclusion of fossil species, there are about 1.75 million recognized species of life with many more being added each year. Current estimates as to the total number of living species range from 3 million to 30 million, with some of the most frequently discovered species being among the archaebacteria. According to the International Institute for Species Exploration, 16,969 new species of plants and animals were discovered in the year 2006 alone.

One of the first steps toward better understanding the world is to label and categorize the things that are found in it. Classifying things reveals relationships between organisms but can also create a picture of the adaptation and evolution of life as part of the bigger picture of Earth and its ecosystems.