Chadwick discovers the neutron 1932

For four years, James Chadwick was a prisoner of war in Germany. When World War I ended, he returned to his native England to rejoin the mentor of his undergraduate days, Ernest Rutherford. Now head of Cambridge University's nuclear physics lab, Rutherford oversaw Chadwick's PhD in 1921 and then made him assistant director of the lab.

Chadwick's own research focused on radioactivity. In 1919 Rutherford had discovered the proton, a positively charged particle within the atom's nucleus. But they and other researchers were finding that the proton did not seem to be the only particle in the nucleus.

As they studied atomic disintegration, they kept seeing that the atomic number (number of protons in the nucleus, equivalent to the positive charge of the atom) was less than the atomic mass (average mass of the atom). For example, a helium atom has an atomic mass of 4, but an atomic number (or positive charge) of 2.

Since electrons have almost no mass, it seemed that something besides the protons in the nucleus were adding to the mass. One leading explanation was that there were electrons and additional protons in the nucleus as well -- the protons still contributed their mass but their positive charge was canceled out by the negatively charged electrons. So in the helium example, there would be four protons and two electrons in the nucleus to yield a mass of 4 but a charge of only 2. Rutherford also put out the idea that there could be a particle with mass but no charge. He called it a neutron, and imagined it as a paired proton and electron. There was no evidence for any of these ideas.

Chadwick kept the problem in the back of his mind while working on other things. Experiments in Europe caught his eye, especially those of Frederic and Irene Joliot-Curie. They used a different method for tracking particle radiation. Chadwick repeated their experiments but with the goal of looking for a neutral particle -- one with the same mass as a proton, but with zero charge. His experiments were successful. He was able to determine that the neutron did exist and that its mass was about 0.1 percent more than the proton's. He published his findings with characteristic modesty in a first paper entitled "Possible Existence of Neutron." In 1935 he received the Nobel Prize for his discovery.

His findings were quickly accepted and Werner Heisenberg then showed that the neutron could not be a proton-electron pairing, but had to be its own unique particle -- the third piece of the atom to be found. This new idea dramatically changed the picture of the atom and accelerated discoveries in atomic physics. Physicists soon found that the neutron made an ideal "bullet" for bombarding other nuclei. Unlike charged particles, it was not repelled by similarly-charged particles and could smash right into the nucleus. Before long, neutron bombardment was applied to the uranium atom, splitting its nucleus and releasing the huge amounts of energy predicted by Einstein's equation E = mc2.

His paper describing his discovery is given below.

Possible Existence of a Neutron

James Chadwick
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It has been shown by Bothe and others that beryllium when bombarded by α-particles of polonium emits a radiation of great penetrating power, which has been an absorption coefficient in lead of about 0.3 $(cm)^{-1}$. Recently Mme. Curie-Joliot and M. Joliot found, when measuring the ionisation produced by this beryllium radiation in a vessel with a thin window, that the ionisation increased when matter containing hydrogen was placed in front of the window. The effect appeared to be due to the ejection of protons with velocities up to a maximum of nearly 3×10^9 cm. per sec. They suggested that the transference of energy to the proton was by a process similar to the Compton effect, and estimated that the beryllium radiation had a quantum energy of 50×10^6 electron volts.

I have made some experiments using the valve counter to examine the properties of this radiation excited in beryllium. The valve counter consists of a small ionisation chamber connected to an amplifier, and the sudden production of ions by the entry of a particle, such as a proton or α-particle, is recorded by the deflexion of an oscillograph. These experiments have shown that the radiation ejects particles from hydrogen, helium, lithium, beryllium, carbon, air, and argon. The particles ejected from hydrogen behave, as regards range and ionising power, like protons with speeds up to about 3.2×10^9 cm. per sec. The particles from the other elements have a large ionising power, and appear to be in each case recoil atoms of the elements.

If we ascribe the ejection of the proton to a Compton recoil from a quantum of 52×10^6 electron volts, then the nitrogen recoil atom arising by a similar process should have an energy not greater than about 400,000 volts, should produce not more than about 10,000 ions, and have a range in air at N.T.P. of about 1.3 mm. Actually, some of the recoil atoms in nitrogen produce at least 30,000 ions. In collaboration with Dr. Feather, I have observed the recoil atoms in an expansion chamber, and their range, estimated visually, was sometimes as much as 3 mm at N.T.P.

These results, and others I have obtained in the course of the work, are very difficult to explain on the assumption that the radiation from beryllium is a quantum radiation, if energy and momentum are to be conserved in the collisions. The difficulties disappear, however, if it be assumed that the radiation consists of particles of mass 1 and charge 0, or neutrons. The capture of the α-particle by the Be^9 nucleus may be supposed to result in the formation of a C^{12} nucleus and the emission of the neutron. From the energy relations of this process the velocity of the neutron emitted in the forward direction may well be about 3×10^9 cm. per sec. The collisions of the neutron with the atoms through which it passes give rise to the recoil atoms, and the observed energies of the recoil atoms are in fair agreement with this view. Moreover, I have observed that the protons ejected from hydrogen by the radiation emitted in the opposite direction to that of the exciting α-particle appear to have a much smaller range than those ejected by the forward radiation. This again receives a simple explanation of the neutron hypothesis.

If it be supposed that the radiation consists of quanta, then the capture of the α-particle by the Be^9 nucleus will form a C^{13} nucleus. The mass defect of C^{13} is known with sufficient accuracy to show that the energy of the quantum emitted in this process cannot be greater than about 14×10^6 volts. It is difficult to make such a quantum responsible for the effects observed.

It is to be expected that many of the effects of a neutron in passing through matter should resemble those of a quantum of high energy, and it is not easy to reach the final decision between the two hypotheses. Up to the present, all the evidence is in favour of the neutron, while the quantum hypothesis can only be upheld if the conservation of energy and momentum be relinquished at some point.

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Cambridge, Feb. 17.