Pearson

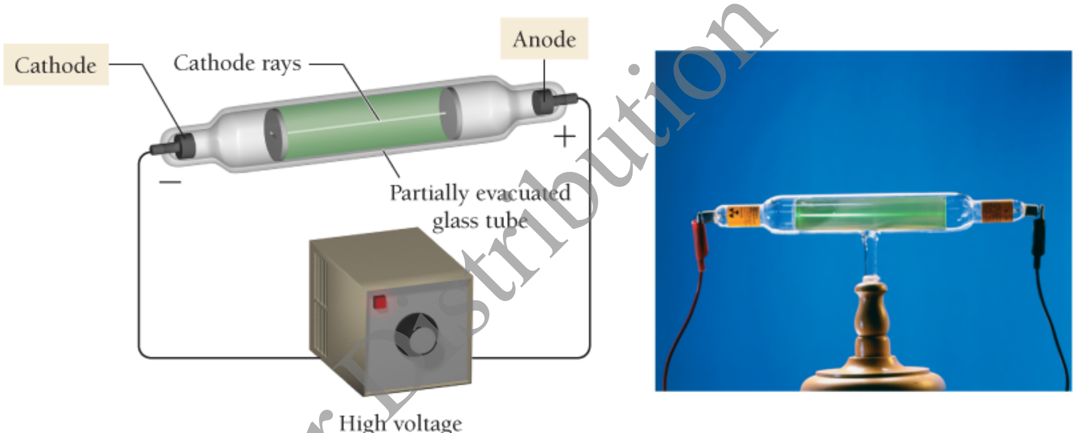
1.6: The Discovery of the Electron

By the end of the nineteenth century, scientists were convinced that matter was made up of atoms—permanent, supposedly indestructible building blocks that compose everything. However, further experiments revealed that the atom itself is composed of even smaller, more fundamental particles.

Cathode Rays

In the late 1800s, an English physicist named J. J. Thomson (1856–1940), working at Cambridge University, performed experiments to probe the properties of **cathode rays**. Thomson constructed a partially evacuated glass tube called a **cathode ray tube**, shown in Figure 1.4. Thomson then applied a high electrical voltage between two electrodes at either end of the tube. He found that a beam of particles, called cathode rays, traveled from the negatively charged electrode (called the cathode) to the positively charged one (called the anode).

Figure 1.4 **Cathode Ray Tube**



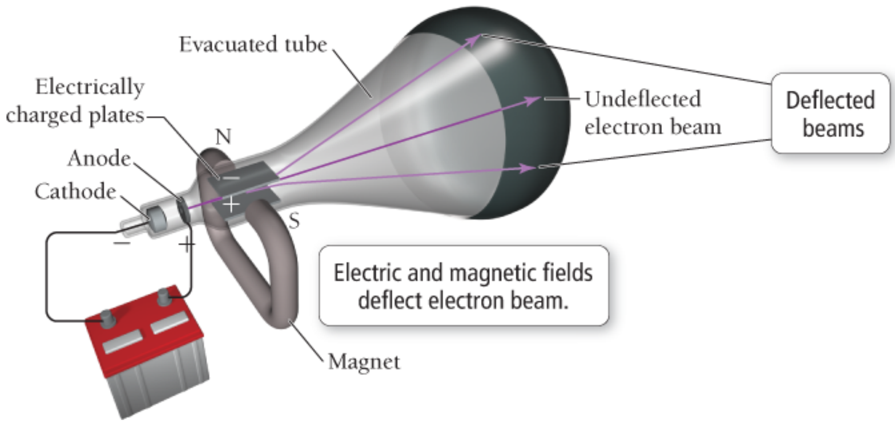
Thomson observed that the particles that compose the cathode ray have the following properties: They travel in straight lines; they are independent of the composition of the material from which they originate (the cathode); and they carry a negative **electrical charge**. Electrical charge is a fundamental property of some of the particles that compose atoms that results in attractive and repulsive forces—called *electrostatic forces*—between those particles. The area around a charged particle where these forces exist is called an *electric field.* The characteristics of electrical charge are summarized in the figure in the margin. You have probably experienced excess electrical charge when brushing your hair on a dry day. The brushing action causes the accumulation of charged particles in your hair, which repel each other, making your hair stand on end.

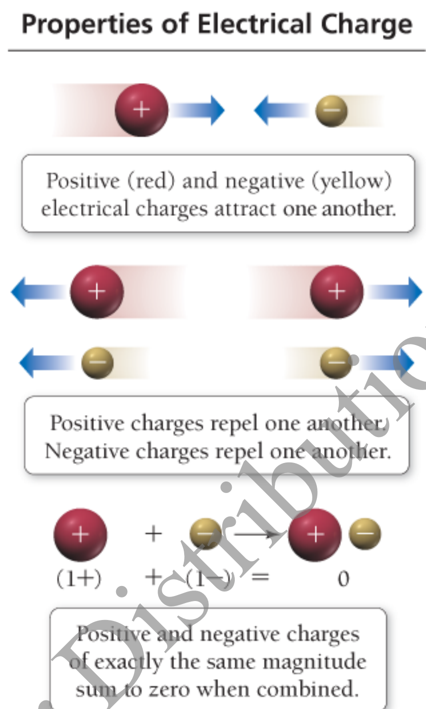
J. J. Thomson measured the charge-to-mass ratio of the cathode ray particles by deflecting them using electric and magnetic fields, as shown in Figure 1.5. The value he measured, -1.76×10^8 coulombs (C) per gram, implied that the cathode ray particle was about 2000 times lighter (less massive) than hydrogen, the lightest known atom. These results were incredible—the indestructible atom could apparently be chipped!

Figure 1.5 **Thomson's Measurement of the Charge-to-Mass Ratio of the Electron**

J. J. Thomson used electric and magnetic fields to deflect the electron beam in a cathode ray tube. By measuring the strengths at which the effects of the two fields (electric and magnetic) canceled exactly, leaving the beam undeflected, he was able to calculate the charge-to-mass ratio of the electron.

Charge-to-Mass Ratio of the Electron





For a more complete explanation of electrical voltage, see Chapter 19. The coulomb (C) is the SI unit for charge.

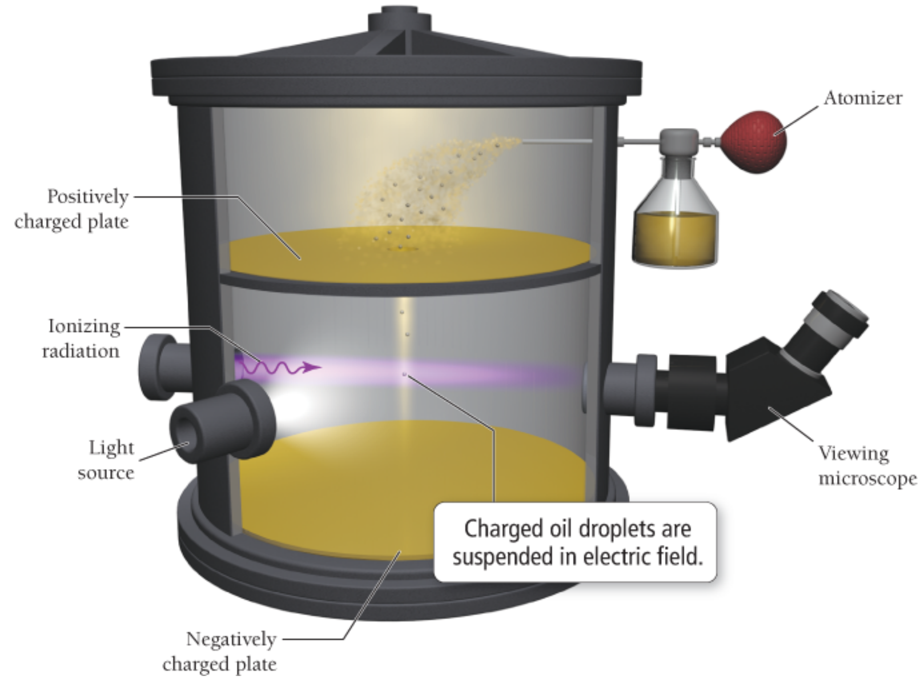
J. J. Thomson had discovered the **electron**, a negatively charged, low-mass particle present within all atoms. He wrote, "We have in the cathode rays matter in a new state, a state in which the subdivision of matter is carried very much further … a state in which all matter … is of one and the same kind; this matter being the substance from which all the chemical elements are built up."

Millikan's Oil Drop Experiment: The Charge of the Electron

In 1909, American physicist Robert Millikan (1868–1953), working at the University of Chicago, performed his now famous oil drop experiment in which he deduced the charge of a single electron. The apparatus for the oil drop experiment is shown in Figure 1.6.

Figure 1.6 Millikan's Measurement of the Electron's Charge

Millikan calculated the charge on oil droplets falling in an electric field. He found that it was always a whole-number multiple of -1.60×10^{-19} C the charge of a single electron.



In his experiment, Millikan sprayed oil into fine droplets using an atomizer (a squeezable bulb). The droplets fell, under the influence of gravity, through a small hole into the lower portion of the apparatus where Millikan viewed them with the aid of a light source and a viewing microscope. During their fall, the drops acquired electrons that had been produced by bombarding the air in the chamber with ionizing radiation (a kind of energy described in Chapter 2). The electrons imparted a negative charge to the drops. In the lower portion of the apparatus, Millikan created an electric field between two metal plates. Since the lower plate was negatively charged, and since Millikan could vary the strength of the electric field, he could slow or even reverse the free fall of the negatively charged drops. (Remember that like charges repel each other.)

By measuring the strength of the electric field required to halt the free fall of the drops, and by figuring out the masses of the drops themselves (determined from their radii and density), Millikan calculated the charge of each drop. He then reasoned that, since each drop must contain an integral (or whole) number of electrons, the charge of each drop must be a whole-number multiple of the electron's charge. Indeed, Millikan was correct; the measured charge on any drop was always a whole-number multiple of -1.60×10^{-19} C, the fundamental charge of a single electron.

With this number in hand, and knowing Thomson's mass-to-charge ratio for electrons, we can deduce the mass of an electron:

$$\cancel{\text{charge}} \times \frac{\text{mass}}{\cancel{\text{charge}}} = \text{mass}$$

$$-1.60 \times 10^{-19}\ \cancel{\text{C}} \times \frac{\text{g}}{-1.76 \times 10^{8}\ \cancel{\text{C}}} = 9.10 \times 10^{-28}\ \text{g}$$

As Thomson had correctly determined, this mass is about 2000 times lighter than hydrogen, the lightest atom.

Why did scientists work so hard to measure the charge of the electron? Since the electron is a fundamental building block of matter, scientists want to know its properties, including its charge. The magnitude of the charge of the electron is of tremendous importance because it determines how strongly an atom holds its electrons. Imagine how matter would be different if electrons had a much smaller charge, so that atoms held them more loosely. Many atoms might not even be stable. On the other hand, imagine how matter would be different if electrons had a much greater charge, so that atoms held them more tightly. Since atoms form compounds by exchanging and sharing electrons (more on this in Chapter 5), there could be fewer compounds or maybe even none. Without the abundant diversity of compounds, life would not be possible. So, the magnitude of the charge of the electron—even though it may seem like an insignificantly small number—has great importance.

Conceptual Connection 1.5 **The Millikan Oil Drop Experiment**

Interactive