Section 1
Development of the Atomic Theory

Key Concept Scientists have done experiments that have revealed important clues about the structure of atoms.

What You Will Learn
- There have been different models of the atom over time.
- The atomic theory has changed as scientists have experimented and dis covered new information about the atom.

Why It Matters
Scientific ideas change as new data are gathered. This is an important characteristic of science.

Have you ever watched a mystery movie and thought you knew who the criminal was? Have you ever changed your mind because of a new fact or clue? The same thing happens in science! Sometimes, an idea or model must be changed as new information is gathered. In this section, you will see how our ideas about atoms have changed over time.

The Beginning of Atomic Theory
Imagine that you cut something in half. Then, you cut each half in half and continue doing so. Could you keep cutting the pieces in half forever? Around 440 BCE, a Greek philosopher named Democritus (di MAHK ruh tuhs) thought that you would eventually end up with a particle that could not be cut. He called this particle an atom. The word *atom* is from the Greek word *atomos,* which means "not able to be divided."

Although it was a long time before most people agreed that matter was made of atoms, Democritus was right in an important way. We now know that matter is made of particles that we call atoms. An **atom** is the smallest particle into which an element can be divided and still have the properties of that element. Today's technology allows us to produce images of atoms. **Figure 1** shows a picture of aluminum atoms made using a scanning tunneling electron microscope (STM). But long before they could actually scan atoms, scientists had ideas about them.

Figure 1 Aluminum cans, like all matter, are made of atoms. Aluminum atoms can be seen here as an image from a scanning tunneling electron microscope.

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Dalton's Atomic Theory Based on Experiments

By the late 1700s, scientists had learned that elements combine in certain proportions based on mass to form compounds. For example, hydrogen and oxygen always combine in the same proportion to form water, H_2O. John Dalton, a British chemist and teacher, wanted to know why. He experimented with different substances. His results suggested that elements combine in certain proportions because they are made of atoms. Dalton, shown in **Figure 2,** published his atomic theory in 1803. His theory stated the following ideas:

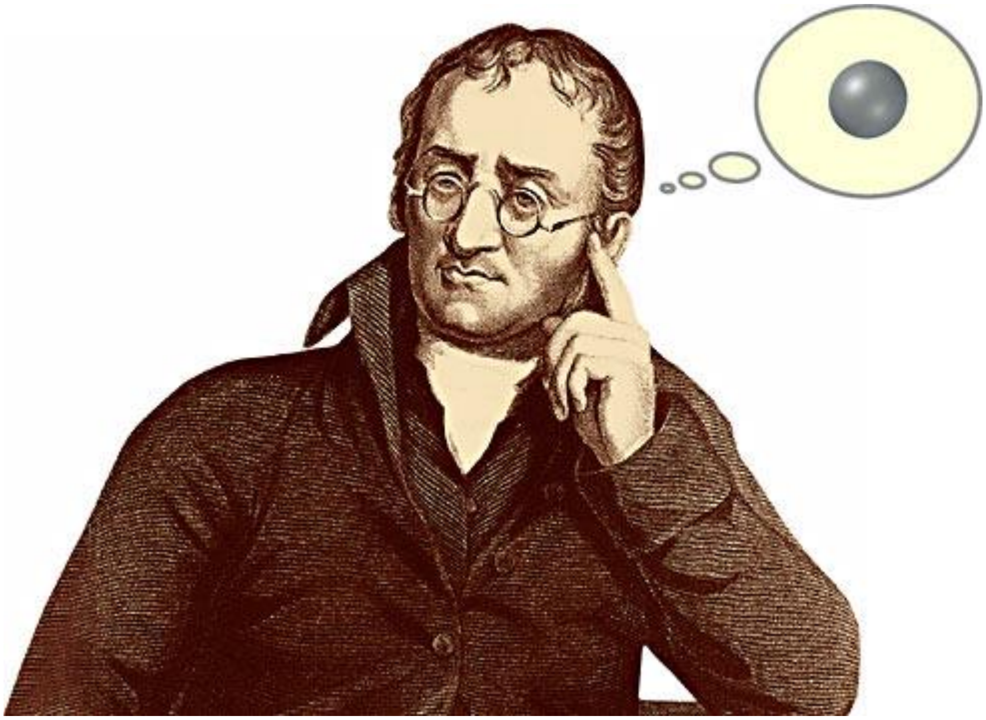


Figure 2 John Dalton developed his atomic theory from observations gathered from many experiments.

- All substances are made of atoms. Atoms are small particles that cannot be created, divided, or destroyed.
- Atoms of the same element are exactly alike, and atoms of different elements are different.
- Atoms join with other atoms to make new substances.

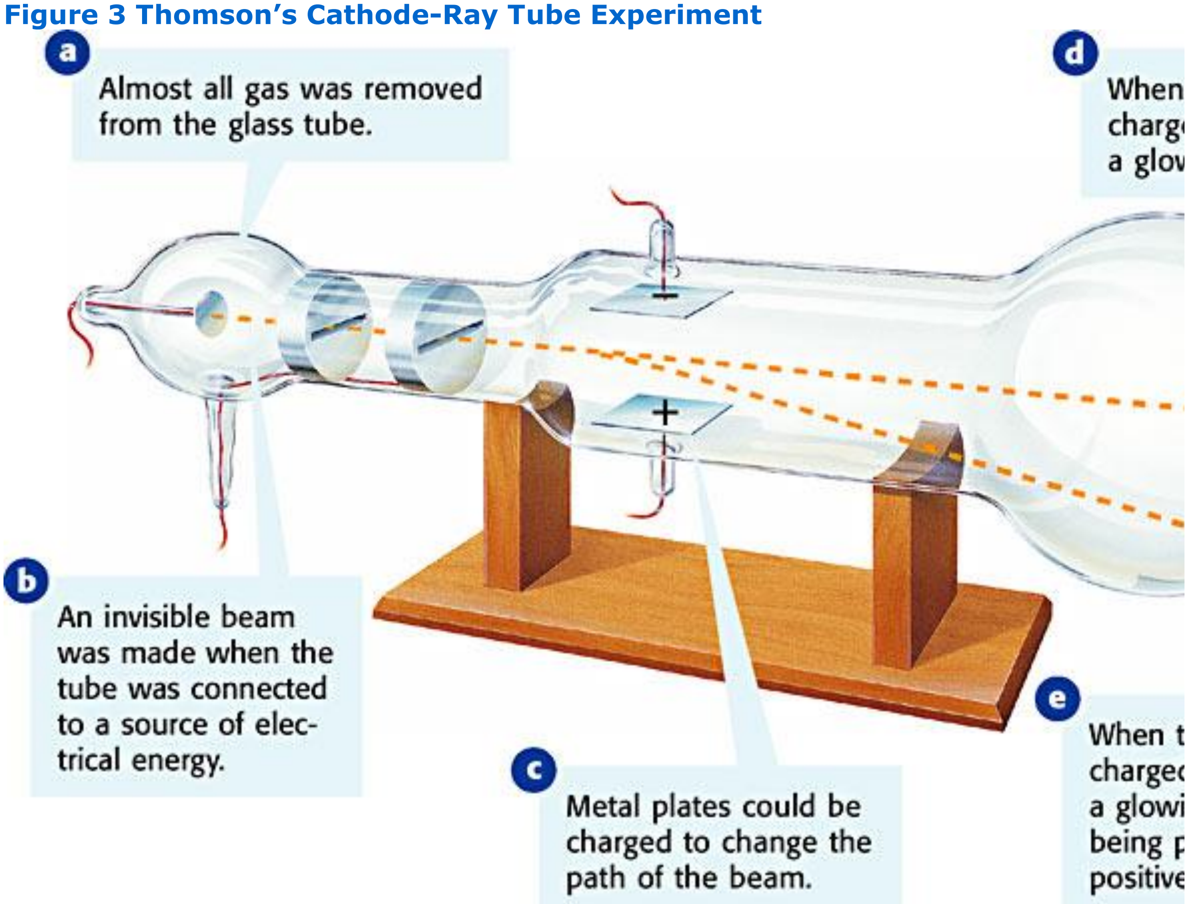
Dalton's theory was an important step toward the current understanding of atoms. By the end of the 1800s, scientists agreed that Dalton's theory explained much of what they saw. However, new information was found that did not fit some of Dalton's ideas. The atomic theory was then changed to describe the atom more accurately. As you read on, you will learn how Dalton's theory has changed, step by step, into the modern atomic theory.

Thomson's Discovery of Electrons

In 1897, a British scientist named J. J. Thomson showed that Dalton's theory was not quite right. Thomson discovered that there are small particles *inside* the atom. Thus, atoms can be divided into even smaller parts.

Thomson experimented with a cathode-ray tube like the one shown in **Figure 3.** He discovered that a positively charged plate (marked with a plus sign in the drawing) attracted the beam and made it bend down. Thomson concluded that the beam must be made of particles that have negative electric charges, because opposite charges attract. The negatively charged particles that Thomson discovered are now called **electrons**.

Figure 3 Thomson's Cathode-Ray Tube Experiment



Thomson showed that electrons are a part of atoms, but his experiment did not provide a way of knowing where electrons were located in atoms. So, he made a guess that the electrons were mixed throughout an atom, like plums in a pudding. Thomson's proposed model of the atom is sometimes called the *plum-pudding model,* after a dessert that was popular in Thomson's day. This model is shown in **Figure 4.** Today, you might call Thomson's model the *chocolate chip ice-cream model.* Chocolate chips represent electrons. The ice cream represents the rest of the atom.

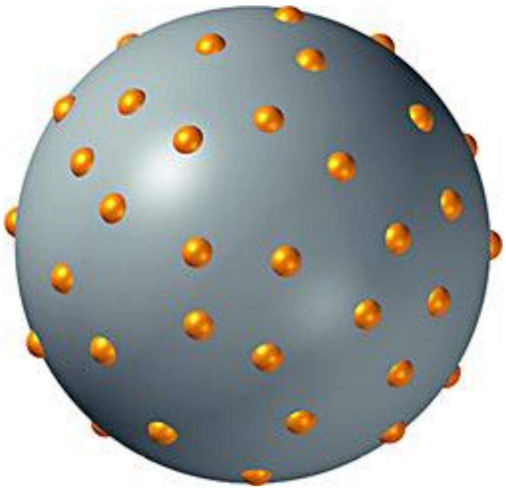


Figure 4 Thomson proposed that electrons were located throughout an atom like plums in a pudding, as shown in this model.

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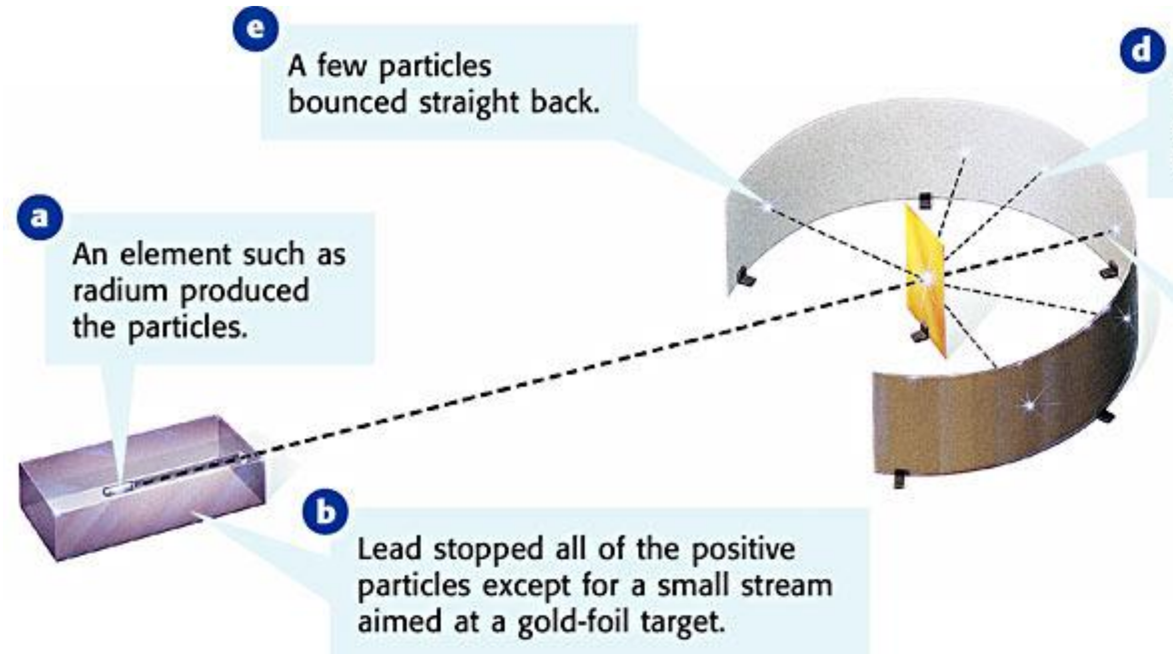
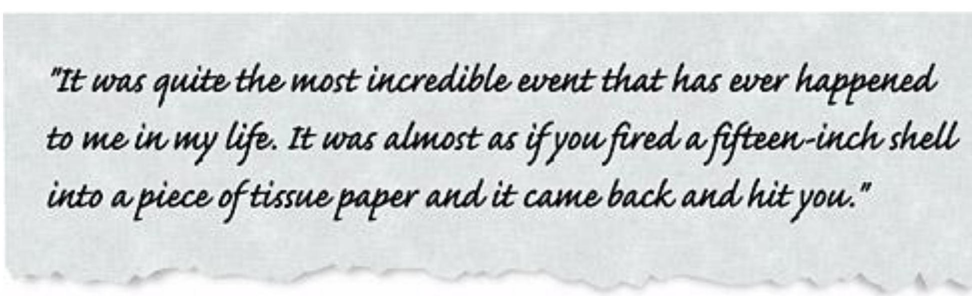
Rutherford's Atomic "Shooting Gallery"

In 1909, a former student of Thomson's named Ernest Rutherford decided to test Thomson's theory. He designed an experiment to study the parts of the atom. He aimed a beam of small, positively charged particles at a thin sheet of gold foil. Rutherford put a special coating behind the foil. The coating glowed when hit by the positively charged particles. Rutherford could then see where the particles went after hitting the gold. This experiment would show if atoms have different parts or if they are all the same throughout, as the plum-pudding model suggested. **Figure 5** shows how Rutherford's experiment was set up.

Figure 5 Rutherford's Gold-Foil Experiment



Rutherford started with Thomson’s idea that atoms are soft “blobs” of matter through which electrons are evenly distributed. Therefore, he expected the particles to pass right through the gold in a straight line. Most of the particles did just that. But to Rutherford’s great surprise, a few of the particles were deflected (turned to one side). Some even bounced straight back. Rutherford reportedly said,



The Nucleus and the Electrons

The plum-pudding model of the atom did not explain what Rutherford saw. Most of the tiny particles went straight through the gold foil. A small number of them were deflected. He realized that the explanation for this must be that most matter in an atom is found in a very small part of the atom.

Based on his experiment, Rutherford revised the atomic theory in 1911. He made a new model of the atom, as **Figure 6** shows. Rutherford proposed that in the center of the atom is a tiny, extremely dense, positively charged area called the **nucleus.** Because like charges repel, Rutherford reasoned that positively charged particles that passed close by the nucleus were pushed away by the positive charges in the nucleus. A particle that headed straight for a nucleus would be pushed almost straight back in the direction from which it came. From his results, Rutherford calculated that the diameter of the nucleus was 100,000 times smaller than the diameter of the gold atom. To get an idea of this difference in size, look at **Figure 7.** From Rutherford's results, the important idea emerged that atoms are mostly empty space with a tiny, massive nucleus at the center.

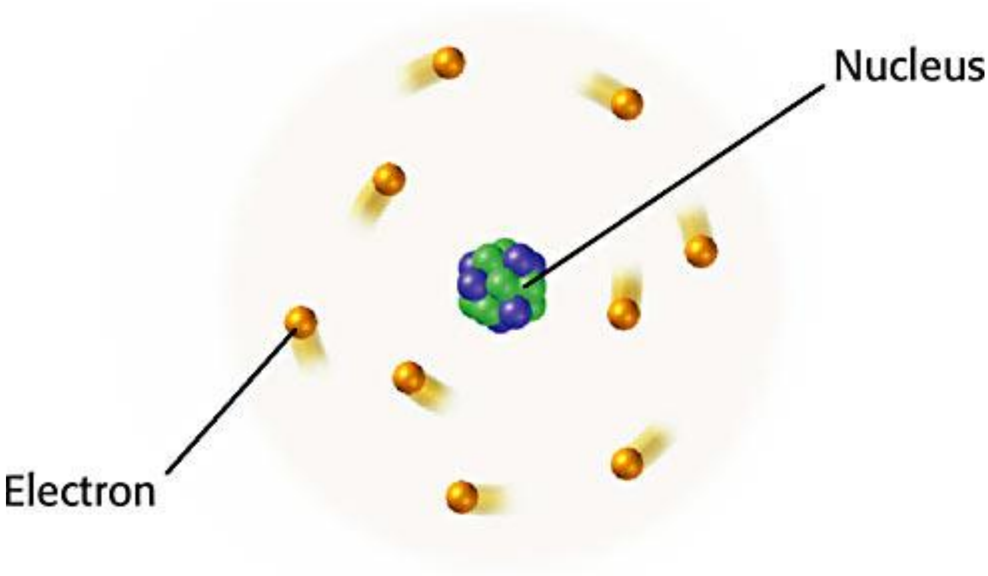


Figure 6 Rutherford's model of the atom had electrons surrounding the nucleus at a distance. (This model does not show the true scale of sizes and distances.)

Figure 7 The diameter of this pinhead is 100,000 times smaller than the diameter of the stadium. This ratio is about the same as the ratio of the diameter of a nucleus to its atom.

Standards Check Describe the structure of the atom according to Rutherford's model.

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Bohr's Electron Levels

In 1913, Niels Bohr, a Danish scientist who worked with Rutherford, studied the way that atoms react to light. Bohr's results led him to propose that electrons move around the nucleus in definite paths. In Bohr's model, there are no paths between the levels. But electrons can jump from a path in one level to a path in another level. Think of the levels as rungs on a ladder. You can stand on the rungs of a ladder but not *between* the rungs. Bohr's model was a valuable tool in predicting some atomic behavior. But the atomic theory still had room for improvement.

The Modern Atomic Theory

Many 20th-century scientists added to our current understanding of the atom. An Austrian physicist named Erwin Schrödinger (ER veen SHROH ding uhr) and a German physicist named Werner Heisenberg (VER nuhr HIE zuhn berkh) did especially important work. They further explained the nature of electrons in the atom. For example, electrons do not travel in definite paths as Bohr suggested. In fact, the exact path of an electron cannot be predicted. According to the current theory, there are regions inside the atom where electrons are *likely* to be found. These regions are called **electron clouds.** Sometimes the regions are called *orbitals.* The electron-cloud model of the atom is shown in **Figure 8.**

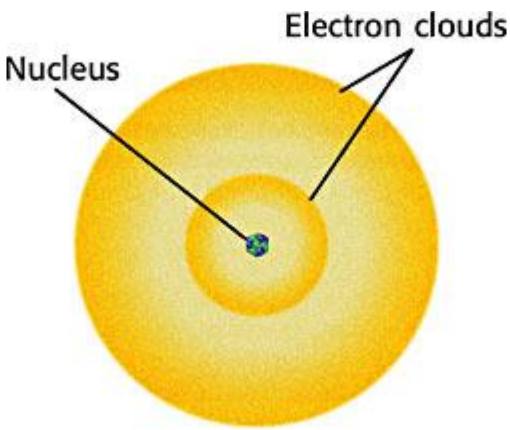

Figure 8 In the current model of the atom, electrons surround the nucleus in electron clouds or orbitals.

Energy Levels

Electron clouds are regions in an atom where electrons are likely to be found. Each electron cloud exists at a certain energy level. Instead of traveling in a definite path, as Bohr suggested, each electron has a definite energy based on its location around the nucleus. The energy of each electron in an atom keeps it in motion around the positive nucleus to which it is attracted.

The bookshelves shown in **Figure 9** can help you understand electrons in atoms. Each shelf represents an energy level. Each book represents an electron. You can move a book to a higher or lower shelf, but the right amount of energy must be used. And the book cannot be between shelves. Likewise, electrons can move by gaining or losing energy, but they are never found between energy levels.

Figure 9 Like books on shelves, electrons have definite energies.

Standards Check What determines the definite energies of electrons?

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The Size of an Atom

Most of what we know about the atom was discovered without seeing a single atom. But how small is an atom? Think about a penny. A penny contains about 2×10^{22} atoms (which can be written as 20,000,000,000,000,000,000,000 atoms) of copper and zinc. That's 20 thousand billion billion atoms— more than 3,000,000,000,000 times more atoms than people on Earth! If there are that many atoms in a penny, each atom must be very small.

Scientists know that aluminum is made of averagesized atoms. An aluminum atom has a diameter of about 0.00000001 cm. That's one hundred-millionth of a centimeter. Take a look at **Figure 10.** Even things that are very thin, such as aluminum foil, are made up of very large numbers of atoms.

Figure 10 This aluminum foil might seem thin to you. But it is about 100,000 atoms thick!

Observing Atoms

In fact, atoms are so small that light waves are too large to be used to observe them. Until recently, there were no tools that could produce images of individual atoms. Even though scientists have figured out a lot about the atom without direct images, theories about the atom can be extended and refined with these images. The tools that scientists now use to observe atoms include the scanning tunneling electron microscope. This tool can provide images like the one shown in **Figure 11.** Still, these images do not show an actual picture of an atom. They show a color-enhanced image of the surface of a material at the atomic level. From Dalton's time to the present day, scientists have done a lot of work showing that the atoms that Democritus suspected to exist really do exist!

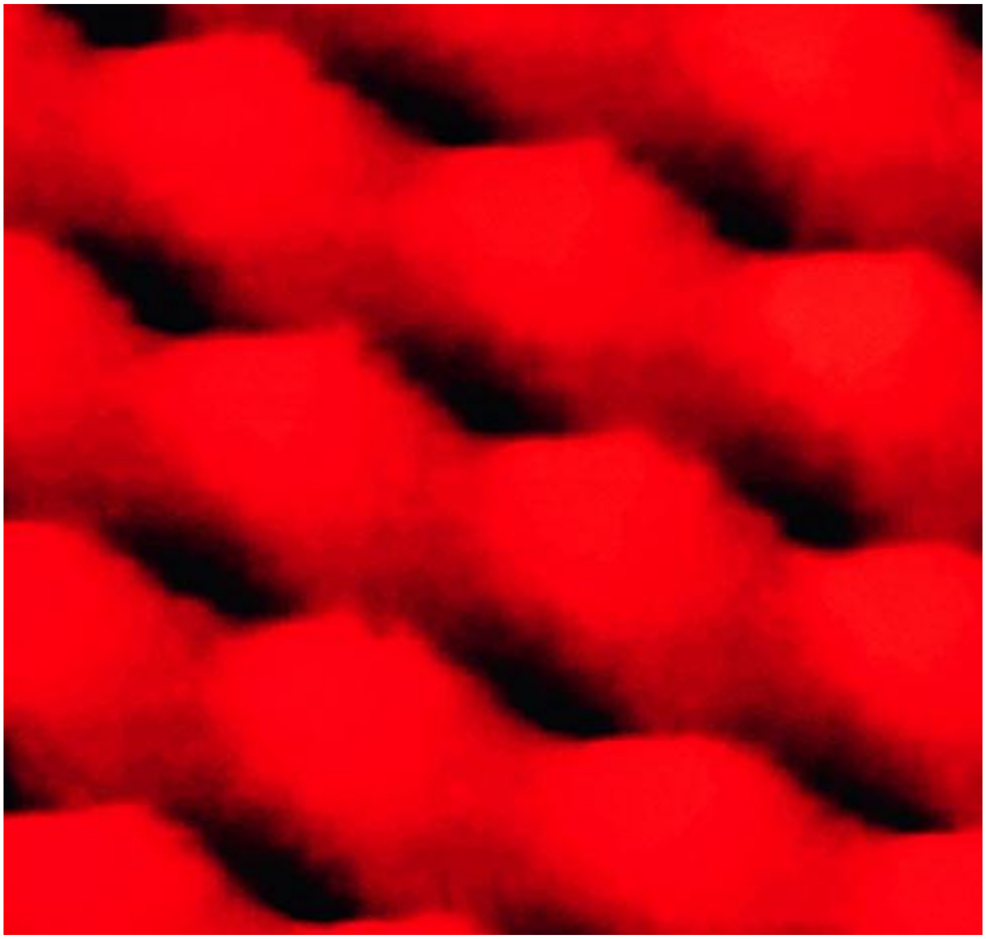

Figure 11 The bumps in this image are individual carbon atoms in graphite.

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Section Summary

- Democritus thought that matter is composed of atoms.
- Dalton based his theory on observations of how elements combine.

- Thomson discovered electrons in atoms.
- Rutherford discovered that atoms are mostly empty space with a dense, positive nucleus.
- Bohr proposed that electrons are located in levels at certain distances from the nucleus.
- The electron-cloud model represents the current atomic theory.
- Atoms are extremely tiny, but scanning tunneling electron microscopes can be used to form direct images of them.

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