Chadwick's Discovery of The Neutron

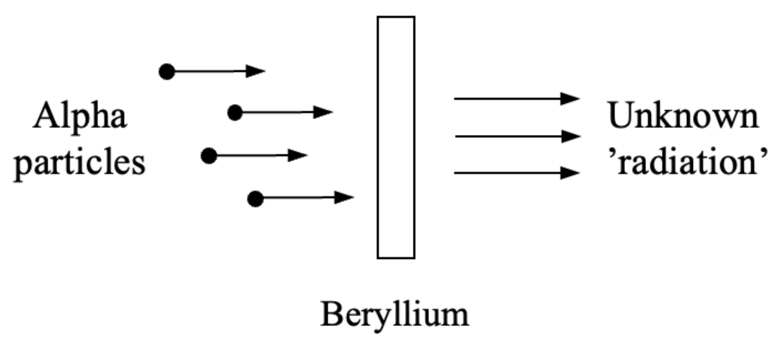
(adopted from https://scienceready.com.au/pages/chadwicks-discovery-of-the-neutron and amended with excerpts from https://www.aps.org/apsnews/2007/05/may-1932-chadwick-reports-the-discovery-of-the-neutron)

By 1920, physicists knew that most of the mass of the atom was located in a nucleus at its center, and that this central core contained protons. Following proposal of his own atomic model, **Ernest Rutherford** realized that **there must be other particles inside the nucleus besides protons** because the mass number of an atom (atomic weight) was always found to exceed its atomic number (number of protons in the nucleus). For instance, helium was known to have an atomic number of 2 but a mass number of 4.

Searching for the neutral subatomic particle proved to be a very difficult task. The eventual discovery of the neutron in 1932 by **James Chadwick** was one factor that led to the year 1932 being considered the "annus mirabilis"—the extraordinary year—of nuclear physics.

Experiments that led to the discovery of the neutron

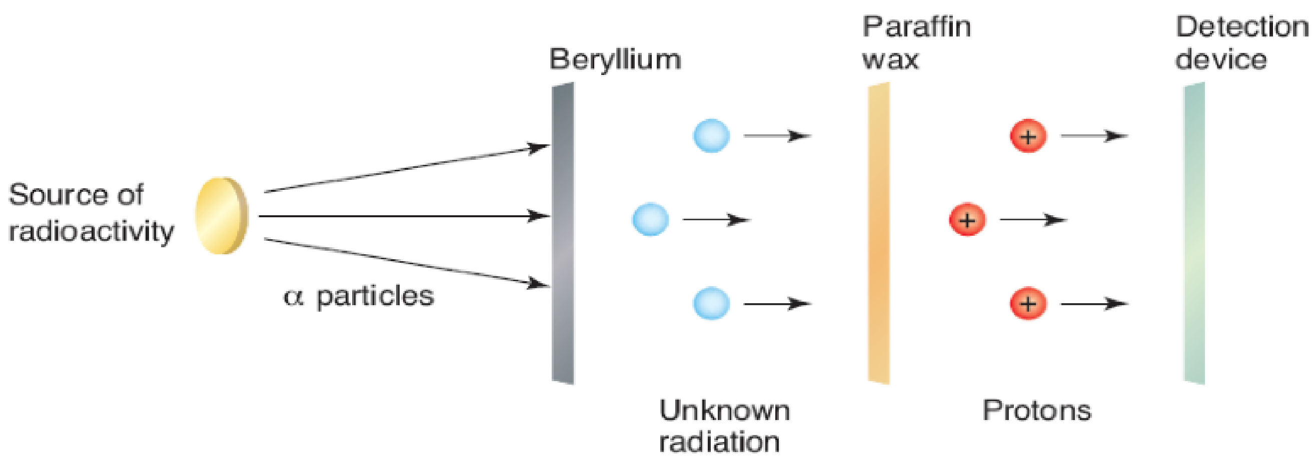
Around 1930, several researchers had begun **bombarding beryllium** (Be, a lightweight and hard metal) **with alpha particles** from a polonium source. The resulting nuclear transmutation (beryllium changing into carbon) was accompanied by the production of unknown ‘radiation’, that was **highly penetrating.**



Some scientists initially thought this ‘radiation’ emitted by the beryllium was in fact **high-energy gamma radiation**, not material particles, because it was **unaffected by electric and magnetic fields** (all particles known at the time - electrons, protons - were charged and responded to electric and magnetic fields). James Chadwick, then Assistant

Director of Cambridge University's Cavendish laboratory, had noticed some odd features of this radiation, namely its extremely high penetrating ability, and began to think it might instead consist of neutral particles such as those Rutherford had proposed.

One experiment in particular caught his attention: Frédéric and Irène Joliot-Curie (Irene was Pierre and Marie Curie's daughter) had studied the then-unidentified **'radiation' from beryllium** as it **hit a paraffin wax target**. The 'radiation' was projected onto a thin proton-rich paraffin wax block, causing **protons to be emitted**.



Analysis of these **protons' momentum and kinetic energies** (energies of motion) provided an **estimation of the energy** of the thought-to-be-gamma 'radiation'. However, the energies of alpha particles that caused the emission of 'radiation' were far too small to allow for this possibility without violating the law of conservation of energy. In other words**, there was too little energy available** at the beginning of the experiment **to yield the amount of energy that was registered** at the last step of the experiment.

Furthermore, **gamma radiation** was known to produce **photoelectric effect** in metals – ejection of electrons from metal surfaces irradiated with gamma rays – but when the 'radiation' emitted by beryllium was projected onto various metal surfaces, **no such effect was observed**. This finding was also pointing to the nature of the **'radiation'** to be **something other than gamma radiation**.

When James Chadwick reported to Ernest Rutherford on the Joliot-Curies' results, Lord Rutherford (knighted in 1914) excitedly exclaimed, "I do not believe it!" – it seemed that the elusive neutral particles could be finally within reach…

Chadwick's Experiment and Discovery of the Neutron

In 1932, Chadwick carefully **conducted the same experiment** using beryllium and paraffin wax block (and also tried other targets, including helium, nitrogen, and lithium), **but provided a different interpretation.** He claimed that this unknown 'radiation' was actually **neutral particles – neutrons -** and reasoned that a neutral massive particle could eject a proton from the paraffin by imparting its momentum onto it, similar to a bullet knocking out pieces of a target following a collision.

Using the kinetic energy and momentum of emitted protons measured in the experiment and applying the law of conservation of momentum and conservation of energy, Chadwick **determined the mass of a neutron** and showed that it was **slightly greater than that of a proton**. This result allowed to account for the "missing" part of the atomic weight by assuming that the mass number of an atom is a total of all its protons and neutrons contained in the nucleus. Chadwick also noted that **because the neutrons had no charge**, they **penetrated much further** into a target than protons would, **unimpeded by electrical charges** of electrons and atomic nuclei within matter.

In February 1932, after **experimenting for only about two weeks**, Chadwick **published a paper** titled "The Possible Existence of a Neutron," in which he proposed that the **evidence favored the neutron rather than the gamma radiation as the correct interpretation of the mysterious beryllium 'radiation'.** Then a few months later, in May 1932, Chadwick submitted the more definite paper titled "The Existence of a Neutron."

The discovery of a neutron quickly changed scientists' view of the atom, and **Chadwick was awarded the Nobel Prize in 1935 for the discovery**. It is interesting to note that the Joliot-Curies' misinterpretation of their (own!) results cost them the Nobel Prize. Not to worry; in 1935, they too received the Nobel Prize - in chemistry - for their discovery of artificial (induced) radioactivity.

Scientists soon realized that the newly discovered neutron, as an uncharged but fairly massive particle, could be used to probe other nuclei. It didn't take long for scientists to find that hitting uranium with neutrons resulted in the fission of the uranium nucleus and the release of incredible amounts of energy, making possible nuclear weapons. Chadwick, whose discovery of the neutron had paved the way for the atomic bomb, worked on the Manhattan Project during WWII.