Neutrinos in the Nursery. The Infancy of an Elusive Entity

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Neutrinos in the Nursery

Pauli proposes a particle

The letter in which Pauli proposed the neutrino, translated from the German of reference 5, reads as follows:

Zürich, 4 December 1930
Gloriastr.

Physical Institute of the
Federal Institute of Technology (ETH)
Zurich

Dear radioactive ladies and gentlemen,

As the bearer of these lines, to whom I ask you to listen graciously, will explain more exactly, considering the "false" statistics of N-14 and Li-6 nuclei, as well as the continuous β-spectrum, I have hit upon a desperate remedy to save the "exchange theorem" * of statistics and the energy theorem. Namely [there is] the possibility that there could exist in the nuclei electrically neutral particles that I wish to call neutrons, which have spin $\frac{1}{2}$ and obey the exclusion principle, and additionally differ from light quanta in that they do not travel with the velocity of light: The mass of the neutron must be of the same order of magnitude as the electron mass and, in any case, not larger than 0.01 proton mass.—The continuous β-spectrum would then become understandable by the assumption that in β decay a neutron is emitted together with the electron, in such a way that the sum of the energies of neutron and electron is constant.

Now the next question is what forces act upon the neutrons. The most likely model for the neutron seems to me to be, on wave mechanical grounds (more details are known by the bearer of these lines), that the neutron at rest is a magnetic dipole of a certain moment μ. Experiment probably requires that the ionizing effect of such a neutron should not be larger than that of a γ ray, and thus μ should probably not be larger than $e.10^{-13}$ cm.

But I don't feel secure enough to publish anything about this idea, so I first turn confidently to you, dear radioactives, with the question as to the situation concerning experimental proof of such a neutron, if it has something like about 10 times the penetrating capacity of a γ ray.

I admit that my remedy may appear to have a small *a priori* probability because neutrons, if they exist, would probably have long ago been seen. However, only those who wager can win, and the seriousness of the situation of the continuous β-spectrum can be made clear by the saying of my honored predecessor in office, Mr. Debye, who told me a short while ago in Brussels, "One does best not to think about that at all, like the new taxes." Thus one should earnestly discuss every way of salvation.—So, dear radioactives, put it to the test and set it right.—Unfortunately I cannot personally appear in Tübingen, since I am indispensable here on account of a ball taking place in Zürich in the night from 6 to 7 of December.—With many greetings to you, also to Mr. Back, your devoted servant,

W. Pauli

* In the 1957 lecture, Pauli explains, "This reads: exclusion principle (Fermi statistics) and half-integer spin for an odd number of particles; Bose statistics and integer spin for an even number of particles."

Pauli to Walter Baade, while staying in his home in Hamburg:

“I’ve done a terrible thing today, something which no theoretical physicist should ever do. I have suggested something that can never be verified experimentally”.

Arnold Wolfendale, in Durham, in 1971

Neutrinos in the Nursery

- A real birthday?
- What *is* a neutrino?
- What was Pauli's *idea*?
- How did neutrinos shape their *identity*?
- When did neutrinos become *real*?
- *Discovery* or *Construction*?
- Do neutrinos *really exist*? Did they exist 80 years ago?
- A *biographical approach* to theoretical entities

Pauli's 1930 idea:

- A "desperate remedy"
- The "false" statistics of N14 and Li6…
- … "as well as" the continuous β-spectrum
- A fermion of mass similar to the electron… or perhaps bigger inside the nucleus
- Magnetic dipole of small ionising power
- It probably does not exist, since this neutron would have already been detected

Is that really a neutrino?!

James Chadwick's neutron (1932-1933)

Enrico Fermi's theory of beta decay (1933-1934)

Pauli – Chadwick + Fermi → Neutrinos

Elementary particles pre-1932

Electron + Proton + (Photon)

Elementary particles post-1932

2 Electrons + 2 Protons + Neutron + Mesotrons + Neutrinos + Photon (or any combination of these)

The theoretical neutrino first turns into an experimental problem in American cosmic rays

John F. Carlson and J. Robert Oppenheimer (1931)

- From Pauli's neutron to three particles:
  - Chadwick's "neutron"
  - Fermi's "neutrino"
  - Carlson and Oppenheimer's "magnetic neutron"

Neutrinos most likely exist but we can't detect them, at least not for the time being.

So… let's wait for nuclear fission to be discovered, atom bombs to be constructed, and ideas for the detection to be developed.

Neutrinos at the Cavendish

"Progress in the field of nuclear constitution is at the moment really so rapid, that one wonders what the next post will bring, and the enthusiasm of which every line in your letter tells will surely be common to all physicists… Perhaps more than ever I wish in these days, that I was not so far away from you and the Cavendish laboratory".

Bohr to Rutherford, 2nd May 1932

Physics Research Students, June 1932.

A guided tour through the Cavendish led by Arthur Eddington (1934)

We next reach Dr. Ellis's department where the "continuous β-ray spectrum" is being attacked. This concerns a phenomenon in radioactivity which has a special interest because it appears to violate the law of conservation of energy. We cannot believe that the law has actually broken down; but in these phenomena energy appears or disappears in a mysterious way, and so far neither the experimenter nor the theorist has been able to trace how it passes. Discrepancies like these are the origin of new advances...

A guided tour through the Cavendish led by Arthur Eddington (1934)

Proceeding on our own way, we come to some of the main rooms where many researchers are at work in a small space. We find Leipunski boldly hunting for the "neutrino," a conjectural particle which some theorists have postulated to account for the untraced energy in the β-ray spectrum.

The “Fewtron” (ca 1931)

The main thing I remember about this paper was that the *fewtron* seemed to have few, if any, properties—in fact, the only property seemed to be a negative one, namely, that if no tracks appeared on a photographic plate after exposure to a Wilson cloud chamber expansion, then you knew that a *fewtron* had passed through the chamber!

- J. Chadwick and D.E. Lea, “An Attempt to Detect a Neutral Particle of Small Mass”, *Proc. Camb. Phil. Soc.*, 30, (1934), 59-61.
  - ionization produced when beta particles are emitted by RaE ($_{83}Bi^{210}$)
  - "we conclude that the neutrino cannot produce more than one pair of ions in traversing 150 km of air.”
  - if a neutral radiation is emitted by radium E to compensate the energy distribution of the β-rays, it must consist of particles of small mass and zero magnetic moment. Such particles would be exceedingly difficult to detect.

- Maurice E. Nahmias, “An Attempt to Detect the Neutrino”, Proc. Camb. Phil. Soc., 31, (1935), 99-107.
  - Two Geiger-Müller counters 11 cm appart
  - “We conclude that the neutrinos certainly do not produce as much as one kick per minute with our arrangement. …they do not produce more than one primary encounter in 9300 km of air at N.T.P.”
  - a neutrino cannot have a magnetic moment larger than one five-thousandth of a Bohr magneton. Since this limit is already smaller than a nuclear moment, it seems probable that the neutrino has no moment at all.

Neutrinos in the Nursery

- Alexander Leipunski, "Determination of the Energy Distribution of Recoil Atoms during β Decay and the Existence of the Neutrino", *Proc. Camb. Phil. Soc.,* 32 (1936), 301, ff.
  - Indirect proof from recoil of nuclei in β-decay
  - …the only conclusion that may be drawn is that these results are in favour of the emission of neutrinos during β decay. It is hoped that more accurate experiments of this type will lead to a definite decision.

C.D Ellis and N. Mott and the long tradition on the upper limit of beta decay.

J.A. Chalmers, B.W. Sargent, N. Feather: sharp upper limit.

F. Terroux: higher energy electrons.

F.C. Champion: upper limits and disintegration constants.

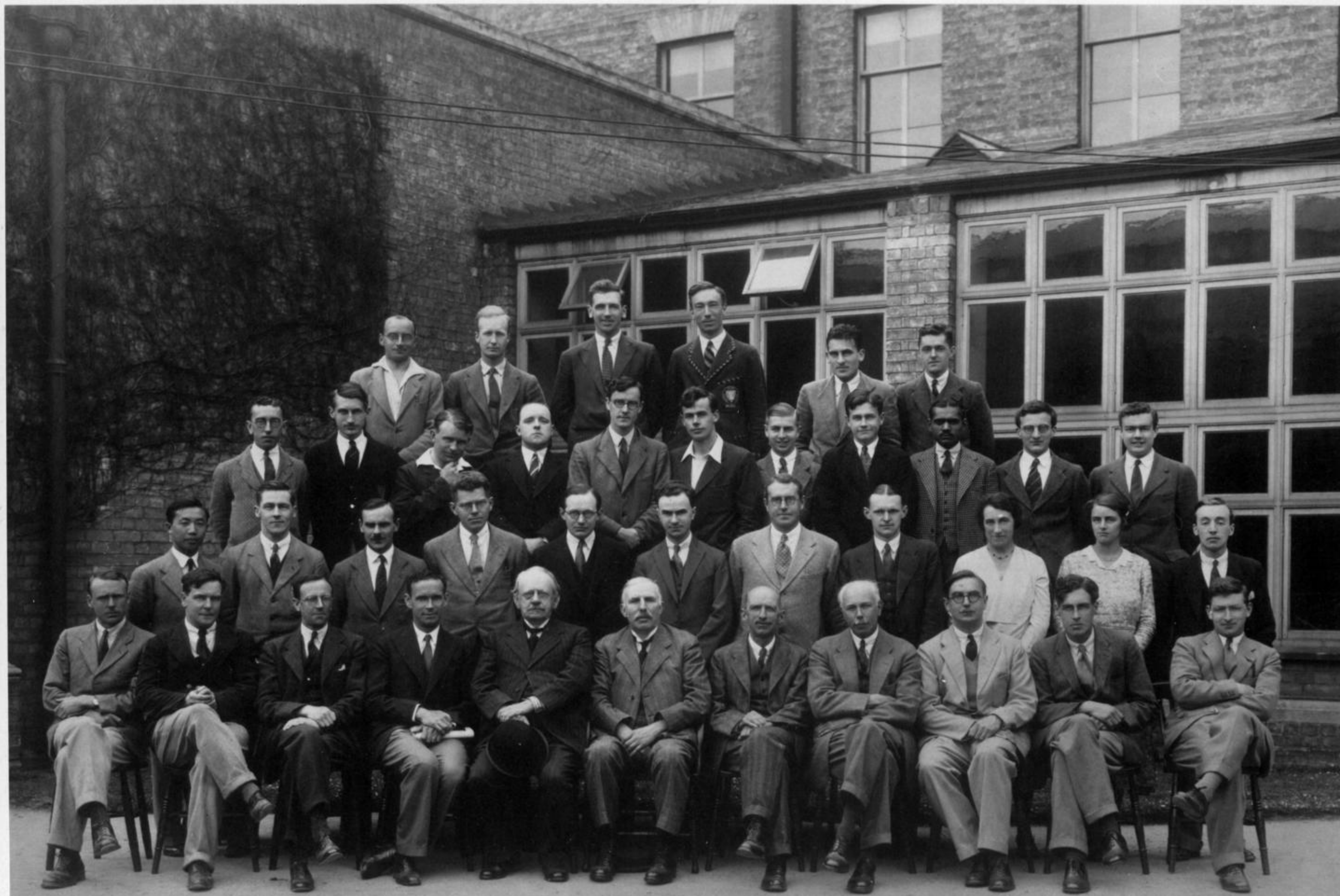
C.D. Ellis and N. Mott, the branching problem.

W.J. Henderson, the branching problem and upper limit.

- C. D. Ellis, 1937:

It is certainly true that if the principles of the conservation of energy and of identity be accepted as universally valid that the evidence, although circumstantial, for the existence of the neutrino is strong. Yet it must be remembered that it is precisely the validity of these principles, which is in question. If clear experimental evidence for the existence of the neutrino could be obtained, then we should have conclusive proof of the validity of these principles; but until this happens the neutrino must remain purely hypothetical. It should be also emphasized that no amount of agreement between the resulting theory of β disintegration and experiment can help to a decision, since the properties of the neutrino are arbitrary. However, there can be no two opinions about the practical utility of the neutrino hypothesis…

Physics Research Students, June 1932.



Physics Research Students, June 1937.