1.1: Chemistry - The Central Science

Learning Objectives

- Define chemistry in relation to other sciences.
- Use physical and chemical properties, including phase, to describe matter.

Chemistry is the study of matter—what it consists of, what its properties are, and how it changes. Being able to describe the ingredients in a cake and how they change when the cake is baked is called chemistry. Matter is anything that has mass and takes up space—that is, anything that is physically real. Some things are easily identified as matter—this book, for example. Others are not so obvious. Because we move so easily through air, we sometimes forget that it, too, is matter.

Chemistry is one branch of science. Science is the process by which we learn about the natural universe by observing, testing, and then generating models that explain our observations. Because the physical universe is so vast, there are many different branches of science (Figure 1.1.1). Thus, chemistry is the study of matter, biology is the study of living things, and geology is the study of rocks and the earth. Mathematics is the language of science, and we will use it to communicate some of the ideas of chemistry.

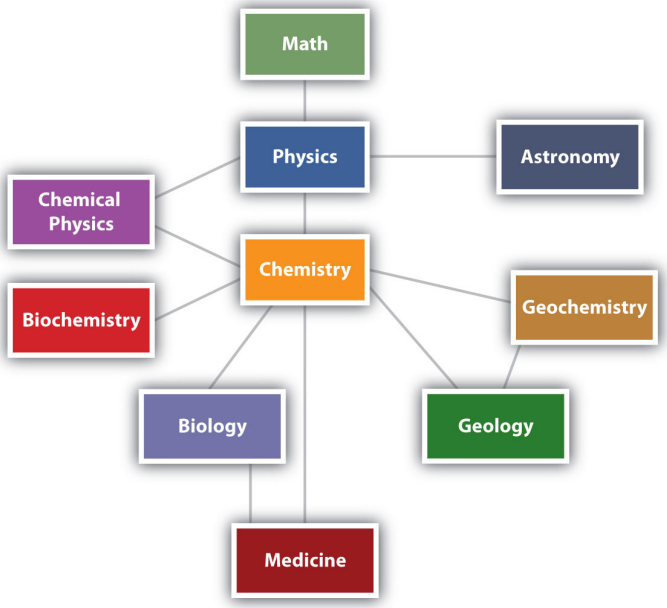

Figure 1.1.1: The Relationships between Some of the Major Branches of Science. Chemistry lies more or less in the middle, which emphasizes its importance to many branches of science. (CC BY-SA-NC; anonymous)

Although we divide science into different fields, there is much overlap among them. For example, some biologists and chemists work in both fields so much that their work is called biochemistry. Similarly, geology and chemistry overlap in the field called geochemistry. Figure 1.1.1 shows how many of the individual fields of science are related; there are many other fields of science in addition to the ones listed here.

How do scientists work? Generally, they follow a process called the **scientific method**. The scientific method is an organized procedure for learning answers to questions and making explanations for observations. The steps of the scientific method may not be as clear-cut in real life as described here, but most scientific work follows this general outline.

1. **Propose a hypothesis.** A scientist generates a testable idea, or hypothesis, to try to answer a question or explain an observation about how the natural universe works. Some people use the word *theory* in place of hypothesis, but the word hypothesis is the proper word in science. For scientific applications, the word theory is a general statement that describes a large set of observations and data. A theory represents the highest level of scientific understanding.
2. **Test the hypothesis.** A scientist evaluates the hypothesis by devising and carrying out experiments to test it. If the hypothesis passes the test, it may be a proper answer to the question. If the hypothesis does not pass the test, it may not be a good answer.
3. **Refine the hypothesis if necessary.** Depending on the results of experiments, a scientist may want to modify the hypothesis and then test it again. Sometimes the results show the original hypothesis to be completely wrong, in which case a scientist will

have to devise a new hypothesis.

Not all scientific investigations are simple enough to be separated into these three discrete steps. But these steps represent the general method by which scientists learn about our natural universe.

Physical and Chemical Properties and Changes

The properties that chemists use to describe matter fall into two general categories. **Physical properties** are characteristics that describe matter. They include characteristics such as size, shape, color, and mass. These characteristics can be observed or measured without changing the *identity* of the matter in question. **Chemical properties** are characteristics that describe how matter changes its chemical structure or composition. An example of a chemical property is flammability—a material's ability to burn—because burning (also known as combustion) changes the chemical composition of a material. The observation of chemical properties involves a *chemical change* of the matter in question, resulting in matter with a different *identity* and different physical and chemical properties. Part of understanding matter is being able to describe it. One way chemists describe matter is to assign different kinds of properties to different categories.

Figure 1.1.1: (left) Ice Melting is a physical change. When liquid water (H_2O) freezes into a solid state (ice), it appears changed; However, this change is only physical as the the composition of the constituent molecules is the same: 11.19% hydrogen and 88.81% oxygen by mass. (right) Burning of wax to generate water and carbon dioxide is a chemical reaction. (CC SA-BY-3.0; Andrikkos)

We know from our experience with water that substances can change from one phase to another if the conditions are right. Typically, varying the temperature of a substance (and, less commonly, the pressure exerted on it) can cause a physical process in which a substance changes from one phase to another. Examples are summarized in Table 1.1.1.

Table 1.1.1: Physical Changes

Change	Name
solid to liquid	melting, fusion
solid to gas	sublimation
liquid to gas	boiling, evaporation
liquid to solid	solidification, freezing
gas to liquid	condensation
gas to solid	deposition

The difference between a physical reaction and a chemical reaction is **composition**. In a chemical reaction, there is a change in the composition of the substances in question; in a **physical change** there is a difference in the appearance, smell, or simple display of a sample of matter without a change in composition. Although we call them physical "reactions," no reaction is actually occurring. In order for a reaction to take place, there must be a change in the elemental composition of the substance in question. Thus, we shall simply refer to "physical reactions" as physical changes from now on.

Example 1.1.1

Classify each of the following changes as physical or chemical:

a. condensation of steam
b. burning of gasoline
c. souring of milk
d. dissolving of sugar in water
e. melting of gold

Solution

The best way to determine whether a change is physical or chemical is to determine if the substance identity has changed or not.

a. Steam is water in the gas phase. When it condenses, changes from gas to liquid, it remains water. Therefore, this is a **physical** change.
b. When gasoline burns, it changes into different substances. This is a **chemical** change.
c. When milk becomes sour, several **chemical** changes have occured; proteins denature, sugars break down, and acid is produced. The milk is now made up of different substances.
d. Sugar dissolves easily into water but it still remains sugar. If the water is evaporated, the sugar will recrystalize as a solid again. Dissolving is a **physical** change, the substance does not change identity.
e. Melting solid gold into liquid gold is a **physical** change much like melting solid water (an ice cube) into liquid water is a physical change.

Exercise 1.1.1

Classify each of the following changes as physical or chemical:

a. coal burning
b. ice melting
c. mixing chocolate syrup with milk
d. explosion of a firecracker
e. magnetizing of a screwdriver

Answer a:
chemical
Answer b:
physical
Answer c:
physical
Answer d:
chemical
Answer e:
physical

Key Takeaways

- Chemistry is the study of matter and how it behaves.
- The scientific method is the general process by which we learn about the natural universe.
- When a substance changes from one state to another, this is a physical change.
- If a substance undergoes a change into one or more different substances, this is a chemical change.