

A science prototype: Rutherford and the atom

In the early 1900s, Ernest Rutherford (Fig. 1) studied (among other things) the organization of the atom—the fundamental particle of the natural world. Though atoms cannot be seen with the naked eye, they can be studied with the tools of science since they are part of the natural world.

Investigating atoms

To study such small entities, Ernest Rutherford relied on alpha particles, which are helium atoms stripped of their electrons. Rutherford had found that when a beam of these tiny, positively-charged alpha particles is fired through gold foil,

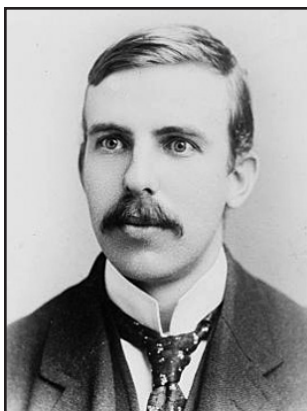


Fig. 1. Ernest Rutherford

the particles don't stay on their beeline course, but are deflected (or "scattered") at different angles (Fig. 2). Rutherford wanted to figure out what this might tell him about the layout of the atoms in the gold foil.

Before 1910, Ernest Rutherford and many other scientists had the idea that the positive charge and the mass of an atom were evenly distributed throughout the whole atom, with electrons scattered throughout. You can imagine this model of the atom as a loosely packed snowball (the positive mass of the atom) with a few tiny grains of sand (the electrons) scattered throughout. The idea that atoms are arranged in this way can be tested by firing an alpha particle beam through a piece of gold foil. If the idea were correct, then the positive mass in the gold foil would be relatively diffuse (the loosely packed snow) and would allow the alpha particles to pass through the foil with only minor scattering (Fig. 3).

Ernest Rutherford's lab tested the idea that an atom's positive mass is spread out diffusely by firing an alpha particle beam through a piece of gold foil, but the evidence resulting from that experiment was a complete surprise: most of the alpha particles passed through the gold foil without changing direction much as expected, but some of the alpha particles came bouncing back in the opposite direction, as though they had struck something dense and solid in the gold foil (Fig. 4). If the gold atoms were really like loosely packed snowballs, all of the alpha particles should have passed through the foil, but they did not!

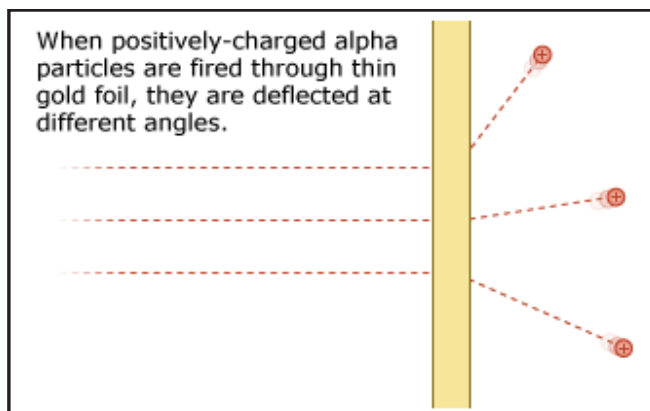


Fig. 2.

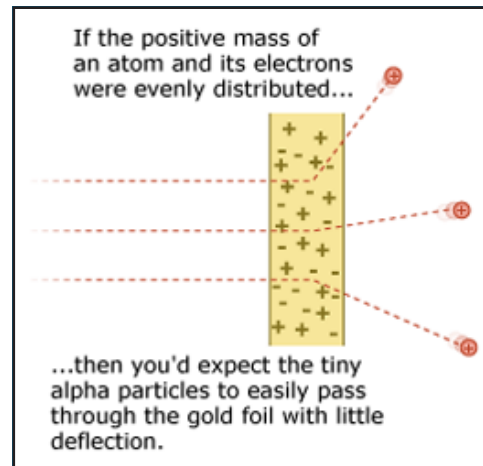


Fig. 3.

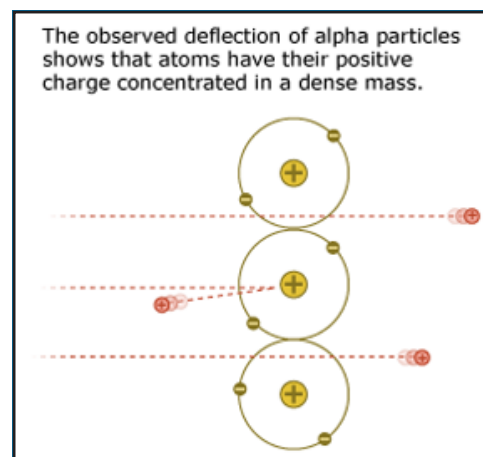


Fig. 4.

Rutherford photo from the Library of Congress

From this evidence, Rutherford concluded that their snowball model of the atom had been incorrect, even though it was popular with many other scientists. Instead, the evidence suggested that an atom is mostly empty space and that its positive charge is concentrated in a dense mass at its core, forming a nucleus. When the positively charged alpha particles were fired at the gold foil, most of them passed through the empty space of the gold atoms with little deflection, but a few of them ran smack into the dense, positively charged nucleus of a gold atom and were repelled straight back (like what would happen if you tried to make the north poles of two strong magnets touch).

The idea that atoms have positively charged nuclei was testable. Rutherford tested it with the alpha particle scattering experiment, of course, but many other researchers tested it as well.

Interacting with the scientific community

Though Ernest Rutherford came up with the idea that atoms have positively charged nuclei, the research that led to this idea was a collaborative effort: Rutherford was assisted by Hans Geiger (Fig. 5), and the critical alpha-scattering experiment was actually carried out by Ernest Marsden, an undergraduate student working in Rutherford's lab.

Furthermore, after his discovery of the layout of the atom, Rutherford published a description of the idea and the relevant evidence, releasing it to the scientific community for scrutiny and evaluation. And scrutinize they did. Niels Bohr (Fig. 6) noticed a problem with Rutherford's idea: there was nothing keeping the orbiting electrons from spiraling into the nucleus of the atom, causing the whole thing to collapse! Bohr modified Rutherford's basic model by proposing that electrons had set energy levels (Fig. 7). This is the model of the atom most commonly portrayed in textbooks: a nucleus orbited by electrons at different levels. It helped solve the problem of the collapsing atom and earned Bohr a Nobel Prize.

Just as Bohr built on Rutherford's model, many other scientists built on and modified Bohr's model. The model wasn't perfect—it raised many new questions (e.g., how do orbiting electrons avoid violating the rules of electricity and magnetism when they don't spiral into the nucleus?)—but it was powerful. With further modification, Bohr's model led to a wide range of accurate predictions and new discoveries: from predicting the outcome of chemical reactions, to determining the composition of distant stars, to conceiving of the atomic bomb.



Fig. 5. Ernest Rutherford (right) and Hans Geiger in the physics laboratory at Manchester University, England, circa 1912. Permission of the Alexander Turnbull Library, Wellington, New Zealand, must be obtained before any reuse of this image; Reference Number: PAColl-0091-1-011.

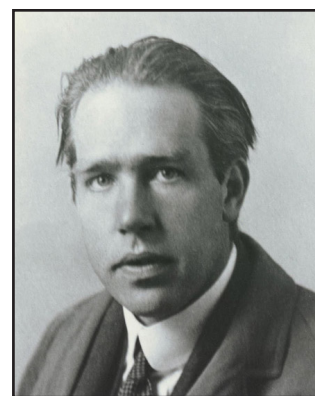


Fig. 6. Niels Bohr

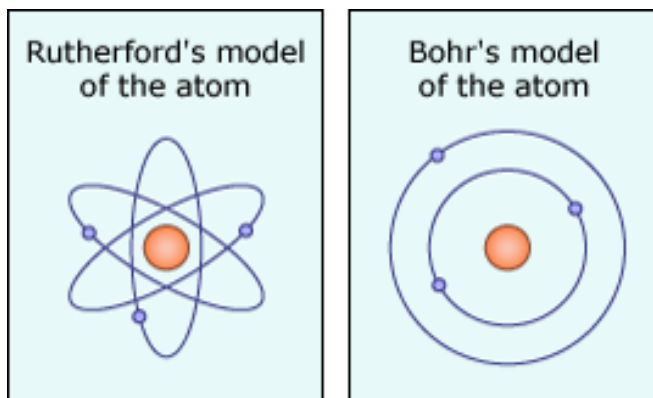


Fig. 7. Lithium atoms, diagrammed in the Rutherford and Bohr models. Rutherford's model does not differentiate between any of the electrons, while Bohr's places electrons into orbits with set energy levels.

Scientific standards

Throughout this investigation, Ernest Rutherford and his colleagues acted in ways that moved science forward:

- They understood the relevant knowledge in their field. Rutherford had studied physics for more than 20 years when he proposed the idea of the nucleus.
- They exposed their ideas to testing. Even though his original view of the atom suggested that no back-scattering should occur, Rutherford decided to look for backscattered alpha particles anyway, just to be thorough.
- They assimilated the evidence. When their experimental results did not support the “snowball” model of the atom, instead of writing those results off as an anomaly, they modified their original ideas in light of the new evidence.
- They openly communicated their ideas so that other physicists could test them as well. Rutherford published the experimental results, a description of his reasoning, and the idea of the nucleus in 1911 in a scientific journal.
- They acted with scientific integrity. In his paper on the topic, Rutherford assigned credit fairly (citing the contributions of his colleagues, Geiger and Marsden) and reported his results honestly—even when experimental results and his theoretical calculations did not match up perfectly.

Such scientific integrity is critical to the progress of science.