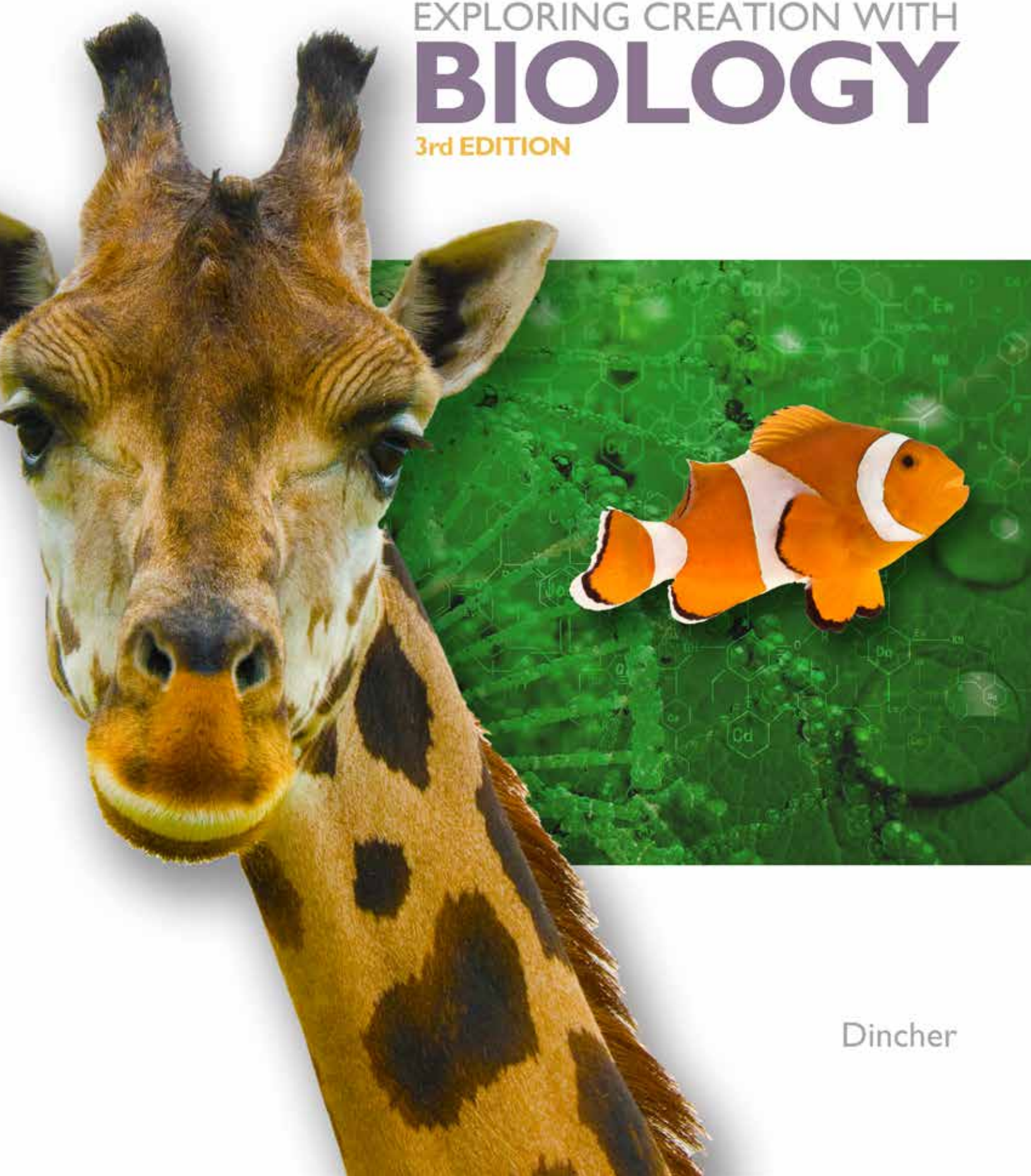
apologia

EXPLORING CREATION WITH BIOLOGY

3rd EDITION



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THE SCIENCE OF LIFE

Studying life is a rich and rewarding endeavor. Through a careful investigation of any creation, we can learn a lot about its designer. You are living at a time when there are wonderful tools (like the microscope pictured in Figure 1.1) available to study even the smallest living things! As you begin your journey through biology, take time to consider what lessons you may learn about the Creator of all.

FIGURE 1.1
Scientist Using a Microscope

signs of life

The Bible tells us, "God saw all that he had made, and it was very good." Of course, God did not have to observe creation to learn anything about it since He was the one who designed it. It means that God is engaged with the world and that He reveals Himself through it. And that means you can bet that in all of your science studies, one of the most important things you will need to master is observation. We could never see things the way God sees them, but there is much to learn about the world through observation. You might think that you notice quite a bit about the things around you, but observation is so much more than simply noticing. When we observe something, we attempt to recognize its significance. You've been gifted with senses to help you keenly observe all that is around you. You've also been gifted with intelligence to help you record data and develop hypotheses, which means you will be encouraged to recognize significance in all that you are taught in this biology course.

I applied my mind to examine and explore through wisdom all that is done under heaven.
Ecclesiastes 1:13

In this module, you will learn the answers to the following questions.

The Process of Science—Why should we study science? How does science enable us to understand the natural world? How can we use science as a framework for making predictions and testing them? Are there limitations to science—if so, what are they?

The Study of Life—What are the criteria for life? How does each criterion contribute to the definition of life?

The Tools of Biology—What tools do biologists use? How do these tools help scientists gather, analyze, and interpret data?

THE PROCESS OF SCIENCE

In this course, you're going to take your first detailed look at the science of **biology**. The word "biology" means the "study of life."

Biology—The study of life. The Greek word *bios* means "life," and *-logy* means "study of."

It is a vast subject with many subdisciplines that concentrate on specific aspects of biology. Microbiology, for example, concentrates on those biological processes and structures that are too small for us to see with our eyes. Biochemistry studies the chemical processes that make life possible, and population biology deals with the dynamics of many life forms interacting in a community. Since biology is such a vast field of inquiry, most biologists end up specializing in one of these subdisciplines. Nevertheless, before you can begin to specialize, you need a broad overview of the science itself. That's what this course is designed to give you.

But first let's look at what science really is. You may think that science is a book full of facts that you need to learn. But that's not what science is at all. While science is a collection of information, it is also much more. Science is a process—a way of investigating, understanding, and explaining the natural world around us. Scientists carefully gather and organize information in an orderly way so that they can find patterns or connections between different phenomena. Scientists then use the patterns, connections, and explanations to make useful predictions.

What Scientists Do

Real scientists use many methods to investigate their area of interest. But all scientists draw conclusions based on the best **evidence** they have available to them at the time.

Evidence—The collected body of data from experiments and observations

In science, evidence refers to all the data collected from observations and experiments conducted in an area of scientific research. Keep in mind that this body of evidence alone isn't enough to convince scientists of the accuracy of their conclusions until the observations and experiments are repeated multiple times with similar results. Regardless of what method scientists use to gather evidence, they use a system with several things in common known as the scientific method. This system provides a framework in which scientists can analyze

situations, explain certain phenomena, and answer certain questions.

Observations and Inferences

The scientific method often starts with observation. Observation allows the scientist to collect data. Observing the world involves using your five senses to gather factual information. Scientific observations should be specific and accurate. Scientists collect data using quantitative observations and qualitative observations.

Quantitative observations—Observations involving numbers, such as counting or measuring

Qualitative observations—Observations that are not easily counted or measured, such as color or texture

Quantitative observations are factual data collected using numbers. For example, in Figure 1.2, a quantitative observation could be "There are five bears in the river." Qualitative observations are factual descriptions that do not use numbers. Some qualitative observations for Figure 1.2 could be "The bears are brown" and "The bears are in a river at a small waterfall." Scientists make as many specific and accurate quantitative and qualitative observations as possible when collecting data about the object or phenomenon they're studying. Once observations are made, scientists will often begin to interpret the data using inference.

FIGURE 1.2
Observation and Inference
Observation uses the five senses to factually describe a situation. Inferring uses previous knowledge and experience to interpret observations.

Inference—Logical interpretation based on prior knowledge, experience, or evidence

An inference is a conclusion drawn by logically thinking about possible relationships between two or more observations. Inferences are based on prior knowledge and experience. In Figure 1.2, for example, it might be inferred that the five brown bears are fishing. This inference is based on observations as well as the knowledge that fish are usually found in rivers and that bears eat fish. Notice, however, that you haven't actually observed the bears eating fish. It is very important not to mix up observations and inferences.

Hypotheses

Once enough data have been collected, the scientist forms one or more hypotheses that attempt to explain some part of the data.

Hypothesis—A suggested, testable answer to a well-defined scientific question or a possible, testable explanation for observations

Hypotheses are possible explanations for a set of observations or possible answers to a scientific question. They are limited in scope so that you can test only one thing at a time.

Usually, several good hypotheses can explain a single observation or phenomenon. In fact, good scientists try to figure out as many possible explanations for an observation as their creativity allows. For example, if it has been observed that the males in a certain species of birds sing, then the following possible explanations could be made:

- Male birds sing to attract mates.
- Male birds sing to drive off territorial rivals.
- Male birds sing to warn other birds of approaching predators.

Scientists would need to design ways of ruling out or testing each of these hypotheses to determine which, if any, of them may explain why male birds sing.

Experiments

Once the hypotheses are formed, the scientist (typically with help from other scientists) collects much more data in an effort to test them. These data are often collected by performing experiments or by making even more observations.

It's important to understand that you can test a hypothesis multiple ways. Designing an experiment is one way. The student notebook that accompanies this text goes into detail about how you can design your own experiment. Scientists use experiments to search for cause-and-effect relationships in nature. In other words, they design experiments where a change in one thing will affect something else in a measurable way. The factors that change in an experiment are called variables.

Variable—A factor that changes in an experiment

Scientific experiments test only one variable at a time. The **independent variable** (cause) is the factor that is changed by the scientist. The independent variable is also called the manipulated variable because it is the variable deliberately altered. The **dependent variable** (effect) is the factor that responds to the independent variable and is sometimes called the responding variable.

Independent variable—The variable manipulated by the experimenter

Dependent variable—The variable responding to the manipulated variable

Having only one independent variable is how a scientist can be sure that the results of the experiment are due to the one factor being investigated. All other factors (variables) that might influence the experiment must be controlled. This is called a controlled experiment

and scientists pay as much attention to controlling all the variables except one as they do to observing the changes in the dependent variable. For example, if you were trying to test if watering plants with coffee causes those plants to grow faster than plants watered with water, you would have two groups of plants. The group of plants that you water normally is called your **control group**. The group of plants that you water with coffee is called the **experimental group** because this group contains the independent variable, the one you want to test. Both groups would be identical—same type of plant, soil, temperature, amount of sunlight, etc.—except for the substance used for watering. Data are collected on both groups.

Experimental group—The group in an experiment that is manipulated (contains the independent variable)

Control group—The group in an experiment that experiences no manipulation (does not contain the independent variable)

Scientific Theories and Laws

If the data collected from experiments or observations are not consistent with the hypothesis, there are a couple things scientists can do. They might completely discard the hypothesis if none of the data supports it. Or they might modify the hypothesis a bit until it is consistent with all data that have been collected. Once a large amount of consistent data is collected from testing one hypothesis (or many hypotheses) related to the subject or phenomenon, then an explanation is formed. This inferred explanation of observable natural phenomena is called a **scientific theory**.

Scientific theory—An explanation of some part of the natural world that has been thoroughly tested and is supported by a significant amount of evidence from observations and experiments

Since a theory has been tested by a large amount of experimental data, it is considered reliable. A scientific theory is more substantial than a hypothesis because it explains as many observations as possible with no exceptions and should be able to predict the outcomes of future experiments. As more and more predictions based on the theory are tested, the theory either will be supported or will need to be changed. If new observations or interpretations of the data arise that cannot be explained by the theory, then the theory is modified so that it continues to be the best possible explanation. Often it takes scientists a while to really analyze data inconsistent with a current theory, but once the new data are thoroughly verified by experiments, a theory will be revised. Sometimes a theory is rejected if an overwhelming amount of evidence from testing hypotheses fails to support the theory.

Unlike a scientific theory, a **scientific law** is a description of a natural event but it doesn't attempt to explain why the event occurs or how it happens.

Scientific law—A description of a natural relationship or principle, often expressed in mathematical terms, and supported by a significant amount of evidence

Most scientists generally accept both scientific theories and laws because they both result when a great body of evidence supports them (often from years of observations and thousands of experiments). You may have learned that with enough research, testing, and time, a theory can become a law. This is actually a common misconception. In fact, laws often precede theories in science because describing a natural phenomenon can be easier than explaining how it happens. For example, you will learn about Mendel's laws of inheritance in Module 7. These laws describe what Gregor Mendel observed about traits (such as the color of peas) as they are passed from parent to offspring. However, Mendel didn't know how these traits were passed from generation to generation so he didn't explain but merely described what he observed. It wasn't until years later, after the discovery of DNA, that an explanation could be formed. This explanation is called the chromosome theory of inheritance and you will learn more about it too in Module 7.

Scientific Method in Action

An example of the scientific method in action can be found in the work of Ignaz Semmelweis, a Hungarian doctor who lived in the early to mid 1800s. He was appointed to a ward in Vienna's most modern hospital, the Allgemeines Krankenhaus. He noticed that in his ward, patients were dying at a rate that far exceeded that of the other wards, even the wards with much sicker patients. Semmelweis observed the situation for several weeks, trying to figure out what was different about his ward as compared to all others in the hospital. He finally determined that the only noticeable difference was that his ward was the first one that the doctors and medical students visited after they performed autopsies on the dead.

Based on his observations, Semmelweis hypothesized that the doctors were carrying something deadly from the corpses upon which the autopsies were being performed to the patients in his ward. In other words, Dr. Semmelweis exercised the first step in the scientific method. He made some observations and then formed a hypothesis to explain those observations.

Semmelweis then developed a way to test his hypothesis. He instituted a rule that all doctors had to wash their hands after they finished their autopsies and before they entered his ward. Believe it or not, up to that point in history, doctors never thought to wash their hands before examining or even operating on a patient! Dr. Semmelweis hoped that by washing their hands, doctors would remove whatever was being carried from the corpses to the patients in his ward. He eventually required doctors to wash their hands after examining each patient so that doctors would not carry something bad from a sick patient to a healthy patient.

Although the doctors did not like the new rules, they grudgingly obeyed them, and the death rate in Dr. Semmelweis's ward decreased significantly! This, of course, was good evidence that his hypothesis was correct. You would think that the doctors would be overjoyed. They were not. In fact, they got so tired of having to wash their hands before entering Dr. Semmelweis's ward that they worked together to get him fired. His successor, anxious to win the approval of the doctors, rescinded Semmelweis's policy, and the death rate in the ward shot back up again. Let's analyze the data in Figure 1.3.

This graph shows the mortality rate or the percent of patients dying in Dr. Semmelweis's ward. Notice that in this experiment the independent variable (the one that was manipulated) is that doctors washed their hands after autopsies and between patients. The

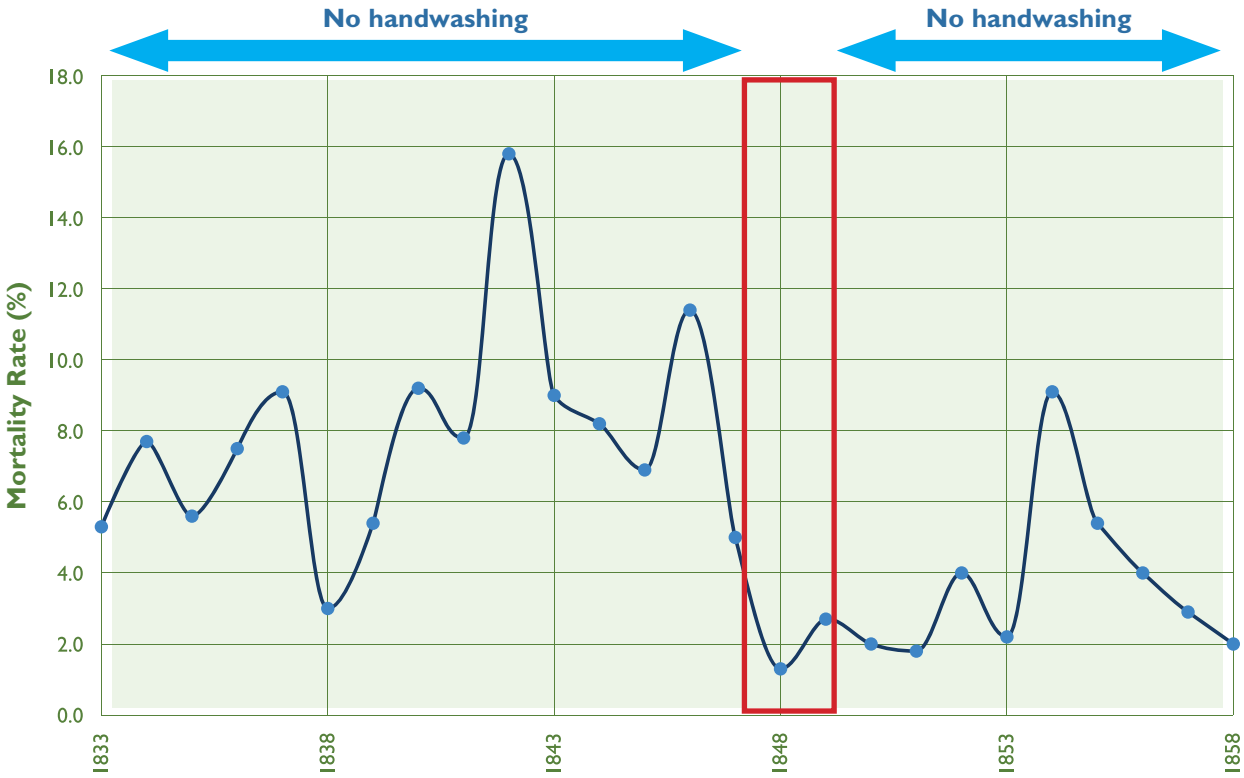


FIGURE 1.3
Puerperal Fever Yearly Mortality Rates 1833–1858

dependent variable (the one that responded to handwashing) is the percentage of patients that died of puerperal fever each year. So the year is plotted on the x-axis and scaled to one-year increments with a red box around the years that handwashing was instituted (when the independent variable was in place). The percentage of patients dying is plotted on the y-axis. You can see the drop-off of deaths occurred when the handwashing protocol was in place in 1848 and then the death rate rose again when handwashing was discontinued.

Semmelweis spent the rest of his life doing more and more experiments to confirm his hypothesis that something unseen but nevertheless deadly can be carried from a dead or sick person to a healthy person. Although Semmelweis's work was not appreciated until after his death, his hypothesis was eventually confirmed by enough experiments (including those by Louis Pasteur and Robert Koch) that the germ theory of disease was accepted as a valid scientific theory. As time went on, more and more data were gathered in support of the theory. With the aid of the microscope, scientists were able to characterize the deadly bacteria and germs that can be transmitted from person to person. Nowadays, doctors do all that they can to completely sterilize their hands, clothes, and instruments before performing any medical procedure.

PROPER HANDWASHING TECHNIQUE

Have you wondered what is considered the proper way to wash your hands? Keeping hands clean is one of the best ways to prevent the spread of infection and illness. In Figure 1.4, a navy nurse shows nurses in training how germs can remain on your hands if not properly washed.

FIGURE 1.4
Navy nurses examining remaining germs with a black light post-handwashing.

What is the right way to wash your hands?

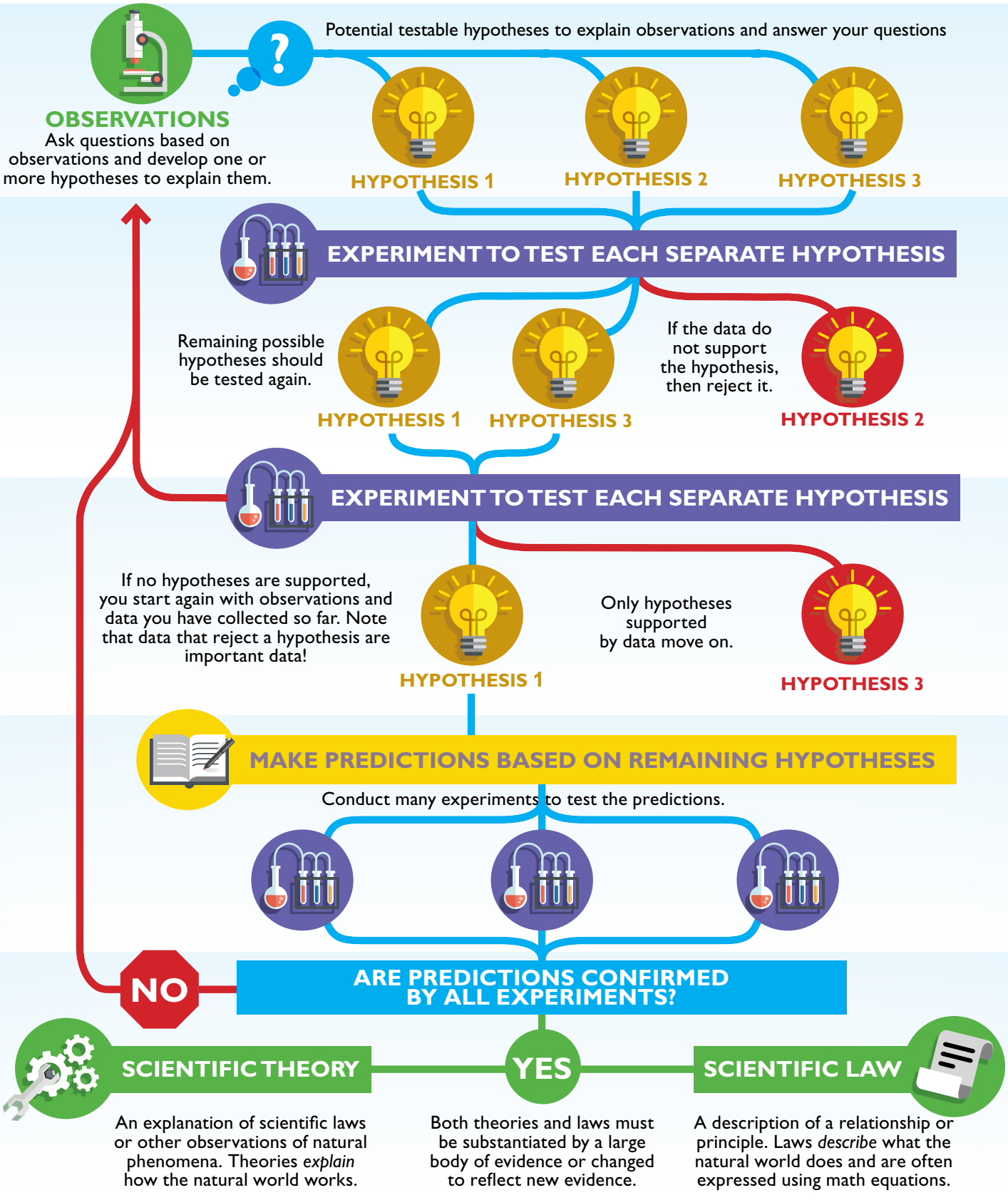
- Wet your hands with clean, running water (warm or cold), and apply soap.
- Lather your hands by rubbing them together with the soap. Be sure to lather the backs of your hands, between your fingers, and under your nails.
- Scrub your hands for at least 20 seconds. Need a timer? Hum the "Happy Birthday" song from beginning to end twice.
- Rinse your hands well under clean, running water.
- Dry your hands using a clean towel or air dry them.

CDC: http://www.cdc.gov/features/handwashing

So you see, the scientific method (summarized in Infographic 1.1) provides a methodical, logical way to examine a situation or answer a question about the natural world. It is the best method scientists have to discover how things in our world work. Scientific theories are reasonably trustworthy and widely accepted because they are backed up by a lot of scientific data. Theories give scientists a framework for further predictions and continued research. You should also be aware that some theories are better than others. Good theories will have a lot of credible evidence supporting them. Poorer theories may continue because there isn't a better explanation yet available.

Complete On Your Own problems 1.1–1.4 to make sure you understand the concepts we covered here before you move on.

INFOGRAPHIC 1.1
Scientific Method



ON YOUR OWN

1.1 When trying to convince you of something, people will often insert "Science has proven..." at the beginning of a statement. Can science actually prove something? Why or why not?

1.2 A scientist makes a few observations and develops an explanation for the observations that she has made. At this point, is the explanation a hypothesis, theory, or scientific law?

1.3 Why is it important for scientists to test only one variable at a time when experimenting?

1.4 Explain the relationship between an independent variable and a dependent variable.

The Limitations of Science

The scientific method is the most powerful process we have for understanding the natural world around us, but it has limitations. For a hypothesis or theory to be valid, it must be able to be tested. This means that conducted experiments could possibly show that the hypothesis or theory is false. Science never really tries to "prove" anything. Instead, we gather evidence, through observations and experiments, that either supports a current theory or shows it to be false. This is why theories are considered reliable—they have stood the test of time, and the experiments conducted based on the theory's predictions have all (to date) supported it. Remember, if new evidence that contradicts a theory is collected, the theory will be modified or discarded after careful verification of the new evidence. In other words, science changes and takes us where the evidence leads.

Since science requires repeatable observations and testable, falsifiable hypotheses, there are limits to the types of questions science can attempt to answer. Science attempts to explain how the world around us works, but it doesn't answer questions about why it works the way it does or even what we should do with that knowledge. While science is a way of knowing or understanding the world around us, it is not the only way. You know your favorite color or your favorite novel, and you didn't need to conduct an experiment to find out! Science can't measure or experiment on emotions or beauty or love. It can't answer questions about value (what is worth more), morals, or ethics. You know right from wrong because God created you to understand the difference and He gave us the Bible to guide us. These are areas in which science cannot attempt to find answers. Science-based knowledge requires that observations be confirmed through repetition and hypotheses be tested. For questions of value, morals, or ethics, you should turn to the Bible, not science.

One other thing to look for as a limitation of science is bias. Scientists are humans and even though they attempt to keep their personal worldview and prejudices out of their work, this sometimes fails. When a researcher or scientist influences results in order to portray a particular outcome, it is called research or experimenter bias. Sometimes bias shows up in the design of the experiment. This happens when a scientist knows that the experiment was conducted in such a way that it eliminated data that might contradict the conclusion he or she was seeking. Other times bias can show up when analyzing the data—if some of the data are removed from the dataset before conclusions are made. It is always important to know who conducted the research you are studying to see if there may be any potential bias found in the report.

Spontaneous Generation

In addition to the limitations mentioned in the last section, sometimes scientific theories or laws are discarded because the experiments that support them are flawed. For example, in about 350 BC, the famous Greek philosopher Aristotle observed that if a person left meat out in the open and allowed it to decay, maggots would appear on the meat within a few days. From that observation, he formed the hypothesis that living maggots were formed from nonliving meat. We call this idea **spontaneous generation**, and Aristotle postulated that this is how many life forms originate. He made many other observations that seemed to support his hypothesis. For example, he showed that eels have a similar smell and feel as the slimy ooze at the bottom of rivers. He considered this evidence that eels spontaneously formed from the ooze.

think about this

The Old Testament contains meticulous instructions that priests were to follow during ritual ceremonies. Even though these instructions were not mentioned in regards to hygiene, Dr. S. I. McMillen observed, "In 1960, the Department [of Health in New York State] issued a book describing a method of washing the hands, and the procedures closely approximate the Scriptural method given in Numbers 19."[1] Medical persons are meticulous in handwashing, especially when they have come in contact with dead and decaying materials. How would you treat an open wound that could be exposed to pathogens? One thing you would probably do is wash your wound; if it is deep, you might also apply alcohol. Consider reading the parable of the Good Samaritan in your Bible. You will find that the wounds are washed with wine.

As time went on, many more experiments were performed that seemed to support the hypothesis of spontaneous generation. As a result, the hypothesis was quickly accepted as the law of spontaneous generation. Of course, the experimentation did not stop there. As late as the mid-1600s, a biologist named Jean Baptist van Helmont performed an experiment in which he placed a sweaty shirt and some grains of wheat in a closed wooden box. Every time he performed the experiment, he found at least one mouse gnawing out of the box within 21 days. Think about it. A hypothesis that was formed around 350 BC was quickly accepted as a law describing how life generates from nonlife since all experiments performed seemed to support it. Keep in mind that the law of spontaneous generation didn't explain how life arose from nonlife; it just described the evidence. Nonetheless, experiments continued for a total of 1,900 years, all seeming to support the scientific law! As a result of this overwhelming amount of data in support of the law of spontaneous generation, it became widely accepted.

Redi's Experiments Refute Spontaneous Generation

About that same time, however, Francesco Redi, an Italian physician, questioned the law of spontaneous generation. Despite the fact that this law was universally accepted by the scientists of his day, and despite the fact that his fellow scientists laughed at him for not believing in the law, Redi challenged it. He argued that van Helmont could not tell whether the mice that supposedly formed from a sweaty shirt and wheat grains had gnawed into the box or out of the box. He said that to really test this law, you would have to completely isolate the materials from the surroundings. That way, any life forms that appeared would have definitely come from the materials and not from the surroundings. He performed

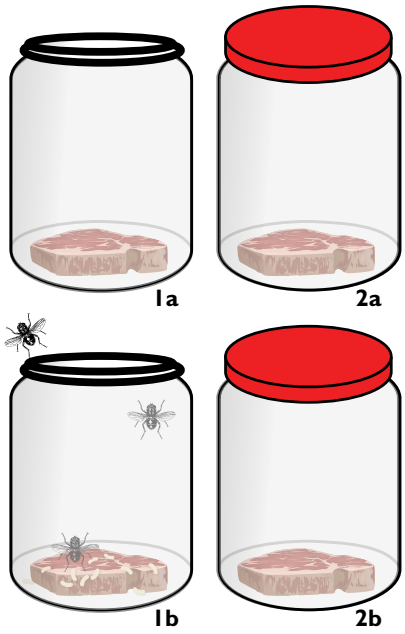


FIGURE 1.5
Redi's Experiments
1a and 1b show the open jar with maggots appearing.
2a and 2b show the sealed jar with no maggots appearing.

experiments (Figure 1.5) in which he put several different types of meat in sealed jars and left them to decay. No maggots appeared on the meat. He claimed that this showed that maggots appear on meat not because they are formed by the meat, but instead because they get on the meat.

Of course, the scientists of his day said that by sealing the jars, Redi was cutting off the air supply, which would stop the maggots from forming. Thus, Redi redesigned his experiment. Instead of sealing the jars, he covered them with a fine netting. The netting was fine enough to keep insects out but allow air in. Still, no maggots formed on the meat, even long after it was decayed. What these experiments showed was that the previous experiments that purportedly demonstrated that maggots could form from decaying meat were simply flawed. If one were to adequately isolate the meat from the surroundings, maggots would never form.

These experiments sent shock waves throughout the scientific community. A scientific theory, one which had been supported by nearly 1,900 years of experiments, was wrong! Of course, many scientists were simply unwilling to accept this. Yes, they agreed, perhaps maggots did not come from decaying meat, but surely there were some types of organisms that could spontaneously generate from nonliving things.

Discovering Microorganisms

In the 1670s, some scientists thought that Antonie van Leeuwenhoek had found such organisms. He had fashioned his own microscope and had used it to study water. As a result, he discovered the world of **microorganisms** (Figure 1.6).

Microorganisms—Living creatures that are too small to see with the naked eye

You will study this fascinating world in more depth later in the course. For right now, you just need to know that because these creatures cannot be seen without the aid of a microscope, scientists prior to 1670 had no idea that they existed.

Van Leeuwenhoek and many others showed that microorganisms did, indeed, seem to generate spontaneously. For example, in the mid-1700s, John Needham did experiments very similar to

FIGURE 1.6
Microorganisms described in depth by van Leeuwenhoek, c. 1795–1798

Redi's. Needham made a liquid broth of nutrient-rich material such as chicken broth. Such broths were called "infusions," and Needham showed that if you boiled an infusion for several minutes, you could kill all microorganisms in it. If you then put a cork in the flask that held the infusion, microorganisms would appear in the infusion within a few days. Needham concluded that since he had put a cork in the flask, the infusion was isolated from the surroundings. These experiments were hailed as support for the beleaguered law of spontaneous generation.

Lazzaro Spallanzani, a contemporary of Needham, did not like Needham's experiments. He thought that either Needham did not boil the infusion long enough to completely kill off the microorganisms or that Needham's corks allowed air to leak into the flask, bringing microorganisms in with it. Spallanzani repeated Needham's experiments, but he boiled the infusions for a long time and sealed the flasks by actually melting their openings shut. That made a truly airtight seal. In these experiments, no microorganisms formed. Of course, those who still held to the law of spontaneous generation argued that once again, without air, nothing could live. Thus, by completely sealing the flask before the infusion was boiled, Spallanzani cut off the process of spontaneous generation.

Pasteur's Experiment

In 1859, however, the great scientist Louis Pasteur finally demonstrated that even microorganisms cannot spontaneously generate. In his experiments, illustrated in Figure 1.7, Pasteur stored the infusion in a flask that had a curved neck. The curved neck allowed air to reach the infusion, but because microorganisms are heavier than air, any microorganisms present would be trapped at the bottom of the curve. When Pasteur repeated Needham's experiments in the curved flask, no microorganisms appeared. In a final blow, Pasteur even showed that if you tipped the flask once to allow any microorganisms that might be trapped to fall into the infusion, microorganisms would appear in the infusion. Thus, Pasteur showed that even microorganisms cannot spontaneously generate.

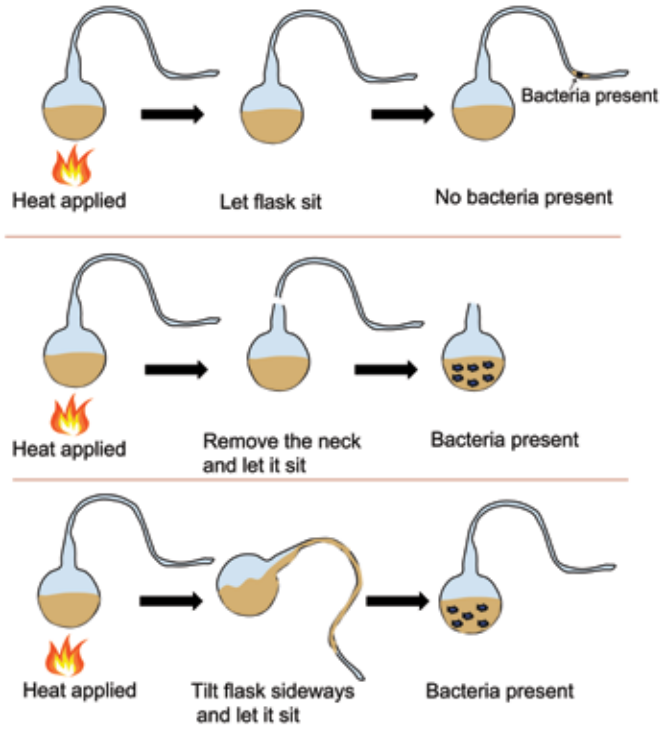


FIGURE 1.7
Pasteur's Experiment

The point of this rather long discussion is simple. Even though a scientific law seems to be supported by hundreds of years of experiments, it might still be wrong because those experiments might be flawed. All of the experiments that were used to support the law of spontaneous generation were flawed. The scientists who conducted the experiments did not adequately isolate them from the surroundings. Thus, the life forms that the scientists thought were being formed from nonliving substances were, in fact, simply finding their

way into the experiment. Since Pasteur's experiments (and a vast amount of supporting evidence), a new law—the law of biogenesis stating that all life comes from previously existing life—is now widely accepted.

These two discussions, then, show the limits of science and the scientific method. First, even scientific laws and theories are not 100% reliable. Most likely, some of the things that you learn in this book will someday be proven to be wrong. That is the nature of science. Because it is impossible to fully test scientific theories and laws and because they are tested by experiments that might be flawed, scientific theories and laws are not necessarily true. They represent the best descriptions and explanations that science has to offer, but they are nevertheless not completely reliable. Thus, putting too much faith in scientific laws or theories will end up getting you in trouble, because some of the laws and many of the theories that we treasure in science today will eventually be shown to be wrong.

If scientific laws are not 100% reliable, what is? The only thing in the universe that is 100% reliable is the Word of God. The Bible contains truths that will never be shown to be wrong because those truths come directly from the Creator of the universe. Many scientific authorities today would have you believe that science is the only way to understand the world around us. Hopefully you now see that it is not wise to put your faith in something that is not completely reliable, like science. Those who put their faith in the Bible, however, are not disappointed because it is never wrong.

Why Study Science?

If science isn't 100% reliable, why study it? The answer to that question is quite simple. Many interesting facts and much useful information are not contained in the Bible. It is worthwhile to find out about these things. Even though we will probably make many, many mistakes along the way, finding out about these interesting and useful things will help us live better lives. Because of the advances made in science, wonderful discoveries in medicine and great technologies like the television, mobile phones, and the computer exist. Thus, there is nothing wrong with science. In fact, it is even a means by which we can celebrate the awesomeness of God. When we learn how well the world and its organisms are designed, we can better appreciate the gift that God has given to us in His creation.

Spontaneous Generation: Some Still Cling to It!

After that long story, it might surprise you to learn that many scientists still believe in spontaneous generation. Now of course, there is no way that they can argue with the conclusions of Pasteur's experiments, so they do not believe that microorganisms can spring from nonliving substances. Nevertheless, they still do believe that life can spring from nonlife! These scientists believe in a theory known as **abiogenesis** (ay' bye oh jen' uh sis).

Abiogenesis—The idea that long ago, very simple life forms spontaneously appeared through chemical reactions

Some scientists say that since all life is made up of chemicals, it is possible that long ago on the Earth, there was no life; there were just chemicals. These chemicals began reacting and, through the reaction of these chemicals, a "simple" life form suddenly appeared.

As we go through this course, you'll see how such an idea is simply inconsistent with

everything that we know about life. At this time, however, we want to make a simple point regarding abiogenesis. Back when scientists believed in spontaneous generation, they had experiments that allegedly backed up their claim. Even before Pasteur's authoritative refutation of spontaneous generation, these experiments were shown to be flawed. Rather than giving up on their law, however, those who fervently believed in spontaneous generation just said, "Well, okay, these experiments are wrong. However, look at these other experiments. Although we now know that life forms that we see with our own eyes cannot spontaneously generate, microorganisms can."

Do you see what the proponents of spontaneous generation did? Because they wanted so badly to believe in their theory, they simply pushed it into an area in which they did not have much knowledge. The whole world of microorganisms was new to scientists back then. As a result, there was a lot of ignorance regarding how microorganisms lived and reproduced. Because of the ignorance surrounding microorganisms, it was relatively easy to say that spontaneous generation occurred in that world. After about 200 years of study, however, scientists began to understand microorganisms a little better, which paved the way for Pasteur's famous experiments.

Nowadays, scientists have pushed the theory of abiogenesis or spontaneous generation back to another area that we are rather ignorant about. They say that although Pasteur's experiments show that microorganisms can't arise from nonliving substances, some (unknown) simple life form might have been able to spontaneously generate from some (unknown) mixture of chemicals at some (unknown) point way back in Earth's history. Since we have very little knowledge about things that happened way back in Earth's history, and since we have only partial knowledge about the chemicals that make up life, and since we have no knowledge of any kind of simple life form that could spring from nonliving chemicals, the proponents of abiogenesis are pretty safe. The fact that we are ignorant in these areas keeps us from showing the error in their theory.

Of course, a few experiments (such as the Miller-Urey experiment) lend some support to the theory of abiogenesis. A discussion of these experiments is beyond the scope of this module, but for right now just know that they are not nearly as convincing as the ones that van Helmont and Needham performed. In fact, they do not even produce anything close to a living organism, as van Helmont's and Needham's experiments seemed to. They just produce some of the simplest organic chemicals that are found in living organisms. Nevertheless, those who cling to the idea of spontaneous generation casually disregard the flaws that can be easily pointed out in these experiments and trumpet their results as data that support their theory. However, if you look at the track record of spontaneous generation throughout the course of human history, it is safe to conclude that at some point, the version of spontaneous generation known as abiogenesis will also be shown to be quite wrong.

Complete On Your Own problems 1.5–1.6 before moving on.

ON YOUR OWN

1.5 Describe the impact Pasteur's work had on the scientific community.

1.6 Should scientific laws be considered 100% reliable? Explain.

THE STUDY OF LIFE

If biology is the study of life, we need to determine what life is. To some extent, we all have an idea of what life is. If you were asked whether or not a rock is alive, you would easily answer "No!" On the other hand, if you were asked whether or not a blade of grass is alive, you would quickly answer "Yes!" Most likely, you can intuitively distinguish between living things and nonliving things.

Even though this is the case, scientists must be a little more deliberate in determining what it means to be alive. Thus, scientists have developed several criteria for life. Not all scientists agree on all of these criteria, but in general, most biology courses will list at least some of the criteria for life found in Figure 1.8.

1 

Cells

All life is composed of cells and cells are the most basic unit of structure and function for living things.

2 **Growth and Development**

All living things grow. Growth can be the increase in cell size or an increase in the number of cells.

3 

Metabolism and Energy

All living things require energy to power activities. This energy comes from the sun (autotrophs) or food (heterotrophs). Metabolism is the sum of all the chemical reactions to obtain and convert energy.

4 **Homeostasis**

All living things maintain a stable internal environment by regulating all of the chemical processes occurring in them.

5 

Sense and Respond to Stimuli

All living things have the ability to sense and respond to their environment. Sunflowers leaning toward the sun is an example.

6 **DNA and Reproduction**

All living things contain hereditary information in their DNA. This remarkable chemical enables life to continue through reproduction.

FIGURE 1.8
Six Criteria for Life

If something meets all these criteria, we can scientifically say that it is alive. If it fails to meet even one of the criteria, we say that it is not alive. If you're not sure exactly what each of these criteria means, don't worry. We will discuss each of them in the next few sections of this module.

Cells and Life

Our first criterion states that all living things consist of **cells**. Cells are the smallest, most basic units of life.

Cells—The smallest units of an organism considered alive

They are self-contained, complex, organized, and separated from their surroundings by a barrier. Cells can grow, acquire energy, maintain homeostasis, reproduce, and respond to their environment. Believe it or not, most living organisms are **unicellular** or composed of a single cell. Other organisms such as plants and animals are **multicellular** or composed of many cells—sometimes even thousands of cells! You will learn more about cells in Module 4.

Unicellular—The Latin prefix *uni* means "one," so unicellular means "single-celled"

Multicellular—The Latin prefix *multi* means "many," so multicellular means "many-celled"

Growth and Development

All living things grow. All cells grow. Cells grow in two different ways: by enlarging, or by dividing, as shown in Figure 1.9. Cell division is the formation of two new identical cells from one existing cell. Multicellular organisms grow when their cells enlarge, divide, or develop. Not all cells have the same function in multicellular organisms. Cell development occurs when cells of multicellular organisms specialize for specific functions. For example, humans begin as a single cell but as adults are composed of trillions of specialized cells. These cells have become specialized to fight infections, carry oxygen, detect light and color, and so on. All of this development occurs while we are still in our mother's womb! You will learn more about cell division in Module 6.

FIGURE 1.9
Cell Division

Metabolism and Energy

In order to live, organisms need energy. This is why the third criterion states that all life forms must be able to absorb energy from the surroundings and convert it into a form of energy that will power their life functions. The production and use of this energy is called **metabolism** (muh tab' uh lizm).

Metabolism—The sum total of all processes in an organism that convert energy and matter from outside sources and use that energy and matter to sustain the organism's life functions

Metabolism can be split into two categories: **anabolism** (uh nab' uh lizm) and **catabolism** (kuh tab' uh lizm).

Anabolism—The sum total of all processes in an organism that use energy and simple chemical building blocks to produce large chemicals and structures necessary for life

Catabolism—The sum total of all processes in an organism that break down chemicals to produce energy and simple chemical building blocks

Although these definitions might seem hard to understand, think about them this way: when you eat food, your body has to break it down into simple chemicals in order to use it. Once it is broken down, your body will either burn those simple chemicals to produce energy or use them to make larger chemicals. The entire process of breaking the chemicals down and then burning them to produce energy is part of your body's catabolism. Once your body has that energy, it will use some of it to take simple chemicals and build large, complex chemicals that are necessary for your body to work correctly. The process of making those complex chemicals from simple chemicals is part of your body's anabolism. As we progress throughout the course, we will discuss specific examples of anabolism and catabolism that will help you better understand the distinction between them. One way to remember these two definitions is to notice that "catabolism" has the same prefix as "catastrophe," so they both involve things being broken down.

Obviously, then, the energy that an organism gets from its surroundings is important. Where does it come from? Ultimately, almost all of the energy on this planet comes from the sun, which bathes the Earth with its light. When you take chemistry, you'll learn a lot more about light. For right now, however, all you need to know is that light is a form of energy and that it is the main energy source for all living organisms on our planet. Green plants (and some other things you will learn about later) take this energy and, by a process called **photosynthesis** (foh' toh sin' thuh sis), convert that energy into food for themselves.

Photosynthesis—The process by which green plants and some other organisms use the energy of sunlight and simple chemicals to produce their own food

We'll be looking at photosynthesis in great detail in Module 5. Photosynthesis is a part of anabolism because the organism takes simple chemicals and converts them into food, which is composed of larger chemicals.

As a point of terminology, organisms that are able to produce their own food are often called **autotrophs** (aw' toh trohfs), the Greek roots of which literally mean "self-feeder."

Autotrophs—Organisms that are able to make their own food

If autotrophs, plants and other photosynthetic organisms, absorb their energy from the sun, where do other life forms get their energy? Well, that depends. Some organisms eat plants. By eating plants, these organisms take in the energy that plants have stored up in their food reserves. Thus, these organisms are indirectly absorbing energy from the sun. They are taking the energy from plants in the form of food, but that food ultimately came from sunlight. Organisms that eat only plants are called **herbivores** (ur' bih vorz).

Herbivores—Organisms that eat only plants

So you see that even though herbivores don't get their energy directly from sunlight, without sunlight there would be no plants, and therefore there would be no herbivores.

If an organism does not eat plants, it eats organisms other than plants. These organisms are called **carnivores** (kar' nih vorz).

Carnivores—Organisms that eat only organisms other than plants

Even though carnivores eat other organisms, their energy ultimately comes from the sun. After all, the organisms that carnivores eat have either eaten plants or have eaten other organisms that have eaten plants. The plants, of course, get their energy from the sun. In the end, then, carnivores also indirectly get their energy from the sun.

Finally, there are organisms that eat both plants and other organisms. We call these **omnivores** (ahm' nih vorz).

Omnivores—Organisms that eat both plants and other organisms

Ultimately, of course, these organisms also get their energy from the sun. But, in contrast to autotrophs, herbivores, carnivores, and omnivores get their energy by eating others and so are called **heterotrophs** (het' er uh trohfs), which literally means "other-feeder."

Heterotrophs—Organisms that depend on other organisms for their food

Think about what we just did in the past few paragraphs. We took a large number of the organisms that live on this Earth and placed them into one of two groups: autotrophs or heterotrophs. We also classified heterotrophs even further into one of three groups: herbivores, carnivores, or omnivores. This kind of exercise is called classification. When we classify organisms, we are taking a great deal of data and trying to organize it into a fairly simple system. In other words, classification is a lot like filing papers. When you file papers, you place them in folders according to their similarities. In this case, we have taken many of the organisms on Earth and put them into one of three folders based on what they eat. This is one of the most important contributions biologists have made in understanding God's creation. Biologists have taken an enormous amount of data and have arranged it into many different classification systems. These classification systems allow us to see the similarities and relationships that exist between organisms in creation. Classifying organisms in different ways is a recurring theme in biology and you will see it again many times during your reading this year. Figure 1.10 illustrates the classification system you have just learned.

FIGURE 1.10
Herbivores, Carnivores, and Omnivores
Herbivores like zebras eat only plants. Carnivores like lions eat only meat. Omnivores like black bears eat both plants and meat.

Homeostasis

Obtaining, using, and storing energy requires many complex reactions. All living organisms must maintain a stable internal balance in the midst of changing external conditions. This internal balance is called **homeostasis,** the fourth criterion for life.

Homeostasis—The maintenance of stable internal conditions

For example, animals such as ducks (Figure 1.11) need to maintain their body temperatures within a specific range for all organ systems to function properly. Many complex processes enable them to stay within this temperature range even when the outside temperature is below zero. Birds and mammals are **endotherms,** meaning they have internal processes to regulate their body temperature. On the other hand, reptiles are **ectotherms** because they use the external environment to help them maintain their body temperatures within a specific range.

FIGURE 1.11
Homeostasis
Left: Ducks maintain a constant, stable internal temperature even during very cold winters.
Right: Reptiles sun themselves using the external environment to help maintain their body temperatures.

Endotherm—Organism that is internally warmed by a heat-generating metabolic process

Ectotherm—Organism that lacks an internal mechanism for regulating body heat

Sensing and Responding to Stimuli

Our fifth criterion for life is the ability to sense and respond to changes in the surroundings. It is important to realize that in order to meet this criterion, an organism's ability to sense changes is just as important as its ability to respond. After all, even a rock can respond to changes in its environment. If a boulder, for example, is perched on the very edge of a cliff, even a slight change in the wind patterns around the boulder might be enough for it to fall off the cliff. In this case, the boulder is responding to the changes in its surroundings. The reason a boulder doesn't meet this criterion for life is that the boulder cannot sense the change.

Living organisms are all equipped with some method of receiving information about their surroundings. Typically, they accomplish this feat with **receptors**.

Receptors—Special structures that allow living organisms to sense the conditions of their internal or external environment

Your skin, for example, is full of receptors. Some allow you to distinguish between hard and soft substances when you touch them. Other receptors react to hot and cold temperatures. To illustrate, let's say you have your hand under a stream of water coming from a faucet. The receptors in your hand react to the temperature of the water by sending information to your brain, which is where your response is determined. If the water is too hot or too cold, you can remove your hand from the stream to avoid the discomfort.

A living organism's ability to sense and respond to changes in its surrounding environment is a critical part of survival because God's creation is always changing. Weather changes, seasons change, the landscape changes, and the community of organisms in a given region changes. As a result, living things must be able to sense these changes and adapt, or they would not be able to survive.

DNA and Reproduction

Our final criterion for life says that all life forms reproduce. Although the necessity of reproduction for the perpetuation of life is rather obvious, it is truly amazing how many different ways God has designed the organisms on Earth to accomplish this feat. Some, for example, can split themselves apart under the right circumstances. The two parts can then grow into wholly separate individuals. This is an example of **asexual reproduction**.

Asexual reproduction—Process by which a single organism produces genetically identical offspring (offspring receives all DNA from one parent)

Other organisms, however, require a male and female in order to reproduce. This method of reproduction (which occurs in most of the life forms with which you are familiar) is called **sexual reproduction** (Figure 1.12).

FIGURE 1.12
Reproduction
Offspring inherit genetic traits from their parents in sexual reproduction.

Sexual reproduction—Process by which two parents produce genetically different offspring (offspring receives a combination of DNA from two parents)

As we go along in this course, you will be studying both of these methods a bit more closely, because there is a great deal of variety among the different means of sexual and asexual reproduction.

Reproduction always involves the concept of **inheritance**. Although this word has several different meanings, in biology the definition is quite specific.

Inheritance—The process by which physical and biological characteristics are transmitted from the parent (or parents) to the offspring

In asexual reproduction, the characteristics and traits inherited by the offspring are, under normal circumstances, identical to the parent. Thus, the offspring is essentially a "copy" of the parent. In sexual reproduction, under normal circumstances, the offspring's traits and characteristics are, in fact, some mixture of each parent's traits and characteristics. Of course, the parents' traits and characteristics are a mixture of each of their parents' traits and characteristics, and their parents' traits and characteristics are a mixture of each of their parents' traits and characteristics, and so on. In the end, then, the inheritance process in sexual reproduction is quite complicated and leads to offspring that often can be noticeably different from both parents.

Notice that in describing inheritance for both modes of reproduction, we used the phrase "under normal circumstances." This is because every now and again, offspring can possess traits that are incredibly different from their parents. These incredibly different traits are the result of **mutations** in the organism's DNA. The study of mutations is quite interesting, and we will focus on it later in the course.

Mutation—An abrupt and marked change in the DNA of an organism compared to that of its parents

So what is DNA? In order for there to be life, the chemicals that make it up must be organized in a way that will promote all functions mentioned in our list of criteria for life. In other words, just the chemicals themselves cannot extract and convert energy (criterion 3), sense and respond to changes (criterion 5), or reproduce (criterion 6). To perform those functions, the chemicals must be organized so that they work together in just the right way. Think about it this way: suppose you go to a store and buy a bicycle. The box says, "Some assembly required." When you get it home, you unpack the box and pile all of the parts on the floor. At that point, do you have a bicycle? Of course not. To make the bicycle, you have to assemble the pieces in just the right way, according to the instructions. When you get done with the assembly, all of the parts will be in just

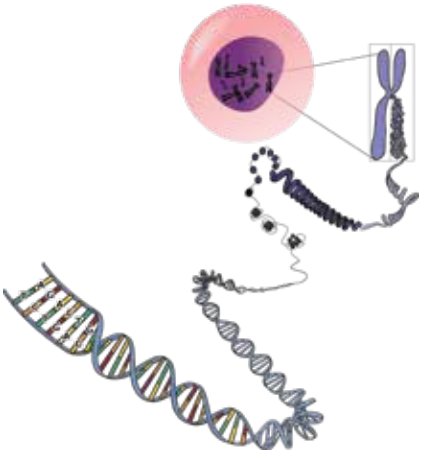


FIGURE 1.13
DNA and Chromosomes
DNA is the set of chemical instructions for life stored in the chromosomes of living organisms.

the right place, and they will work together with the other parts to make a functional bike.

In the same way, DNA is the set of instructions, contained in chromosomes (Figure 1.13), that arranges the chemicals that make up life in just the right way to produce a living system. Without this instruction set, the chemicals that make up a life form would be nothing more than a pile of goo. However, directed by the information in DNA, these molecules can work together in just the right way to make a living organism.

Of course, the exact way in which DNA does this is a little complicated. Nevertheless, in an upcoming module, we will spend some time studying DNA and how it works in detail.

Before we leave this discussion of reproduction, it is important to note that some living organisms cannot actually produce viable offspring. When a horse and a donkey mate, for example, they can produce an offspring called a mule (Figure 1.14). Adult mules, however, cannot produce offspring of their own. Nevertheless, mules do not fail to meet the reproduction criterion for life. Even though they cannot produce offspring, their cells (we will discuss cells more thoroughly in Module 4) reproduce quite frequently so that the mules can grow, repair wounds and so forth. Thus, they satisfy the reproduction criterion on the cellular level.

Before continuing, check your understanding by completing On Your Own questions 1.7–1.9.

FIGURE 1.14
A mule is the offspring of a male donkey and a female horse. They have characteristics of both, but are infertile or unable to produce offspring.

ON YOUR OWN

1.7 List the criteria all living organisms possess.

1.8 A biologist studies an organism and then two of its offspring. They are all identical in every possible way. Do these organisms reproduce sexually or asexually?

1.9 How are unicellular and multicellular organisms alike? How are they different?

creation connection

Now that you have a good idea of whether or not something is alive, another question should come to mind. What gives life the characteristics that we learned in the previous sections? As mentioned before, if we chemically analyzed an organism, gathered together all of the chemicals contained in it, and threw them in a pot, we would not have a living organism. Those chemicals would be useless without the information stored in the organism's DNA. Further, even if we were able to isolate a full set of the organism's DNA and were to throw it into the pot as well, we would still not have a living organism.

You see, life is something more than a collection of chemicals and information. Scientists have tried to understand what that "something more" is, but to no avail. The secret ingredient that separates life from nonlife is still a mystery to modern science. Of course, to believers, that secret ingredient is rather easy to identify. It is the creative power of God. In Genesis 1:20-27, the Bible tells us that God created all creatures, and then He created man in His own image. Only God has creative power, and that is why all life comes from Him.

TOOLS OF BIOLOGY

In the beginning of this module, you read about how van Leeuwenhoek saw microorganisms using the primitive microscopes he made. Imagine what it would have been like to take a drop of the pond water you regularly swam in and see tiny living creatures for the first time. What it must have been like to discover a whole world of living things never known before! Have you thought that maybe worlds of living things exist undiscovered because we don't yet have the tools to see them?

Studying living things requires tools and procedures. You will get to practice using some of these while conducting your experiments in this course. Scientists use balances to measure the mass of specimens, microscopes to see things too small to see with their eyes alone, telescopes to see things far away, and computers and robots to work with data and DNA.

A Common Measurement System

To work as a scientist, you must be familiar with taking measurements for quantitative observations. Since biology researchers need to replicate each other's experiments and compare their results, scientists need a common system of measurement. Most scientists use the metric system when measuring lengths, volumes, masses, or temperatures. The metric system uses units that are scaled to multiples of 10. The metric-based system of units is called the International System of Units, or SI. The abbreviation SI comes from the French *Le Système International d'Unités*.

International System of Units—The metric system (abbreviated SI), which is the most widely used system of measurement in science

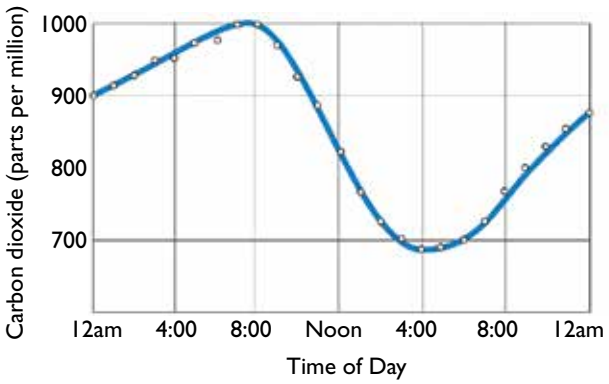
Because the metric system is based on multiples of 10, it is easy to use, which makes it the system of choice for most scientists when collecting quantitative data. Notice in Table 1.1 how the basic unit of length, the meter, can be multiplied or divided by 10, 100, or 1,000 to measure lengths larger or smaller than one meter. The same is also true for measuring mass and volume.

TABLE 1.1

Common Metric Units Reference Chart	
Length	Mass
1 meter (m) = 100 centimeters (cm) 1 meter = 1,000 millimeters (mm) 1 meter = 1,000,000 micrometers (μm) 1 meter = 1,000,000,000 nanometers (nm) 1,000 meters = 1 kilometer (km)	1 gram (g) = 1,000 milligrams (mg) 1 kilogram (kg) = 1,000 grams (g) 1,000 kilograms = 1 metric ton (t)
Volume	Temperature
1 liter (L) = 1,000 milliliters (mL) 1 liter = 1,000 cubic centimeters (cm^3 or cc)	0 °C = freezing point of water 100 °C = boiling point of water

TABLE 1.2
Experimental Data Reported in Table and Graph Form

Carbon Dioxide Production of Plants in Enclosed Environment			
Time	CO_2 (ppm)	Time	CO_2 (ppm)
12 AM	900	NOON	820
1 AM	915	1 PM	760
2 AM	930	2 PM	722
3 AM	955	3 PM	705
4 AM	950	4 PM	687
5 AM	961	5 PM	692
6 AM	960	6 PM	700
7 AM	998	7 PM	725
8 AM	1000	8 PM	758
9 AM	972	9 PM	800
10 AM	928	10 PM	830
11 AM	890	11 PM	870
		12 AM	885



Tables and Graphs

Once measurements are taken and data collected, scientists need to organize, analyze, and interpret the information they've gathered. What scientist are ultimately looking for are relationships or trends between the variables in their experiments. In other words, they try to determine whether certain factors change or remain the same. Most often, the tools scientists use to accomplish this are data tables and graphs. Scientists organize data from experiments in tables and plot the data on graphs to make it easier to interpret. Look at Table 1.2.

Data tables make organizing and examining the data easier, but it may still be difficult to see any patterns in the data just by looking at the table. Graphing data allows scientists to visualize patterns and see the relationship between variables. Notice the data table and graph in Table 1.2. It is much easier to recognize and understand

think about this

At some point in the future, scientists might be able to catalog every chemical that makes up a living organism. Scientists might even decode the information stored in DNA and determine all of the instructions necessary to form those chemicals into a living organism. Even after those incredible feats, however, science would be no closer to creating life. Without the creative power of God, lifeless chemicals will never become a living organism. There is also a discussion point here that is beyond the scope of this textbook, but we are going to ask you to ponder it. Where did those chemicals come from? Who created them? Renowned French microbiologist and chemist Louis Pasteur posed a similarly thought-provoking question long ago when he wrote:

You place matter before life and you decide that matter has existed for all eternity. How do you know that the incessant progress of science will not compel scientists to consider that life has existed during eternity, and not matter?[2]

the pattern of photosynthesis during the day from the graph than it is from the data table.

Sometimes there is so much data to interpret that scientists use computers to make sense of it. For example, computers help scientists determine the structure of molecules. Computers can take data and make pictures of molecules to help scientists "see" the molecular structure. Figure 1.15 shows the computer-generated structure of myosin, a protein molecule used in muscle contraction. Today biologists use computers to search through DNA databases for gene sequences and to analyze weather data collected by satellites.

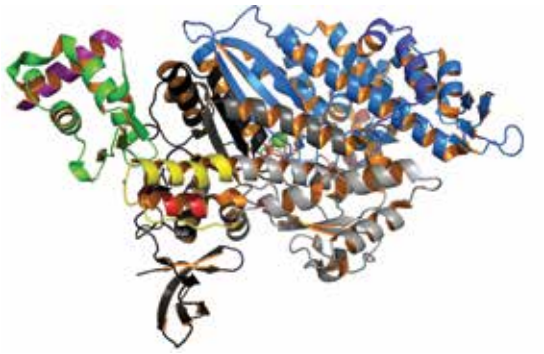


FIGURE 1.15
A Computer-Generated Image of a Myosin Molecule
Illustration by EOS (CCBYSA 3.0)

FIGURE 1.16
A Compound Light Microscope and Magnified Image of an Insect

Microscopes

When you think of the tools of a biologist, chances are you think of microscopes. Microscopes have come a long way since van Leeuwenhoek looked at pond life in the mid-1600s. These modern-day instruments magnify images of structures too small to see with eyes alone and are designed to produce the largest image that will still remain sharply focused. There are different kinds of microscopes—light microscopes and electron microscopes, to name a couple.

Light Microscopes

Light microscopes are the most commonly used type of microscope. They can produce a clear image to magnifications of about 400 times or 1,000 times when using oil immersion. The microscope shown in Figure 1.16 is a compound light microscope, the type you may have available to you. Compound light microscopes use a combination of two lenses to form the image. The specimen being observed must be thin enough for light to pass through so that the lenses can produce the image.

Compound light microscope—A microscope that shines light through a specimen using two lenses to magnify an image

Compound light microscopes are used to study specimens of dead organisms as well as living cells and aquatic microorganisms. You will learn how to make a wet-mount slide to enable you to view living organisms in Experiment 1.1. In order to better see specific structures in microscopic images, biologists have developed staining techniques and procedures. You will get to practice staining cells in a later experiment.

Electron Microscopes

It may be hard to imagine, but some things are too small for light microscopes to magnify. In the 1950s, biologists developed electron microscopes. Electron microscopes use lenses made of electromagnets, which gather and focus a beam of electrons. The specimen must be placed inside of a vacuum because the beam of electrons has to travel directly to the sample without hitting anything—even air molecules. Electron microscopes can form images of objects 1,000 times smaller than objects magnified with light microscopes! We can now see even the tiniest creatures, like the yellow mite shown in Figure 1.17. Many colleges and universities now have electron microscopes for student research. Biologists use two main types of electron microscopes: the **transmission electron microscope** (TEM) and the **scanning electron microscope** (SEM).

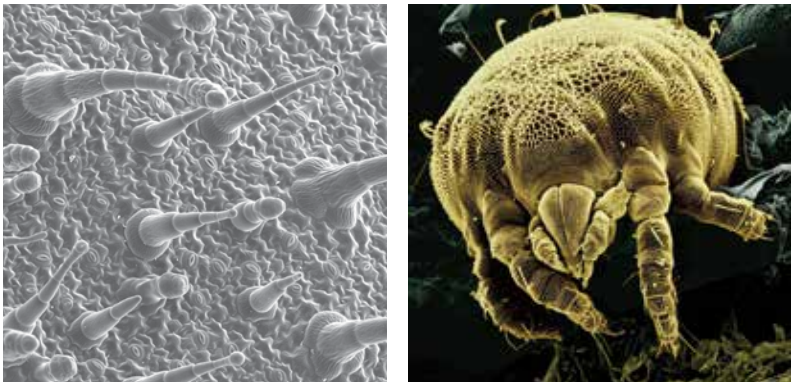


FIGURE 1.17
Scanning Electron Microscope Images of a Leaf Surface (left) and a Yellow Mite (right)

Transmission electron microscope—A microscope that transmits a beam of electrons through a thinly sliced specimen

Scanning electron microscope—A microscope that passes a beam of electrons over the surface of a specimen

TEMs send an electron beam through a thin specimen so we can see the internal structures. SEMs run an electron beam back and forth over the surface of a specimen to produce realistic 3-D images of the surface of the object. Examine Figure 1.17 to see SEM images of the surface of a leaf epidermis (left) and a yellow mite (right). Notice the leaf hairs protruding from the surface of the leaf and the amazing detail of the mite. We can now see details that we've never been able to before, all because of these microscopes!

Electron microscopes do not use light so the untouched images they produce have no color. Scientific illustrators add color to electron microscope images to give definition. The color added to the mite image is realistic and lifelike. Because electron microscopes must be used inside a vacuum, only dead specimens can be viewed. Both types of microscopes are valuable tools for biologists.

Since much of what we will study in biology are microorganisms, the labs we will do as we study them are heavily microscope-oriented. If you don't have a microscope, however, don't be concerned. A microscope isn't essential for taking this course. It does, however, help to make things clearer and more interesting. So for those who do have one, you need to perform Experiment 1.1. If you don't have a microscope, please read through the experiment so that you get a basic idea of what it covers and then complete the On Your Own questions that follow.

EXPERIMENT 1.1
INTRODUCTION TO THE MICROSCOPE

PURPOSE
To learn the various parts of the microscope and to learn to use the microscope properly

MATERIALS
- Microscope
- Lens paper
- Slides
- Coverslips
- Cotton swabs
- Eyedropper
- Water
- Small pieces of brightly colored thread
- Prepared slide: Ranunculus root or Zea mays root

PROCEDURE
A. Learn the parts of the microscope:

1. Place the microscope on your table with the arm of the microscope nearest you. With the aid of the illustration, locate all the parts of the microscope and become familiar with them.
2. Label in your notebook the parts of the microscope listed on Figure 1.18 as you locate them on your microscope.
   a. The **eyepiece (the ocular)** is what you look through. It usually contains a 10x lens.
   b. The **body tube** starts at the eyepiece and runs to the part that holds the revolving nosepiece.
   c. The **revolving nosepiece** is the disc that holds the lenses (which are called objectives).
   d. The **objectives** are metal tubes that contain lenses of varying powers, usually 4x, 10x, and 40x. Some microscopes have a 100x objective as well.
   e. The **arm** supports the body and stage and is attached to the base.
   f. The **stage with clips** is a platform just below the objectives and above the light source. The clips are used to hold the slide in place.
   g. The **diaphragm** regulates the amount of light that passes through the specimen. It is located between the stage and the light source. It might be a disc that has several holes (a disc diaphragm), or it might be a single hole whose diameter can be varied (an iris diaphragm).

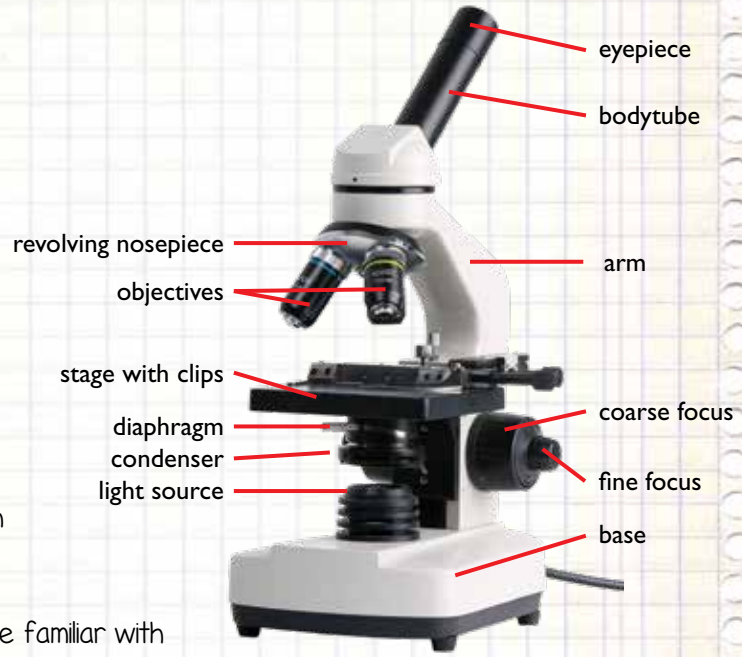


FIGURE 1.18
Microscope

h. The **condenser** is also located between the light source and stage. It is a lens system that bends and concentrates the light coming through the specimen.
i. The **coarse focus** is controlled by two large knobs on each side of the microscope. It allows for quick focus, but it does not make the image as sharp as it could be.
j. The **fine focus knobs** are used to produce sharp focus. They are usually smaller and lower than the coarse focus knobs, but in some scopes they are mounted on top of the coarse focus knobs.
k. The **light source** is on the base and provides necessary light for the examination of specimens.
l. The **base** is the heavy structure at the bottom that supports the microscope and makes it steady.

Magnification is an important feature of any microscope. In Table 1.1 in the student notebook, write down the magnifications of the objectives on your microscope.
You calculate the total magnification of the scope by multiplying the power of the ocular (usually 10x) by the power of each objective. Thus, if your ocular is 10x and your objectives are 4x, 10x, and 40x, your three magnifications are 40x, 100x, and 400x. In Table 1.1, label your three magnifications as low, medium, and high and include the total magnification of each.

B. The letter e slide:

1. Make a wet-mount slide by cutting out a piece of newsprint with a letter e on it. (You can use newspaper, but a magazine works best.) Place the letter on a clean slide right side up and mark the slide on the bottom below the e. Add one drop of water on top of the paper letter. Add the coverslip by sliding it at a 45^0 angle until it touches the water drop, and then drop it onto the slide. If there are air bubbles, gently tap the coverslip with the eraser of your pencil. (You can also use a prepared e slide if you have it.)
2. Look at the slide with the unaided eye (without the microscope). Draw the letter as you see it (Do this is in Figure 2 of your notebook. Try to draw it as close to what you see (size and shape) as possible inside the observation circle. Record the magnification and identify what you are drawing.
3. Place your microscope in front of you with the eyepiece toward you and projecting over the arm. Plug it in and turn your light on. If you have a mirror instead of a light, look through the eyepiece and adjust the mirror until you see bright light.
4. Before placing your slide on the stage, turn the revolving nosepiece until the low-power (4x) objective is directly over the opening in the stage. You will feel a slight click as the objective moves into correct position. You should always focus using the low-power objective first before using a higher-power objective for any slide you are viewing.
5. Using the coarse adjustment knob, lower the stage away from the objective. This allows more room to put the slide onto the stage. Place the slide on the stage and use the stage clips to hold.
6. Three adjustments must be made in order to clearly see the letter on the slide. These same adjustments are necessary when viewing any slide:
   a. First, use your hands to move the slide in order to center the object to be viewed (letter e) directly over the stage opening so light can pass through it.
   b. Second, if you have an electric microscope, adjust the light by moving the diaphragm knob

so that you can see the letter best. The light may need to be readjusted with each objective—a low-power lens has a larger opening to allow in more light than a high-power lens. This means that more light is required as the power of the lens increases.

c. Third, focus the object being viewed. Using your coarse adjustment knob, raise the stage while looking through the eyepiece until the letter is visible. Then, slowly turn the fine adjustment knob until the image comes into sharp focus. Do not force the adjustment knobs beyond their stops.

As you look through the eyepiece, you should see your letter with a white circle of light as its background. This is called the field of view. You will also notice a dark line extending from the periphery to the center of the field of view. This is a pointer which can be used to point out objects to anyone else looking through the microscope.

7. Draw the letter as it appears under low power (Do this in Figure 3 of your notebook). Make sure to record the total magnification power used. Describe in your notebook the position of the image of the letter e through the microscope compared to the position of the letter e as viewed with the naked eye in Observation Box 1. You should notice two differences between the appearance of your letter when unmagnified compared to what you see using low-power magnification.
8. Move the slide to the left and describe in your notebook how the image moves in Observation Box 2.
9. Move the slide away from you and describe in your notebook how the image moves in Observation Box 3.
10. Remaining in focus without touching anything else, rotate the nosepiece until the 10x (medium power) objective clicks into place.
11. To see the letter clearly, the same three adjustments used with the low-power lens may be needed:
    a. Move your letter into the center of the field of view, if needed.
    b. Increase the light, if needed.
    c. Focus the lens, but use only the fine adjustment knob.
12. Redraw your letter as it appears under 10x (medium power) in your notebook's Figure 4 and label the total magnification.
13. Again, remaining in focus, rotate the nosepiece until the 40x (high power) objective clicks into place. Use the same three adjustment steps to see your letter clearly, making certain to use only the fine focus adjustment knob to focus your lens. Never use the coarse focus adjustment knob on high power (40x) since the working distance is so minimal. If you are unable to get a clear image using fine focus, return to 10x and begin the focusing process again.
14. Redraw the letter as it appears under 40x (high power) in your notebook's Figure 5 and label the total magnification.
15. When you are finished, always rotate your nosepiece to the lowest power objective. This is important so that you do not scratch your lens. When you are at the lowest power, it is safe to remove your slide.

C. Now that you are familiar with the parts of the microscope, you are ready to use it to view thread.

1. Rotate the low-power objective so that it is in line with the eyepiece. Listen for a click to make sure it is in place.
2. Turn your light on. If you have a mirror instead of a light, look through the eyepiece and adjust the mirror until you see bright light.
3. Using the coarse focus, raise the stage (or lower the body tube) until it can move no more. (Never force the knobs.)
4. Place a drop of water on a clean slide and add several short pieces of brightly colored thread.
5. Add a coverslip. Remember, this works best by sliding the coverslip at a 45-degree angle until it touches the water drop, and then drop it gently onto the slide. If air bubbles form, tap the coverslip gently with the eraser of your pencil. When you have the slide made, draw what you see with the unaided eye in your notebook's Figure 6, identify your drawing, and note the magnification.
6. Put the slide on the stage and clip it down, making sure the coverslip is over the hole in the stage.
7. Looking in the eyepiece, gently move the stage down (or body tube up) with the coarse focus. If you do not see anything after a couple of revolutions, move your slide a little to make sure the threads are in the center of the hole in the stage. This indicates that the threads are in the field of view.
8. When you have focused as best you can with the coarse focus, fine-tune the image with the fine focus. When you have the image in focus, draw what you see in the microscope in your notebook's Figure 7, identify your drawing, and note the magnification.
9. Place the threads in the very center of the field of view by moving the slide as you look at it through the microscope. Make sure that the threads are at the center of the field, or you will lose them when you change to a higher magnification.
10. Turn the nosepiece so that the medium-power objective is in place. Until you are very familiar with any microscope, do not turn the nosepiece without checking to make sure it will not hit the slide. Always move the nosepiece slowly, making sure that it does not touch the slide in any way. A lens can easily be damaged if it hits or breaks a slide.
11. Once the medium-power objective is in place, you should use only the fine focus to make the image sharp. Once again, move the slide so that the thread is at the center of the field. When you have the image in focus, draw what you see in the microscope in your notebook's Figure 8, identify your drawing, and note the magnification.
12. Again, watching to make sure you don't hit the slide, turn the nosepiece so that the high-power objective is in place. You should use only the fine focus to sharpen the image. When you have the image in focus, draw what you see in the microscope in your notebook's Figure 9, identifying your drawing and noting the magnification.
13. (Optional) If you like, repeat steps 1–12 using a strand of your own hair.

If we wanted to look at the threads at high magnification, why didn't we just start with the high-power objective? If we had tried to bring the threads into focus under high magnification without first looking at them under low and then medium magnification, we almost certainly would have never found

them. When you look at the slide at high magnification, you are looking at a very, very tiny portion of the slide, and it is unlikely that what you are looking for will be there. As a result, you should always start your microscope investigation with the lowest magnification and then work your way up, centering the specimen in the field of view each time before you increase magnification.

D. Now it is time to get your first look at cells!

1. Place the prepared slide of either Ranunculus root or Zea mays root on the microscope and begin the procedure outlined in section B, looking at the cells under low, then medium, and then high magnifications. Draw what you see at each magnification in your notebook's Figures 10, 11, and 12; identify each drawing; and note the magnification.
2. Clean up and return everything to the proper place. To properly clean slides, coverslips, and eyedropper, wash them carefully with soap and water and dry them carefully with paper towels. To properly clean microscope lenses, wipe them carefully with lens paper.
3. Be sure to record any changes you made to your materials or procedure. Sometimes we are required to make changes to procedures that are listed. This can be for many reasons, such as you drew a letter e instead of cutting one out of the newspaper. If you make any changes to the materials or existing procedure, you need to make note of it in your notebook so that others would be able to make the same changes if they want to duplicate your experiment. There is space in your notebook to list any changes to the materials or procedure.
4. In the Conclusions section of your notebook, summarize what you learned in this experiment and make connections to the readings in your text. While this might seem simple or even silly in this first experiment, as you progress through this textbook, you will begin to *experience* science in addition to just reading about it. It is very important that you can connect the facts presented in your studies to your actual experiences. This is also a good place to discuss what you might consider changing in the future to further test an idea.

ON YOUR OWN

1.10 Why is it important that scientists use a common SI system of measurement?

1.11 What is the difference in the way light microscopes and electron microscopes produce images?

1.12 A biologist is studying viruses, which are much smaller than cells. Which type of microscope should the biologist use if she wants to study the internal structure of the virus?

Safety in Biology

You will have the opportunity to do experiments like Experiment 1.1 many times during this course. You'll also have opportunities to do field studies where you can observe living things in their natural environment. Studying living things, whether under the microscope or out in the field, is interesting, fun, and rewarding, but you also must be careful. At times you will be instructed to heat things or use chemicals and stains; it is important to be cautious when handling flames or chemicals. Common sense should always prevail.

In a science laboratory, scientists have procedures and protocols they follow to ensure their safety and the well-being of any living creatures they study. God has instructed us to be stewards of the world He's given us, so we should be mindful of this whenever we're working with living creatures. As you're conducting your experiments in this course, if you have any questions, ask your parent for help.

Believe it or not, we are at the end of the first module. Now you need to take a look at the Study Guide found at the end of this module. In the accompanying student notebook or on a separate sheet of paper, write out all of the definitions listed in the Study Guide, and answer all of the questions. After you have completed the Study Guide, check your work with the solutions. When you are confident that you understand the material covered in the Study Guide, you are ready to take the test.

salt and light

You read about van Leeuwenhoek's discovery of microorganisms in this module, but what is most interesting about him is that he thought these creatures were amazing marvels expressing the creativity of God the Creator. Leeuwenhoek called these little organisms, "animalcules" or "cavorting beasties" as he watched them move around in a drop of pond water.

Van Leeuwenhoek was the first to discover many of the microorganisms that you will study in this course. He found protists and bacteria in pond water and hay infusions. If you have a microscope, you too will get to see the "cavorting beasties" that so amazed van Leeuwenhoek. From his writings, it's clear that van Leeuwenhoek saw the fascinating detail of these creatures as evidence of design:

FIGURE 1.19
Antonie van Leeuwenhoek

From all these observations, we discern most plainly the incomprehensible perfection, the exact order, and the inscrutable providential care with which the most wise Creator and Lord of the Universe had formed the bodies of these animalcules, which are so minute as to escape our sight, to the end that different species of them may be preserved in existence. And this most wonderful disposition of nature with regard to these animalcules for the preservation of their species; which at the same time strikes us with astonishment, must surely convince all of the absurdity of those old opinions, that living creatures can be produced from corruption of putrefaction.[3]

Van Leeuwenhoek studied living things all his life. Studying them gave him confidence to speak against spontaneous generation, which was a prominent scientific theory of his time. He wrote of the discoveries that so greatly fascinated him, "This must appear wonderful, and be a confirmation of the principle that all living creatures deduce their origin from those which were formed at the Beginning."[4]

ANSWERS TO THE ON YOUR OWN PROBLEMS

1.1 **Science cannot prove anything. The best science can say is that all known data support a given statement.** However, since all data come from experiments that might be flawed, there is no way that science can prove anything. If the experiments that produced the data that support a particular statement are flawed, the statement might be quite wrong.

1.2 **It is a hypothesis.** The explanation will have to be tested with a significant amount of data before it can even be considered a theory.

1.3 **Scientists should test only one variable at a time so that they know the variable they're testing is the only factor affecting the outcome of the experiment.**

1.4 **An independent variable is manipulated by the scientist and a dependent variable responds to the independent variable.**

1.5 **Pasteur showed that all living things come from other living things and that spontaneous generation was not possible.** This was a major shift in how scientists viewed living things.

1.6 **Scientific laws should not be considered 100% reliable. The nature of science is to change theories and laws when new evidence requires it.** Because it is impossible to fully test a scientific law and because laws are tested by experiments that might be flawed, scientific laws are not necessarily true. They represent the best conclusions that science has to offer, but they are nevertheless not completely reliable.

1.7 **All living things:**

- **are composed of cells.**
- **grow.**
- **require energy to power activities.**
- **maintain a stable internal environment.**
- **sense and respond to their environment.**
- **contain hereditary information in their DNA.**

1.8 **Since the offspring are identical in every way to the parent, it is asexual reproduction.**

1.9 **Unicellular and multicellular organisms are alike in that they all possess the criteria for life. They are different in that unicellular organisms are one-celled and multicellular organisms have more than one cell.**

1.10 **Scientists use the SI system of measurements so that they can compare results and replicate each other's research more easily.**

1.11 **Light microscopes use visible light passing through a specimen and a combination of two lenses. Electron microscopes do not use light; they use electron beams** to either pass through or scan across the surface of thin specimens.

1.12 **She should use a transmission electron microscope (TEM) because TEMs send an electron beam through a thin specimen so that we can see the internal structures, whereas SEMs run the electron beam back and forth over a specimen to give an image of its surface.**

STUDY GUIDE FOR MODULE 1

1. In the student notebook, write the definitions for the following terms (if you have not yet written them).

   a. Evidence
   b. Observation (include the different types)
   c. Inference
   d. Hypothesis
   e. Variable (include the different types)
   f. Experimental group
   g. Control group
   h. Scientific theory
   i. Scientific law
   j. Microorganisms
   k. Abiogenesis
   l. Metabolism
   m. Anabolism
   n. Catabolism
   o. Photosynthesis
   p. Autotrophs
   q. Heterotrophs
   r. Herbivores
   s. Carnivores
   t. Omnivores
   u. Homeostasis
   v. Endotherm
   w. Ectotherm
   x. Receptors
   y. Asexual reproduction
   z. Sexual reproduction
   aa. Inheritance
   bb. Mutation
   cc. International System of Units
   dd. Compound light microscope
   ee. Transmission electron microscope
   ff. Scanning electron microscope

2. What are the criteria for life?
3. Why are cells considered the most basic unit of life?
4. An organism has receptors on tentacles that come out of its head. If those tentacles were cut off in an accident, what life function would be most hampered?
5. A parent and two offspring are studied. Although there are many similarities between the parent and the offspring, there are also some differences. Do these organisms reproduce sexually or asexually?
6. What is wrong with the following statement?

   "Science has proven that energy must always be conserved."

7. Suggest two observations and two inferences a biologist might make about the scene in Figure 1.20.

FIGURE 1.20
Photo: Ikiwaner (GNU 1.2)

8. Briefly explain the scientific method.
9. Why does the story of spontaneous generation illustrate the limitations of science?
10. Where does the wise person place his or her faith: science or the Bible?
11. Why is the theory of abiogenesis just another example of the idea of spontaneous generation?
12. What are some common tools scientists use in the study of biology?
13. Why do scientists use the metric system? Why do they use tables and graphs?
14. What is the difference between a compound light microscope, a transmission electron microscope, and a scanning electron microscope? What is one advantage of a light microscope and one advantage of electron microscopes?
15. Why do scientists have procedures and protocols in the laboratory?

ENDNOTES

[1] S. I. McMillen, *None of These Diseases* (Old Tappan, NJ: Fleming H. Revell, 1963), 18.
[2] Patrice Pinet, *Pasteur et la Philosophie* (Paris: Editions L'Harmattan, 2004), 63.
[3] A. Schierbeek, ed., *Measuring the Invisible World* (New York: Abelard-Schuman, 1959).
[4] Clifford Dobell, *Antonie van Leeuwenhoek and His "Little Animals"* (London: Staples Press, 1932), 171.

APPENDIX B

A COMPLETE LIST OF LAB SUPPLIES

Most items used in an experiment are typical household items. They can be commonly found at supermarkets, hardware stores, or drug stores. Items in blue type are found in the laboratory equipment sets that are sold for the course.

MODULE 1

- Microscope
- Lens paper
- Slides
- Coverslips
- Eyedropper
- Prepared slide: *Ranunculus* root or *Zea mays* root
- Cotton swabs
- Water
- Small pieces of brightly colored thread

MODULE 2

- Penny
- Medicine dropper (or eyedropper)
- Graduated cylinder (10 mL)
- 3 clear plastic or glass cups, or beakers (one for Exp. 2.1 and two for Exp. 2.2)
- Detergent
- Wax paper
- Felt-tip marker
- Strip cut from a coffee filter (½" x 6," or as long as you can get it)
- Stopwatch or clock
- Metric ruler
- 2 different antacids (try to find white tablets, like Tums, Rolaids, or generic)
- Self-sealing plastic sandwich bag
- Mallet or hammer
- Graduated cylinder

- Water
- 2 plastic spoons
- pH indicator strips
- White vinegar
- Part of a fresh pineapple (it cannot be canned. It must be fresh.)
- A blender or fine cheese grater
- 3 small bowls
- A small box of Jell-O gelatin mix—any flavor (Generic brands work just as well.)
- Pot
- 2 tablespoons

MODULE 3

- Thermometer (It must be able to read temperatures from room temperature to at least 100 degrees Fahrenheit. The smaller the thermometer, the better.)
- A large, clear Ziploc® freezer bag (It must be large enough for the thermometer to fit inside once it is zipped.)
- Plastic, two-liter soda pop bottle
- Vinegar
- Baking soda
- Teaspoon
- Bean seeds (about 20)
- 2 paper cups
- 2 saucers
- Marking pen or pencil
- Potting soil

MODULE 4

- Microscope
- Lens paper
- Slides (concave and flat)
- Coverslips
- Eyedroppers
- Methylene blue stain
- Iodine
- Concave slide and coverslip
- Knife or scalpel
- Tweezers
- Water
- Onion
- *Elodea* leaf* (will use for two experiments)—Sometimes called "waterweeds" or Anacharis, they can be purchased at aquarium stores. If you live in a state that has outlawed the sale of these plants due to their tendency to take over an ecosystem, ask the salesperson at the aquarium shop what they are selling in place of Anacharis. You could also use thin leaves from another plant like Impatiens. The main point is that the leaves need to be alive and very thin.

- Banana
- Toothpicks
- Paper towel
- Sodium chloride (table salt)
- Water
- Paper towel or tissue
- Three coffee mugs or wide-mouth pint-sized mason jars
- A measuring cup for liquids
- A tape measure
- One fresh, raw egg, which is about 90% water
- White vinegar, which is about 5% acetic acid and 95% water
- Clear sugar syrup (like Karo® syrup), which is about 25% water
- Distilled water (available for purchase at any large supermarket) which is close to pure water
- Measuring spoons

MODULE 5

- 2 coffee filter papers
- 2 250-mL beakers
- 2 squares of aluminum foil (big enough to cover the mouth of the beaker)
- 2 rubber bands
- Acetone such as nail polish remover or 70% isopropyl alcohol (solvents)
- Quarter (coin)
- Pencil
- Metric ruler
- Fresh spinach leaf
- Red leaf such as Coleus leaves or red lettuce
- 3 60-mL (2-oz) bottles (bottles can be purchased at most drug stores as travel size reusable bottles)
- 1 to 2 packets of fresh baker's yeast (make sure to check the expiration date)
- Apple cider (not apple cider vinegar) at room temperature
- Sugar
- Water
- 50-mL graduated cylinder
- Funnel
- Three 7- to 9-inch latex balloons
- ½ teaspoon measuring spoon or metric kitchen scale
- Tape measure or string (not yarn) and metric ruler

MODULE 6

- Blender
- Toothpick
- Clear liquid hand soap or dish soap (The liquid hand soap tends to work just a bit better, and colorless will work a bit better than soap that is tinted with a color.)
- Salt

- Water
- Strainer
- Small glass
- Meat tenderizer (Make sure it has been bought within the last year or so.)
- Rubbing alcohol
- ½ cup of split peas
- Measuring cups and spoons
- Flashlight
- Microscope
- Prepared slide of *Allium* (onion) root tip
- Prepared slide of *Ascaris Mitosis*

MODULE 7

- 60 radish seeds (purchase locally)
- 2 shallow pans or dishes
- Potting soil
- Clear plastic wrap
- Box to cover on dish
- Water
- Magnifying glass
- Eyedropper
- Your parents, grandparents, aunts, uncles, and siblings (Even if your grandparents, aunts, and uncles are not living, you might be able to find pictures of them. Or if they are living far away you could ask them over the phone, which is all that you might need for the experiment. If you don't have many siblings or cannot determine the characteristics listed in the background section of your grandparents, aunts, and uncles, you might consider studying another family as well so that you can get even more information.)
- Mirror

MODULE 8

There are no experiments in module 8.

MODULE 9

- 1 cup of plain unflavored yogurt (You can buy this at the grocery store. Just make sure it says "Live Cultures" or "Active Cultures" on the container. You can also get a yogurt starter culture at most health food stores.)
- 4 cups whole milk (or 2%)
- 2-quart saucepan
- Wooden spoon
- Whisk
- Sink, plugged and filled to about 2 inches with ice water
- 5 pint-sized sterilized canning jars with lids (You can sterilize them by running them through the dishwasher.)

- Oven or heating pad and towel
- Wide-mouth funnel (Optional)
- Candy thermometer (Optional, but great if you have it.)

MODULE 10

- 4 jars with lids (You do not want a lot of light to get into the jars. Thus, jars made of darker glass or plastic work really well. If you can't find that kind of jar, cover your jars with paper or foil to keep the light out.)
- A small amount of chopped hay (Dried grass will work as a substitute.)
- Uncooked white rice (Brown rice will not work as well.)
- Egg yolk (This should come from a boiled egg so that the yolk is cooked.)
- A small amount of rich soil
- A long-handled ladle (A good one can be made by attaching a kitchen ladle to a broom handle with duct tape.)
- A pond or small body of water (A still creek will do in a pinch, but it will not be ideal.)
- Something to rest your lab notebook on while you draw in it
- Colored pencils
- Microscope
- Prepared slide: amoeba
- Prepared slide: paramecium
- Prepared slide: euglena
- Prepared slide: volvox
- Prepared slide: spirogyra
- Prepared slide: diatoms
- Slides
- Coverslips for the slides
- 4 pipets or eyedroppers (one for each jar)
- Methylene blue
- 4 jars of water collected at the pond
- A small amount of cotton (from a cotton ball, for example)
- Bread, jelly, and/or fruit mold grown earlier (Only one specimen is necessary, but if you observe more than one specimen, you will learn more.)
- Magnifying glass
- Knife
- Needle (or probe from your dissection kit)
- Water (warm and cool)
- Packet of active dry yeast (This can be purchased at a grocery store. Be sure to check the expiration date.)
- Measuring spoons
- Measuring cup
- Glass that holds at least 2 cups of water
- Sugar
- Mushrooms
- Puffballs

- Shelf fungi
- Gloves

MODULE 11

- Sharp scissors (If you have the dissection kit, use the scissors in it.)
- Sharp blade (If you have the dissection kit, use the scalpel in it.)
- Slides and coverslips
- Water
- Eyedropper
- Magnifying glass
- Microscope (optional)
- Colored pencils and lab notebook
- A variety of flowers (Most flower shops will save old flowers for you if you contact them ahead of time and tell them why you want them. They do not need to be fresh, but you should get a good variety. An example of a good variety would be a rose, a carnation, a daisy, a lily, and a tulip. At least one of them, preferably more, should have stamens and at least one carpel that are easy to see. In the list above, the lily and tulip will have easily visible stamens and a carpel. The rose and carnation will have them as well, but they will be harder to find. Look in the very center of the flower. The daisy is a composite flower, so its reproductive organs will be even harder to see.)
- A variety of different fruits (suggested fruits: apple, plum, orange, tomato, walnut, sunflower seed, maple seed, pea in pod, strawberry, and raspberry)

MODULE 12

- Prepared slide: *Zea mays* (corn) cross section of stem
- Prepared slide: *Zea mays* (corn) cross section of root
- Prepared slide: *Ranunculus* (buttercup) cross section of stem
- Prepared slide: *Ranunculus* (buttercup) cross section of root
- Prepared slide: Leaf cross section with vein
- Microscope
- Lab notebook
- Colored pencils
- Red (some people call it purple) cabbage (just a few leaves)
- Stove
- Stirring spoon
- Pot
- White vinegar (It must be clear. Apple cider vinegar will not work for this experiment.)
- Clear ammonia solution (This is sold in grocery stores with the cleaning supplies.)
- Water
- 2 eyedroppers
- 2 small cups or glasses
- 1 small glass (It must be see-through!)
- A sheet of white paper (preferably without lines)

- Measuring cups (1 cup and ¼ cup)
- Tablespoon

MODULE 13

- Microscope
- Prepared slide: sponge—Grantia spicules
- Prepared slide: Hydra
- Prepared slide: planarian
- Lab notebook
- Colored pencils
- Natural sponges (optional)
- Dissecting tools and tray that came with your dissection kit
- Earthworm specimen
- Magnifying glass

MODULE 14

- Dissecting tools and tray that came with your dissection kit
- Crayfish specimen
- Magnifying glass
- Laboratory notebook

MODULE 15

- Dissecting tools and tray that came with your dissection kit
- Perch specimen
- Frog specimen
- Magnifying glass
- Laboratory notebook
- Water
- Small bowl
- Colored pencils
- Magnifying glass (if available)
- Field guide (This will help you identify the organisms that you see. Most libraries have field guides. Try to find one on plants and one on animals.)

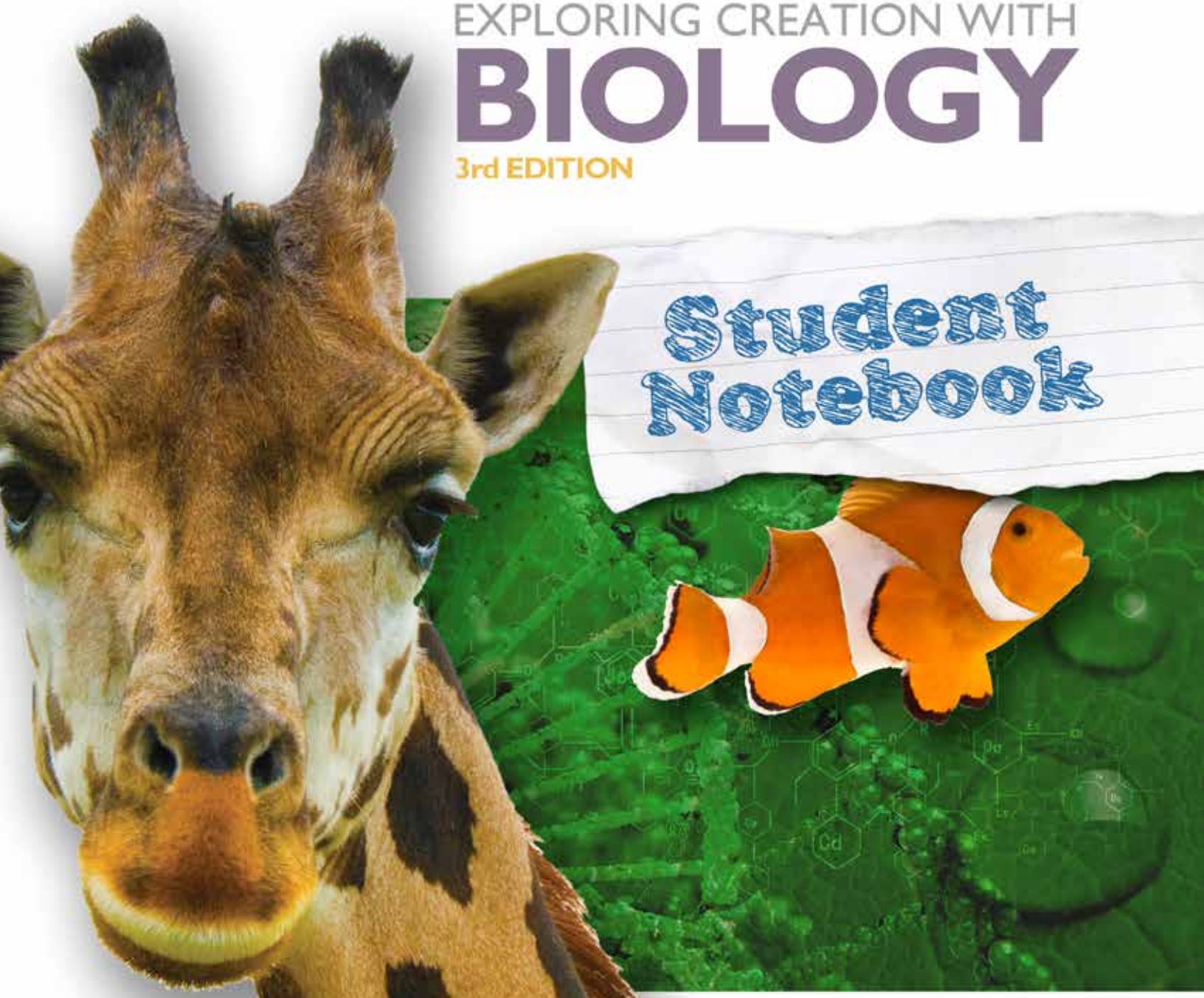
MODULE 16

- Magnifying glass
- Desk lamp
- Lab notebook
- Colored pencils
- Bird field guides (available online or at your local library)
- Binoculars (if available)
- Bird seed

apologia

EXPLORING CREATION WITH BIOLOGY

3rd EDITION



Student Notebook

Written by:

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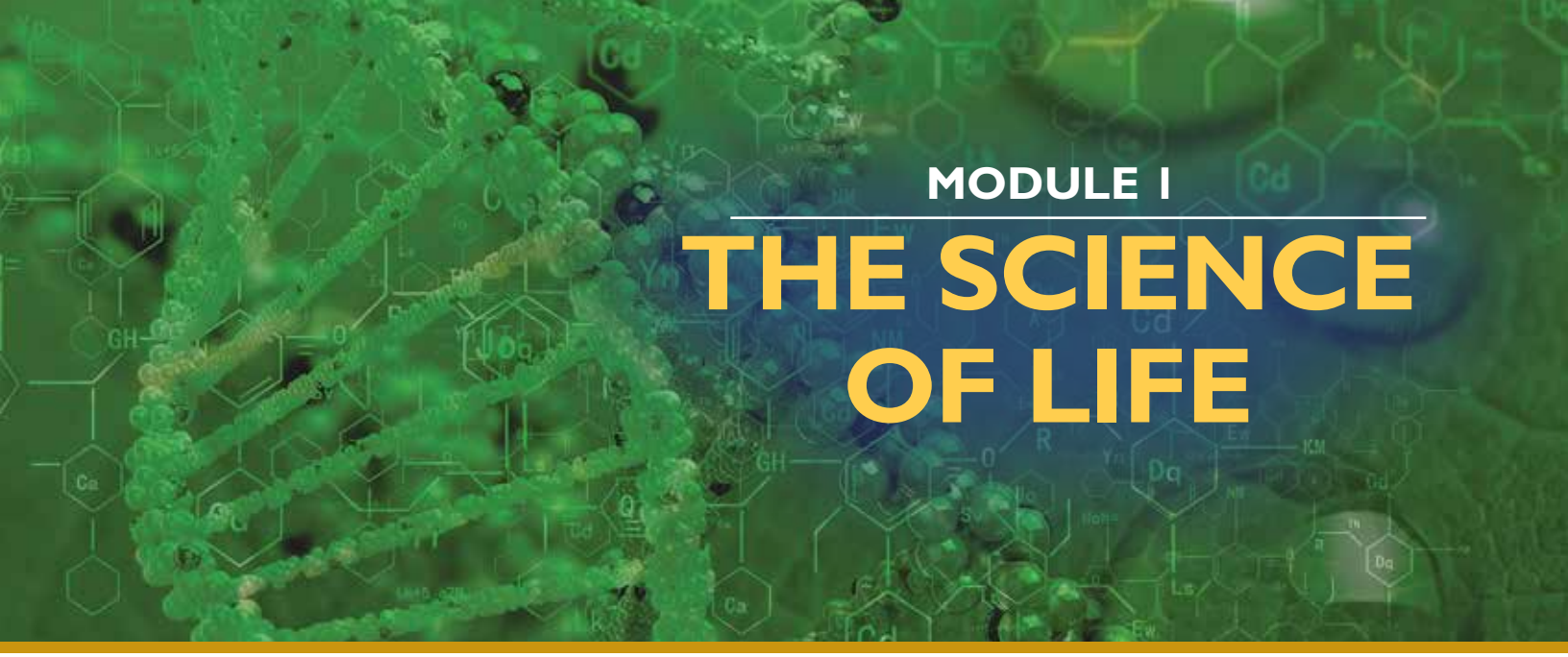
9	Study Guide	Study for the test	**TAKE MODULE 4 TEST**	Study for quarterly test 1	**TAKE QUARTERLY TEST 1**
10	**MODULE 5** Read pp. 179–183 OYO 5.1–5.2	Read pp. 184–187 Experiment 5.1 OYO 5.3–5.5	Read pp. 188–192 OYO 5.5–5.8	Read pp. 193–195 OYO 5.9–5.12	Read pp. 196–203 OYO 5.13–5.20

NOTEBOOK
Daily Schedule

MODULE 1 **DATE:** _____

PAGES: _____



MODULE 1

THE SCIENCE OF LIFE

ON YOUR OWN QUESTIONS

1.1 When trying to convince you of something, people will often insert "Science has proven..." at the beginning of a statement. Can science actually prove something? Why or why not?

1.2 A scientist makes a few observations and develops an explanation for the observations that she has made. At this point, is the explanation a hypothesis, theory, or scientific law?

1.3 Why is it important for scientists to test only one variable at a time when experimenting?

1.4 Explain the relationship between an independent variable and a dependent variable.

1.5 Describe the impact Pasteur's work had on the scientific community.

1.6 Should scientific laws be considered 100% reliable? Explain.

1.7 List the criteria all living organisms possess.

1.8 A biologist studies an organism and then two of its offspring. They are all identical in every possible way. Do these organisms reproduce sexually or asexually?

1.9 How are unicellular and multicellular organisms alike? How are they different?

1.10 Why is it important that scientist use a common SI system of measurement?

1.11 What is the difference in the way light microscopes and electron microscopes produce images?

1.12 A biologist is studying viruses, which are much smaller than cells. Which type of microscope should the biologist use if she wants to study the internal structure of the virus?

STUDY GUIDE QUESTIONS

1 As we stated in the Student Notes section of your notebook, this first question for each Study Guide module contains the vocabulary words for that module. If you haven't already, it might be helpful to mark this section when you begin a new module. This will give you easy access each time you're introduced to a new vocabulary word in your textbook. That way, you can write out the definitions of new words as you come to them in the reading. Define the following terms:

TERM	DEFINITION
a. Evidence	
b. Observation (include the different types)	
c. Inference	

TERM	DEFINITION
d. Hypothesis	
e. Variable (include the different types)	
f. Experimental group	
g. Control group	
h. Scientific theory	
i. Scientific law	
j. Microorganisms	
k. Abiogenesis	
l. Metabolism	
m. Anabolism	
n. Catabolism	
o. Photosynthesis	
p. Autotrophs	

TERM	DEFINITION
q. Heterotrophs	
r. Herbivores	
s. Carnivores	
t. Omnivores	
u. Homeostasis	
v. Endotherm	
w. Ectotherm	
x. Receptors	
y. Asexual reproduction	
z. Sexual reproduction	
aa. Inheritance	
bb. Mutation	

TERM	DEFINITION
cc. International System of Units	
dd. Compound light microscope	
ee. Transmission electron microscope	
ff. Scanning electron microscope	

2 What are the criteria for life?

3 Why are cells considered the most basic unit of life?

4 An organism has receptors on tentacles that come out of its head. If those tentacles were cut off in an accident, what life function would be most hampered?

5 A parent and two offspring are studied. Although there are many similarities between the parent and the offspring, there are also some differences. Do these organisms reproduce sexually or asexually?

6 What is wrong with the following statement?
"Science has proven that energy must always be conserved."

7 Suggest 2 observations and 2 inferences a biologist might make about the scene below.

8 Briefly explain the scientific method.

9 Why does the story of spontaneous generation illustrate the limitations of science?

10 Where does the wise person place his or her faith: science or the Bible?

11 Why is the theory of abiogenesis just another example of the idea of spontaneous generation?

12 What are some common tools scientists use in the study of biology?

13 Why do scientists use the metric system? Why do they use tables and graphs?

14 What is the difference between a compound light microscope, a transmission electron microscope, and a scanning electron microscope? What is one advantage of a light microscope and one advantage of electron microscopes?

15 Why do scientists have procedures and protocols in the laboratory?

MODULE I

THE SCIENCE OF LIFE

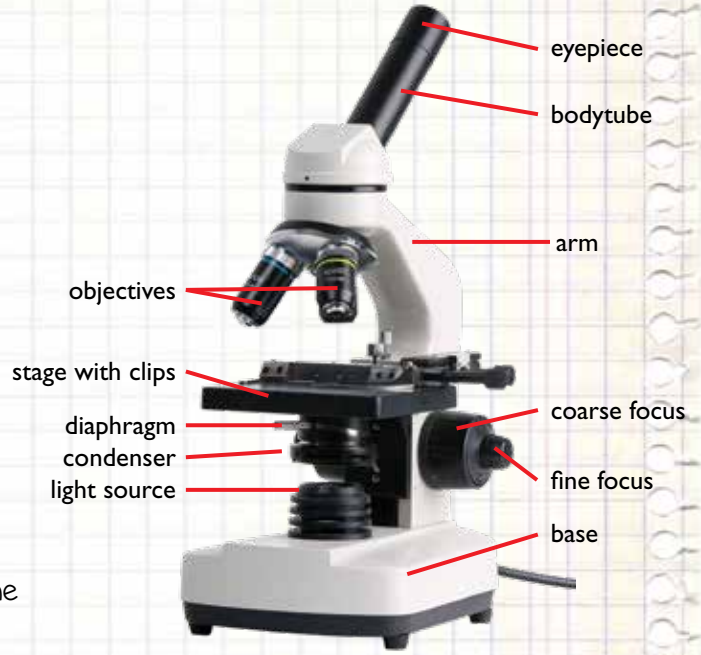
EXPERIMENT 1.1
INTRODUCTION TO THE MICROSCOPE

PURPOSE:

To learn the various parts of the microscope and to learn to use the microscope properly

MATERIALS:

- Microscope
- Lens paper
- Slides
- Coverslips
- Cotton swabs
- Eyedropper
- Water
- Small pieces of brightly colored thread
- Prepared slide: Ranunculus root or Zea mays root



PROCEDURE:

A. **Learn the parts of the microscope:**

1. Place the microscope on your table with the arm of the microscope nearest you. With the aid of the illustration, locate all the parts of the microscope and become familiar with them.
2. In the data section, label the parts of the microscope listed on the figure at the right as you locate them on your microscope.
   a. The **eyepiece (the ocular)** is what you look through. It usually contains a 10x lens.
   b. The **body tube** starts at the eyepiece and runs to the part that holds the revolving nosepiece.

c. The **revolving nosepiece** is the disc that holds the lenses (which are called objectives).
d. The **objectives** are metal tubes that contain lenses of varying powers, usually 4x, 10x, and 40x. Some microscopes have a 100x objective as well.
e. The **arm** supports the body and stage and is attached to the base.
f. The **stage with clips** is a platform just below the objectives and above the light source. The clips are used to hold the slide in place.
g. The **diaphragm** regulates the amount of light that passes through the specimen. It is located between the stage and the light source. It might be a disc that has several holes (a disc diaphragm), or it might be a single hole whose diameter can be varied (an iris diaphragm).
h. The **condenser** is also located between the light source and stage. It is a lens system that bends and concentrates the light coming through the specimen.
i. The **coarse focus** is controlled by two large knobs on each side of the microscope. It allows for quick focus, but it does not make the image as sharp as it could be.
j. The **fine focus knobs** are used to produce sharp focus. They are usually smaller and lower than the coarse focus knobs, but in some scopes they are mounted on top of the coarse focus knobs.
k. The **light source** is on the base and provides necessary light for the examination of specimens.
l. The **base** is the heavy structure at the bottom that supports the microscope and makes it steady.

Magnification is an important feature of any microscope. In table 1.1 in the data section, write down the magnifications of the objectives on your microscope. You calculate the total magnification of the scope by multiplying the power of the ocular (usually 10x) by the power of each objective. Thus, if your ocular is 10x and your objectives are 4x, 10x, and 40x, your three magnifications are 40x, 100x, and 400x. In table 1.1, label your three magnifications as low, medium, and high and include the total magnification of each.

B. The letter e slide:

1. Make a wet-mount slide by cutting out a piece of newsprint with a letter e on it. (You can use newspaper, but a magazine works best.) Place the letter on a clean slide right side up and mark the slide on the bottom below the e. Add one drop of water on top of the paper letter. Add the coverslip by sliding it at a 45-degree angle until it touches the water drop, and then drop it onto the slide. If there are air bubbles, gently tap the coverslip with the eraser of your pencil. (You can also use a prepared e slide if you have it.)
2. Look at the slide with the unaided eye (without the microscope). Draw the letter as you see it (Do this is in Figure 2 in the data section. Try to draw it as close to what you see (size and shape) as possible inside the observation circle. Record the magnification and identify what you are drawing.
3. Place your microscope in front of you with the eyepiece toward you and projecting over the arm. Plug it in and turn your light on. If you have a mirror instead of a light, look through the eyepiece and adjust the mirror until you see bright light.
4. Before placing your slide on the stage, turn the revolving nosepiece until the low-power (4x) objective is directly over the opening in the stage. You will feel a slight click as the objective

moves into correct position. You should always focus using the low-power objective first before using a higher-power objective for any slide you are viewing.

5. Using the coarse adjustment knob, lower the stage away from the objective. This allows more room to put the slide onto the stage. Place the slide on the stage so that the sliding spring arm holds it in place.
6. Three adjustments must be made in order to clearly see the letter on the slide. These same adjustments are necessary when viewing any slide:
   a. First, use your hands to move the slide in order to center the object to be viewed (letter e) directly over the stage opening so light can pass through it.
   b. Second, if you have an electric microscope, adjust the light by moving the diaphragm knob so that you can see the letter best. The light may need to be readjusted with each objective—a low-power lens has a larger opening to allow in light than a high-power lens has. This means that more light is required as the power of the lens increases.
   c. Third, focus the object being viewed. Using your coarse adjustment knob, raise the stage while looking through the eyepiece until the letter is visible. Then, with the fine adjustment knob, clear the image until it is sharp for your eye. Do not force the adjustment knobs beyond their stops.

   As you look through the eyepiece, you should see a background white circle of light around your letter. This is called the field of view. You will also notice a dark line extending from the periphery to the center of the field of view. This is a pointer which can be used to point out objects to anyone else looking through the microscope.

7. Draw the letter as it appears under low power (Do this in figure 3 in the data section). Make sure to record the total magnification power used. Describe the position of the image of the letter e through the microscope compared to the position of the letter e as viewed with the naked eye in observation box 1. You should notice two differences between the appearance of your letter when unmagnified compared to what you see using low-power magnification.
8. Move the slide to the left and describe how the image moves in observation box 2.
9. Move the slide away from you and describe how the image moves in observation box 3.
10. Remaining in low power, without touching anything else, rotate the nosepiece until the 10x (medium power) objective clicks into place.
11. In order to see the letter clearly, the same three adjustments used with the low-power lens may be needed:
    a. Move your letter into the center of the field of view, if needed.
    b. Increase the light, if needed.
    c. Focus the lens, but use only the fine adjustment knob.
12. Redraw your letter as it appears under 10x (medium power) in Figure 4 and label the total magnification.
13. Again, remaining in focus, rotate the nosepiece until the 40x (high power) objective clicks into place. Use the same three adjustment steps to see your letter clearly, making certain to use only the fine focus adjustment knob to focus your lens. Never use the coarse focus adjustment knob on high power (40x) since the working distance is so minimal. If you are unable to get a clear image using fine focus, return to 10x and begin the focusing process again.
14. Redraw the letter as it appears under 40x (high power) in Figure 5 and label the total

magnification.

15. When you are finished, always rotate your nosepiece to the lowest power objective. This is important so that you do not scratch your lens. When you are at the lowest power, it is safe to remove your slide.

C. Now that you are familiar with the parts of the microscope, you are ready to use it to view thread.

1. Rotate the low-power objective so that it is in line with the eyepiece. Listen for a click to make sure it is in place.
2. Turn your light on. If you have a mirror instead of a light, look through the eyepiece and adjust the mirror until you see bright light.
3. Using the coarse focus, raise the stage (or lower the body tube) until it can move no more. (Never force the knobs.)
4. Place a drop of water on a clean slide and add several short pieces of brightly colored thread.

Add a coverslip. This works best if you hold the coverslip close to the drops of water and then drop it gently. If air bubbles form, tap the coverslip gently with the eraser of your pencil. When you have the slide made, draw what you see with the unaided eye in Figure 6 in the data section, identify your drawing, and note the magnification.

6. Put the slide on the stage and clip it down, making sure the coverslip is over the hole in the stage.
7. Looking in the eyepiece, gently move the stage down (or body tube up) with the coarse focus. If you do not see anything after a couple of revolutions, move your slide a little to make sure the threads are in the center of the hole in the stage. This indicates that the threads are in the field of view.
8. When you have focused as best you can with the coarse focus, fine-tune the image with the fine focus. When you have the image in focus, draw what you see in the microscope in Figure 7, identify your drawing, and note the magnification.
9. Place the threads in the very center of the field of view by moving the slide as you look at it through the microscope. Make sure that the threads are at the center of the field, or you will lose them when you change to a higher magnification.
10. Turn the nosepiece so that the medium-power objective is in place. Until you are very familiar with any microscope, do not turn the nosepiece without checking to make sure it will not hit the slide. Always move the nosepiece slowly, making sure that it does not touch the slide in any way. A lens can easily be damaged if it hits or breaks a slide.
11. Once the medium-power objective is in place, you should use only the fine focus to make the image sharp. Once again, move the slide so that the thread is at the center of the field. When you have the image in focus, draw what you see in the microscope in Figure 8, identify your drawing, and note the magnification.
12. Again, watching to make sure you don't hit the slide, turn the nosepiece so that the high-power objective is in place. You should use only the fine focus to refocus. When you have the image in focus, draw what you see in the microscope in Figure 9 identifying your drawing and noting the magnification.
13. (Optional) If you like, repeat steps 1–12 using a strand of your own hair.

If we wanted to look at the threads at high magnification, why didn't we just start with the high-power objective? If we had tried to bring the threads into focus under high magnification without first looking at them under low and then medium magnification, we almost certainly would have never found

them. When you look at the slide at high magnification, you are looking at a very, very tiny portion of the slide, and it is unlikely that what you are looking for will be there. As a result, you should always start your microscope investigation with the lowest magnification and then work your way up, centering the specimen in the field of view each time before you increase magnification.

D. Now it is time to get your first look at cells!

1. Place the prepared slide of either Ranunculus root or Zea mays root on the microscope and begin the procedure outlined in section B, looking at the cells under low, then medium, and then high magnifications. Draw what you see at each magnification in Figures 10, 11, and 12 in the data section; identify each drawing; and note the magnification.
2. Clean up and return everything to the proper place. To properly clean slides, coverslips, and eyedropper, wash them carefully with soap and water and dry them carefully with paper towels. To properly clean microscope lenses, wipe them carefully with lens paper.
3. Be sure to record any changes you made to your materials or procedure. Sometimes we are required to make changes to procedures that are listed. This can be for many reasons, such as you drew a letter e instead of cutting one out of the newspaper. If you make any changes to the materials or existing procedure, you need to make note of it in your notebook so that others would be able to make the same change if they want to duplicate your experiment. There is space in your notebook to list any changes to the materials or procedure.
4. In the Conclusions section of your notebook, summarize what you learned in this experiment and make connections to the readings in your text. While this might seem simple or even silly in this first experiment, as you progress through this textbook, you will begin to experience science in addition to reading about it in your textbook. It is very important that you can connect the facts presented in your studies to your actual experiences. This is also a good place to discuss what you might consider changing in the future to further text an idea.

CONCLUSIONS:

Summarize what you learned in this experiment and make connections to the text.

Note any changes made to the materials or procedure of this experiment here.

DATA AND OBSERVATIONS:

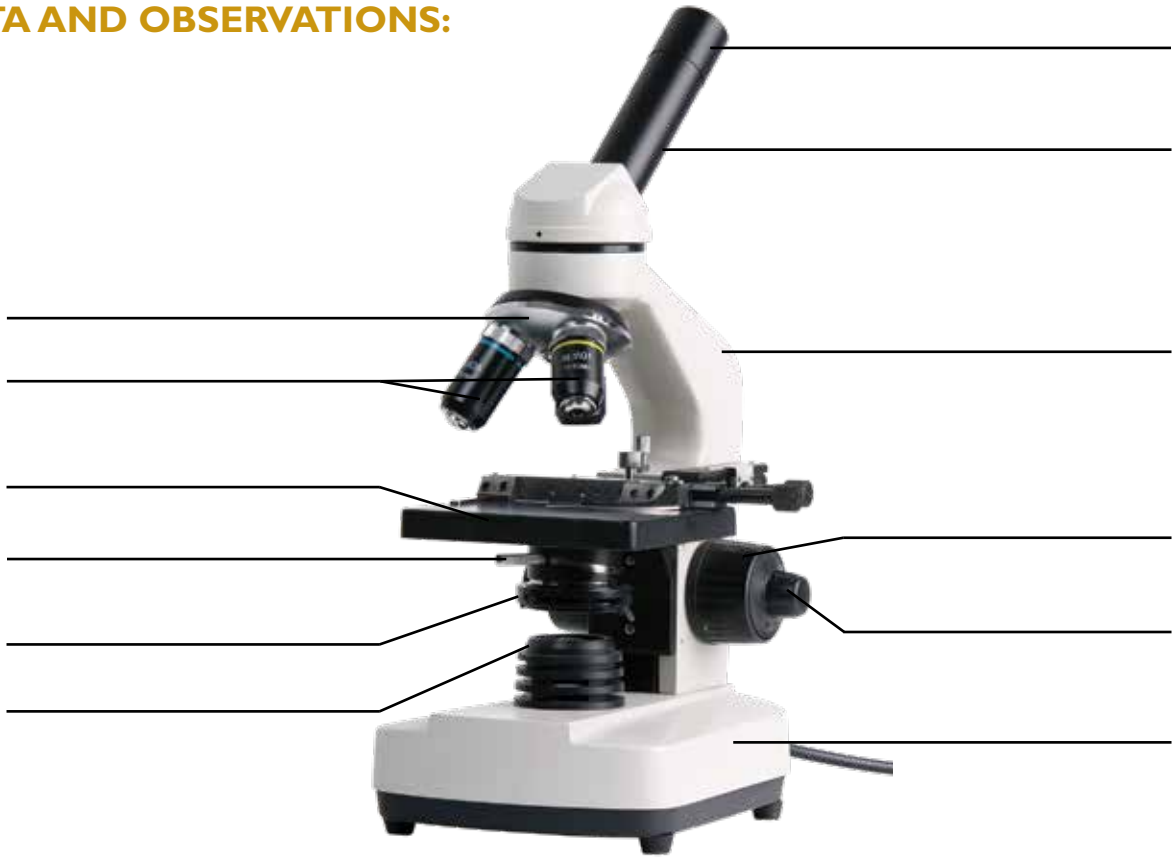


FIGURE 1.18
Microscope
Label the parts of the microscope as you locate them on your microscope.

TABLE 1.1: MICROSCOPIC MAGNIFICATION

Ocular Objective	Nosepiece Objectives	Total Magnification	Magnification Label

Magnification _____

Fig 2: _____

Magnification _____

Fig 3: _____

Magnification _____

Fig 4: _____

Magnification _____

Fig 5: _____

Observation 1:

Observation 2:

Observation 3:

Magnification _____

Fig 6: _____

Magnification _____

Fig 7: _____

Magnification _____

Fig 8: _____

Magnification _____

Fig 9: _____

Magnification _____

Fig 10: _____

Magnification _____

Fig 11: _____

Magnification _____

Fig 12: _____

CONCLUSIONS:

Summarize what you learned in this experiment and make connections to the text.