CONCEPT 1

Dalton developed an early atomic theory.

Activity

Explaining Differences in Matter

Your teacher will provide you with three different white solids. Examine the solids using a magnifying glass. How would you describe each solid? How are they different and how are they the same? Add vinegar to a small amount of each and describe what you observe. With your teacher's permission, heat a scoopula-tip's worth of each substance on a piece of foil on a hot plate and describe what you observe. Summarize your observations in a table. Does kinetic molecular theory help you explain the differences you observed?

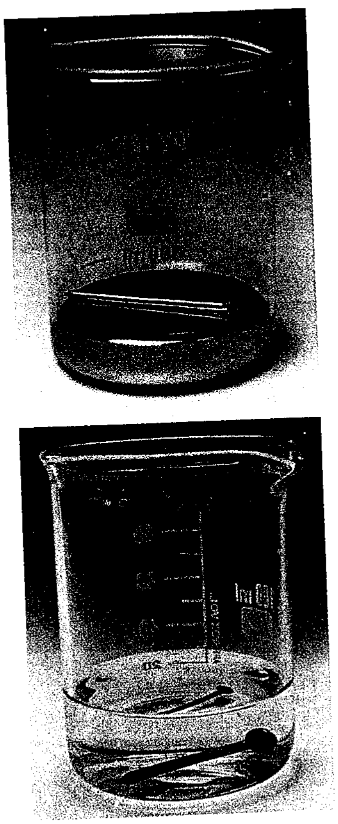


Figure 2.20 The kinetic molecular theory of matter cannot explain why mercury and water are so different.

The kinetic molecular theory of matter is based on the idea that matter is made up of tiny particles in motion. This theory does a good job of explaining why substances can exist in different states, and what happens when matter changes from one state to another. But there are many observations about matter that it cannot explain. For example, it does not explain why water and mercury have such different properties, even though both are liquids. Water is essential to life, while even small amounts of mercury can be deadly. **Figure 2.20** shows the difference in their densities. What causes these differences?

Greek Philosophers and *Atomos*

Various peoples throughout history have used storytelling, philosophical debate, and other modes of communication and analysis to share and explore ideas about the properties and changes of matter. The idea that matter is made up of different kinds of tiny particles is actually thousands of years old. A Greek philosopher named Democritus proposed the idea that matter was made up of tiny particles that exist in empty space. He called these particles *atomos*, which means "uncuttable," because they could not be created, destroyed, or divided any further. Although this idea is similar to the idea of atoms that was developed by scientists in the 19th and 20th centuries, Democritus did not use experiments to support his ideas. As a philosopher, he used only reason and logic.

Philosophies of Matter

A well-respected and very influential philosopher, Aristotle, disagreed with Democritus's ideas, in large part because he did not believe that empty space could exist. Like many disagreements on social media today, the argument was won partly by popularity (**Figure 2.21**). In fact, Aristotle's influence was so great that his denial of the existence of atoms persisted for 2000 years.

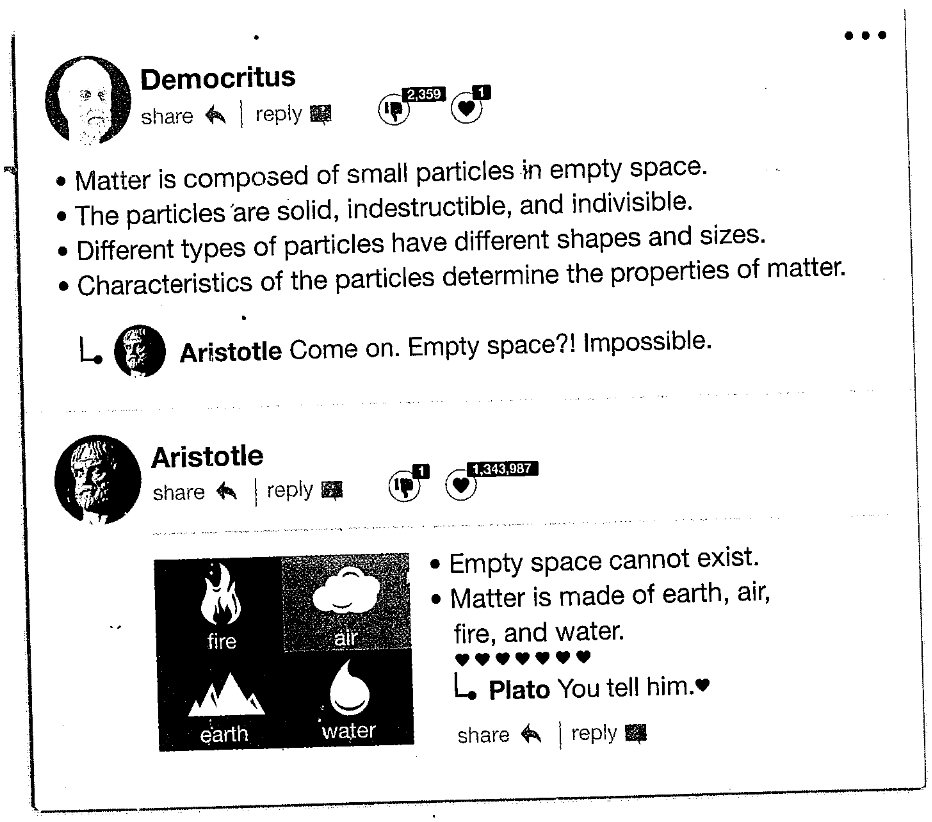


Figure 2.21 If Democritus and Aristotle had been able to use social media thousands of years ago, their posts might have looked like this.

Atomic Theory Begins

Over the centuries, people in different countries read about the idea of *atomos*, and many (including some scientists) agreed with it. However, it was not until the early 1800s in England that the *atomos* idea reappeared with the support of experimental results and analysis. John Dalton (1766–1844), shown in **Figure 2.22**, was a schoolteacher and scholar. Unlike Democritus, he was able to conduct controlled scientific experiments. He could do this because the general methods of scientific inquiry had already been developed. He also had access to instruments such as glassware and accurate balances that enabled him to measure changes in matter.

Figure 2.22 John Dalton

Dalton's Theory of the Atom

Dalton's experiments allowed him to develop, refine, and support a hypothesis about matter. Studying many chemical reactions, he made careful observations and measurements that led him to propose in 1803 what has now come to be known as *Dalton's atomic theory*. He published his ideas in a book, a page from which is shown in **Figure 2.23**. The key points of his theory are described below.

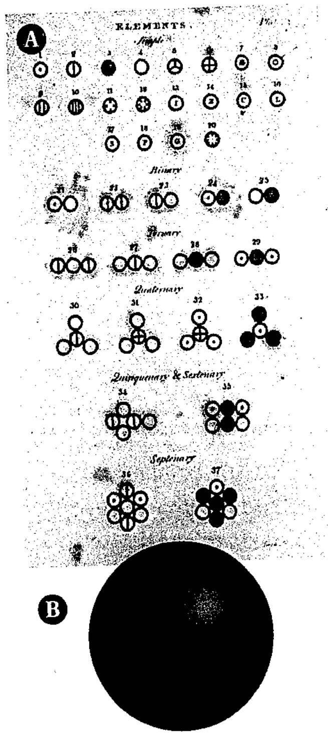


Figure 2.23 Ⓐ This page from Dalton's book, *A New System of Chemical Philosophy*, shows the symbols he used to represent atoms of different elements. Ⓑ According to Dalton's theory, atoms were solid, indestructible spheres.

Dalton's Atomic Theory

- All matter is made of extremely small particles called atoms.
- Atoms cannot be created, destroyed, or divided.
- All atoms of the same element are identical in size, mass, and chemical properties. Atoms of a specific element are different from those of another element.
- Different atoms combine in simple whole-number ratios to form compounds. In a chemical reaction, atoms are separated, combined, or rearranged.

Dalton's Theory Was Just the Beginning

Dalton's theory explained many existing observations about matter and its interactions. One example is the observation that mass is conserved in a chemical reaction—Lavoisier's law of conservation of mass. Since atoms were not created, destroyed, or divided in chemical reactions, it made sense that the mass of reactants and products in a chemical reaction did not change.

As scientists continued to study matter and to develop new technologies to allow them to perform different kinds of experiments, it became clear that Dalton's atomic theory could not explain all of the observations that scientists were making. Scientific theories are always subject to being changed or discarded if they prove insufficient to explain new observations. Dalton's atomic theory was just the beginning.

Before you leave this page . . .

1. Compare and contrast Democritus's *atomos* with Dalton's atomic theory.
2. How is a philosophical idea different from a scientific theory?

CONCEPT 2

Many scientists contributed to the further development of atomic theory.

Activity

Mystery Box

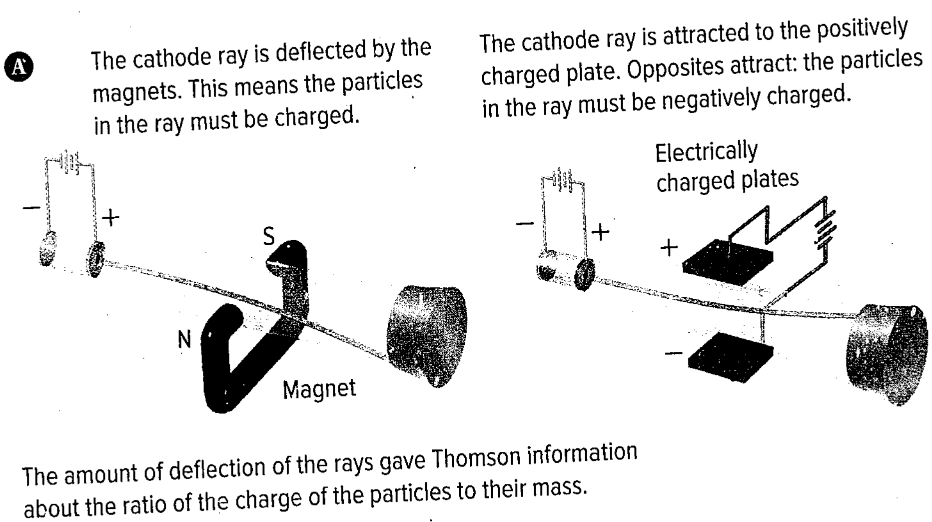
Your teacher will give your group a box, which you are not allowed to open. Using your skills of observation and the materials your teacher provides, perform as many tests as you can think of on the box to infer what is inside. How does this activity relate to the study of matter?

After Dalton got modern atomic theory rolling in the early 1800s, a series of discoveries followed that resulted in its adjustment and refinement. Throughout the remainder of the 19th century, many different scientists and inventors contributed to this work. A scientist named JJ Thomson was among the first.

JJ Thomson and the Electron

Joseph John Thomson (1856–1940) was a British physicist who studied electric currents in cathode ray tubes, as shown in **Figure 2.24**. Scientists had discovered that when they attached a battery to the tube, a ray travelled through the tube. They called this ray a *cathode ray* because it appeared to originate from the negative terminal or *cathode* in the discharge tube. Further experiments revealed the following:

- Cathode rays were streams of negatively charged particles.
- All substances produced these particles.



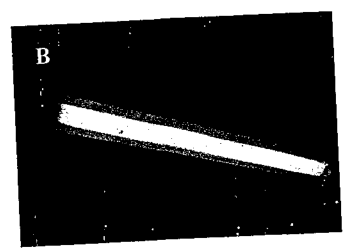


Figure 2.24 Ⓐ Thomson used magnets and charged plates to manipulate cathode rays and measure the effects. Ⓑ Fluorescent lights are familiar examples of cathode ray tubes.

Thomson's Model of the Atom

Connect to Investigation 2-H on pages 168–169

Thomson's key cathode ray tube experiments involved determining the charge-to-mass ratios of the negative particles. He did not determine the mass of the particles directly, but his experiments did allow him to compare their mass to that of a hydrogen atom, the lightest known atom. To his surprise, he found that the mass of the charged particles was much less than an atom of hydrogen. This meant that there were particles smaller than the atom! The conclusion was surprising because it contradicted the part of Dalton's theory that defined atoms as being indivisible. Based on the results of Thomson's experiment, Dalton's theory had to be revised, and a new model of the atom was developed.

Thomson proposed what he called a "plum-pudding" model of the atom. Plum pudding was a popular dessert in England at the time, but thinking of this model as a more familiar blueberry muffin gives the same results. Thomson's model, shown in **Figure 2.25**, pictured a positively charged ball (the "muffin") with negatively charged **electrons** embedded in it like blueberries. This model successfully explained the observations to date, but it soon had to be revised based on the findings of Thomson's student, Ernest Rutherford.

electrons negatively charged particles that are found in the space surrounding the nucleus

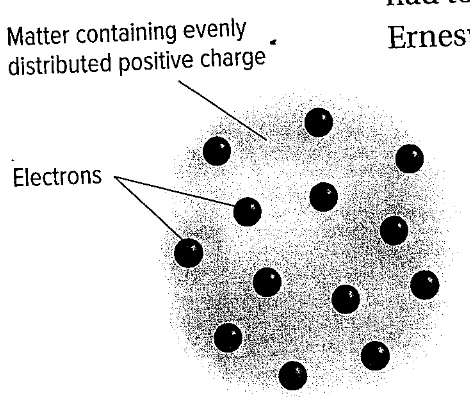


Figure 2.25 Thomson proposed a model of the atom similar to a blueberry muffin. Negatively charged particles (now called electrons) were embedded in matter with a positive charge that was evenly spread out.

Thomson's Contribution to Modern Atomic Theory
Atoms are not indivisible. They contain smaller, negatively charged particles, now known as electrons.

Ernest Rutherford and the Nucleus

Ernest Rutherford (1871–1937) was a scientist from New Zealand who worked for a while at McGill University in Montreal. In 1909 he designed an experiment to find out more about the structure of atoms. He exposed a very thin sheet of gold to a stream of high-speed particles with a positive charge, called alpha particles. The alpha particles acted like tiny bullets. Rutherford wanted to see what would happen to the alpha particles when they made contact with the gold atoms. He surrounded the gold foil with a detector screen. An alpha particle would become visible whenever it struck the screen. **Figure 2.26** shows how the experiment was set up.

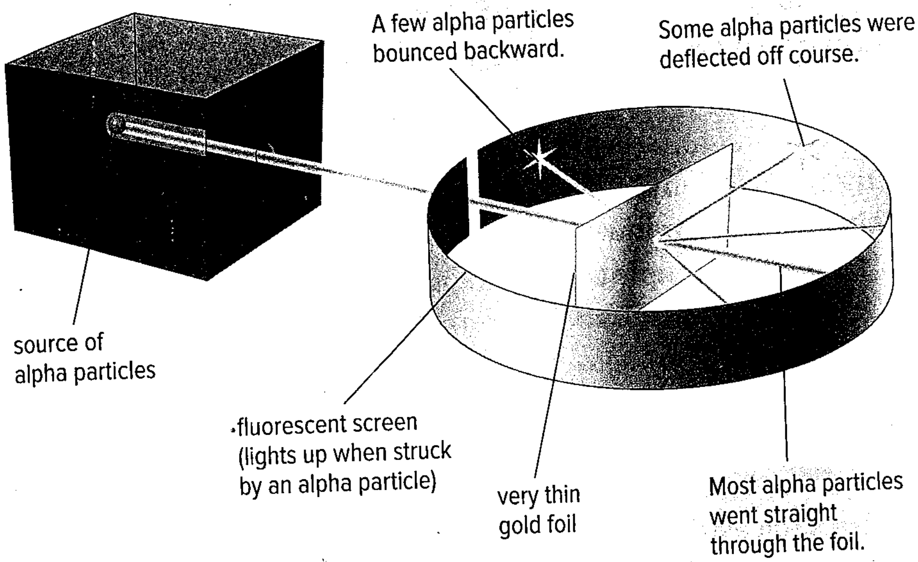


Figure 2.26 In Rutherford's experiment, most of the alpha particles went straight through the foil as expected. But a few bounced back, some at large angles. Rutherford had discovered the nucleus.

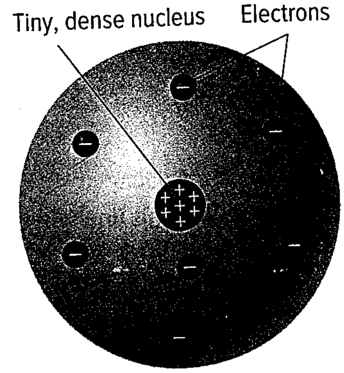


Figure 2.27 Rutherford revised the model of the atom to include a dense nucleus with a positive charge that was very tiny compared to the overall size of the atom. Electrons moved freely in the space surrounding the nucleus.

Most of the alpha particles went right through the gold atoms without their path being affected. This result was not surprising; it was consistent with Thomson's model. (Imagine a bullet going through a muffin.) The surprising result was that a small percentage of the alpha particles rebounded from the foil, much as a ball bounces off a wall. Rutherford had discovered the **nucleus**—the tiny, dense, positively charged centre of the atom.

Once again atomic theory had to be revised, and a new model of the atom, as shown in **Figure 2.27**, was proposed. According to Rutherford's model, virtually all of the mass of an atom was concentrated in the nucleus. The nucleus was so small compared to the volume occupied by the surrounding electrons that the majority of the atom's volume was empty space!

By 1920, it had been discovered that the nucleus contained positively charged particles that Rutherford called **protons**. James Chadwick (1891–1974), a coworker of Rutherford's, found that the nucleus also contained neutral particles called **neutrons**.

nucleus the positively charged centre of an atom that contains protons and neutrons; tiny compared with the size of the atom

protons positively charged particles found in the nucleus of an atom

neutrons particles with no charge that are found in the nucleus of an atom

Rutherford and Chadwick's Contribution to Modern Atomic Theory

The vast majority of an atom's volume is empty space occupied by very tiny negatively charged moving electrons.

The positive charge in an atom is contained in a tiny, dense nucleus. The nucleus is made up of two types of particles, each with about the same mass: protons, which are positively charged, and neutrons, which have no charge.

Niels Bohr and Energy Levels

Niels Bohr (1885–1962) was a Danish physicist. While working as a student in Rutherford's lab, he studied electrons and the region around the nucleus. Bohr analyzed the results of experiments on the light released by various gases. In the experiments, the gases had been made to glow by passing an electric current through a low-pressure sample contained inside a glass tube. Each gas produced a characteristic spectrum of light as a result, called a *line spectrum*. The line spectrum for hydrogen is shown in **Figure 2.28**.

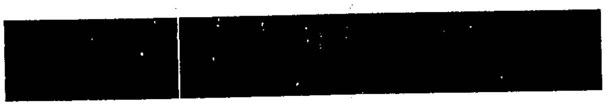


Figure 2.28 This line spectrum for hydrogen provides evidence that electrons can have only certain allowed energies.

The colour or wavelength of light is related to its energy. Bohr knew that the light emitted by the gases was a result of high-energy electrons releasing energy. But why did the electrons of a given gas emit light only of certain wavelengths? Rutherford's model of the atom could not explain this result because electrons could possess any amount of energy in that model.

Electron Energy Levels

As shown in **Figure 2.29**, Bohr proposed that electrons surrounding the nucleus could occupy only specific "energy levels" or "energy shells." Each energy shell was associated with a certain amount of energy. The larger the shell, the higher the energy of an electron occupying it.

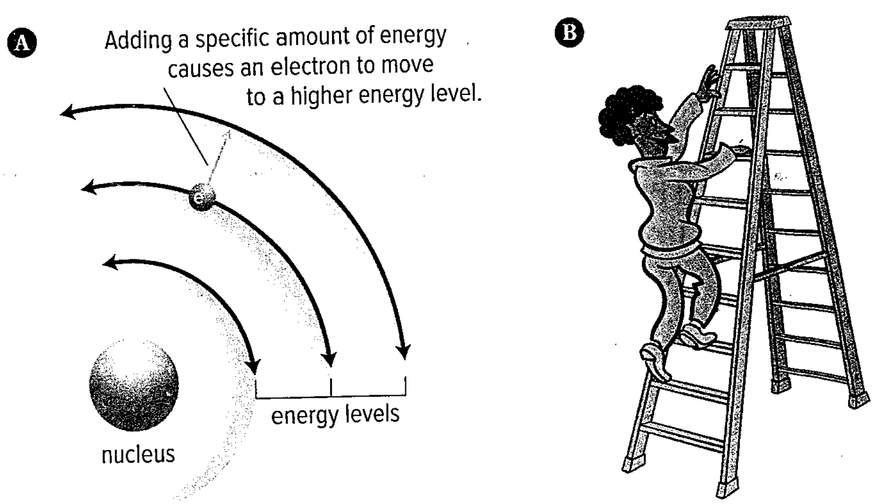


Figure 2.29 **A** In Bohr's model of the atom, electrons can have only certain amounts of energy. They occupy energy shells surrounding the nucleus. **B** The energy shells are like rungs on a ladder. When you climb a ladder, your foot can rest on any of the rungs but not in between.

Bohr's Contribution to Modern Atomic Theory

Electrons can have only certain amounts of energy. They occupy defined energy levels or shells in the space surrounding the nucleus.

Visible Effects of Electron Energy Shells

A neon light is an example of the visible effect of electrons jumping from one energy level to another. When electricity is added to the neon gas, the electrons in the neon atoms gain energy, causing them to jump to higher energy levels. Electrons can then fall back down to lower energy levels, releasing energy in the form of visible light of a characteristic colour. The light is the evidence that the electrons exist in specific energy levels and can move from one level to another. The characteristics of the line spectra of various elements can also be used to identify them, as shown in **Figure 2.30**.

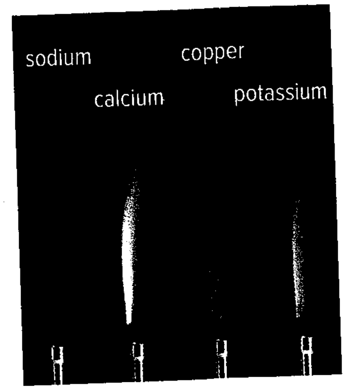


Figure 2.30 Flame tests work by placing a small sample of a compound containing a metal element in a flame. The added energy causes electrons in the atoms to jump up into higher shells and then fall back down, giving off light of characteristic colours.

Atomic Theory—A Group Effort

Bohr did not come up with his ideas in isolation—he built on the existing atomic model and theory, but also on work that Albert Einstein and others were doing regarding the nature of energy and light. Similarly, Thomson, Rutherford, and all of the other scientists who contributed to the development of modern atomic theory built on the work of scientists who had published results before them and who were working simultaneously on related ideas. They also depended on communication and teamwork with their colleagues, students, and laboratory assistants.

Activity

Atomic Theory Timeline

Working in groups, make a digital or paper timeline to show the development of atomic theory. Include the scientists and discoveries discussed in this book, but also research the contributions of additional scientists. You may wish to include some or all of the following people and events: Robert Boyle, William Crookes, Marie Curie, Robert Millikan, Eugen Goldstein, Lise Meitner, the first particle accelerator, the splitting of the uranium atom, the development of atomic weapons, the discovery of quarks and other particles, and the founding of CERN. Include any additional items you find through your research. You may also wish to include key historical events to anchor the events of the timeline, such as World Wars I and II.

Before you leave this page . . .

1. Compare and contrast models of the atom.
2. In your own words, describe Bohr's contribution to atomic theory.