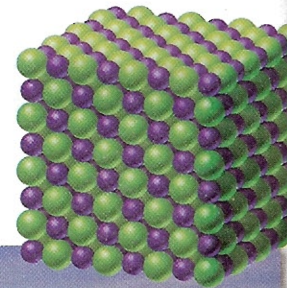
CHAPTER

# 1 Introduction to Chemistry





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Thousands of years ago, a giant salt lake dried up leaving a salt desert in what is now Bolivia. These piles of salt account for 25,000 tons of salt annually from a deposit of 10,000,000,000 tons.

*"There are in fact two things, science and opinion; the former begets knowledge, the latter ignorance."*
Hippocrates, Greek Physician (ca. 460–377 B.C.)

In the United States, Canada, and other developed countries, we enjoy a standard of living that could not have been imagined a century ago. Owing to the evolution of science and technology, we have abundant harvests, live in comfortable, climate-controlled buildings, and travel the world via automobiles and airplanes. We also have extended life spans free of many diseases that previously ravaged humanity.

The development of technology has provided machinery and equipment to perform tedious tasks, which gives us time for more interesting activities. The arrival of the computer chip has given us electronic appliances that afford ready convenience and dazzling entertainment. We can select from a multitude of audio and video resources that offer remarkable sound and brilliant color. We can access these audio and video resources from the internet or a compact disc (Figure 1.1).

Our present standard of living requires scientists and technicians with educational training in chemistry. The health sciences as well as the life sciences, physical sciences,

◀ **Figure 1.1 Compact Disc** A laser beam reflects off the surface of the compact disc to read the information on the CD; for example, the information can be printed text, musical sounds, or visual images.

and earth sciences demand an understanding of chemical principles. In fact, chemistry is sometimes referred to as the central science because it stands at the crossroads of biology, physics, geology, and medicine. Just as personal computers are becoming indispensable in our everyday activities, chemistry is assuming an essential role in our daily lives.

## 1.1 EVOLUTION OF CHEMISTRY

**OBJECTIVES**

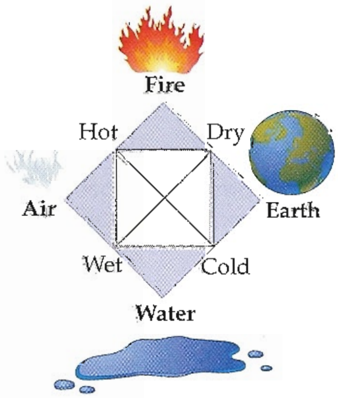
- To describe the early practice of chemistry.
- To identify the three steps in the scientific method.

The earliest concept of science began with the ancient Chinese, Egyptian, and Greek civilizations. The Chinese believed that the universe was created from the interaction of two forces. Yin, the feminine force, was manifested in darkness, cold, and wetness. Yang, the masculine force, was manifested in light, heat, and dryness. When the yin and yang forces interacted, they brought the earthly world into existence and were responsible for everything in nature.

As early as 600 B.C., the Greeks began to speculate that the universe was composed of a single element. Thales, the founder of Greek science, mathematics, and philosophy, suggested that water was the single element. He claimed that Earth was a dense, flat disc floating in a universe of water. He also believed that air and space were less dense forms of water.

A few years later, another Greek philosopher proposed that air was the basic element. This theory was followed by the proposals that fire, and later earth, was the basic element. About 450 B.C., the Greek philosopher Empedocles observed that when wood burned, smoke was released (air), followed by a flame (fire). He also noticed that a cool surface held over a fire collected moisture (water) and that the only remains were ashes (earth). Empedocles interpreted his observations as evidence for air, fire, water, and earth as basic elements. He further speculated that other substances were examples of these four elements combined in varying proportions as illustrated in Figure 1.2.

In about 350 B.C., Aristotle adopted the idea that air, earth, fire, and water were basic elements. In addition, he added a fifth element, ether, that he believed filled all space. Aristotle's influence was so great that his opinions dominated other Greek philosophers and shaped our understanding of nature for nearly 2000 years.




▲ **Figure 1.2 The Four Greek Elements** The four elements proposed by the Greeks: air, earth, fire, and water. Notice the properties hot, cold, wet, and dry associated with each element.

### The Scientific Method

In 1661, the English scientist Robert Boyle (1627–1691) published *The Sceptical Chymist*. In his classic book, Boyle stated that theoretical speculation was worthless unless it was supported by experimental evidence. This principle led to development of the scientific method, which marked a turning point in scientific inquiry and the beginning of modern science.

**Science** can be defined as the methodical exploration of nature followed by a logical explanation of the observations. The practice of science entails planning an investigation, carefully recording observations, gathering data, and analyzing the results. In an **experiment**, scientists explore nature according to a planned strategy and make observations under controlled conditions.

The **scientific method** is a systematic investigation of nature and requires proposing an explanation for the results of an experiment in the form of a general principle. The initial, tentative proposal of a scientific principle is called a **hypothesis**.

After further experimentation, the initial hypothesis may be rejected, modified, or elevated to the status of a scientific principle. However, for a hypothesis to become a scientific principle, many additional experiments must support and verify the original proposal. Only after there is sufficient evidence does a hypothesis rise to the level of a scientific **theory**. We can summarize the three steps in the scientific method as follows:


▲ **Robert Boyle** This stamp honors Boyle for his invention of the vacuum pump in 1659. Boyle's classic textbook, *The Sceptical Chymist*, laid the foundation for the scientific method.

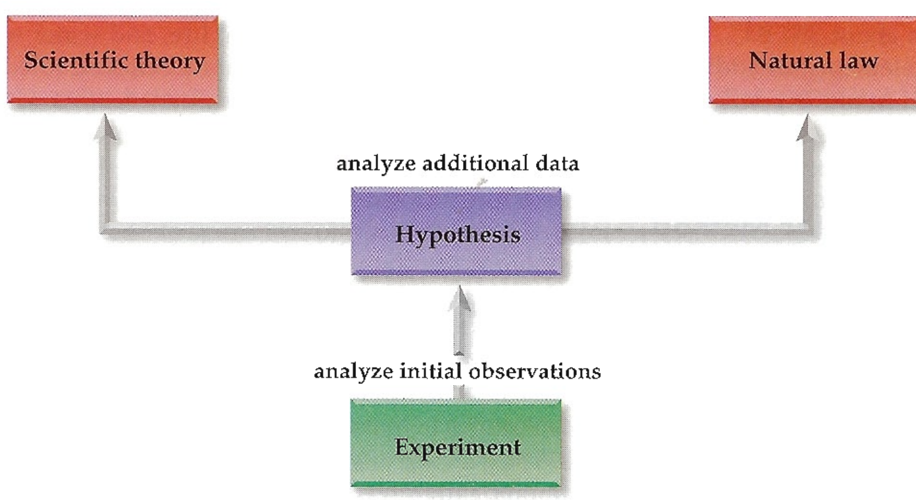
## Applying the Scientific Method

**Step 1:** Perform a planned experiment, make observations, and record data.
**Step 2:** Analyze the data and propose a tentative hypothesis to explain the experimental observations.
**Step 3:** Conduct additional experiments to test the hypothesis. If the evidence supports the initial proposal, the hypothesis may become a theory.

We should note that scientists exercise caution before accepting a theory. Experience has shown that nature reveals its secrets slowly and only after considerable probing. A scientific theory is not accepted until rigorous testing has established that the hypothesis is a valid interpretation of the evidence. For example, in 1803, John Dalton (1766–1844) proposed that all matter was composed of small, indivisible particles called atoms. However, it took nearly 100 years of gathering additional evidence before his proposal was universally accepted and elevated to the status of the atomic theory.

Although the terms "theory" and "law" are related, there is a distinction between the two terms. A theory is a model that explains the behavior of nature. A **natural law** does not explain behavior, but rather states a measurable relationship. To illustrate, it is a *law* that heat flows from a hotter object to a cooler one because we can measure experimentally the change in temperature if we drop an ice cube into water. It is a *theory* that the transfer of heat is due to changes in the motion of molecules in the ice and water.

We can distinguish between a theory and a law by simply asking the question, "Is the proposal measurable?" If the answer is yes, the statement is a law; otherwise, the statement is a theory. Figure 1.3 summarizes the relationship of a hypothesis, a scientific theory, and a natural law.




▶ **Figure 1.3 The Scientific Method** The initial observations from an experiment are analyzed and formulated into a hypothesis. Next, additional data is collected from experiments conducted under various conditions and the data is analyzed. If the additional data supports the initial proposal, the hypothesis may be elevated to a scientific theory or a natural law.

## CRITICAL THINKING Rise and Fall of a Theory

**Q: What is the difference between wood burning, iron rusting, and gasoline exploding?**

In the late seventeenth century, the *phlogiston theory* was proposed to explain how matter underwent combustion. The theory stated that for a material to burn it must contain phlogiston (from the Greek *phlogistos*, meaning flammable), which was believed to be a colorless, odorless essence. Through the process of burning, a material was reduced to a substance called calx. According to the theory, calx was a basic element that had lost phlogiston. For example, wood burns to an ash (calx) after losing phlogiston. Similarly, iron is reduced to rust (calx) after releasing phlogiston.

Oxygen was first discovered by the Swedish chemist Carl Scheele (1742–1786), although he did not publish his work. In 1774, the English chemist Joseph Priestley (1733–1804) rediscovered the element, published his finding, and is usually given credit for the discovery of oxygen. However, it was the French chemist Antoine Lavoisier who gave us the name oxygen for the element.

As time passed, skeptics began to doubt the phlogiston theory. They pointed out that metals, such as magnesium, *gain* mass when they burn even though they *lose* phlogiston. Some defenders of the theory explained that phlogiston was lighter than air. Other die-hard proponents suggested that phlogiston had negative mass.

The phlogiston theory remained credible until Lavoisier showed that combustion requires oxygen gas from the air in order to burn. In the late eighteenth century, Lavoisier conducted experiments in which he burned yellow sulfur in a closed container and simultaneously burned yellow sulfur in an open container. He found that the sulfur in the closed container stopped burning, while the sulfur exposed to air continued to burn. He also observed that the product weighed more than the original sulfur, thus offering evidence that sulfur gained mass when it combined with oxygen from the air.

The study of combustion is a good example of how scientists apply critical thinking and the scientific method in order to explore nature and unravel the truth of its most closely guarded secrets.

▲ **Combustion** We observe burning when wood combines with oxygen from the air, not when wood loses phlogiston.

**A: Wood burning, iron rusting, and gasoline exploding are all examples of combustion. That is, wood, iron, and gasoline are combining with oxygen gas from the air. Burning is rapid, rusting is a slow process, and an explosion is instantaneous.**

## 1.2 MODERN CHEMISTRY

**OBJECTIVE**

- To describe the modern practice of chemistry.

In the A.D. eighth century, the Arabs introduced the pseudoscience of **alchemy**. Alchemists conducted simple experiments and believed in the existence of a magic potion that had miraculous healing powers and could transmute lead into gold. Although alchemy did not withstand the test of time, it preceded the planned, systematic, scientific experiments that are the cornerstone of modern chemical research.

In the late eighteenth century, the French chemist Antoine Lavoisier (1743–1794) organized chemistry and wrote two important textbooks. Lavoisier also built a magnificent laboratory and invited scientists from around the world to view it; his many visitors included Benjamin Franklin and Thomas Jefferson. Lavoisier was a prolific experimenter and published his work in several languages. For his numerous contributions, he is considered the founder of modern chemistry.

Today, we can define **chemistry** as the science that studies the composition of matter and its properties. Chemists have accumulated so much information during the past two centuries that we now divide the subject into several branches or specialties. The branch of chemistry that studies substances containing the element carbon is called **organic chemistry**. The study of all other substances, those that do not contain the element carbon, is called **inorganic chemistry**.

The branch of chemistry that studies substances derived from plants and animals is called **biochemistry**. Another branch, analytical chemistry, includes qualitative analysis (what substances are in a sample) and quantitative analysis (how much of each substance is present). Physical chemistry is a specialty that proposes theoretical and mathematical explanations for chemical behavior. Recently, environmental chemistry has become an important specialty that focuses on the safe disposal of chemical waste.

Chemistry plays a meaningful role in medicine, especially in the dispensing of pharmaceutical prescriptions. Chemists help ensure agricultural harvests by formulating fertilizers and pesticides. Chemistry is indispensable to many industries including the manufacture of automobiles, electronic components, aluminum, steel, paper, and plastics. One of the largest industries is the petrochemical industry. Petrochemicals are chemicals derived from petroleum and natural gas. They can be used to manufacture a wide assortment of consumer products including paints, plastics, rubber, textiles, dyes, detergents, and explosives.

In each chapter of this textbook, you will find example exercises that put learning into action. Each example exercise poses a question and shows the solution. There is

## CHEMISTRY CONNECTION "Worth Your Salt?"

**Q: What are the sources of ordinary table salt?**

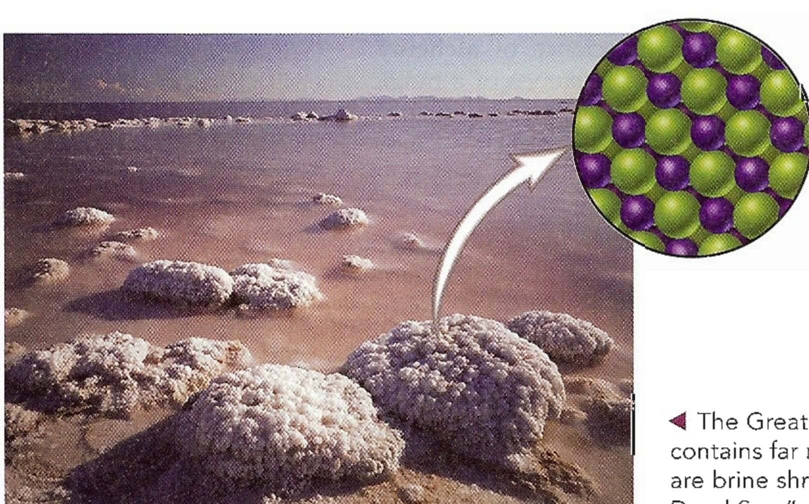
The uses for salt predate modern history. In the ancient world, towns and settlements were near salt reservoirs, as salt is a dietary necessity and a food preservative. Hippocrates, the Greek founder of medicine, urged physicians to soak their patients in salt water as treatment for various ailments. Since most natural salt is not suitable for consumption, pure salt was a rare and valuable commodity. So called "salt roads" were used by caravans of camels to transport salt long distances in trade for gold and textiles.

The familiar phrases "salt of the earth" and "worth your salt" refer to people who are deserving of respect. The origin of "worth your salt" goes back to Roman times when soldiers were given rations of salt and other necessities. These rations were referred to as *sal* (Latin, salt), and when soldiers were paid money, the stipend was called a salarium. Our modern term salary is derived from the phrase meaning "salt money."

Salt is a necessity in the diet of humans and animals, but toxic to most plants. Table salt comes from three sources: (1) salt mining, (2) solution mining, and (3) solar evaporation of salt water. The United States and Canada have extensive deposits of salt, and the Great Salt Lake in Utah is so concentrated and dense that humans easily float.

(1) In salt mining, salt is obtained by drilling shafts deep into the earth. The salt is excavated using a "room and pillar" system of mining that offers support while the salt is removed. After crushing, the salt is hauled to the surface on conveyor belts. (2) In solution mining, wells are placed over salt beds and water is injected to dissolve the salt. The resulting salt solution is pumped to a nearby plant for evaporation. The brine is then evaporated to dryness and refined. (3) Salt can also be obtained by the solar evaporation of seawater and salt lakes. The wind and sun evaporate the water in shallow pools, leaving solid salt. The salt is collected when the crust reaches a certain thickness; the salt is then washed and allowed to recrystallize.

Table salt (99% sodium chloride) is necessary in the human diet; however, too much sodium has been linked to high blood pressure that can lead to diabetes and heart problems. A teaspoon of salt contains approximately 2400 mg of sodium. Surprisingly, most salt in the human diet does not come from table salt, but from processed foods, especially ketchup, pickles, snack foods, and soy sauce. Table salt contains iodine in the form of potassium iodide. Humans require iodine in small quantities for proper function of the thyroid gland. The hormone thyroxine, which contains iodine, is largely responsible for maintaining our metabolic rate. The amount of iodine in one teaspoon of iodized table salt contains about 0.3 mg, which is twice the minimum recommended daily allowance (RDA).



◀ The Great Salt Lake was created in prehistoric times and contains far more salt than seawater. Although its habitat are brine shrimp and aquatic birds, it is called "America's Dead Sea."

**A: Table salt is obtained from mining rock salt, dissolving salt beds, and evaporating salt water.**

also a practice exercise and a concept exercise to further your understanding. Example Exercise 1.1 illustrates a topic question, practice exercise, and concept exercise.

### Example Exercise 1.1 Introduction to Chemistry

What is the difference between ancient chemistry and modern chemistry?

**Solution**

The principal difference is that modern chemistry is founded on the scientific method. Ancient chemistry was based on speculation, while modern chemistry is based on planned experiments and the analysis of data.

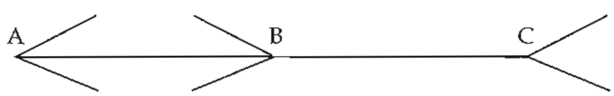
**Practice Exercise**

What question can we ask to distinguish between a scientific theory and a natural law?

***Answer:*** We can distinguish a theory from a law by asking the question, "Is the proposed statement measurable?" If we take measurements and verify a relationship by a mathematical equation, the statement is a law; if not, it is a theory.

**Concept Exercise**

Which of the line segments in the image below appears to be longer, AB or BC?




***Answer:*** See Appendix G


▲ **Antoine Lavoisier** This stamp honors Lavoisier for his numerous achievements, including the establishment of a magnificent laboratory that attracted scientists from around the world.

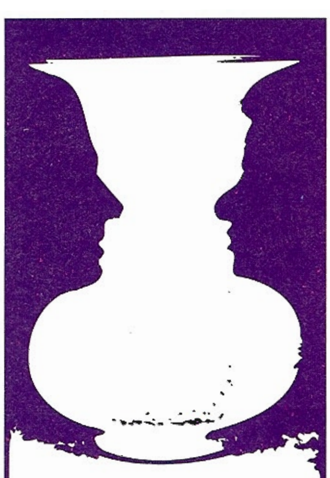
## 1.3 LEARNING CHEMISTRY

**OBJECTIVE**

▸ To appreciate that chemistry is an interesting and relevant subject.

In a survey published by the American Chemical Society, entering college students were asked to express their attitudes about science courses. The students rated chemistry as the most relevant science course, and as highly relevant to their daily lives. Unfortunately, many of the students thought chemistry is a difficult subject. In view of the results of the student survey, perhaps we should take a moment to consider perceptions in general, and attitudes about chemistry in particular.

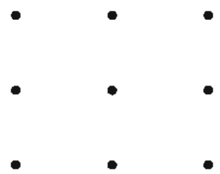
You are probably familiar with the expression that some people see a glass of water as half full, while others see the same glass as half empty. This expression implies that different people can respond to the same experience with optimism or pessimism. Moreover, experimental psychologists have found that they can use abstract visual images to discover underlying attitudes regarding a particular perception. A practical lesson involving two perceptions obtained from the same image is revealed by the following picture.



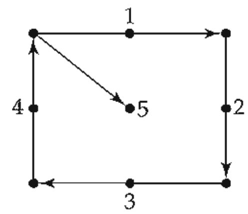
What do you see? Some students see a white vase on a dark background; others see two dark profiles facing each other. After a short period of time, one image switches to the other. If you concentrate, can you view only one of the images? Can you choose to switch the images back and forth? This exercise is an example of our brains registering dual perceptions from the same image.

Your experience of learning chemistry may be somewhat like the preceding exercise that tests your perspective. Sometimes your perception may be that chemistry is challenging, while a short time later your attitude may be that chemistry is easy and fun.

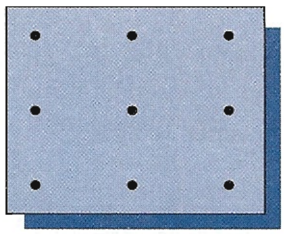
Perception is often affected by unconscious assumptions. Let's consider a type of problem that is slightly different from the vase perception. In the following problem try to connect each of the nine dots using only *four* straight, continuous lines.



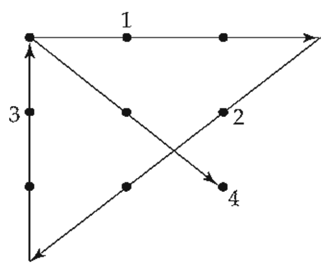
We can begin to solve the problem by experimenting. For example, let's start with the upper left dot and draw a line to the upper right dot. We can continue to draw straight lines as follows:



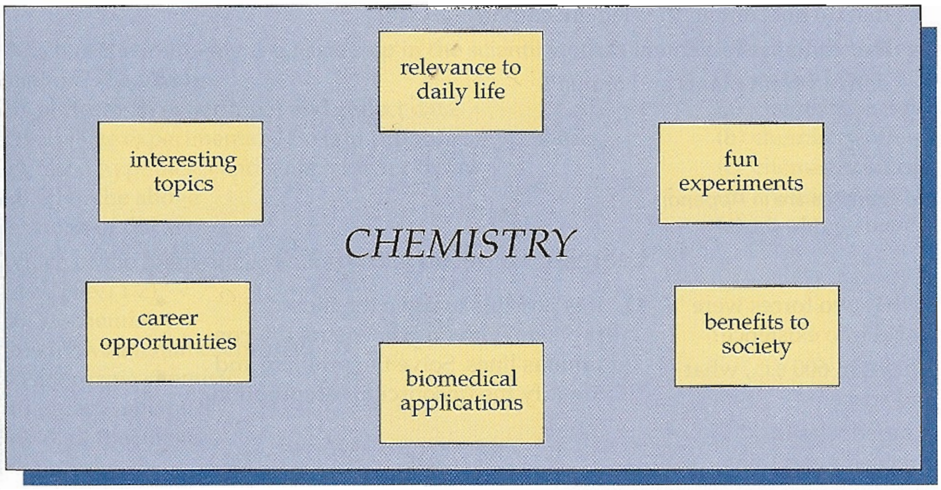

Notice that we connected the nine dots, but that it was necessary to use *five* straight, continuous lines. If we start with a different dot, we find that *five* lines are required no matter where we start. Perhaps we are bringing an underlying assumption to the nine-dot problem. That is, we may be unconsciously framing the nine dots, thus limiting the length of the four straight lines.



What will happen if we start with the upper left dot and draw a line through the upper right dot? If we continue, we can complete the problem with *four* straight, continuous lines as follows:



The "secret" to solving this nine-dot problem is to recognize that we may be unconsciously confining our thinking and making it impossible to solve. Similarly, we should not confine our concept of chemistry to a preconceived attitude that learning chemistry will be difficult. Or better yet, we should choose positive associations for our concept of chemistry.




## Summary

**Section 1.1** This chapter traces the development of chemistry from a historical point of view. Beginning in the period 600–350 B.C., the early Greeks used reason and thoughtful mental exercises to understand the laws of nature. Although they often arrived at conclusions based on speculation, they did unveil some of nature's secrets and had a profound influence on Western civilization that lasted for 20 centuries.

The term **science** implies a rigorous, systematic investigation of nature. Moreover, a scientist must accumulate significant evidence before attempting to explain the results. In the seventeenth century, Robert Boyle founded the **scientific method**, and laboratory experimentation became essential to an investigation. After an **experiment**, scientists use their observations to formulate an initial proposal, which is called a **hypothesis**. However, a hypothesis must be tested repeatedly before it is accepted as valid. After a hypothesis has withstood extensive testing, it becomes either a scientific **theory** or a **natural law**. A scientific theory is an accepted explanation for the behavior of nature, whereas a natural law states a relationship under different experimental conditions and is often expressed as a mathematical equation.

**Section 1.2** The pseudoscience of **alchemy** introduced the practice of laboratory experimentation and was the forerunner of modern **chemistry**. Today, chemistry is quite diverse and has several branches, including **inorganic chemistry**, **organic chemistry**, and **biochemistry**. The impact of chemistry is felt in medicine and agriculture, as well as in the electronics, pharmaceutical, petrochemical, and other industries.

**Section 1.3** In this section we examined some dual perceptions and pointed out that our brains have the ability to respond to the same image in two ways. Before beginning to learn chemistry, most students have already made associations with the subject. It is hoped that you will be able to focus on chemistry as being an interesting and relevant subject and put aside any preconceived limiting attitudes.

## Key Terms *Answers to Key Terms are in Appendix H.*

Select the key term that corresponds to each of the following definitions.

____ **1.** the methodical exploration of nature and the logical explanation of the observations

____ **2.** a scientific procedure for gathering data and recording observations under controlled conditions

____ **3.** a systematic investigation that entails performing an experiment, proposing a hypothesis, testing the hypothesis, and stating a theory or law

____ **4.** a tentative proposal of a scientific principle that attempts to explain the meaning of a set of data collected in an experiment

____ **5.** an extensively tested proposal of a scientific principle that explains the behavior of nature

**(a)** alchemy *(Sec. 1.2)*
**(b)** biochemistry *(Sec. 1.2)*
**(c)** chemistry *(Sec. 1.2)*
**(d)** experiment *(Sec. 1.1)*
**(e)** hypothesis *(Sec. 1.1)*
**(f)** inorganic chemistry *(Sec. 1.2)*
**(g)** natural law *(Sec. 1.1)*