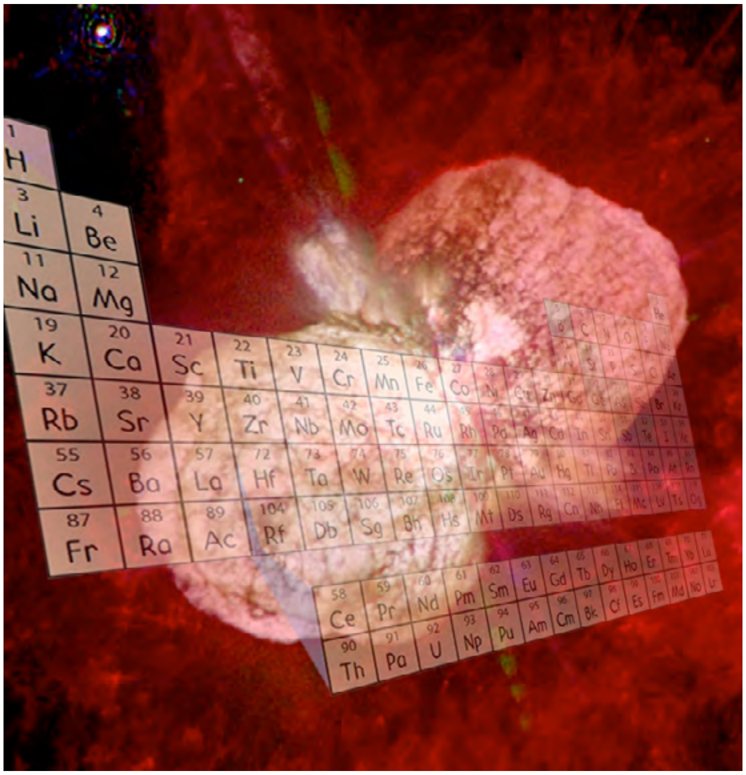


Chapter 2

Particles of Matter

THE MAIN IDEA

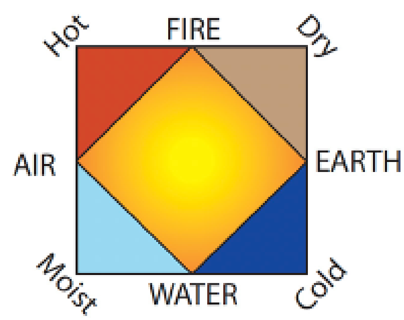
Matter is made of particles called atoms

2.2 Discovering the Atom

In the 4th century BCE, the influential Greek philosopher Aristotle described the composition and behavior of matter in terms of the four qualities shown in **Figure 2.3**: hot, cold, moist, and dry. Aristotle's model was a remarkable achievement for its day, and people using it in Aristotle's time found it made sense. When pottery is made, for example, wet clay changes to ceramic because the heat of the fire drives out the moist quality of the wet clay and replaces it with the dry quality of the ceramic.

Aristotle's views on the nature of matter made so much sense that less obvious views were difficult to accept. One alternative view was the forerunner of our present-day model: matter is composed of a finite number of incredibly small but discrete units we call atoms. This model was advanced by several Greek philosophers, including Democritus (460–370 BCE), who coined the term atom from the Greek phrase *a tomos*, which means "not cut" or "that which is indivisible" (**Figure 2.4**). So compelling was Aristotle's reputation, however, that the atomic model would not reappear for 2000 years.

According to Aristotle, it was theoretically possible to transform any substance to another substance simply by altering the relative proportions of the four basic qualities. This meant that, under the proper conditions, a metal like lead could be transformed to gold. This concept laid the foundation of alchemy, a field of study concerned primarily with finding potions that would produce gold or confer immortality. Alchemists from the time of Aristotle to as late as the 1600s tried in vain to convert various metals to gold. Despite the futility of their efforts, the alchemists learned much about the behavior of many chemicals and developed many useful laboratory techniques.



Λ Figure 2.3

Aristotle thought that all materials were made of various proportions of four fundamental qualities: hot, dry, cold, and moist. Various combinations of these qualities gave rise to the four basic elements: hot and dry gave fire, moist and cold gave water, hot and moist gave air, and dry and cold gave earth. He supposed that a hard substance like rock contained mostly the dry quality, for example, and a soft substance like clay contained more of the moist quality.

Figure 2.4 >

In his atomic model, Democritus imagined that atoms of iron were shaped like coils—making iron rigid, strong, and malleable—and that atoms of fire were sharp, lightweight, and yellow.

With the advent of modern science, Aristotle's views on the nature of matter came into question. For example, in the late 1700s the French chemist Antoine Lavoisier discovered the law of mass conservation, as was discussed in Section 1.4. This verifiable law ran counter to Aristotle's idea that matter could lose or gain mass as its hot, dry, cold, or moist qualities changed. Lavoisier further hypothesized that an element is any material made of a fundamental substance that cannot be broken down into anything else. Through experiments, he was able to transform water into two different substances—hydrogen and oxygen. According to Lavoisier, Aristotle was wrong to think of water as an element.

READING CHECK
How did Lavoisier define an element?

Further experimental work by Lavoisier and others led the English chemist John Dalton (1766–1844) to reintroduce the atomic ideas of Democritus (**Figure 2.5**). Dalton wrote a series of postulates—claims he assumed to be true based on experimental evidence—some of which are as follows:

1. Each element consists of indivisible, minute particles called atoms.
2. Atoms can be neither created nor destroyed in chemical reactions.
3. All atoms of a given element are identical.
4. Atoms of different elements have different masses.

^ Figure 2.5

John Dalton was born into a very poor family. Although his formal schooling ended at age 11, he continued to learn on his own and even began teaching others when he was only 12. His primary research interest was weather, which led him to conduct many experiments with gases. Soon after publishing his conclusions on the atomic nature of matter, his reputation as a first-rate scientist increased rapidly. In 1810, he was elected into Britain's premiere scientific organization, the Royal Society.

It didn't matter that these tiny atoms were too small to be seen. What did matter was that Dalton's atomic model worked to explain much of what was then known about chemical reactions. Where alchemists using Aristotle's model failed, chemists using Dalton's model succeeded—not in making gold but in being able to understand and control the outcome of numerous chemical reactions. Imagine their amazement at finally being able to control the creation of new materials. . . as though finally being given the wizard's cookbook, where the wizard in this case was nature herself.

In 1869, a Russian chemistry professor, Dmitri Mendeleev (1834–1907), produced a chart summarizing the properties of known elements for his students (**Figure 2.6**). Mendeleev's chart was unique in that it resembled a calendar. Elements were listed in horizontal rows in order of increasing mass. The first row contained the lightest elements, the second row contained the next heaviest elements, and so forth. Aligning rows of elements above and below each other (like days of a calendar) revealed that elements within the same vertical column had similar properties, such as chemical reactivity. In order to achieve this pattern, however, he had to shift some elements left or right occasionally. This left gaps—blank spaces that could not be filled

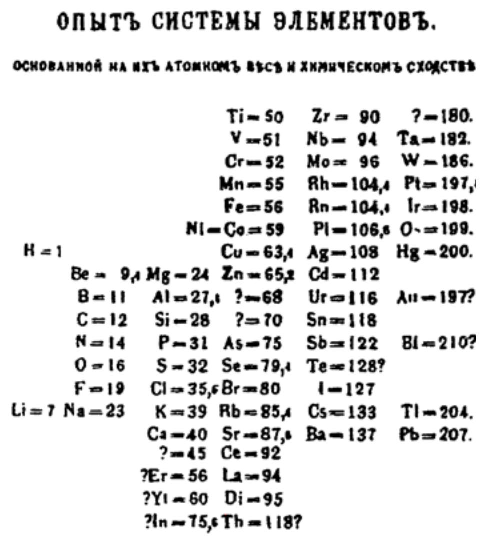
Figure 2.6 >

Dmitri Mendeleev was a devoted and highly effective teacher. Students adored him and would fill lecture halls to hear him speak about chemistry. Much of his work on the periodic table occurred in his spare time following his lectures. Mendeleev taught not only in the university classrooms but anywhere he traveled. During his journeys by train, he would travel third class with peasants to share his findings about agriculture.

by any known element (**Figure 2.7**). Instead of looking on these gaps as defects, Mendeleev boldly predicted the existence of elements that had not yet been discovered. His predictions about the properties of some of those missing elements led to their discovery.

That Mendeleev was able to predict the properties of new elements helped convince many scientists of the accuracy of Dalton's atomic hypothesis, upon which Mendeleev's periodic table was based. This in turn helped promote Dalton's proposed atomic nature of matter from a hypothesis to a more widely accepted theory. Mendeleev's chart ultimately led to our modern periodic table, which we discuss more fully in Chapter 3.

Since the time of Lavoisier, Dalton, and Mendeleev, our understanding of atoms has grown substantially. Although we have not discovered the alchemist's dream of immortality, we have learned how to design medicines that cure numerous diseases. From crude oil we can make fuels, plastics, clothing, and more. From the thin air we can produce fertilizer. Virtually every aspect of modern society has been and will continue to be affected by our ability to manipulate atoms to meet our needs. Of all the discoveries made by humans, our discovery of the atom is arguably one of our greatest and most profound. Are atoms for real? Today we have the technology to capture images of individual atoms, as shown in **Figure 2.8**.



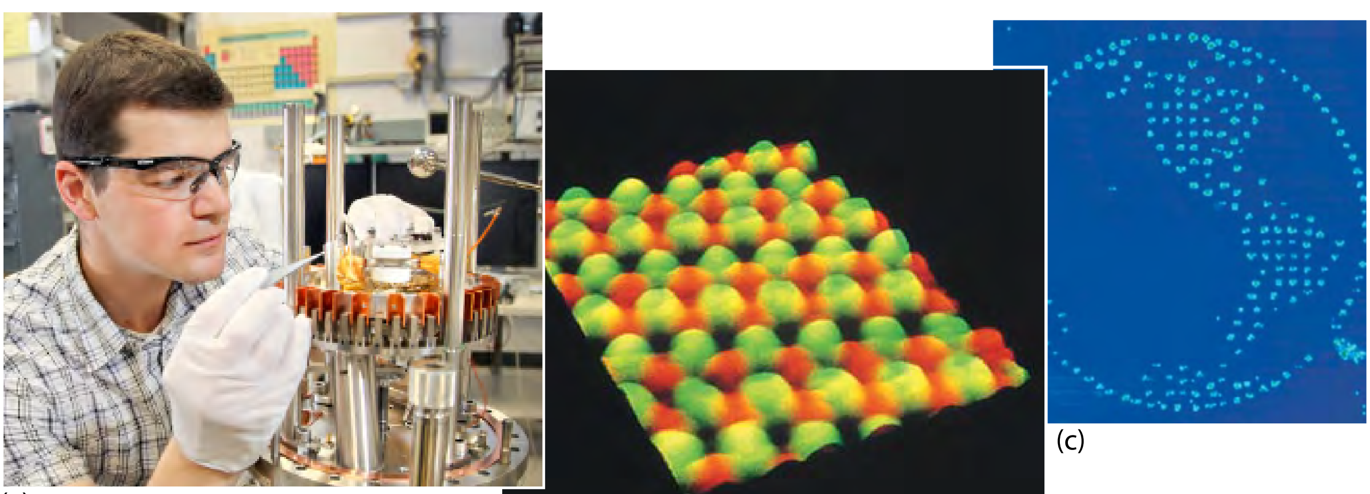
ОПЫТЪ СИСТЕМЫ ЭЛЕМЕНТОВЪ.

ОСНОВАННОЙ НА ИХЪ АТОМНОМЪ ВѢСѢ И ХИМИЧЕСКОМЪ СХОДСТВѢ

			Ti=50	Zr=90	?=180.
			V=51	Nb=94	Ta=182.
			Cr=52	Mo=96	W=186.
			Mn=55	Rh=104,4	Pt=197,
			Fe=56	Rn=104,4	Ir=198.
			Ni=Co=59	Pl=106,6	Os=199.
H=1			Cu=63,4	Ag=108	Hg=200.
	Be=9,4	Mg=24	Zn=65,2	Cd=112	
	B=11	Al=27,4	?=68	Ur=116	Au=197?
	C=12	Si=28	?=70	Sn=118	
	N=14	P=31	As=75	Sb=122	Bi=210?
	O=16	S=32	Se=79,4	Te=128?	
	F=19	Cl=35,5	Br=80	I=127	
Li=7	Na=23	K=39	Rb=85,4	Cs=133	Tl=204.
		Ca=40	Sr=87,6	Ba=137	Pb=207.
		?=45	Ce=92		
		?Er=56	La=94		
		?Yt=60	Di=95		
		?In=75,6	Th=118?		

Figure 2.7 >

An early draft of Mendeleev's periodic table.



(a) (b) (c)

∧ Figure 2.8

(a) Scanning probe microscopes are relatively simple devices used to create submicroscopic imagery. (b) An image of gallium and arsenic atoms. (c) Each dot in the world's tiniest map consists of a few thousand gold atoms, each dot moved into its proper place by a scanning probe microscope.

FOR YOUR INFORMATION

To help finance his scientific projects, Lavoisier took part-time employment as a tax collector, in which position he introduced reforms to help ease the tax burden on peasants. But because of this employment, he was beheaded in 1794 during the French Revolution. After hearing appeals to spare Lavoisier's life, the judge determined that "the Republic needs neither scientists nor chemists; the course of justice cannot be delayed." About 18 months after Lavoisier's execution, the French government sent a formal apology to his widow, Marie-Anne.

Just as important is the fact that atoms and molecules can be used to explain common observations. For example, heat transforms moist clay into ceramic by driving off water molecules. In ice, water molecules are stuck together in a fixed orientation. Warmth melts the ice by helping the water molecules break away from each other. Consider placing a fragrance, such as cinnamon oil, within an inflated rubber balloon. The balloon is sealed. How then does the outer surface of the balloon smell like cinnamon? We can explain how this occurs by assuming the fragrance consists of tiny molecules that can pass through the micropores of the inflated rubber balloon. Similarly, we can use the idea of molecules to explain how moisture can collect on a tabletop before disappearing, as shown in **Figure 2.9**, or how a dark-colored powdered drink mix dissolves in water with no stirring, as shown in **Figure 2.10**. The explanatory powers of the atomic model are great. This, along with our hi-tech evidence, leads us to trust that matter is made of these super-small particles we call atoms.

Figure 2.9

(a) Place your palms down on a cool, dark, and reflective table such as a slate lab benchtop. Water molecules exiting from your skin collect onto this surface. (b) Lift your hands to see this moisture, which quickly disappears as the water molecules evaporate into the air.

FOR YOUR INFORMATION

Most atoms are ancient. They have existed through imponderable ages, recycling through the universe in innumerable forms, both nonliving and living. In this sense, you don't "own" the atoms that make up your body–you are simply their present caretaker. There will be many caretakers to follow.

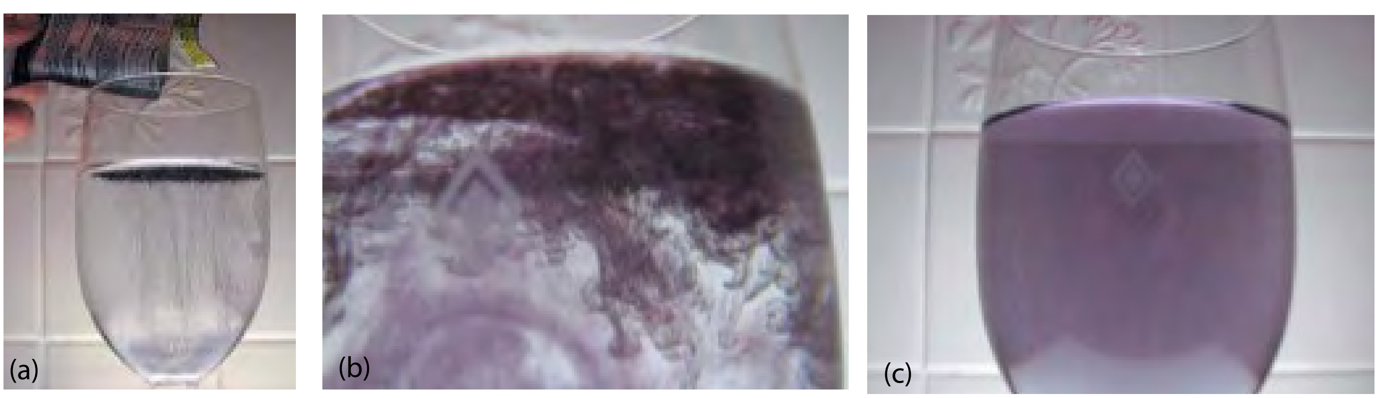


Figure 2.10

(a) Kool-Aid crystals settle to the bottom of a container of water. (b) Without stirring, the crystals begin to dissolve as they are bombarded by water molecules in the liquid phase. (c) The bustling movement of the water molecules eventually causes the Kool-Aid to be uniformly mixed with the water.

FOR YOUR INFORMATION

Some atoms are larger than others, but they are all exceedingly small. Gold atoms, for example, are so small that about 4,000,000,000,000 (4 trillion) of them could fit within the period at the end of this sentence.

CONCEPT **CHECK**

Lavoisier hypothesized that an element was a material made of a fundamental substance that cannot be broken down into anything else. According to Dalton, this fundamental substance was made of

a. water. b. fire. c. atoms. d. molecules

CHECK YOUR ANSWER

The answer is (c). Dalton reintroduced the concept of atoms put forth by Democritus some 2000 years earlier. Unlike Democritus, however, Dalton assumed that the atoms of different elements differed from each other by their mass.