Chapter 1: Introduction to Biology

Genesis 1:1 – *In the beginning, God created the heavens and the earth.*

Genesis 2:7 – *Then the LORD God formed man of dust from the ground, and breathed into his nostrils the breath of life; and man became a living person.*

In Genesis 1, we learn that God created the physical world. Many scientists throughout history have studied His creation, learning more and more about the world and its Creator. It is clear that there is a design to this world, and much of how it works can be described in terms of mathematical equations. However, there has been a growing number of scientists who think that all there is to know is simply matter and energy, i.e., there is nothing real beyond the physical world. This materialistic worldview has limited the way the world is being studied to only things that can be measured. When Albert Einstein (1879-1955) showed that matter and energy can be changed from one form to another, this seemed to confirm that only matter and energy are needed to explain the physical world. [This was revealed in his famous equation: $E = mc^2$, where E is energy, m is mass (matter), and c (the speed of light) is a conversion coefficient.]

Recent findings, however, have shown that the basic components of the physical world also include **information**. In other words, there is a design that requires something nonmaterial – something beyond matter and energy. This is a significant problem for the materialistic worldview, because information comes only from a mind. That requires a Designer who exists outside the physical world. For example, in this textbook, we will be describing DNA, which provides information that all cells use to carry out their life functions. What is the source of the information in the structure of living organisms? In other words, how did the information in DNA come to be present in cells? Clearly, the presence of information must be examined to understand the biological world.

Figure 1.1: The more we learn about the world around us, the more we see that information is a necessary component of nature.

The Genesis 2 account indicates that people were created from the matter (and therefore, energy) of the physical world. But even with information, that is not sufficient for life. It was not until *the breath of life* was added did people come to be living. This suggests that life is more than physical. As you use this course to learn more about the physical world, it is important to recognize that while the structures that are described might be present and even functional, there is more to life than what is described. Life is only possible when there is more than the physical, which is very difficult to explain within a materialistic worldview but easy to fit within a creation worldview.

While all that life truly entails is not known, we want to give you an introductory description of what is known about **biology**, which is the study of life. To help in explaining the many forms of life, the relationships of these diverse forms to each other, and their interaction with the physical world, the chapters are grouped into three units:

Unit 1 – What is the design of the basic structures? (Chapters 1-6)
Unit 2 – What is the design of living organisms? (Chapters 7-14)
Unit 3 – What is the design of the relationships of life with the world? (Chapters 15 and 16)

Unit 1 examines the physical components that are necessary for life, from the simplest building blocks (atoms) through their assembly into the fundamental unit of life, the **cell**. The processes that provide the energy for life are then presented. The unit concludes with a discussion of basic processes that are involved in passing information from generation to generation.

Unit 2 explores the tremendous diversity of life found throughout the world, beginning at the microscopic level and continuing through the plants and animals that are easily seen with the naked eye. The distinction between the simplest life forms and the most complex life forms (and those in between) will be a fascinating part of the discussion. It is important to recognize that even the simplest life forms are highly complex and require a great deal of design to function. Single-celled organisms (like bacteria and protists) and multi-celled organisms (like fungi, plants, and animals) all exhibit the same basic properties associated with life.

Unit 3 is the shortest unit, but it encompasses the broadest range of perspective. It describes how individual organisms live with each other (in both helpful and harmful relationships). It further examines how these organisms interact with the physical world. The design of the **habitats** (living spaces) for each form of life gives evidence to the purpose of the creation, which is to reveal the wonder of the Creator.

Figure 1.2: These microscopic organisms, and many others, were unknown to scientists until Anton van Leeuwenhoek's work.

Scientific progress in understanding the physical world has been closely associated with the advancement of technology. For example, microscopic life was completely unknown until Anton van Leeuwenhoek (lay' vun huk, 1632-1723) used special magnifying lenses (before actual microscopes were developed) to view what he called *animalcules*. This opened the door to a miniature world of living organisms now called microorganisms (my' kroh or' gun iz uhmz, also called **microbes**). As technology has improved, we have developed the ability to see not just these organisms, but even the components that work together to enable their life functions. This helps us understand them better. Pay attention throughout this book for the relationship between technology and new scientific knowledge (and understanding).

Section 1.1: The Characteristics of Life

While the definition of biology is fairly standard (the study of life), the definition of **life** varies significantly among scientists. Most scientists accept a common set of characteristics as indicating that an organism is living (or was living at some point in the past), but there are differences of opinion. These differences exist because some of the things we study in biology (like viruses) do not have all the characteristics, but they are closely associated with life. This textbook will follow a traditional approach and discuss viruses as if they are living organisms, even though they may not have all the characteristics of life.

There are seven characteristics of life recognized by most biologists: (1) organization, (2) metabolism, (3) homeostasis, (4) response to a stimulus, (5) adaptation, (6) reproduction and heredity, and (7) growth and development.

Characteristic 1: Organization

There are three levels of organization that are important to understand when examining living organisms: **order**, **complexity**, and **design**. These levels help distinguish between non-living and living matter. Order is a description of the sequencing or positioning of items. For example, *abcdef* is the sequence of the first six letters of the alphabet. Complexity is a reference to order that is not specified or specific. An example would be *acdfeb*. This would be the same letters, but not in any apparent order. Both Georges Cuvier (1769-1832) and Michael Behe (b. 1952) have proposed **irreducible complexity** as a special example of complexity in a living organism.

<u>Irreducible complexity</u> – When a system is made up of several interacting components, each of which is necessary for the system to function, and none of which can be made by modifying an already-existing component

Design (sometimes called **specified complexity**) would be an arrangement that conveys meaning or purpose. For example, if one speaks English, the following complex order of letters would have meaning: *read this sentence*. In the natural world, order might be the repeating pattern in a salt crystal. Complexity could be represented by large molecules that are composed of several smaller molecules joined together. However, design (specified complexity) would be present in DNA. These examples will be explored more fully in Chapter 2 (chemistry) and Chapter 3 (cells).

Characteristic 2: Metabolism

A living organism must have the ability to obtain energy and use it for building molecules that are essential for life and carrying out the various life processes. It gets that by **metabolism** (muh tab' uh liz' um).

<u>Metabolism</u> – The sum of all chemical reactions occurring in an individual cell to sustain life

These reactions can be divided into two categories: **catabolism** (kuh tab' uh liz' um) and **anabolism** (uh nab' uh liz' um).

<u>Catabolism</u> – The chemical reactions occurring in an individual cell that break down complex molecules into simple ones, releasing energy that the organism can use

For example, food contains molecules that can be broken down to release energy in a form that enables the cell to use it for specific tasks, such as building large molecules.

<u>Anabolism</u> – The chemical reactions that build complex molecules from simple ones, usually requiring the input of energy

Where does all this energy come from? Ultimately, almost all of it comes from the sun. Plants and certain microbes can use the solar energy to generate energy-storing molecules that they use for food. This process is **photosynthesis** (foh' toh sin' thuh sus), and it is an example of anabolism. When the energy is needed, catabolism occurs to break down the molecules and release it. Organisms that perform photosynthesis make more energy-storing molecules than they use, so as other organisms eat them (or eat things that ate them), those energy-storing molecules get passed on. Ultimately, however, those energy-storing molecules were made using the power of the sun.

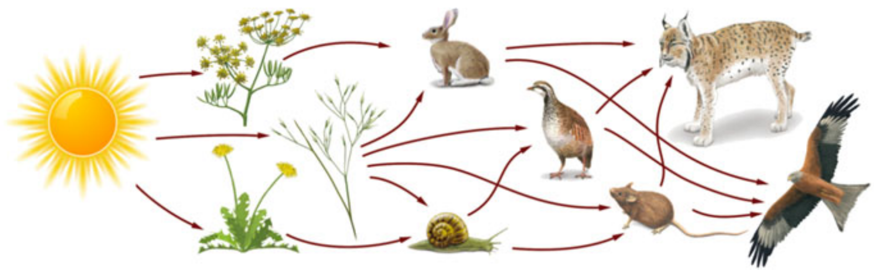


Figure 1.3: Almost all energy in biology comes from the sun. Some organisms (like plants) use that energy to make food for themselves via photosynthesis, while others (like animals) eat them or other organisms that ate them. Thus, energy is passed from the sun to all organisms on the earth.

There are also forms of life at the bottom of the ocean that never receive sunlight. Here, there are hydrothermal vents that spew hot water with all sorts of chemicals dissolved in it. Microbes turn those chemicals into food for themselves and the other organisms that live there. But these chemicals originally were part of the earth's surface and were brought to the bottom of the ocean. Thus, even the chemicals at the bottom of the ocean were made with energy from the sun. How do chemicals move from the earth's surface to the bottom of the ocean? You will learn about that in Chapter 15.

Characteristic 3: Homeostasis

Organisms live in environments that are constantly changing. Unfortunately, not every change is good for the organism, so it is important for an organism to control its internal environment without being harmed. That way, when the external environment changes, the organism can continue keeping its internal environment constant. This is called **homeostasis** (ho' mee uh stay' sus).

<u>Homeostasis</u> – The ability of an organism to maintain a constant internal environment

All living things, even the "simplest" cell, must be able to achieve homeostasis. In complex organisms like animals, the various systems work together to enable the entire organism to maintain a constant internal environment. For example, humans require a constant body temperature of about 98.6 ºF (37.0 ºC). To accomplish this, the nervous system monitors the body's temperature. When it is too low, a signal is sent to reduce the amount of blood flowing to the skin, which reduces the amount of heat lost. Another signal also goes to the muscles, which begin to contract suddenly, generating some local heat (i.e., you shiver). Other things happen when your body temperature gets too high, and those things reduce your body's temperature. Both scenarios are examples of homeostasis in the human body. Whether we are talking about a single cell or a multi-celled organism, homeostasis is a highly complex integration of systems that enables life to continue. The integration is an excellent example of irreducible complexity – if any one of the components is missing, the system cannot function, and homeostasis cannot be maintained.

Characteristic 4: Response to a stimulus

In addition to being able to maintain an internal environment, a living organism must be able to respond to a stimulus. This differs from homeostasis in that there are occasions when an organism receives information about its environment which doesn't involve the internal environment of the organism. For example, cells need energy for life. If an energy-rich molecule that can be used by the organism is detected in the environment, it moves toward the molecule to obtain it. Alternatively, if a harmful substance is detected, the organism will move away from it.

Organisms are constantly being exposed to changes. If they are unable to respond, their lives are threatened. Consider what happens to you in the morning. Sunlight fills the bedroom, stimulating your nervous system to start waking you up. An alarm clock rings to remind you that it is time to get up and prepare for the day. As you swing your feet over the edge of the bed and onto the floor, your blood pressure falls slightly, causing a signal to be sent to your brain to signal your heart to beat faster, returning your blood pressure to normal. If this did not occur, you would faint, and possibly hit your head. All this occurs in the first few moments of your day. These types of responses to various stimuli occur throughout every day of your life.

Characteristic 5: Adaptation

If homeostasis can be viewed as a short-term adjustment to a changing environment, **adaptation** would be viewed as a long-term adjustment. Each organism lives in a specific habitat, which is often called a **niche** (neesh). It is designed to fit in its habitat, having the proper structure and processes that allow it to survive and thrive. For example, certain animals (like the snow flea pictured in Figure 1.4) and plants have the ability to live in cold climates. This is possible because they are designed to make chemicals that act like antifreeze in a car. In Chapter 2, you will see that water expands when it freezes. If that happened inside a cell, the cell would die. Antifreeze chemicals keep that from happening, allowing the organism to withstand colder temperatures. Plants and animals that do not have such protection would not survive. This is why frosts in spring can damage the young plants that a farmer has in the field, destroying the crop.

Figure 1.4: This snow flea can survive frigid temperatures because it produces chemicals that keep the water in its cells from freezing.

Sometimes an organism needs to adapt to a change that occurs in the environment. We now know that all life forms have the ability to adapt to modest changes without dying. In some instances, these changes are related to how the cell performs its chemical reactions. In other instances, the homeostatic mechanisms adjust to the new conditions. Consider, for example, a person moving from a warm climate to a cold climate. Initially, he or she is uncomfortable when the temperature drops. However, as the days go by, the person's homeostatic temperature regulation mechanism adjusts, making the person more comfortable at the lower temperatures. This adjustment might take several weeks, but it will happen. If the person returns to a warm climate, the adaptation can be reversed.

Adaptation can also happen over several generations instead of within a single organism. For example, on the Galapagos Islands, there are birds called "Darwin's finches." When the climate on these islands is arid, the plants produce little seeds inside hard shells. If the climate stays that way for several years, each new generation of finches will have beaks that are (on average) shorter and stouter than those of the previous generation. That's because a short, stout beak is better for breaking the seeds' hard shells. However, when there is abundant rain for many years, the plants produce a great deal of soft food, and each new generation has (on average) beaks that are more slender, which helps them eat the soft food. These adaptations continue back and forth, depending on the environmental conditions.

One final example of adaptation is found in long-term relationships between organisms of different species. This is called **symbiosis** (sim' by oh' sus).

Symbiosis – A long-term relationship between organisms of different species

Figure 1.5: The nodules on this root hold bacteria that take nitrogen from the air and make it useful to the plant.

For example, all plants require nitrogen to make specific chemicals that they need. However, they can't use the nitrogen that is in the air; they need it in a different chemical form. There are bacteria that can take nitrogen from the air and convert it to a form the plants can use, so many plants engage in symbiosis with those bacteria. They allow the bacteria to live in their roots, and the bacteria "pay" for their "housing" by giving the plants nitrogen in the form the plants need. Without this symbiosis, the nitrogen must be supplied through other means, either natural (decomposition of dead plants and animals in the soil) or artificial (adding fertilizer to the soil).

Characteristic 6: Reproduction and heredity

All forms of life must be capable of reproducing and passing genetic information along to their offspring. The specific processes involved in inheritance will be explored more fully in Chapters 4, 5, and 6. In general, since the basic unit of life is the cell, each cell must be able to reproduce. Single cells accomplish this through a variety of forms of **asexual reproduction**.

Asexual reproduction – A mode of reproduction in which the offspring comes from only one organism

This kind of reproduction produces offspring that are genetically identical to the parent. However, when multi-celled organisms are involved, a more complex approach is needed. Here, **sexual reproduction** is involved.

Sexual reproduction – A mode of reproduction which combines genetic information from a male individual and a female individual to produce offspring

In both sexual and asexual reproduction, the genetic information is transmitted through the molecule known as **deoxyribonucleic** (dee ahk' see ry boh nyoo kley' ik) **acid**, or **DNA**. You will learn a lot more about DNA later. For now, however, realize that DNA stores information more efficiently than even the very best digital devices that human technology can produce. A single gram of DNA, for example, can store 215 million gigabytes of data (215 million one-gigabyte flash drives)! To see that cells contain DNA, perform the following experiment.

Experiment 1.1: Fruit DNA

Supplies:
- A large strawberry, two small strawberries, or a banana
- A large plastic bag that zips shut
- Three small glasses, like juice glasses
- A $\frac{1}{4}$-cup measuring cup
- A $\frac{1}{3}$-cup measuring cup
- A 1-teaspoon measuring spoon
- A $\frac{1}{4}$-teaspoon measuring spoon
- A spoon for stirring
- A wood rod for stirring, like a bamboo skewer
- A strainer
- Salt
- Dish soap
- Rubbing alcohol
- A freezer

Instructions:

1. Put $\frac{1}{4}$ cup of rubbing alcohol in one of the juice glasses and put it in the freezer to make it cold.
2. Add $\frac{1}{3}$-cup of water to the other glass.
3. Add 2 teaspoons of dish soap to the water in the glass.
4. Add $\frac{1}{4}$ teaspoon of salt to the soap and water mixture in the glass.
5. Use the spoon to stir the contents of the glass.
6. Put the strawberries or about $\frac{1}{4}$ of the banana (without the peel) in the plastic bag.
7. Push as much air as you can out of the bag and then zip it shut.
8. Squeeze the bag to mash the piece of strawberry or banana inside. Continue to squeeze it in multiple ways to make the piece of fruit look like pudding.
9. Open the bag and carefully add the saltwater/soap mixture.
10. Push as much air as you can out of the bag and then zip it shut.
11. Gently knead the contents of the bag so that you thoroughly mix the liquid and the mashed fruit together. Do this for a full two minutes.
12. Set the remaining glass upright in the sink and hold the strainer on top of it.
13. Open the plastic bag and pour its contents into the strainer so that liquid drains into the glass.
14. Once most of the liquid has dripped in the glass, put the strainer out of the way.
15. Pull the glass of alcohol out of the freezer.
16. Slowly and carefully add about half of the cold alcohol to the liquid that is in the glass so it forms a layer on top of the liquid. If the layer is very thin, add more alcohol to make it thicker.
17. Put the wood stirrer into the alcohol layer (not the liquid below) and gently move it around in the alcohol. You should see clumps of material clinging to the wood.
18. Periodically pull the wooden stirrer out of the alcohol to examine the material clinging to it. It should look like clear, thin snot. That's the DNA (and some other chemicals associated with the DNA) from the cells of the fruit plant!
19. Clean up your mess.

In the experiment, you broke down the cells that were in the fruit by crushing it and mixing it with the soapy saltwater. The broken-down cells released their DNA and the other chemicals found inside. The alcohol caused the DNA (and some specific chemicals associated with the DNA) to clump together, forming the thick, clear ooze that clung to the wood. Don't worry about the details of what each step accomplished. For right now, just realize that you isolated the fruit's DNA from most of the other chemicals found in its cells.

The ability to reproduce is a critical factor to the limitation of Artificial Intelligence (AI). There is a great deal of interest currently in producing robots that can think and reproduce. However, what is known about DNA and the information it contains suggests that AI will never be able to produce robots without periodic help from humans. For this reason, the robots will never be living. While movies show robots that are capable of taking over the world, it is not possible outside the realm of science fiction.

Characteristic 7: Growth and development

The final characteristic of life is the ability to grow and develop. The size of organisms varies greatly throughout the world. Some are microscopic and others are large enough to be seen with the naked eye. For example, viruses are about 100-1000 times smaller than a bacterium, which is about 100 times smaller than a typical cell (10-100 µm). The largest cell in the human body extends from the lower portion of your back all the way to your feet.

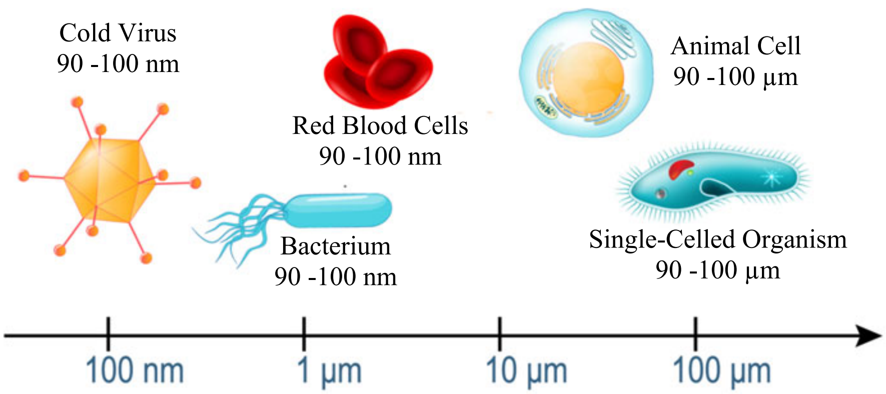


Figure 1.6: The sizes of a virus and various cells are compared. Note that the drawings are not to scale. The numbers at the bottom indicate size, where "nm" is a billionth of a meter and "µm" is a millionth of a meter.

When an organism **grows**, it increases its number of cells, the size of its cells, or both. Single-celled organisms do not increase in cell number, but they might be capable of increasing the size of the cell to a small degree. For multi-celled organisms, both are quite common. For example, when an animal is newborn, e.g., a puppy, it is quite small. As it grows, individual cells reproduce and there are more of them. Therefore, the puppy becomes larger. In addition, some of the individual cells increase in size, which also causes the puppy to be larger.

Development entails the process of becoming mature. Some cells undergo a fundamental change in their appearance and function across time. For example, when an egg and a sperm come together, a new life forms, but at that moment, it is a single cell. That single cell will undergo mitosis (my toh' sis – a form of reproduction that you will learn about later) many times to become a multi-celled organism. However, as this happens, the cells start to change. Some of the cells develop into the cells found in the heart. Others become cells for the brain. Still others give rise to muscle cells. This process is called **differentiation**.

<u>Differentiation</u> – The process by which a cell becomes specialized to perform a specific set of tasks

As differentiation occurs, the relationships between the cells undergo a change. For example, those cells that become part of the stomach remain associated with each other and stop being associated with those that form the skin.

Comprehension Check

1.1 You will learn later that DNA not only governs reproduction, but it also tells cells what chemicals they need to build and how to build them. In this role, does DNA direct anabolism or catabolism?

1.2 A dog is put in a very warm environment. At first, it reduces its activity and sweats a lot. After several weeks, however, it sheds a lot of its hair and is more active. Which would be considered adaptation? Which would be considered response to stimulus?

1.3 A mule is the offspring of a male donkey and a female horse. It cannot produce offspring, but it still has the sixth characteristic of life. Why?

Section 1.2: Organization of Life

The various forms of life do not exist in isolation, but in relationship with other forms of life and with the physical world. Scientists currently estimate that there are more than 8 million species, and each species can contain millions of individuals. To understand how all these organisms live requires grouping them into categories that can be examined. This provides a way to determine some of the basic similarities and differences among the groups. This section presents the groupings, beginning with the smallest entities and ending with the largest.

To fully understand the forms of life, it is necessary to understand how the basic components come together to form structures that assemble into larger structures. This means the first level of organization lies in the **pre-biotic** (non-living) area. **Atoms** are made of protons, neutrons, and electrons. The 98 naturally-occurring atoms combine to form all parts of the physical world. In living organisms, only about 25 of these atoms are found. They combine in characteristic ways to form thousands of different **molecules**, which have specific properties that are important in living organisms. Some of these molecules are called **inorganic** because they are found in the non-living parts of the physical world. Others join together to form larger molecules, called **macromolecules**. These are

Figure 1.7: God's creation has been designed with specific levels of organization.

organic molecules, since they are present in living organisms. Chapter 2 examines such molecules in more detail.

The physical properties of macromolecules enable them to join together to form the basic structures that make up cells. These structures, called **organelles**, act like the organs you have in your body, performing specific functions that are necessary for life. In fact, the term literally means "little organs." We will cover them in Chapter 3.

The transition from non-living to living is highly significant. As mentioned earlier in this chapter, life is much more than just matter and energy. When these organelles are arranged together and a **cell** is formed, the result is much more than the sum of the parts. It is the creation of something far grander than simple chemistry and physics. Trying to understand how abiotic (non-living) components can join together to make life is a key challenge to a materialistic view of biology, but it is quite understandable if a scientist realizes that God created life.

The next level of organization in life is the **tissue**. Here, cells join together and work as a unit for a specific purpose. As a result, this level is present only in multi-celled organisms. In animals, there are only four basic types of tissue: **epithelial** (ep' uh thee' lee uhl), **connective**, **muscle**, and **nervous**. There are many variations within each of these, but all animal tissues can be classified as one of these basic types. Epithelial tissue acts to cover surfaces. Connective tissue holds various tissues together. Muscle tissue provides protection and the ability to move. Nervous tissue plays an important role in communication between various parts of the animal.

Plants also have four basic types of tissue: **meristematic** (mer' uh stuh mad' ik), **epidermal** (ep' uh der' muhl), **ground**, and **vascular**. Meristematic tissue holds the cells that will differentiate into cells that make up one of the other three types of tissue. Epidermal tissue forms an outer covering for protection. Ground tissue is inside the epidermal layer. It serves as an aid in support and provides a place for the vessels inside the roots, stem, and leaves. You might not be familiar with ground tissue, but when eating a plant, the soft parts in the stem are ground tissue. Vascular tissue is important in support, but also is important in the formation of the vessels that allow substances to be transported throughout the plant.

The next level of organization of life is present when two or more types of tissue join to form an **organ**. Here, these tissues work as a unit for a specific purpose. Examples of organs in plants would be the roots, stems, leaves, flowers, and fruits. In an animal, organs would include the brain, heart, lungs, and stomach. Organs are joined together to form an **organ system** (or simply a **system**), which functions for a specific purpose. Your digestive system, for example, is named for its function (digestion), and is made of several organs, including the esophagus, stomach, small intestine, and large intestine.

An individual form of life is an **organism**. (A single organism is often called an individual.) There are probably trillions of organisms. However, they can be grouped further at a higher level of organization. A **species** is often defined as organisms that are capable of interbreeding only among themselves, although biologists have a difficult time holding to a good definition of species, since some species have the ability to mate with other closely-related species.

A **population** is a group of one species interacting in a particular environment. For example, this might be the group of cardinals living in a certain town or a herd of steers grazing in a field. Usually, there are populations of different species in any given location. The interaction of these different populations is a **community**. For example, birds, insects, and plants relate to each other in a meadow community.

Up to this point, all the levels of organization from a cell to a community have focused on living organisms. An **ecosystem** broadens that focus to include the interactions of these living organisms with the physical world they inhabit. For example, the study of an ecosystem would include the microbes, plants, and animals in a geographic location as well as the rainfall, temperature, and sunlight. Ecosystems can interact to form **biomes** (by' ohmz). There are 7 terrestrial biomes (tundra, coniferous (evergreen) forests, temperate forests, rainforests, scrublands, grasslands, and deserts) and 3 aquatic biomes (lakes, coastal, and ocean). When all of these biomes are viewed collectively, including their interactions with each other, this is a **biosphere**, which is the earth. Ecosystems and biomes will be discussed in Chapter 16.

Clearly, the division of the forms of life into groupings allows us to describe the basic elements of life in general. It also allows us to explore the interactions between the living and non-living worlds. Without these levels, it would be much more difficult to make sense of the design that we see in the natural world.

Comprehension Check

1.4 Suppose you count all the members in one level of organization. How does the number of members of that level compare to the number of members of the level right below it? For example, if you are considering tissues, how does the number of tissues compare to the number of cells?

Section 1.3: Nomenclature

While knowing the general levels of organization of life is helpful, the overwhelming number of organisms makes it hard to make sense of the biological world. To address this, we divide organisms into specific groups. This has been done since Genesis 2:19-20, where Adam named all the animals. However, as more and more organisms were identified, including the microbes, a more detailed system of naming was needed. Carl von Linné (or Carolus Linnaeus or Carl Linnaeus, 1707-1778) developed a **taxonomy** (tak sah' nuh mee) system that forms the basis of what scientist still use to this day.

Taxonomy – The science of classifying things, such as organisms

The modern divisions used today are: **domain**, **kingdom**, **phylum**, **class**, **order**, **family**, **genus**, **species**. They are illustrated on the next page. One way to remember these (and their sequence) is with the following mnemonic:

Dear King Phillip Came Over From Germany Swimming

Each of these divisions separates organisms into smaller groups to facilitate studying them. The similarity between members of a group increases as you move down the various levels, but the number of groups increases as well. So, for example, the organisms in each family are more similar than the organisms in each order, but there are more families than there are orders. Also, there is a lot of disagreement among biologists regarding the number of groups at each level, making it difficult to precisely describe taxonomy. In this course, we will use a more traditional approach and address the variations you might see in other courses. It also important to note that taxonomy also includes both **extant** (currently living) organisms and **extinct** (no longer living) organisms. Since identifying extinct organisms is quite difficult, placing them in the proper groupings is subject to revision as new findings arise.

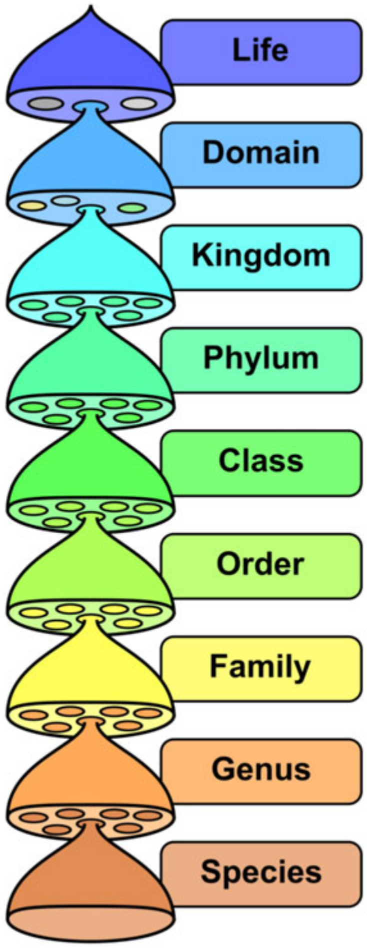


Figure 1.8: This is the taxonomy system we will use.

All organisms can be divided into one of three **domains**: **Bacteria**, **Archaea** (ar kay' uh), and **Eukarya** (yoo' kehr ee uh), based on their cells. As you will learn in more detail later, there are two basic kinds of cells in creation: **prokaryotic** (pro' kehr ee ah tik') and **eukaryotic** (yoo' kehr ee ah tik').

<u>Prokaryotic cell</u> – A cell without organelles

<u>Eukaryotic cell</u> – A cell with organelles

The **nucleus** (new' klee us) is an example of an organelle. It contains a eukaryotic cell's DNA. Prokaryotic cells have DNA, but it is not contained in an organelle. Eukaryotic cells have many organelles besides just the nucleus, but the nucleus is the easiest organelle to see and serves as a good way to distinguish between these two basic kinds of cells. In general, prokaryotic cells are smaller and simpler than eukaryotic cells. You will learn more about this in Chapter 3.

Each member of Domains Bacteria and Archaea is a single, prokaryotic cell. Bacteria are found in almost any environment in the world, including inside other organisms. For example, you have symbiotic relationships with many bacteria that live in your intestines. When bacteria are living in their proper habitat, they are essential for a proper balance within an ecosystem. However, if they become too abundant or if they start living in locations where they are not normally found, they can cause disease and damage the balance of the ecosystem. Members of Domain Archaea are similar to bacteria, but they are found in places that are considered to be inhospitable, such as extremely high-temperature and extremely low-temperature environments. For example, Archaea live in the geysers of Yellowstone National Park and in the glaciers of Antarctica. Both Bacteria and Archaea are discussed in Chapter 7.

All other forms of life are in Domain Eukarya. These organisms are characterized by eukaryotic cells, whether they are single-celled organisms or multi-celled organisms.
It is worth noting that recent approaches to taxonomy based on the evolution model have resulted in a **supergroup** within Domain Eukarya, which includes the proposed evolutionary lineage for the appearance of these organisms. However, this is highly controversial and undergoing rapid change. As a result, this level of organization is not included in this textbook.

Within Domain Eukarya, there are four **kingdoms**: Protista (pro' tee stuh), Fungi (fun' jee), Plantae, and Animalia. Members of these kingdoms are comprised of eukaryotic cells but have specific differences in structure and/or function. Protists (members of kingdom Protista) are the most diverse. They are primarily single-celled organisms, but a few are multi-celled. Protists are discussed in Chapter 8. Fungi play an important role in breaking down dead matter and returning the components back to the earth so they can be used by other living organisms. Examples of fungi include yeasts and mushrooms. They are also discussed in Chapter 8. Animals (members of kingdom Animalia) may be the most familiar, but they are quite diverse as well. These organisms must obtain their food from other sources. As a result, they are dependent on the other forms of life for survival. The range of size in animals is quite large. Some animals are very small (e.g., planarians typically are less than 1 inch long), and others are very large (e.g., blue whales can be more than 100 feet in length). Since animals are often of most interest to students, they are the most extensively discussed organisms in this textbook. Members of kingdom Animalia are discussed in Chapters 9 through 12. Plants (members of kingdom Plantae) play an important role in photosynthesis, using the energy in sunlight to produce energy-rich molecules for themselves and other forms of life. These have the largest range in size, going from very small (e.g., watermeal, which is about the size of the candy sprinkles placed on cakes and ice cream) to extremely large (e.g., redwood trees in California, which can be taller than 300 feet). Plants are discussed in Chapters 13 and 14.

Each kingdom can be divided into Phyla (plural of "phylum"). Each **phylum** represents a group of organisms that have a lot more similarities with one another than with other members of the same kingdom. Within Kingdom Animalia, there are 9 phyla. Each phylum contains animals that are more similar to one another than they are to the other animals. For example, phylum Platyhelminthes (plad' ee hel min' theez) contains flatworms, while phylum Annelida (uh nuh' lid uh) contains worms with segmented bodies, like earthworms. All worms are animals, but flatworms have more in common with one another than with earthworms, so they are grouped in different phyla.

There are multiple **classes** within each phylum so that the members of each class have more in common with one another than they do with other members of the phylum. For example, the largest animal phylum is Arthropoda (ar thruh' pah duh), which contains all animals that have segmented bodies and jointed limbs. There are 5 classes in that phylum. Two of the more familiar ones are Hexapoda (hek' suh pah' duh), which contains the insects, and Crustacea (kruh stay' shuh), which contains lobsters and crabs. Members of both classes have segmented bodies and jointed limbs, but the insects have more in common with one another than they do with crustaceans.

The same pattern follows for order, family, genus, and species: more groupings and fewer organisms within each group. As a result, the "lower" you go in the taxonomy system, the more similar the animals are. To see the complete taxonomy of three organisms, consider the Table 1.1. Look first at the columns for the human and the domesticated dog. Both are made of eukaryotic cells, so they are both in Domain Eukaryota. They both must obtain food, so they are in Kingdom Animalia. They both have a backbone, which makes them more similar to members of Phylum Chordata. They have hair and are warm-blooded, which gives them much in common with members of class Mammalia. It isn't until the level of order that people and dogs go into different groups. Humans are more similar to the members of Order Primates, while

Taxonomy Level	Human 	Domestic dog 	Bright Gem Tulip 
Domain	Eukaryota	Eukaryota	Eukaryota
Kingdom	Animalia	Animalia	Plantae
Phylum*	Chordata	Chordata	Subkingdom Tracheobionta Superdivision Spermatophyta Division Magnoliophyta
Class	Mammalia	Mammalia	Liliopsida
Order	Primates	Carnivora	Liliales
Family	Hominidae	Canidae	Liliaceae
Genus	*Homo*	*Canis*	Tulipa L.
Species	*Homo sapiens*	*Canis lupus familiaris*	*Tulipa batalinii* Regel

Table 1.1: The complete taxonomy of people, domestic dogs, and bright gem tulips.

dogs are more similar to members of Order Carnivora. When you get down to the bottom of the table, the species and genus names are in italics. The species name starts with the genus name, and the additional word is not capitalized. We call this **binomial** (by no' mee uhl) **nomenclature** (no' men klay' chur), since the name has two words in it. Thus, the scientific name for the species to which we belong is *Homo sapiens*.

Notice that even though we just talked about *binomial* nomenclature, the species for the domestic dog is made of three words. That's because even within the species *Canis lupus*, there is a lot of variety. In addition to domesticated dogs, wolves are members of *Canis lupus*. Thus, this species is split up into **subspecies**. When that happens, you can add a third word to indicate the subspecies. While the domesticated dog is *Canis lupus familiaris*, for example, the Arabian wolf is *Canis lupus arabs*.

Finally, notice that for plants, the taxonomy is slightly different. Instead of using phylum, plants use three categories: Subkingdom, Superdivision, and Division are used instead of Phylum. In addition, notice that the subspecies is written differently for plants. It is capitalized, and it is not in italics. You don't have to worry about all that right now. Just realize that plant taxonomy is different from the taxonomy of other organisms.

One other approach to taxonomy was proposed by Frank Marsh (1899-1992) and expanded by Kurt Wise (born 1959). This system is based on the created kinds (called "baramins") presented in the book of Genesis. This approach, called **Baraminology** (bare' uh min' ah luh jee), attempts to correlate the created kinds in Genesis with the known organisms today. However, it is not clear how they relate to the modern taxonomy system. As a result, there is some degree of disagreement even among the biologists who accept that system. It is generally accepted that a baramin is not equivalent to species. In fact, it is more likely to be equivalent to family or even order. An example of a baramin would be the *cat kind*. It is thought that God initially created the cat kind with DNA that had the potential to produce a lot of variety. As the pair of cats that walked off Noah's ark began to reproduce and move to different environments, this variety produced all the different cats that we see today.

Comprehension Check

1.5 You randomly pick two organisms from a specific Class, and then you randomly pick out two organisms from a Family. In which case do you expect the organisms to be more similar?

1.6 A bear's full taxonomy is Domain Eukaryota, Kingdom Animalia, Phylum Chordata, Class Mammalia, Order Carnivora, Family Ursidae, Genus *Ursus*, Species *Ursus arctos*. Do bears have more in common with humans or domestic dogs?

Section 1.4: Philosophy of Science

The definition of science varies significantly among scientists. Classically, science was viewed as a search for truth about the physical world. In the 1960s, there was a move away from this goal and toward a general search for anything that produces information using specific tools and methods. This shift occurred mostly because the prevailing worldview in the scientific community has changed over the years.

As a result, we usually think of science as including four realms: **Experimental Science**, **Inferential Science**, **Philosophy of Science**, and **History of Science**. While the vast majority of this textbook focuses on Experimental Science within biology, it is helpful to understand a little more about each of these realms since often when people refer to science, they do not realize there are differences that are important.

Experimental Science deals with the normal operation of the physical world. This area is what is commonly meant when someone speaks about science. It asks the question, "How does the physical world work?" It entails conducting experiments to test our understanding of the world as it occurs now. The reasoning associated with Experimental Science includes both inductive reasoning (moving from specific observations to general principles) and deductive reasoning (moving from general principles to specific applications). Examples of Experimental Science include biology, chemistry, and physics.

Inferential Science deals with examining present events and using them to indicate what event happened in the past. It asks the question, "How did the physical world come to be the way it is now?" Since it is very difficult to determine what occurred in the past, the possible causes are examined in light of what occurs today. Then, the best explanation is selected. This is called "Inference to the Best Explanation," and it should be evident that such a conclusion is quite temporary, since it depends on the information available at the moment. As further evidence becomes available, the conclusion may be changed. Examples of Inferential Science include geology, evolutionary science, forensic science, and paleontology. Please note that some books use the term "Historical Science," but students can confuse it with History of Science. Because of its use of inference, we choose to call it Inferential Science.

Philosophy of Science focuses on the nature of science itself. It addresses the questions such as, "What is science? What data will be acceptable? How will the data be interpreted?" It is this realm that reminds us that your worldview is vital to the scientific endeavor. What you believe plays a critical role in interpreting what you discover, not only in Inferential Science but also to some degree in Experimental Science.

The fourth realm of science, History of Science, is an exploration of the historical events that shaped the progress of science. This knowledge reveals what was understood in the past and how advancement occurred. It also reveals the limitations of science. Modern Western culture, and in some regards Eastern culture as well, has moved to a view that science is able to provide answers to all of the questions of life. However, when you look at the History of Science, you find that many scientific conclusions that were considered valid at one time (based on the evidence that was available then) are wrong. This is even true for those aspects of Experimental Science where empirical evidence was present. As a result, it is clear that ***science cannot prove***. It can only provide an understanding based on the evidence currently available.

In addition, when you consider a person's worldview, you find that many questions are not scientific. For example, science is able to provide a description of the appearance of a particular form of life, and even how that organism grows and lives in its habitat. However, science cannot tell you *why* that organism exists. Questions like that that are philosophical in nature and cannot be addressed using science. Unfortunately, this simple fact is often ignored. As a result, some believe that only science can give us the proper understanding of life's issues. This is called **scientism**, and while it is a popular view among some, it is simply not correct. True science recognizes that (a) there are limits to knowledge that can be gained through science and (b) the other approaches (e.g., religion, philosophy, art, music, literature) provide insight that also is valuable for understanding the meaning of life.

Comprehension Check

1.7 A scientist finds a fossil and measures its dimensions, determines the minerals that make it up, and determines the characteristics of the rock in which it was found. She then looks to see if someone else has already found a fossil like hers. She then attempts to figure out the habitat in which the animal that left the fossil lived. Identify all of her activities as belonging to Experimental Science, Inferential Science, Philosophy of Science, or History of Science.

Section 1.5: The Scientific Method

Many courses discuss the **scientific method**, implying that there is a single method that governs how science is done. However, as you just learned, Experimental Science and Inferential Science utilize different methods. Therefore, there is no single scientific method used today. However, it is important for you to learn the classic description of the scientific method, since it brought science to where it is today.

Figure 1.9: This drawing, from a book published 400 years after his birth, imagines Roger Bacon conducting an experiment.

The Christian worldview gave rise to modern science, because Christians believe that just as God gave them laws to follow to live a good life, He also gave His creation laws to follow. They believe that all of creation follows those laws, since all of creation was made by God. As a way of learning more about God by studying His handiwork, then, they set out to discover those laws. The beginning often is associated with Roger Bacon (c. 1220-1292), a Franciscan friar. He emphasized that knowledge should be rooted in observation. Up to that point, most people who were interested in studying the natural world simply used logic and reasoning. If there was consistency in the reasoning, a conclusion was accepted as valid. However, Bacon argued that observations were needed to confirm a conclusion. If not, the idea was to be rejected.

For example, the ancient Greeks reasoned that the sun must move around the earth, since they saw the sun rise every morning, travel across the sky, and set at night. This view was accepted by most scientists for a couple of thousand years. However, Nicolaus Copernicus published a book the same year in which he died (1543) that proposed the ancient Greeks were wrong. Instead, the earth traveled around the sun. He gave some observations that led him to believe this was the case, and he also showed that if this were the case, the universe would be more orderly, which is how he thought God would make it. Galileo Galilei (1564-1642) gathered more observations that supported the view, and other scientists did as well. Eventually, scientists came to realize that Copernicus was correct. In other words, while the Ancient Greeks' logic and reasoning seemed valid, observations showed that their view was wrong.

The emphasis that the scientific method puts on observations helped science develop into what it is today. There are six fundamental components to the scientific method: **observation**, **hypothesis**, **prediction**, **experimentation**, **analysis**, and **conclusion**. While these generally are presented as if the process truly is linear, in actual practice, there is a great deal of interweaving, going forward and backward.

The scientific method begins with observation. When exploring the physical world, any finding is considered to be an observation. These data could be **qualitative** in nature, which means they do not include measurements. Alternatively, the data could be **quantitative** in nature, which means they include an objective measurement. For example, the color pattern on the abdomen of a flying insect might be described as alternating bands of black and yellow. This is a qualitative observation. Counting the number and position of the body segments, legs, and antennae would be quantitative data.

Once a sufficient number of observations are obtained, you can produce a preliminary proposal that explains the relationships between the observations. This hypothesis must be able to account for all the observations available at the present time. This involves inductive reasoning since the hypothesis is an educated or informed guess about the data. The goal is to find the general principle that would explain all the observations whenever and wherever appropriate.

Once a hypothesis has been developed, it must be tested to see if it is accurate. To do this, a prediction is made. Here, deductive reasoning takes a general explanation (in this case, a hypothesis) and attempts to propose what would be found if a search or study were made. For example, after observing the insect described above, you could form a hypothesis that all flying insects have a black-yellow pattern on their abdomens.

The activity most commonly associated with science, in particular Experimental Science, is experimentation. Here, an experiment is designed to test the predictions of a hypothesis. There are two elements that are necessary for an experiment: a *control* and a *variable*. The control is the portion of the environment being tested that remains constant throughout the entire study. This is necessary to confirm that what is being found in the experiment is the result of the changes being put forth. If there is no control, it is not possible to determine whether the experiment actually tested the hypothesis or was the result of other factors that were not considered. The testing portion of the study comes with the variable. This is the element that changes during the course of the experiment. While it is possible to have multiple variables in a given study, analysis of the findings becomes very complex in this situation. Therefore, a well-designed experiment only has one variable being studied at a time. In the case of the flying insect we are discussing, we could capture and examine several flying insects. The only variable would be the color pattern on the abdomen.

Generally, it is best to obtain as much data as possible. However, it is not possible to gather all the data. In the case of the flying insect, it would mean obtaining all the flying insects in the world! So, a sample of the data is collected. For example, 20-30 flying insects could be captured and examined. A careful count of the total number of insects that have the specific color band pattern would be made. Every insect with the pattern would be considered as a positive. Any without the pattern would be considered to be a negative. The total number of positives and the total number of negatives would be recorded.

The experimental data must then be analyzed. In this example, the hypothesis is that all flying insects would have the described pattern. So, if there are any negatives (flying insects without the specific color pattern), the conclusion would be that the hypothesis is false. This necessitates rejection of the original hypothesis, and any further study would require a new hypothesis.

Unfortunately, even if the hypothesis is shown to be true, we can't say for sure that it is. It could be correct, but it could be that the sample size was too small. If we only caught flying insects with that color pattern, we would think that the hypothesis is true. However, if we had found more insects, we would have seen that it was false. This means there are three conclusions from the analysis of experiments: (1) the hypothesis fails to fit the explanation of the original observations and is rejected, (2) the hypothesis might be accepted if small revisions are made, or (3) the hypothesis is accepted for future reference. The most common result in scientific study is the second outcome – revision of an idea followed by more experimentation.

Since Experimental Science often involves observation, experimentation, and revision, progress sometimes requires additional levels of development. Early in the understanding of a given study, you might not have a lot of insight regarding the relationships between the data. However, as time progresses, certain relationships become more clear. When this happens, **models** can be developed which help to explain what is being studied. These might be archetypes, frameworks, or concepts that can be applied in new situations. For example, in healthcare, animal models are developed that show how a particular disease begins and progresses in the animal. This insight is then used to examine whether the same progression occurs in humans. Development of an animal model is a requirement before a drug is permitted to be brought to the market for general use in patients.

Experimental Science is performed using the scientific method that has been described, and there are instances where the hypothesis has been confirmed so often that scientists have a lot of confidence in it. At that point, it can be considered a **theory**. A scientific theory is not like a theory in other disciplines, which usually means merely a guess or suggestion. A scientific theory has four requirements for it to be accepted:

1. It must include the widest range of observations possible.
2. It must explain the observations with a few simple principles.
3. There must be a very large body of evidence that supports the theory.
4. There must be no exceptions to the theory.

Clearly, the conditions for something to be a scientific theory are quite rigorous. Examples in biology would be Cell Theory (all cells come from other cells) and Germ Theory (there are diseases that are caused by microbes). It also is important to note that theories also could be either a good theory (i.e., one that explains the data well) or a poor theory (i.e., one that does not explain the data well). It also is possible for a theory to go from being well-accepted to being rejected as more data are obtained. This occurred for the theory of Spontaneous Generation, where it was held for centuries that life could arise from non-living material. This theory was rejected when Louis Pasteur (1822-1895) performed a series of experiments that tested the theory and found that it was not correct.

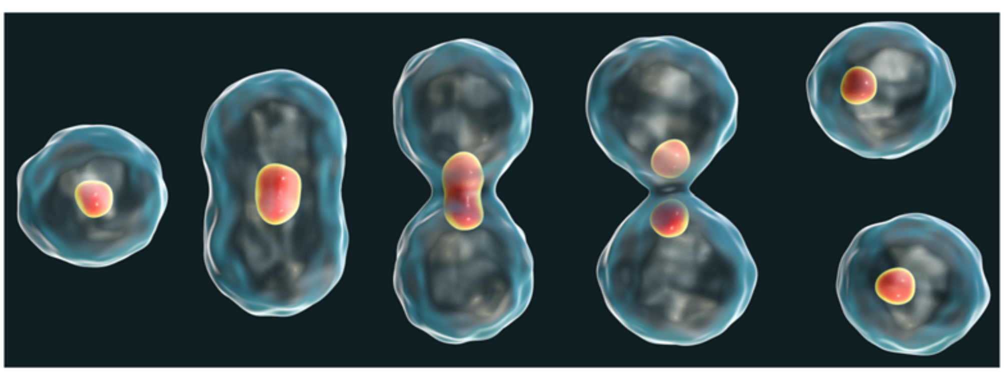


Figure 1.10: Cell Theory states that cells can only be produced by other cells. This illustration gives an example: A single, eukaryotic cell can asexually reproduce to become two new cells. Cell Theory has been confirmed by all observations made so far.

If a theory stands the test of time, i.e., no exceptions are found over a long period of time, and is valid in a wide range of circumstances, the theory is called a **Scientific Law** or a **Scientific Principle**. However, even these might be found to be faulty should additional evidence be found to demonstrate the law does not hold true. For this reason, one concludes that ***science does not prove***; it only provides an explanation based on what is currently known. This is why it is important to understand that absolute truth lies outside the realm of science. With the changes that come in science, it is good to know there is a Creator who does not change (Malachi 3:6).

Comprehension Check

1.8 A farmer notices that his cows seem to produce more milk when they are fed in the morning. The later in the day they are fed, the less milk they produce. Based on this observation, what hypothesis could be made? What prediction could be made from it? How could that hypothesis be tested?

Section 1.6: Energy Flow

Energy is required for all of life's processes, whether building a structure like a cell, moving from one location to another, or reproducing. So, it is essential that some form of energy is available at all times.

Energy – The ability to do work

This can be divided into two groups: **potential energy** and **kinetic energy**. Potential energy refers to energy in position, i.e., the arrangement of the energy by the position of the components. For example, a rock at the top of the hill has the potential to roll down the hill and hit a parked car. Kinetic energy refers to energy in motion. For example, when the rock starts rolling down the hill, it has kinetic energy.

There are several forms that may be found for energy. For living organisms, it may be present in one of five forms: **chemical**, **mechanical**, **electrical**, **heat**, and **radiant**. To get some experience with three of these forms of energy, do the following experiment.

Experiment 1.2: Energy in Chemicals

Supplies:

- Hydrogen peroxide (Sold at drug stores to clean wounds.)
- Yeast (Any yeast used for baking, even bread machine yeast, will work.)
- A small glass, like a juice glass
- A ½-cup measuring cup
- A measuring teaspoon
- A sink

Instructions:

1. Put a teaspoon of yeast in the glass.
2. Put the glass in an empty sink, because the next part will get a bit messy.
3. Measure out ½ cup of hydrogen peroxide and pour it into the glass with the yeast.
4. Observe what happens.
5. Put your hand near the opening of the glass so that the bubbles hit it as they flow over the top.
6. What do you notice about the bubbles?
7. Clean up your mess.

In the experiment, you should have seen bubbles forming in the glass. Eventually, enough of them formed that they rose to the top and spilled over in the sink. When you put your hand in the way of the bubbles, you should have noticed that the bubbles were warm. Why? Hydrogen peroxide has chemical energy stored in its bonds. The yeast caused hydrogen peroxide to break one of its bonds, releasing that energy. Some of that energy produced the motion of the bubbles, and some produced heat. In this experiment, then, some of the chemical energy in the hydrogen peroxide was converted to mechanical energy (the motion of the molecules), and some of it was converted into heat energy (which you felt with your hands).

The chemical energy in the bonds of the hydrogen peroxide is potential energy, because it is stored in the molecules. It will stay in the molecules until it is released by breaking a bond. The mechanical energy of the bubbles is kinetic energy, since the bubbles were in motion. It might be a bit harder to understand, but the heat energy is also kinetic energy, because it moved from a warmer area (the bubbles) to a colder area (your hand).

You didn't see any electrical energy in your experiment, but you actually used it, because it is present in the electrical signaling that occurs in the nervous system. You were able to notice the heat energy produced because nerves in the skin of your hand sent electrical signals to your brain, and your brain interpreted those signals to mean that the bubbles were warm. You also used radiant energy in the experiment, because it is the energy associated with specific kinds of waves, including light waves. If there had been no light, you wouldn't have been able to see the bubbles. While the light we see is the most obvious form of radiant energy, it is also found in other waves, such as X-rays, which play an important role in diagnosing damage to structures like bones.

Since energy is necessary for life, there must be a readily-available source to sustain it. The primary source is the sun, which produces radiant energy. There are organisms that are capable of using photosynthesis to trap that radiant energy, convert it to chemical energy, and store it in energy-rich molecules. These organisms are called **producers**.

<u>Producers</u> – Organisms that can produce energy-rich molecules as their food source

Producers can also be called **autotrophs** (aw' duh trohfs). Some, like plants, use the energy from the sun to produce their own food, and they are called **photoautotrophs**. Others use the energy from chemical reactions, and they are called **chemoautotrophs**. Producers are designed to make more food than they need so the consumers that eat them are able to get the energy that they need.

<u>Consumers</u> – Organisms that must eat other organisms for food

Consumers can also be called **heterotrophs** (hed' uh ruh trophs'). If heterotrophs eat plants, they are **herbivores**. Horses, for example, are herbivores. If they eat other animals, they are **carnivores**. Lions and crocodiles fall into that category. Those animals that eat both plants and animals are **omnivores**. People are omnivores.

While you might think that all organisms are either producers or consumers, there is a third category of organisms called **decomposers**.

<u>Decomposers</u> – Organisms that decompose dead organisms

Decomposers are necessary, because there is a lot of material stored up in an organism's body. When the organism dies, those materials must be returned to the environment so that new organisms can use them. If that didn't happen, the earth would eventually run out of the raw materials that organisms need. Decomposers, then, are the "recyclers" of creation. Fungi, for example, are decomposers.

From this description, it is apparent that the relationships between the various organisms can be quite complex. There is a flow of energy and chemicals throughout the living world. While the energy flow moves in one direction (from the sun to all living organisms), the movement of the chemicals can best be described as a cycle. Figure 11.1 attempts to show this. Notice that without the decomposers, the cycle would not be complete.

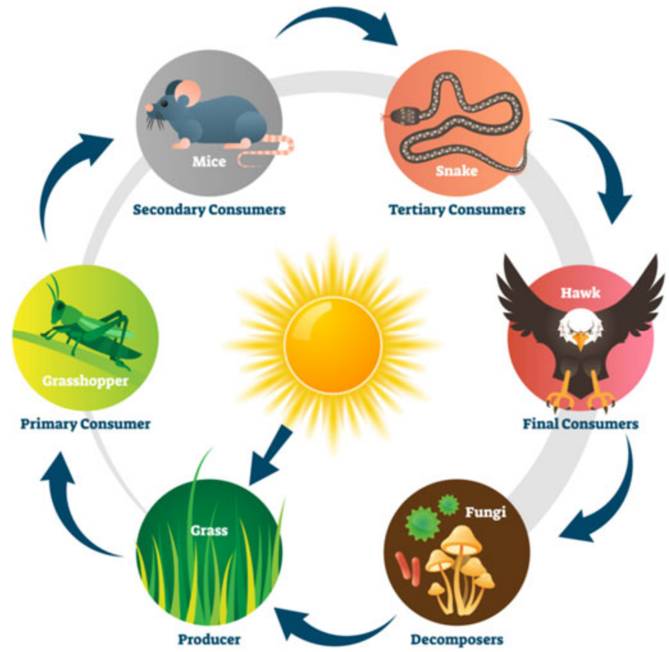


Figure 1.11: Producers use the sun's energy to make their own food, which is then eaten by the consumers. Decomposers then recycle chemicals to be used again.

The intricate relationships regarding energy flow in nature has traditionally been presented as the **food chain**, as shown in Figure 1.11. In this view, solar energy is converted by a producer into a chemical nutrient, which is used by a series of consumers. For example, the consumer that eats a plant (the producer) would be a **primary consumer**. An animal that eats a primary consumer would be a **secondary consumer**. If the secondary consumer is eaten, the animal that ate it would be a **tertiary consumer**. Anything that eats a tertiary consumer is also considered another tertiary consumer. Eventually, the energy reaches an animal that is not eaten. That animal could be called the final consumer (or top carnivore), but it is really just another tertiary consumer. When the final consumer dies, decomposers recycle the chemicals in its remains back into nature.

However, these relationships are much more complex than this linear arrangement, so energy flow is more properly presented by a **food web**, which is pictured in Figure 1.12. For example, when the hawk eats the mouse, it is acting as a secondary consumer, since the mouse eats plants, making it a primary consumer. However, when the hawk eats a frog, it is acting as a tertiary consumer, since the frog is a secondary consumer.

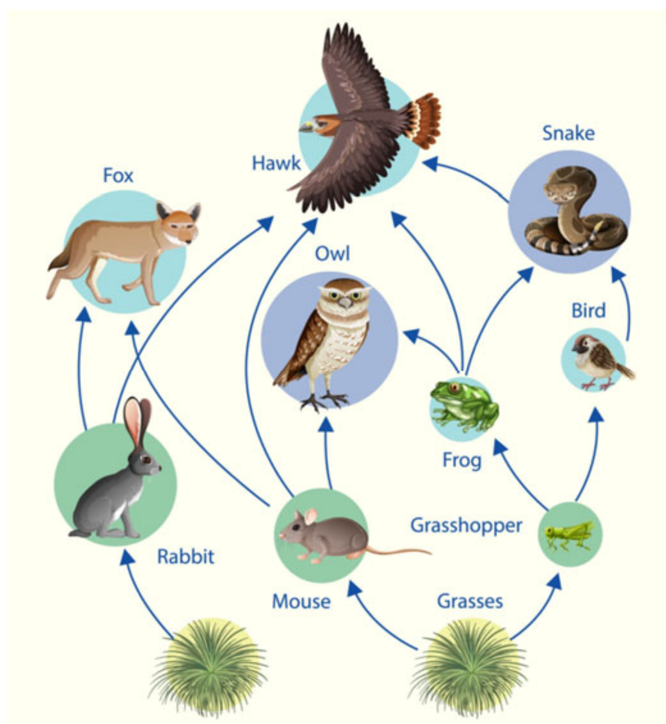


Figure 1.12: Energy flow in nature is better represented as a food web.

It is important to note that the primary focus in the food web is the energy flow from the sun to the producers and then to the consumers. Because of this, the terms associated with consumers and producers are called **trophic levels**. Each level is a depiction of the energy available at this point relative to the amount of the original solar energy. At the lowest level, the number of producers is quite high. Therefore, the amount of energy here would be very large. It doesn't equal all the radiant energy captured by the producers, because when plants make food for themselves, they don't capture all the sunlight, and not all of the energy in the captured sunlight is converted into food. Thus, the amount of energy in the producers is less than the amount of energy given to the earth by the sun. We will discuss this in more detail in Chapter 15.

The next trophic level, primary consumers, contains less energy than the first trophic level, because a consumer cannot get all of the energy stored in the producers it eats. In the same way, secondary consumers can't get all the energy in the primary consumers, and tertiary consumers can't get all the energy in the secondary consumers. As a result, energy flow is a stepwise loss from the energy given off by the sun to the final consumer in the process. This also shows why the availability of food becomes a key factor in survival. If there are not sufficient nutrients for all the organisms in a given location, the energy needs cannot be met and the diversity of life is threatened, as happens in a drought. Similarly, if there is an abundance of nutrients, the number and diversity of life grows significantly. This is one reason that the diversity of life is so extensive in a tropical rainforest.

In addition to the energy needs, all forms of life require certain substances to build the chemicals they need in order to carry out the processes of life. Four important substances are worthy of special emphasis since they are recycled throughout the earth: water, carbon, nitrogen, and phosphorus. This recycling occurs on a global scale, leading to the term **global biogeochemical cycles**, which will be discussed in Chapter 15.

Comprehension Check

1.9 In which trophic levels can a carnivore be found?

1.10 When you eat a salad, what is your trophic level? What about when you eat meat from a cow?

Section 1.7: Natural Selection

An understanding of life focuses on the structure and function of the various organisms, which is the primary purpose of this course. However, there also is a significant discussion of how these organisms came into existence. Any proposed explanation of this origin must address these key features of life: (1) the origin of the specified complexity in DNA, (2) the origin of the system for storing and encoding the information in DNA, and (3) the origin of the functional interdependence of parts within a cell. Throughout history, many proposals have been put forth to address the origin of the many forms of life. However, in this course, only the creation and evolution models will be discussed. At the end of selected chapters, then, a final section will address issues related to these models.

There are three common meanings for evolution: (1) change over time, (2) universal common descent (all living organisms arose from a single common ancestor), and (3) the creative power of unguided natural selection acting on random mutations. There is strong evidence in support of the first meaning. One of the characteristics of life is the ability to adapt to changing conditions. So, it is expected that there will be change over time.

There also is evidence that organisms are designed to be able to adjust to environmental changes, even producing new structures and functions. As a result, this suggests that the original design included sufficient genetic variation to respond to these changes, leading to new forms of life. However, these changes appear to be limited. Therefore, the proposal that there is universal common descent from a single life form does not seem to match the most recent evidence.

The third definition usually is viewed as the fundamental component of the Darwinian model of evolution. (For the purposes of this textbook, reference to the evolution model indicates the neo-Darwinian model, which is also known as the Modern Evolutionary Synthesis.) When Charles Darwin (1809-1882) proposed his idea in 1859 (*On the Origin of Species by Means of Natural Selection, or the Preservation of Favoured Races in the Struggle for Life*), he was not the first to suggest evolution. However, he was the first to suggest a mechanism by which this was possible – **natural selection**.

Natural selection – The process by which organisms better adapted to an environment will be more likely to survive and reproduce, passing those adaptations to their offspring

Darwin observed that breeders used selection to produce new forms of domesticated animals and plants. For example, pigeon breeders would choose the fanciest-looking pigeons and breed them together. If they did that for several generations, the resulting pigeons looked significantly different from the original pigeons that the breeder started with, as shown in Figure 1.13. He called this "artificial selection" and concluded that nature could do the same thing. By "selecting" for traits that made an organism more likely to survive, nature would cause those traits to accumulate over the generations, producing completely new kinds of organism. Through this process, he imagined that all organisms alive in his day could have come from a single organism that lived in the earth's distant past.

Figure 1.13: Pigeon breeders used artificial selection to turn pigeons like the one above into pigeons like the one below.

Natural selection as the primary mechanism driving evolution requires (1) variation, (2) heritability, and (3) competition. In any given population, the organisms are not all alike. These **variations** arise naturally and provide differing abilities to respond to changes in the environment. If any of the characteristics are able to be passed along to the next generation (heritability), then they could appear in the offspring. Because there are limited resources in any given environment, when a change in the environment occurs, only those individuals that have an advantage in the new condition will overcome the **competition** and survive, passing this along to offspring. This is why the phrase "survival of the fittest" is often used when discussing evolution. Therefore, Darwin's model contends that natural selection has the potential to bring about new forms of life, i.e., new species.

As data have been obtained since this model was proposed in the 19th Century, a more detailed understanding of how the variation might arise has been developed. The requirement is that the genetic information undergoes **mutation**.

<u>Mutation</u> – A change in an organism's DNA that alters the information contained in the DNA

Since mutation changes DNA, it can fundamentally change the organism. If those changes are bad for the organism's survival, the organism is unlikely to pass it on to the next generation. If those changes make the organism more likely to survive, it is very likely to pass them on to the next generation.

Data accumulated since Darwin originally proposed his mechanism show that natural selection does occur. Sometimes, mutations are not required to produce the changes upon which natural selection acts. Remember Darwin's finches on the Galapagos Islands? There is a natural variability in the types of beaks these finches have. When long periods of drought occur, natural selection chooses shorter, stouter beaks, which produces a population that, overall, has those types of beaks. However, after long periods of wet weather, natural selection chooses more slender beaks, which once again changes the overall prevalence of beak types.

Mutations were once thought to be the source of significant variability, which could produce offspring that are significantly different from the original organisms that gave rise to them. However, detailed studies of mutations show that this really isn't the case. For example, there is a very famous experiment called the "Long Term Evolution Experiment." It has been studying 12 separate populations of bacteria since 1988. Because bacteria live short lives and reproduce quickly, each population has produced more than 70,000 generations! Those generations have been exposed to a wide range of conditions, producing a multitude of mutations.

Natural selection has acted on some of those mutations, producing changes in the population. Those changes made the bacteria more likely to survive in whatever new conditions were made, but they have yet to produce any change that could be deemed significant. For example, one population was exposed to a food source that the bacteria couldn't normally use when oxygen is present. However, over time, mutations occurred that allowed them to use that food source, even when oxygen was present. While this made them more likely to survive, it didn't represent a fundamental change, since the bacteria could already use that food, but only when there was no oxygen present. Thus, there was nothing new produced in the bacteria. They simply were able to eat the same food they could always eat, but under different conditions.

Based on the data that have been collected so far, it seems that the original design of the genomes of the various organisms includes more elements than are needed at any one time. When there are changes in the environment, some of the elements that aren't currently expressed become available to the offspring, and natural selection chooses those new elements so that the organisms can survive. This means that natural selection operates to enable survival of existing life forms, but not as a means to generate new forms. Remember, for example, our discussion of cats. It is reasonable to assume that all cats we see today come from the originally-created cat kind, because the DNA of the cat kind had more possible traits than any one cat needed. As a result, natural selection would choose one set of traits for one environment (producing tigers in a forest, for example) and another set of traits for another environment (lions on the plains, for example). While this could certainly be called "evolution," it is really long-term adaptation.

But does it really make sense that all the cats we see today came from a single cat kind that existed after the worldwide Flood? Genetic studies show only minor differences between the genomes of the different species of cats that exist today. This can be demonstrated by the fact that many cat species can interbreed. Figure 1.14, for example, is a picture of a liger, the offspring of a male lion and female tiger. There are many other examples, such as a leopon (offspring of a male leopard and a female lion), savannah cat (offspring of a domesticated cat and a serval), pumapard (offspring of a puma and leopard), and a jaglion (offspring of a male jaguar and a female lion). It turns out that there are many examples of these kinds of animals, which are often called **hybrid** animals. In fact, it has been estimated that about 10% of animal species can form hybrids with other species. From a genetic standpoint, then, the idea that all animals we see today descended from the animals on Noah's ark is quite reasonable.

Figure 1.14: Hybrids like this liger give us evidence that the cats we see today could all be descendants from a single cat kind.

Comprehension Check

1.11 Suppose an animal experiences a mutation that reduces its desire to reproduce. As a result, it is less likely to have offspring than other individuals of the same species. Do you expect that mutation to become prevalent in the population? Why or why not?

Answers to the Comprehension Check Questions

1.1 It directs anabolism, because it tells the cell how to build chemicals. Catabolism involves breaking down chemicals.

1.2 Sweating and reducing activity is response to stimulus, while shedding and resuming activity are adaptation. Short-term effects come from response, while long-term effects come from adaptation.

1.3 Its cells still reproduce. Remember, animals make more cells to grow, which happens only through reproduction. They must also replace dead cells and repair injuries, which also requires reproduction at the cellular level.

1.4 The number of members in the level below is greater than the number in the level above. A single tissue is made of many cells, so there must be a lot more cells than tissues.

1.5 The organisms from the same family will be more similar. Family is lower than class in the taxonomy system, and the lower you go, the more similar the organisms become.

1.6 They are more similar to domestic dogs. They have the same domain, kingdom, phylum, and class as both domestic dogs and humans. However, bears are in the same Order as dogs, which is different from the order to which humans belong. That means they have more in common with domestic dogs than people.

1.7 Measuring its dimensions, determining the minerals that make it up, and determining the characteristics of the rock in which it was found are Experimental Science. Looking to see if someone else has already found the fossil is History of Science. Attempting to figure out the habitat in which the animal that left the fossil lived is Inferential Science. Experimental science deals with the operation of the physical world, which is what she is trying to determine by measuring the characteristics of the fossil and the rock that holds it. Looking to see if someone else has found it is looking at past scientific endeavors, which is History of Science. Looking at the fossil in the present and trying to figure out what the animal did in the past is Inferential Science.

1.8 The hypothesis would be that the time at which cattle are fed affects how much milk they produce. Based on the observation, you could predict that a group of cows fed in the morning will produce more milk than a group of cows fed in the evening. You could test this by feeding two groups of cows at two different times in the day (morning and evening, for example), and comparing their milk production.

1.9 It could be a secondary or tertiary consumer. Carnivores do not eat plants or other producers, which is what would be required for a primary consumer. Remember, final consumers are considered tertiary consumers.

1.10 When you eat salad, you are a primary consumer. When you eat meat from a cow, you are a secondary consumer. Plants are producers, and organisms that eat producers are primary consumers. Cows eat plants, so they are primary consumers. Anything that eats them is a secondary consumer.

1.11 It probably will not become prevalent in the population. Remember, natural selection favors animals that can survive and reproduce. This animal might survive fine, but if it is less likely to reproduce, its mutation will not be chosen by natural selection.

Chapter 1 Review

1. Define the following terms:

a. Irreducible complexity	f. Symbiosis	k. Prokaryotic cell	p. Decomposers
b. Metabolism	g. Asexual reproduction	l. Eukaryotic cell	q. Natural selection
c. Catabolism	h. Sexual reproduction	m. Energy	r. Mutation
d. Anabolism	i. Differentiation	n. Producers	
e. Homeostasis	j. Taxonomy	o. Consumers	

2. What are the seven characteristics of life?

3. The digestion process breaks down the molecules in food to make smaller molecules that cells can use for energy. Is this anabolism or catabolism?

4. Where does almost all the energy in biology come from?

5. If plant cells don't get enough water, they cannot stay rigid, and the plant wilts. Thus, if they start to lose rigidity, they absorb more water. Which characteristic of life is this an example of?

6. An animal changes its long-term behavior based on changes that occur in its environment. Which characteristic of life is this an example of?

7. What molecule transmits information from parent to offspring?

8. You started out as a single cell. However, you are now composed of trillions of cells. Which two characteristics of life produced that change?

9. Put these biological levels of organization in order, from the smallest to the largest:

biosphere, system of organs, molecule, organelle, ecosystem, cell, organ,
organism, tissue, population, community, atom, biome

10. List the eight divisions of taxonomy, starting with the broadest and ending with the narrowest.

11. You randomly choose two organisms from an order and compare them. You then randomly choose two organisms from the same genus and compare them. In which case do you expect the organisms to be more similar?

12. Here is the taxonomy of the domestic cat: Domain Eukaryota, Kingdom Animalia, Phylum Chordata, Class Mammalia, Order Carnivora, Family Felidae, Genus *Felis*, Species *Felis catus*. What is the scientific name for the domestic cat? When we name a species that way, what kind of nomenclature is being used?

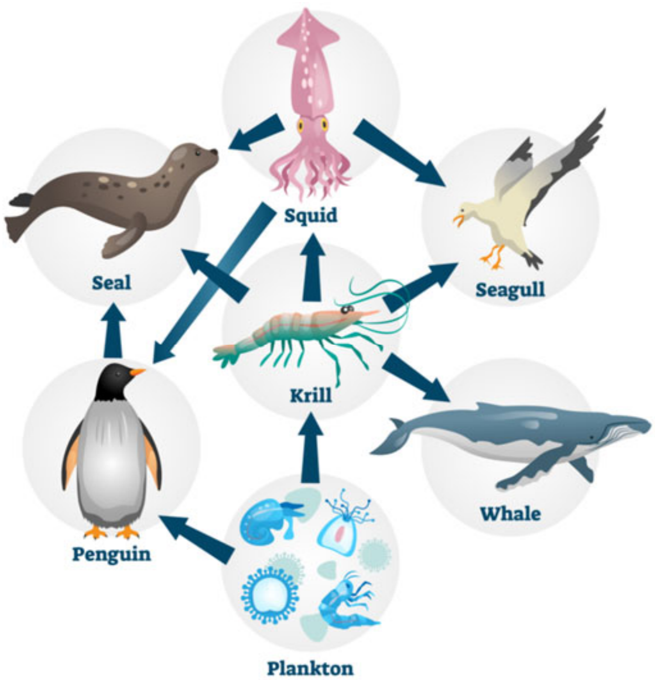
13. The scientific name for a domestic dog is given in a textbook as Canis Lupus Familiaris. What's wrong with that?

14. When biologists attempt to correlate the organisms we see today to the original ones that were created, what is that called?

15. A teacher tells you that science has proven that the earth orbits the sun. Is the teacher correct?

16. Put these steps of the scientific method in their proper order: conclusion, observation, prediction, hypothesis, experimentation, analysis.

17. List the trophic levels in order, starting with those that directly use the sun's energy and ending with those that use the energy last.



18. For the aquatic food web shown on the left answer the following questions:

   a. List the producers.
   b. What are the possible trophic levels of the penguin?
   c. What are the possible trophic levels of the whale?

19. A population of fish is being studied. In one generation, a few of the fish have a mutation that makes them faster swimmers. Others in that same generation have a mutation that makes it more difficult for them to perform metabolism. If the same population is studied two generations later, which mutation is more likely to be found in many of the fish?

20. Members of species A are able to mate and produce viable offspring with members of species B. Members of species C are unable to mate and produce viable offspring with members of either species A or species B. Which two species have the more similar DNA?

21. Based on the data we have right now, what is the main thing that natural selection accomplishes?