the anode without being blocked by gas molecules. He discovered that a new and penetrating form of radiation was emitted by the anode. This radiation, which he called *x rays*, traveled with ease through paper, wood, and flesh but was absorbed by heavier substances such as bone and metal. Röntgen demonstrated that x rays were not deflected by electric or magnetic fields and therefore were not beams of charged particles. Other scientists suggested that the rays might be electromagnetic radiation like light, but of a shorter wavelength. Max von Laue proved this hypothesis 18 years later when he diffracted x rays with crystals (Section 3–7).

In 1896, Henri Becquerel (1852–1928) observed that uranium salts emitted radiation that penetrated the black paper coverings of photographic plates and exposed the photographic emulsion. He named this behavior *radioactivity*. In the next few years, Pierre and Marie Curie isolated two entirely new, and radioactive, elements from uranium ore and named them *polonium* and *radium*. Radioactivity, even more than x rays, was a shock to physicists of the time. They gradually realized that radiation occurred during the breakdown of atoms, and that atoms were not indestructible but could decompose and decay into other kinds of atoms. The old certainties, and the hopes for impending certainties, began to fall away.

The radiation most commonly observed was of three kinds, designated alpha (α), beta (β), and gamma (γ). γ Radiation proved to be electromagnetic radiation of even higher frequency than x rays. β Rays, like cathode rays, were beams of electrons. Electric and magnetic deflection experiments showed that α radiation has a mass of 4 amu and a charge of +2; α particles were simply nuclei of helium, ^4_2He.

The next certainty to slip away was the quite satisfying model of the atom that had been proposed by J. J. Thomson.

7–1 RUTHERFORD AND THE NUCLEAR ATOM

Thomson had proposed a model of the atom in which all of the mass and positive charge were distributed uniformly throughout the atom, with electrons embedded in the atom like raisins in a pudding. Mutual repulsion of electrons separated them uniformly. The resulting close association of positive and negative charges was reasonable. Ionization could be explained as a stripping away of some of the electrons from the pudding, thereby leaving a massive, solid atom with a positive charge.

In 1910, Ernest Rutherford (1871–1937) disproved the Thomson model more or less by accident, while measuring the scattering of a beam of α particles by extremely thin metal foils. (His experimental arrangement is shown in Figure 7–1.) He expected to find a relatively small deflection of particles, as would occur if the posi-

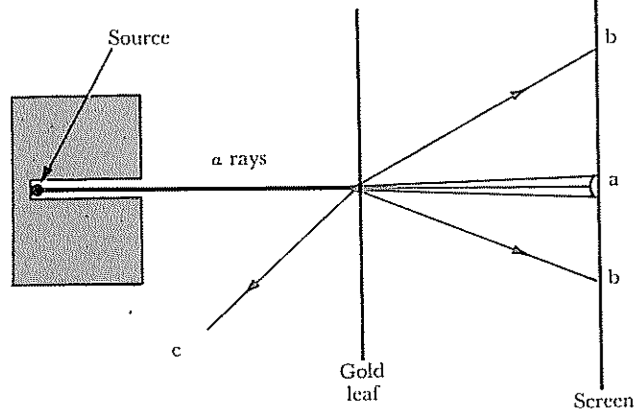

Figure 7–1. The experimental arrangement for Rutherford's measurement of the scattering of α particles by very thin metal foils. The source of the α particles is radioactive polonium, encased in a lead block that protects the surroundings from radiation and confines the α particles to a beam. The gold foil used was 4×10^{-5} cm *thick. Most of the α particles pass through the gold leaf with little or no deflection,* a. *A few are deflected at wide angles,* b, *and occasionally a particle rebounds from the foil,* c, *to be detected only by a screen or counter placed on the same side of the foil as the source.*

tive charge and mass of the atoms were distributed over a large volume in a uniform way [Figure 7–2(a)]. What he observed was quite different, and wholly unexpected. In his own words:

> In the early days I had observed the scattering of α particles, and Dr. Geiger in my laboratory had examined it in detail. He found in thin pieces of heavy metal that the scattering was usually small, of the order of one degree. One day Geiger came to me and said, "Don't you think that young Marsden, whom I am training in radioactive methods, ought to begin a small research?" Now I had thought that too, so I said, "Why not let him see if any α particles can be scattered through a large angle?" I may tell you in confidence that I did not believe they would be, since we knew that the α particle was a very fast massive particle, with a great deal of energy, and you could show that if the scattering was due to the accumulated effect of a number of small scatterings, the chance of an α particle's being scattered backwards was very small. Then I remember two or three days later Geiger coming to me in great excitement and saying, "We have been able to get some of the α particles coming backwards." . . . . It was quite the most incredible event that has ever happened to me in my life. It was almost as incredible as if you fired a 15-inch shell at a piece of tissue paper and it came back and hit you.