7.1 Life from Life

Figure 7.1 shows maggots hatching from the fly’s eggs. Where did these maggots come from? For a long time, people believed that maggots arose spontaneously from rotting material. The theory of spontaneous generation, or abiogenesis, was widely accepted for over 2000 years. This theory explained how mice seemed to develop suddenly in a pile of wheat husks or why frogs would appear in mud. Aristotle based his support for this explanation of the origin of life on many such observations. However, Aristotle did not check the validity of his hypothesis. That is, he did not conduct experiments to test his idea that some types of animals arose by spontaneous generation.

Redi’s Controlled Experiment

An Italian physician, Francesco Redi (1626–1697), was the first person to use scientific experiments to test the theory of spontaneous generation. He suspected that the maggots that appeared on rotting meat did not actually arise from the meat itself. Redi had observed flies depositing objects on the meat. He hypothesized that maggots hatched from the objects dropped by the flies.

In 1668, he tested his idea by performing a simple controlled experiment. Redi placed pieces of meat into two glass jars, as shown in Figure 7.2 on the next page. He tightly covered one jar with a piece of cloth that let air pass through but kept out flies. He left the other jar open, making the meat accessible to flies. A few days later, he inspected the jars’ contents. If maggots could arise on the rotting meat through spontaneous generation, then both jars should have contained maggots. In fact, maggots squirmed over the meat in the open jar. In the cloth-covered jar, however, no maggots developed. This experiment convinced Redi that maggots found in rotting meat were not produced by spontaneous generation.

As you will read on page 262, the discovery of microscopic single-celled organisms occurred only a few years after Redi’s experiments. Ironically, this discovery renewed the debate over spontaneous generation. Some scientists considered micro-organisms as new evidence for spontaneous generation. Such organisms could not reproduce in the manner of flies. How else would new micro-organisms be produced, it was argued, if not by spontaneous generation? Many people believed an “active principle” in the air created the micro-organisms. For another 200 years, people debated their differing theories.
Pasteur's Evidence

French scientist Louis Pasteur (1822–1895) was convinced that spontaneous generation did not occur. Many people were interested in micro-organisms, but Pasteur was curious about what these unicellular organisms did. For instance, he studied fermentation, the biochemical process that sours milk. In other cases, fermentation converts grape juice into wine and barley into beer. From previous studies and his own experiments, Pasteur knew that living micro-organisms carried out fermentation.

Pasteur hypothesized that the so-called “active principle” in air was also an organism. To test his idea, he designed a glass flask with a long, S-shaped neck (see Figure 7.3). He filled a number of the “swan-neck flasks” with nutrient-rich broth and boiled them to force out air and kill any microbes. As each flask cooled, fresh air was drawn in and moisture condensed in the curve of the neck. Pasteur predicted that air entering the neck of the flask would contain micro-organisms, but that they would settle by gravity in the neck and never reach the broth. The results of his experiment showed that his hypothesis was valid. Several days after broth was boiled in the flask, the broth remained clear. Even in the presence of air, no organisms appeared in the broth. If the flask was tilted to bring the broth in contact with the neck, however, the broth quickly became clouded with micro-organisms.

Pasteur conducted other experiments in which he purposely placed small amounts of micro-organisms in nutrient broth. The process was much like planting seeds. The micro-organisms produced more micro-organisms. Using a microscope, Pasteur was able to observe the microbes multiplying.

Other scientists also questioned the theory of spontaneous generation. Instead, they believed in biogenesis, the theory that living organisms could arise only from other living organisms. German physician Rudolf Virchow (1821–1902) suggested the theory in 1858. Pasteur's experiments provided supporting evidence for biogenesis. In the investigation on the next page, you will compare the ideas and experiments of Aristotle, Redi, and Pasteur.
Evaluating Spontaneous Generation

Think About It

How do we know where living things come from? How can we determine whether micro-organisms are present if they are too small to see without microscopes? The ideas and experiments of Aristotle, Redi, and Pasteur illustrate ways of using observations, hypotheses, predictions, and experiments to develop scientific knowledge. In this investigation, you will examine how these methods were used to create arguments both for and against spontaneous generation.

What to Do

1. Working in a small group, collect information about the ideas and work of Aristotle, Redi, and Pasteur. Use the information in this chapter to identify each of the following elements of their research. For each scientist, identify:
   - Observations
   - Hypothesis
   - Predictions
   - Experimental design
   - Experimental results
   - Conclusions

2. Organize the information you have collected in a table. Note: Not every cell in your table will contain data. Some researchers used observations only, whereas others used observations and experiments to develop their ideas.

Analyze

1. Compare and contrast the approaches of the three scientists. How were they similar? How did they differ?

2. Evaluate the quality of the evidence the researchers used to back each of their arguments.
   - (a) What were the experimental controls?
   - (b) In what way did the evidence support the researchers’ conclusions?
   - (c) Which, if any, of the scientists’ arguments are the most convincing? Explain why.

3. How did each researcher’s work change our knowledge about life?

4. Apply Some fungi, such as the earth-star, produce millions of spores. If a spore lands where nutrients are available, it starts to grow. What might have led early scientists to conclude that fungi could be produced by spontaneous generation?

Extend Your Skills

5. Experiments can provide clear answers to some questions. They also often generate new questions. Identify a new question that Aristotle, Redi, and Pasteur might have left unanswered. Propose a hypothesis, a prediction, and a controlled experiment to answer the question. What are some possible outcomes of the experiment? Present your ideas to the class.
Discovering Cells

Scientists could learn only so much by making observations with their unaided eyes. Imagine, for instance, how difficult it would have been to conceive of germs without being able to see them! Gradually, however, scientists learned more about the details of the living and non-living world. The invention of microscopes made it possible to magnify objects and observe them in greater and greater detail. Tools and methods for growing micro-organisms were invented and refined. By examining this microscopic world, scientists were able to answer many questions about the structure of organisms. Eventually, scientists concluded that all living things are composed of cells (the smallest functional units of life). However, the first researchers to observe cells with microscopes had little concept of what they were seeing. As you will learn, some scientists never understood the groundbreaking nature of their own discoveries.

View the micrographs in Figure 7.4, which are in chronological order. These micrographs represent what early scientists may have observed. How did the images — and the information they provided — change over time? Answer this question in your notebook.

A Cork cells, such as those pictured here, were first observed in the mid-1600s.

B These are pond-water organisms. Microscopic observations of similar organisms were first described by the 1670s.

C Scientists in the 1820s–1830s relied on microscopes to observe plant tissues closely. The nucleus of the plant cell was described in 1831, and the cytoplasm in 1836.

D By 1839 microscopic examination of animal tissues led researchers to the important conclusion that all animals are made of cells.

Figure 7.4 Early users of microscopes were able to view individual cells and observe basic structures never seen before. By today’s standards these scientists saw little detail. However, their observations would eventually lead scientists to the knowledge that all living things are made of cells.
Developing the Cell Theory

Ideas about the scientific basis of life have changed a great deal throughout history. The discovery of cells was a breakthrough that shed new light on how healthy organisms function and what can make them unhealthy. Today, scientists' understanding of cells continues to grow. How are discoveries about cells made? How are one observer's ideas transformed into a widely accepted theory?

Over time, researchers have collected evidence about the structures and functions of living things. They have communicated their findings to other scientists, who have repeated their observations and tested their ideas. As new information has become available, scientists have expanded and revised their explanations. The invention of new technologies, such as the microscope, has helped scientists to overcome limits to their understanding. This process led to our current understanding of the cellular basis of life.

Hooke's Discovery

Over 300 years ago, an English scientist named Robert Hooke (1635–1703) looked at thin slices of cork from the bark of an oak tree under a crude compound light microscope. His microscope had a magnification of about 30×. To Hooke, it looked as if the cork was made up of hundreds of empty boxes or tiny rooms (see Figure 7.5). Because they reminded him of monks' small rooms or cells in a monastery, he named the structures "cells." Hooke did not know that he was looking at the walls of dead cells. It would take decades to confirm that cells were common to all organisms. As a result, Hooke never realized the significance of his own discovery.

Hooke published drawings and descriptions of the cells in a book entitled *Micrographia*. When other scientists read about his observations, they were encouraged to develop his work further. They began to look for cells in other organisms.

A Miniature World

In 1674, a Dutch linen merchant named Antony van Leeuwenhoek (1632–1723) became the first person to describe single-celled micro-organisms. He studied blood cells, pond-water organisms, and matter scraped from his teeth. Van Leeuwenhoek's hobby was making magnifying lenses. He performed his studies with a single-lens microscope that he had built himself (see Figure 7.6). His skillfully constructed lenses had magnifications of up to 500×. Of the matter scraped from his teeth, van Leeuwenhoek wrote, "There were many very little living animalcules, very prettily a-moving." His "animalcule" sightings were among the first observations of single-celled organisms.

Van Leeuwenhoek, who had been inspired by Hooke's writings, also wrote about his own observations. His letters were printed in *Philosophical Transactions of the Royal Society of London*, a scholarly journal that continues to publish new scientific research today. The public was excited by his ideas. Some scientists who learned of these discoveries hoped that they could explain the basis of life.

**Figure 7.5** Robert Hooke's drawing of cork cells, published in his book *Micrographia* in 1665.

**Figure 7.6** Antony van Leeuwenhoek observed a variety of cells with his simple microscope (top image), including relatively small cells (shown just above in his drawing). These smaller cells were probably bacteria.

Write a note to suggest why van Leeuwenhoek called the cells he viewed "animalcules. Check a dictionary based on historical principles to see if you were correct.
The Stuff of Life

People often comment, "Two heads are better than one." This is especially true of science. Scientific discovery often advances when investigators share knowledge. Two German scientists, Matthias Jakob Schleiden (1804–1881) and Theodor Schwann (1810–1882), came to an important conclusion after comparing their results.

Like many other scientists of their day, Schwann and Schleiden believed that the way to understand life was to understand how it developed. After studying cells in hundreds of plants, Schleiden concluded that all plants are composed of cells and the materials produced by cells. In very young cells, Schleiden consistently observed nuclei. He concluded that each new cell developed from the nucleus. Schleiden described his findings to his colleague Schwann. The animal tissues Schwann studied under the microscope did not closely resemble plant cells. Schleiden's description of plant nuclei, however, reminded Schwann of objects he had observed in developing animal tissues. Schwann reasoned that where there were nuclei, there were cells.

Based on his hypothesis and his observations of animal tissues, Schwann concluded that animal tissues contained cells. In 1839, he argued that all organisms contain cells. "There is one universal principle of development for the elementary parts of organisms, however different," said Schwann, "and this principle is the formation of cells." Schwann had stated the first principle of what came to be known as the cell theory: all organisms are composed of one or more cells.

Other scientists began testing Schwann's claim for themselves. In their studies of other organisms, they repeated his findings. By doing so, they provided supporting evidence for Schwann's hypothesis.

Cells from Cells

Schleiden and Schwann thought that cells formed from the crystallization of non-living materials or by budding from the surfaces of other cells. However, they did not test these hypotheses. The German physician Rudolf Virchow corrected these misconceptions. Virchow showed in experiments that bone cells could develop from cartilage cells. He also made microscopic observations of dividing cells from multicellular organisms. He concluded that cells divide to produce more cells. "Where a cell exists, there must have been a pre-existing cell," said Virchow.

The Cell Theory

The observations of the researchers discussed in this section have been replicated and reconfirmed many times. These conclusions form the basis of an important theory. The cell theory states the following:

1. All organisms are composed of one or more cells.
2. The cell is the smallest functional unit of life.
3. All cells are produced from other cells.

There are important differences among plant cells, animal cells, and single-celled organisms. Even so, all cells share several basic similarities. You will look at some cells in the next activity. In the next section you will also look at some non-cellular structures that have some properties of life.

WordConnect

Using a dictionary or other resource, look up the roots of the word "biogenesis." Write a literal meaning for "biogenesis" in your notebook.

Figure 7.7: Rudolf Virchow was a supporter of the theory of biogenesis. He critized Schwann's and Schleiden's ideas about the origin of cells because the crystallization of non-living materials implied that cells are created by spontaneous generation.
Find Out

The Diversity of Cells

How do the structures of different kinds of single-celled organisms relate to their functions? How do different types of structures enable cells to carry out similar activities? Follow the steps below to observe different methods of locomotion in single-celled organisms in pond water.

Safety Precautions

- Be careful when using sharp objects such as tweezers.
- Dispose of your materials according to your teacher's instructions.

Materials

- chicken egg
- beaker
- microscope
- transparent plastic ruler
- cotton batting
- tweezers
- microscope slide
- medicine dropper
- pond water
- cover slip
- prepared slides of typical pond organisms

Procedure

1. Some cells, such as chicken eggs, are large enough to see with the unaided eye. Examine the chicken egg in the beaker.

2. Before examining samples under the microscope, use the plastic ruler to measure the field of view at low power.

3. Pull two or three fibres from the cotton batting. Using tweezers, spread the fibres across the centre of a clean microscope slide.

4. Using a medicine dropper, place one drop of pond water in the centre of the slide, on top of the cotton threads. The fibres will slow the movement of organisms in the pond water.

5. Place a cover slip over the sample.

6. Study the pond water under low power on the microscope. Draw three or more cells. Estimate the size of one of the cells based on the diameter of the field of view.

7. Turn to medium power. Again, estimate the size of one of the cells. Draw and describe any internal or external structures that you can see. Repeat this step at high power.

8. Remove the pond-water sample and replace it with a prepared slide of a pond organism. Repeat steps 6 and 7 with the prepared slide.

9. Wash your hands when you have completed the activity and cleaned up your work area.

What Did You Find Out?

1. Were the estimated sizes of the animal cells the same for low, medium, and high power?

2. Other than size, what are the differences between the structure of the egg and other cells that you observed?

3. What differences did you observe between the pond organisms in the prepared slides and the pond-water organisms?

4. Compare the movement of the different pond-water organisms. What structures did they use for locomotion?

Extension

5. Relate the different structures of the cells you observed to their different functions.
Section 7.1 Summary

In this section, you learned how observations, scientific experiments, and the invention of the microscope have led to the discovery of cells, the smallest functional units of life. You have been introduced to several influential scientists whose observations and experiments all contributed to the understanding of cells. Their work resulted in the cell theory, which states:

1. All organisms are composed of one or more cells.
2. The cell is the smallest functional unit of life.
3. All cells are produced from other cells.

Check Your Understanding

1. List the five characteristics of living organisms.
2. Compare and contrast the theory of biogenesis with the concept of spontaneous generation.
3. Describe the three major principles that constitute the cell theory.
4. Describe Rudolf Virchow's contribution to the cell theory.
5. What microscopic observations provided evidence for the theory of biogenesis?
6. Thinking Critically Why is communication, such as through oral presentations or written publications, essential to the development of knowledge in science?
7. Apply Imagine that you have discovered a new organism on another planet. Describe an experiment that you could do to determine if the organism is composed of cells.
8. Thinking Critically Review Figure 7.4.
   (a) What conclusions can you draw about the make-up of living organisms based on the information provided by the images?
   (b) Can you generalize your conclusions to other types of organisms? Why or why not?
9. Thinking Critically
   (a) How would you design an experiment to test the hypothesis that wasps found living in a backyard composter were produced by spontaneous generation?
   (b) What would be an alternative explanation for the source of the wasps?
10. Apply If a microscope was unavailable, a researcher might infer that an organism exists by making observations of the organism's effects on its surroundings. Describe one simple experiment that you could do to determine whether microscopic organisms are present in a sample of pond water.
11. Thinking Critically Virchow knew that single-celled organisms, such as yeast, could multiply to produce more similar organisms. What might these findings have suggested to Virchow about growth in multicellular organisms?