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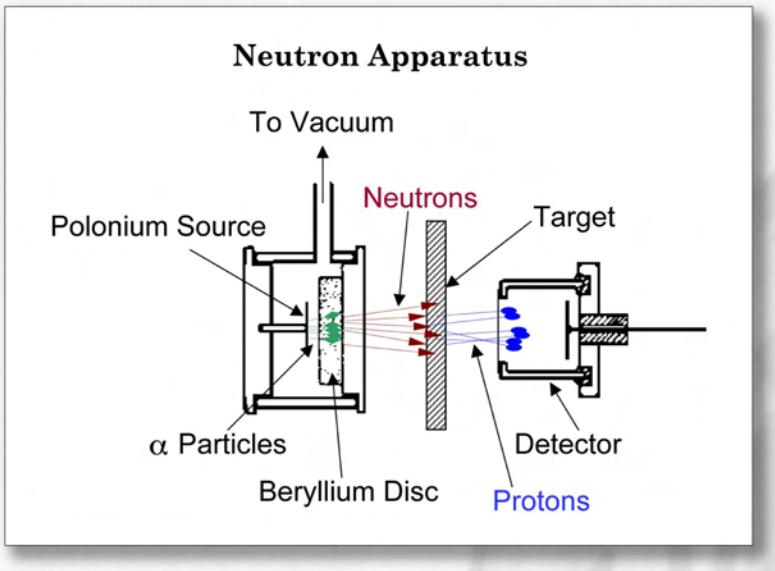
The Neutron

In 1930 Bothe and Becker working in Berlin found that when beryllium is bombarded with α-particles, a penetrating radiation emerges, which they ascribed to γ-rays. In 1931 Irene Curie and her husband Joliot, repeated the experiment, and found that the radiation knocked protons out of a sheet of paraffin wax. They also ascribed the radiation to γ-rays; and, from the energy of the protons, calculated the energy of the γ-ray quantum to be about 55 MeV. However, this value was unusually high; typical values of the energy of γ-rays produced in a nuclear reaction being about 10 MeV or less.



In 1932 Chadwick solved the riddle of the radiation in a series of direct and compelling measurements. The replica shown here is of a cylinder 3 cm in diameter and 12 cm in length. Inside is a silver disc on which polonium, a source of α-particles, was deposited. Parallel to this disc is a disc of beryllium. The radiation emerged through an aluminum window at the end of the chamber, and its effects were detected by an ionization chamber. The pulse amplitude from the ionization chamber was a measure of the energy of the particle producing the pulse.

Chadwick allowed the penetrating radiation to knock out protons from a series of elements from hydrogen to argon placed at the target. In each case he measured the energies of the ejected protons. The results showed that the γ-ray hypothesis gave inconsistent results; the energy of the γ-ray quantum, calculated from the energy of the particles ejected from the beryllium increased with the atomic weight of the element in the target. However, if the unknown radiation was assumed to be neutral particles of mass approximately equal to that of the proton, the energies of the recoil nuclei from all the elements in the target were consistent.

The reaction that knocks neutrons (n) from the beryllium is: $^{4}_{2}He + ^{9}_{4}Be \rightarrow ^{1}_{0}n + ^{12}_{6}C$

While some scientists labor for years to obtain results worthy of recognition by the Nobel Committee even more years later; Chadwick's work on the neutron was at the opposite end of the spectrum. From the beginning of his experiments until he submitted his letter to Nature reporting his discovery was a scant fifteen days in 1932. In 1935, the Nobel Committee awarded him the Physics Prize "for the discovery of the neutron". Of course, Chadwick was steeped in the knowledge of sub-atomic physics, having spent two years of his early education working under Lord Rutherford in the Physical Laboratory in Manchester in the early 'teens. After World War I he moved to Cambridge and later rejoined Rutherford at the Cavendish Laboratory. In 1920 Rutherford suggested the possibility that the neutron, which he envisaged as a combination of a proton and an electron, might exist. Thus the workers at the Cavendish were on the lookout for such a particle. We now know that the neutron is not the combination that Rutherford suggested, but is an elementary particle in its own right. The discovery of the neutron forms the basis of the present model of the atomic nucleus, which consists of protons and neutrons.

In a journal publication in 1906 and again in his 1913 book "Rays of Positive Electricity and Their Application to Chemical Analysis" Thomson foresaw the analytical utility of the mass spectrograph to the chemist. His farsighted vision was not realized until several decades later in the mid '40s when Consolidated Engineering Corporation introduced an analytical mass spectrometer for the analysis of hydrocarbons. Thomson overlooked some of the obvious problems with the instrumentation of his era: Ionization by electrical discharge limited analysis to samples that were in the gas phase. The mass range of early instruments was severely limited. One or possibly two physicists would be required to keep the instrument in operating order. Vacuum systems were unreliable and slow. In short, the technology of 1920 was not adequate for a workable analytical mass spectrometer of use to the chemist. As Aston wrote in 1941:

"Sir J. J. Thomson . . . was a theoretical physicist, unskilled in manipulation, he did not realize the formidable experimental difficulties involved, and it was not until many years later, when these had been alleviated by improvements in vacuum and other techniques, that any progress was made".

Today Thomson's vision has been realized beyond even his wildest dreams.

With the understanding that came from these discoveries, the primary constituents of the atom were known; the electron, the proton and the neutron. While sub-atomic particle physics continues to investigate ever more subtle features of the nucleus, these fundamental discoveries at the turn of the last century formed the basis of knowledge necessary for the advancement of the chemical and biological sciences.