The neutron before the neutron: Pontremoli's compound models

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Abstract: Rutherford's 1920 Bakerian Lecture was the first attempt to advance the existence of the neutron as a proton-electron compound structure, similar to but much smaller than a hydrogen atom. The first attempts to detect the formation of compound neutrons in hydrogen-filled discharge tubes were due to Glasson in 1921. The negative result was not considered definitive because of the general lack of knowledge about the neutron's properties. Aldo Pontremoli, at that time at the Cavendish Laboratory, was aware of both theoretical and experimental problems concerning the existence of the neutron. Once back to Rome he faced the theoretical analysis of the problem of the neutron's compound structure in the framework of Bohr's atomic theory. The smallest permitted stable orbital radius prevented the existence of a compound state with an electron in orbit around a positive nucleus at a much smaller distance. Pontremoli advanced two models. According to the first one, the neutron was a compound system with the electron tangent to the nucleus. Using Silberstein's relativistic formula of the electromagnetic mass of compound systems, Pontremoli calculated the difference in mass between the neutron and the hydrogen atom. The second model advanced by Pontremoli considered the neutron as an extremely contracted hydrogen molecule with the nuclei in orbit around the two electrons. The consequent modification of the dynamical formulae of the hydrogen molecule made Pontremoli able to confirm the neutron's nuclear dimensions. This result appeared promising of an experimental study of the spectral lines of the two nuclei's transitions, for a spectroscopic confirmation of the model. Furthermore, a comparison of the mass defects with the electromagnetic mass due to the close charges proximity would have been a confirmation of the electromagnetic origin of matter.

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1. Rutherford's Neutron

In his 1920 Bakerian Lecture, Ernst Rutherford (1920) devoted part of his talk about the nuclear constitution of atoms to the possible existence of neutral compound structure, later called neutron by Rutherford himself. The simplest advanced compound structure, a 1-mass neutron, was an extremely shrunk hydrogen atom with the electron orbiting around the nucleus on an orbit very close to it. The combination of some doublets of this kind would correspond to neutrons of mass 2 or greater.

Rutherford's compound neutron had therefore a zero electrical charge and nuclear dimensions. Except for the points very close to the nucleus, the external electric field of the compound structure was null. This fact, together with its smallness, made the compound neutron able to freely go through matter and hardly contained inside a vessel. Interacting with matter, the neutron could penetrate into an atomic nucleus. Were it captured by the nucleus, then the neutron could transform it into the nucleus of an isotope of the same element. Were it disintegrated by the nucleus' electric field, then the neutron would emit the electron (as a β decay) and change the nucleus' Z number.

The then accepted hypothesis on heavy elements synthesis considered a positive charge (a proton) hitting a nucleus and being captured by it against the action of its electric field. Rutherford's compound neutron would permit its capture and disintegration by a nucleus even at low energies.

Being an anomalous hydrogen atom, the compound neutron would not have a behaviour typical of normal hydrogen. Since it was thought to be an extremely stable system, it would have been hardly discovered with standard spectroscopic analyses.

Glasson, a member of Rutherford's team at the Cavendish Laboratory, tried to detect the creation of compound neutrons amongst the positive rays in a hydrogen discharge tube (Glasson 1921). Inside a tube of this kind, a large number of free electrons and hydrogen nuclei could be found. Some of the fast nuclei might capture one free electron giving birth to a neutron doublet. According to Glasson, a neutron hitting a heavy element nucleus would cause the neutron and/or the neutron to break; the fragments distributions could have been detected as a local ionization. After various attempts with different experimental settings, Glasson concluded by stating that no positive evidence was found.

2. Pontremoli's First Compound Model

Aldo Pontremoli[1] was born in Milano in 1896 and graduated in Physics in Rome in 1920 with Orso Mario Corbino. He volunteered to the First World War and was honoured with some military decorations. Thanks to his military activity he won a 8.000 Italian liras scholarship from the National Fighters Association to spend a research period at the Cavendish Laboratory in Cambridge. There he studied with Joseph Larmor, Joseph John Thomson, Arthur Eddington, Rutherford and Charles Galton Darwin. He worked in theoretical and experimental nuclear physics (McAulay 1921) in Rutherford's group; he was therefore aware of the latter's suggestion of the existence of a neutron. On December 1st 1920 he was appointed assistant to the Physics Institute in Rome, where he worked on the birefringence in fluids, spectroscopy and electromagnetism with Corbino. He also envisaged two possible models of neutron following Rutherford's ideas.

[1] For more details on Pontremoli see (Finzi 1928; Gariboldi 2011; Giordana 1933; Pugno Vanoni 1930).

Pontremoli's criticism on Glasson's experiment highlighted the lack of knowledge about the energy necessary to form compound neutrons from free electrons and hydrogen nuclei. The voltage applied to Glasson's hydrogen tube varied between 2 and 50 kV so that it might have been insufficient to create a compound neutron. Furthermore, even if compound neutrons had been created, the ignorance about tentative formation statistics would have prevented to know if they were created in a detectable number.

According to Bohr's theory of the hydrogen atom, Rutherford's compound neutron could not be considered a hydrogen atom. The smallest orbit, with $r \sim 0.5$ Å, was not of nuclear dimensions. No other smaller orbit was permitted by Bohr's theory unless to refute the angular moment quantization postulate.

Pontremoli advanced a first model of the compound neutron by changing the its structure: the electron would not have been in orbit around the hydrogen nucleus but tangent to it giving birth to a neutral doublet.

From the relativistic energy-mass relation $E = mc^2$, the mass of Pontremoli's first neutron would have been $m = E/c^2$ with E potential energy of the electric fields of both charges: $m_n = m_1 + m_e + \Delta m$ (with m_n = neutron mass, m_1 = hydrogen nucleus mass, m_e = electron mass).

Pontremoli supposed the electron and the hydrogen nucleus to be spherical in shape. He was therefore able to apply Silberstein's formula (Silberstein 1911) to find the mass defect (Δm) of a system made by two electric distributions. Ludwik Silberstein proposed his formula in December 1910 in Naples at the Conference of the Italian Society for the Advancement of Sciences. According to Lorentz, the usual distances between any two electrons was too large for making the mass defect detectable; he suggested to study the macroscopic effects of the superposition of very close electrons. Silberstein thus found the solution for a couple of spherical electrons of uniform charge density with spherical radiuses r_1 and r_2, at a distance a:

$$\Delta m = \frac{e_1 e_2}{ac^2}\left(1 - \frac{1}{5}\frac{r_1^2 + r_2^2}{a^2}\right)$$

Pontremoli used Silberstein's formula with the electromagnetic radiuses of the nucleus and the electron: $r_e = 3e^2/5m_e c^2$; $r_1 = 3e^2/5m_1 c^2$. Since the electron was tangent to the hydrogen nucleus the distance a was equal to $a = r_e + r_1$. The ratio between the nucleus and the electron masses was found to be $m_1 = \alpha\, m_e$ with $\alpha = 1846.9$ and the hydrogen nucleus mass was $m_1 = 1.66 \times 10^{-24}$ g from spectroscopic measurements of Rydberg's number variation due to the nuclear motion around the atomic mass centre (Flamm 1917).

By the combination of Silberstein's formula with Flamm's results, Pontremoli obtained the formula for the mass defect:

$$\Delta m = -\frac{4}{3} m_1 \frac{\alpha + 2(1+\alpha)^2}{(1+\alpha)^3} = -2.396 \times 10^{-27} \mathrm{g}$$

corresponding to $\Delta E = -2.156 \times 10^{-6}$ erg. The latter is the energy emitted during the creation of one neutron. The energy emitted due to the creation of one mole of neutrons (-1.31×10^{18} erg) would be easily detected altogether in a calorimetric experiment. The radiation quantum would instead not be actually detectable with spectroscopic measurements since its wavelength would have been extremely short (0.009 Å).

A comparison with the helium nucleus (as a compound structure of four hydrogen nuclei and two electrons) showed that the energy necessary for the creation of any given mass of helium was about 200 times that for the creation of the same mass of neutrons. Pontremoli's first neutron was therefore much less stable than the helium nucleus and could have been disintegrated by hitting it with the RaC-emitted α particles (which has a kinetic energy of $8.1x10^{18}$ erg/mol).

3. Pontremoli's second compound Model

Given the experimental problems concerning the stability and the detection of the first model neutron, Pontremoli advanced a second model following Rutherford's suggestion of the existence of possible neutrons with mass greater than and multiple of 1. Also in this case, the charge distribution had to be compatible with Bohr's postulates. The simplest model with mass 2 was similar to a plane hydrogen molecule with two nuclei and two electrons whose positions were exchanged: the hydrogen nuclei were held in orbit around the two electrons placed on the orbital axis. This second neutron had also a null electric charge and nuclear dimensions. Pontremoli used Sommerfeld's formulae (Sommerfeld 1922) to calculate: the radius of the nuclear orbits ($2.75x10^{-12}$ cm), the distance between the two electrons ($1.59x10^{-12}$ cm), the angular speed and the total energy of any orbit, the dissociation work and the ionization potential.

According to Bohr's theory, the transition of the hydrogen nuclei between any two possible orbits caused the emission (or absorption) of an X-ray spectrum whose lines were like those of the hydrogen spectrum multiplied by 1846.9.

Because of calculus difficulties, Pontremoli was not able to find the mutual mass corresponding to the superposition of the four electrostatic fields. If this mass were equal to the experimentally determined mass defect, then, according to Pontremoli, this would confirm the electromagnetic origin of matter.

The experimental search for the neutron will be pursued by James Chadwick. In 1930, Walther Bothe and Herbert Becker discovered that the interaction of Polonium-emitted α-rays with Beryllium did not produce protons but a highly penetrating radiation, which they identified as nuclear γ-rays. In 1932, Irène Curie and Frédéric Joliot found that this highly penetrating radiation make protons free from hydrogenated matter. Chadwick understood that this radiation was made of neutral particles with a mass similar to the proton's one somehow corresponding to Pontremoli's first model.

References

Finzi B. (1928). "Aldo Pontremoli". *Rendiconti del Seminario Matematico e Fisico di Milano*, II, pp. xi-xii.

Flamm L. (1917). "Die charakteristichen Maßzahlen für das Elektron in ihrer Verknüpfung mit den Strahlungskonstanten". *Physikalische Zeitschrift*, 18, pp. 515-521.

Gariboldi L. (2011). *Aldo Pontremoli e l'Istituto di fisica di Milano*, in Giannetto E., Giannini G., Toscano M., *Intorno a Galileo: la storia della fisica e il punto di svolta galileiano*. Bergamo: Guaraldi.

Giordana G. (1933). *Vita di Aldo Pontremoli*. Roma: Formiggini.

Glasson J.L. (1921). "Attempts to Detect the Presence of Neutrons in a Discharge Tube". *Philosophical Magazine*, 42, pp. 596-600.

McAulay A.L. (1921). "The Recoil of Hydrogen Nuclei from Swift α Particles". *Philosophical Magazine*, 42 pp. 892-904.

Pontremoli A. (1923). "Sul neutrone del Rutherford". *Atti della Reale Accademia Nazionale dei Lincei. Rendiconti*, 32, pp. 277-280.

Pugno Vanoni E. (1930). "Aldo Pontremoli. Note biografiche". *Il Nuovo Cimento*, VII, pp. 41-49.

Rutherford E. (1920). "Nuclear Constitution of Atoms". *Proceedings of the Royal Society*, A 97, pp. 374-400.

Silberstein L. (1911). "Über die gegenseitige Masse kugelförmiger Elektronen". *Physikalische Zeitschrift*, 12, pp. 87-91.

Sommerfeld A. (1922). *Atombau und Spektrallinien*. Braunschweig: Vieweg.