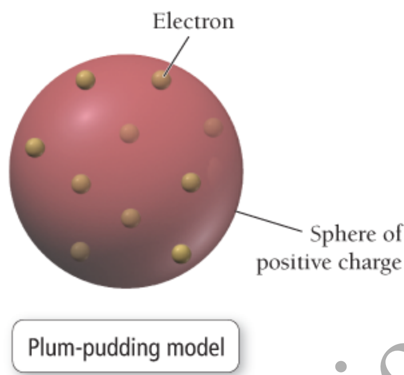
Pearson

1.7: The Structure of the Atom

The discovery of negatively charged particles within atoms raised a new question: Since atoms are charge-neutral, they must contain positive charge that neutralizes the negative charge of the electrons—but how do the positive and negative charges fit together? Are atoms just a jumble of even more fundamental particles? Are they solid spheres? Do they have some internal structure? J. J. Thomson proposed that the negatively charged electrons were small particles held within a positively charged sphere, as shown here.



This model, the most popular of its time, became known as the plum-pudding model. The model suggested by Thomson, to those of us not familiar with plum pudding (a British dessert), was like a blueberry muffin, where the blueberries are the electrons and the muffin is the sphere of positive charge.

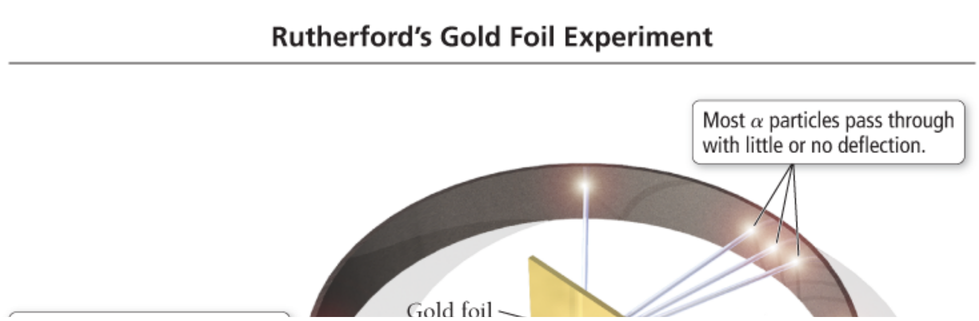
The discovery of **radioactivity**—the emission of small energetic particles from the core of certain unstable atoms—by scientists Antonie-Henri Becquerel (1852–1908) and Marie Curie (1867–1934) at the end of the nineteenth century allowed researchers to experimentally probe the structure of the atom. At the time, scientists had identified three different types of radioactivity: alpha (α) particles, beta (β) particles, and gamma (γ) rays. We will discuss these and other types of radioactivity in more detail in Chapter 20. For now, just know that α particles are positively charged and that they are by far the most massive of the three.

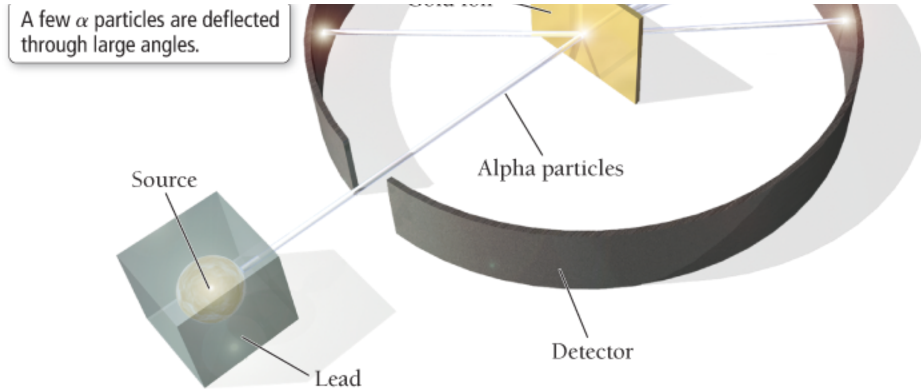
> Alpha particles are about 7000 times more massive than electrons.

In 1909, Ernest Rutherford (1871–1937) and his coworkers performed an experiment in an attempt to confirm Thomson's model (Rutherford had worked under Thomson and subscribed to his plum-pudding model). Instead, Rutherford's experiment, which employed α particles, proved Thomson wrong. In the experiment, positively charged α particles were directed at an ultrathin sheet of gold foil, as shown in Figure 1.7.

Figure 1.7 Rutherford's Gold Foil Experiment

Alpha particles were directed at a thin sheet of gold foil. Most of the particles passed through the foil, but a small fraction were deflected and a few even bounced backward.





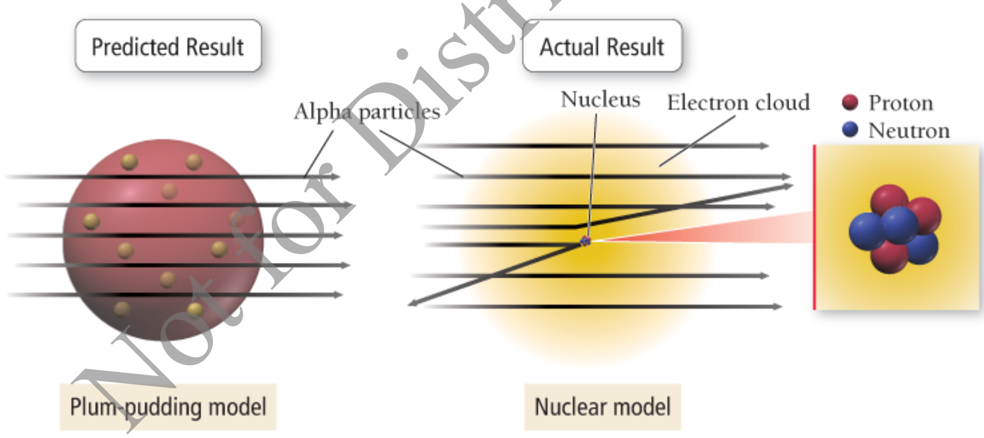
These particles were to act as probes of the gold atoms' structure. If the gold atoms were indeed like blueberry muffins or plum pudding—with their mass and charge spread throughout the entire volume of the atom—these speeding probes should pass right through the gold foil with minimum deflection.

When Rutherford and his coworkers performed the experiment, the results were not what they expected. A majority of the particles did pass directly through the foil, but some particles were deflected and some (approximately 1 in 20,000) even bounced back. The results puzzled Rutherford, who wrote that they were "about as credible as if you had fired a 15-inch shell at a piece of tissue paper and it came back and hit you." What sort of atomic structure could explain this odd behavior?

Rutherford created a new model—a modern version of which is shown in Figure 1.8 beside the plum-pudding model—to explain his results.

Figure 1.8 The Nuclear Atom

Rutherford's results could not be explained by the plum-pudding model. Instead, they suggested that the atom has a small, dense nucleus.



Rutherford realized that to account for the observed deflections, the mass and positive charge of an atom must be concentrated in a space much smaller than the size of the atom itself. He concluded that, in contrast to the plum-pudding model, matter must not be as uniform as it appears. It must contain large regions of empty space dotted with small regions of very dense matter. Building on this idea, he proposed the **nuclear theory** of the atom, with three basic parts:

1. Most of the atom's mass and all of its positive charge are contained in a small core called the **nucleus**.
2. Most of the volume of the atom is empty space, throughout which tiny, negatively charged electrons are dispersed.
3. There are as many negatively charged electrons outside the nucleus as there are positively charged particles (named **protons**) within the nucleus, so that the atom is electrically neutral.

Although Rutherford's model was highly successful, scientists realized that it was incomplete. For example, hydrogen atoms contain one proton, and helium atoms contain two, yet a hydrogen atom has only one-fourth the mass of a helium atom. Why? The helium atom must contain some additional mass. Subsequent work by Rutherford and one of his students, British scientist James Chadwick (1891–1974), demonstrated that the previously unaccounted for mass was due to **neutrons**, neutral particles within the nucleus. The mass of a neutron is similar to that of a proton, but a neutron has no electrical charge. The helium atom is four times as massive as the hydrogen atom because it contains two protons *and two neutrons* (while hydrogen contains only one proton and no neutrons).

The dense nucleus contains over 99.9% of the mass of the atom but occupies very little of its volume. For now, we can think of the electrons that surround the nucleus as analogous to the water droplets that make up a cloud —although their mass is relatively small, they are dispersed over a very large volume. Consequently, an atom, like a cloud, is mostly empty space.

Rutherford's nuclear theory was a success and is still valid today. The revolutionary part of this theory is the idea that matter—at its core—is much less uniform than it appears. If the nucleus of the atom were the size of the period at the end of this sentence, the average electron would be about 10 m away. Yet the period would contain nearly all of the atom's mass. Imagine what matter would be like if atomic structure were different. What if matter were composed of atomic nuclei piled on top of each other like marbles in a box? Such matter would be incredibly dense; a single grain of sand composed of solid atomic nuclei would have a mass of 5 million kg (or a weight of about 11 million pounds). Astronomers believe there are some objects in the universe composed of such matter—neutron stars.

If matter really is mostly empty space, as Rutherford suggested, then why does it appear so solid? Why do we tap our knuckles on a table and feel a solid thump? Matter appears solid because the variation in its density is on such a small scale that our eyes cannot see it. Imagine a scaffolding 100 stories high and the size of a football field. The volume of the scaffolding is mostly empty space. Yet if you viewed it from an airplane, it would appear as a solid mass. Matter is similar. When you tap your knuckle on the table, it is much like one giant scaffolding (your finger) crashing into another (the table). Even though they are both primarily empty space, one does not fall into the other.