

## The neutrino and the Nobel prize in physics 2015

<sup>1</sup> Celso Levada L., <sup>2</sup> Huemerson Maceti, <sup>3</sup> Ivan José Lautenschleguer, <sup>3</sup> Miriam de Oliveira Levada M

<sup>1</sup> FHO|Uniararas / AFA – Academia da Força Aérea

<sup>2</sup> FHO|Uniararas / Colégio Puríssimo Coração de Maria

<sup>3</sup> FHO|Uniararas/ Av. Dr. Maximiliano Baruto 500 – CEP: 13607-339 – Araras (SP), Brasil.

---

### Abstract

On December 4, 1930 Pauli wrote the famous letter "Dear Radioactive Ladies and Gentlemen" to physicists who met in Tübingen. He speculated the hypothesis of the existence of a new particle, currently known as the neutrino. At the time, Pauli considered his idea too immature to be published. Pauli proposed a new particle to explain the non-conservation of energy during beta decay. Even without being detected, it does not have electric charge and very little mass, neutrinos carrying part of the energy. This actually happened 26 years before Fred Reines and Clyde Cowan claim the first detection of neutrino in 1956. The Japanese Takaaki Kajita and the Canadian Arthur McDonald received in 2015 the Nobel Prize in Physics for the discovery of neutrino oscillation, which shows that these particles have mass. The discovery of both physicists changed our understanding of the deepest operation of matter, since neutrinos have mass, contrary to what was thought for decades. McDonald and Kajita managed to refute the established theory that neutrinos lacked mass to the point of discovering that different neutrinos have different characteristics, through direct observation of solar particles.

**Keywords:** neutrino; radioactive decay; Kajita and McDonald.

---

### Introduction

Arthur Bruce McDonald <sup>[24]</sup> is a Canadian astrophysicist, director of Neutrino Observatory Institute in Canada. He was awarded the Nobel Prize in Physics in 2015 together with the Japanese physicist Takaaki Kajita. McDonald was born on August 29, 1943, in Sydney, Nova Scotia. He graduated with a B.Sc. degree in Physics in 1964 and M.Sc. in Physics in 1965 from Dalhousie University in Nova Scotia. He then obtained his Ph.D. degree in Physics in 1969 by Technology Institute of California. Takaaki Kajita <sup>[24]</sup> is a Japanese physicist, known for neutrino experiments at the Kamiokande and Super-Kamiokande. In 2015, he was awarded the Nobel Prize in Physics jointly with the Canadian physicist Arthur B. McDonald. Kajita was born in 1959 in Higashimatsuyama, Saitama, Japan. Kajita studied at the University Saitama and graduated in 1981. He obtained the title of Ph.D. in 1986 at the University of Tokyo. Since 1988 he is a researcher at the Cosmic Research Institute, University of Tokyo, where he became assistant professor in 1992. In 1999 he became director of the Center for Cosmic Neutrinos at the Institute for Cosmic Ray Research (ICRR). In 1998, Kajita team in the Super-Kamiokande found that when cosmic rays hit the Earth's atmosphere, the resulting neutrinos are divided into two beams before they reach the detector in Kamioka Mt. This discovery helped prove the existence of neutrino oscillation and that neutrinos have mass. The Kajita and McDonald's <sup>[24]</sup> work solved the longstanding problem of the solar neutrino which had a large discrepancy between the predicted and measured results. Arthur B. McDonald was director of the Sudbury Neutrino Observatory, one neutrino observatory located 2100 meters underground in Inco Creighton mine in Sudbury, Ontario, Canada. The detector is designed to detect solar

neutrinos through its interactions with a large heavy water tank. Super Kamiokande detector consists of a stainless steel tank possessing a diameter of 39 meters and a height of 41 meters, filled with ultrapure water. About 13,000 photomultiplier were installed in the tank wall. The detector is located at 1,000 meters deep in the Kamioka mine in Hida City, Gifu, Japan, hence its name.

### Neutrino an ad hoc hypothesis

Postulated by Pauli (1930) <sup>[1]</sup>, as an ad hoc hypothesis to solve the problem of apparent non-conservation of energy in beta decay, only in 1956 neutrinos were observed experimentally. After the photons, neutrinos are the most abundant particles in the universe. It was the Italian scientist Enrico Fermi who used the term small neutron, or neutrino, in order to name the particle proposed by Pauli. In 1956, 26 years later, Frederick Reines and Clyde Cowan <sup>[18]</sup> detected the mentioned particle. To frame on the laws of physics, with regard to energy conservation, the neutrino should be electrically neutral and totally massless, a kind of ghost particle. On December 4, 1930, Austrian physicist Wolfgang Pauli communicated by letter that would not appear at the Nuclear Physics conference in Tübingen, but indicated a possible solution to a problem that plagued the scientists of the time on the beta decay. In that case, the energy of the emitted electron takes values ranging from zero to a maximum value by providing a continuous spectrum of energy, when it was expected to assume only a fixed value. In that letter, exposed during the conference, W. Pauli <sup>[2]</sup> solved the mystery by postulating the existence of a new particle. Thus, in the thirties of the last century, some scientists have officially adopted a seemingly nonexistent particle through an ad hoc hypothesis, to escape the dilemma was to explain the "disappearance" of

certain amount of energy in experiments involving beta decay for which is not observed coherence between theory and experience. With the assumption of new particle, the objective was to confirm the principle of energy conservation. The tenuous and mysterious neutral particle postulated by Pauli seventy-five years was named the neutrino, or small neutron, by Enrico Fermi (1934) [7], in his theory about beta decay, published in the journal *Phys. Z* 1934. Experimentally, a nucleus A decayed into a nucleus B, and it was detected an electron and nothing else. So, the suggestion of the existence of this particle was accepted reluctantly, since "most conservative" experts felt they were evoking elements of magic to explain the properties of matter. This statement is deduced from reading the comment by Eric Carle, the presentation of the book entitled "The neutrino, ghost particle of the atom" Asimov (1966) [1]. This book refers to the neutrino as a ghost particle or "nothing particle", initially proposed as a work of fiction or imagination in order not to breach energy conservation. Bush and Silvidi (1964) [4] mention interesting passages and information to some picturesque point on the subject neutrino, an imaginary particle that has become real. The way in which "nothing particle" was reluctantly proposal and then triumphantly revealed is one of exciting adventures of the history of science.

### **Dilemmas on energy conservation**

During the  $\beta^-$  decay, a neutron turns into a proton plus an electron and, at first, during this issuing process, the same fact always happens. Thus, the emitted electron energy would always be the same for a given sample. However, each electron emitted has a different amount of energy, leading to a very extensive energy spectrum. In general, it is obtained a smaller amount of the electron energy. Physicists of the past asked: Where have gone the energy that was missing? In order to understand the experimental procedures used to verify the non-energy conservation, we suggest consulting the Kaplan's Nuclear Physics book [12] which makes references to the work of Meitner and Orthman (1930) among the countless publications referenced [14]. So it consisted on an ad hoc hypothesis for the purpose of non-infringement of energy conservation. Thus, the embryo that allowed the knowledge of the neutrino was the following question: why not all  $\beta^-$  particles emitted by a same isotope had the same energy? Among the pioneer studies which refer to these facts emphasize Ellis and Wooster (1927) [6], Richardson and Paxton (1936), Marinelli, Brinkerhoff and Hine (1947) [16] which, among other aspects, suggest the possibility that the core disintegration process should not be the same for different atoms of a same radioactive sample. That is, the phenomenon should be characteristic of the type of atom in disintegration would also be different from one core to another. Niels Bohr, one of the founders of quantum theory came to think of "a possible limitation of the conservation theorems". In fact, many famous physicists were supporters of an explanation for the beta spectrum were aware of the breach in the energy conservation. The first plausible argument imposing serious doubts about the validity of the conservation of energy in small-scale phenomena was presented in 1919 by Franz Exner, (cited Schrödinger 1958) [20]. According to Dirac (1936), the law of conservation of energy to atomic processes was formally challenged by a well-founded theory proposed by Bohr, Kramer and Slater, the BKS theory (1924) [3], aiming to end to serious conflicts existing between

the corpuscular and wave aspects of light. According to BKS theory, there would be no conservation of energy for individual atomic processes but it would be guaranteed the conservation statistically upon the occurrence of a large number of events. The BKS theory failed to survive in the face of experimental evidence especially after the advent of quantum mechanics, as it can be seen in the comments made by Niels Bohr (1936) in the letters section to Nature journal editor. Thus says Bohr at a given point of his statement: "... with respect to the generalization of the classical theory of radiation to solve the dilemma about the wave or corpuscular nature of radiation, doubts were expressed about the validity of the conservation of energy for individual quantum processes, but the situation at that time was very different from today. Not only we have subsequent experimental findings, but above all, we have the establishment of rational methods of quantum mechanics and electrodynamics, providing the compatibility of existence of the quantum of action with strict validity of the laws of conservation in phenomena such as electron diffraction and Compton Effect. The examination started by Heisenberg, on supplementary limitations of quantum theory of measurement of mechanical quantities and the electromagnetic field components removed all possible paradoxes in this regard".

On the other hand, several experiments associated with nuclear physics, especially those obtained by Shankland (1936), were at odds with the law of conservation of energy and, according to Dirac (1936) [5], it would be necessary to resort to a theory the BKS type for explanation of Shankland's experimental data. Dirac further argues that the adoption of this theory would imply drastic changes in the fundamentals of physics, such as giving up the conservation of energy and momentum in phenomena of nuclear physics. Pauli's letter presented at the conference in Tübingen changed this whole picture, since he suggested that the disintegration of the core A created not only the core B and the electron, but also a third particle (X) to be neutral and hardly detected. This new particle would carry the energy that was missing the electron, satisfying the law of conservation. Fermi (1939) proposed the name neutrino to the particle X meaning neutral and little mass. Fermi's theory explained the experimental data without difficulty, but still disliked the physicists, as the neutrino had not been detected. The first attempts revealed that the particle could pass through vast distances without interacting with some atom. Bethe and Peierls (1934) [2] suggested that if the decay of neutron created the neutrino, a proton and an electron, there should be the reverse process, in which the neutrino would be absorbed by a proton, generating a neutron and antielectron, process called inverse beta decay. Hence, in 1934, Bethe concluded to be virtually impossible to observe the neutrino. However, it was exactly in this way that the hypothesis of neutrino was confirmed later.

### **Particle acceptance**

The concrete fact that martyred theorists of the time is that during beta decay ( $\beta^+$  or  $\beta^-$ ) are ejected from the core particles with energy between zero and a maximum value ( $E_{max}$ ), offering an average value about  $(1/3) E_{max}$ , as indicated by several experimental works, such as Meitner and Orthman, for example. Many famous physicists, including Bohr, Schrödinger and Dirac were supporters of an explanation for the beta spectrum that took into account the violation of conservation of energy. Dirac (1936) points out in his article the BKS theory [3]

(Bohr, Kramer and Slater), agreeing with the fact exposed by theory that there would not be energy conservation for individual atomic processes, only occur conservation statistically upon the occurrence of a large number of events. Gradually, the proposal of the neutrino was taking shape and gaining fans. An important episode in neutrino consolidation role as particle was the work of Gamow-Schemberg (1940)<sup>[10]</sup>, with the inclusion of the neutrino to explain the process occurred in star formation, which became known as Urca effect, a successful proposition. In the end, the imaginary particle until then came to life in the Cowan and Reines experiments as reported in the journals *Science* and *Nature*, 1956. Despite this experimental evidence, many questions were still related to the detection object, as point out some works at that time such as the Schrodinger<sup>[20]</sup> published in the journal *Nuovo Cimento* (1958) in whose title reads "Could the energy be a purely statistical concept?"

### Detection

The search for neutrino begins with Hans Albrecht Bethe and Ernst Rudolf Peierls in 1934<sup>[2]</sup>, when they showed that the probability of interaction between neutrinos and matter is extremely small, this is, thousands of millions of times less than that of an electron with matter. The neutrino interacts weakly with the matter so that it can pass through the earth without interacting with any atom. Experimentalists could not detect the neutrino and did not even know what procedures to do so, since the neutrinos are neutral particles that interact with matter at very low intensity penetrating the bodies for a long time and in great depth. In 1933, French physicist Francis Perrin<sup>[13]</sup> showed that the mass of the neutrino has to be much smaller than the electron. Since then, physicists have made great advances in understanding the weak interaction. Thus, the equipment isolation process should be the best possible, preventing any register spurious nuclear event. Then, as commented Natale Guzzo (1999)<sup>[17]</sup> the experiment should be performed in an extremely shielded location and also in the presence of a large the neutrino flux. Thus, Clyde Cowan and Frederick Reines in 1956, adapted detectors in plants to more than 20 meters deep in large tanks containing scintillator liquid in a subsurface region under a nuclear reactor in South Carolina (USA), an inexhaustible controllable source of particles, especially neutrinos. In order to achieve complete shielding for other signals, among the tanks of the scintillator tanks were interspersed with water containing cadmium chloride diluted. In this arrangement, when the neutrino is absorbed by a proton of the solution, it occurs the release of a neutron moving through the environment and through collisions with other particles, it loses energy to a level where it is captured by a cadmium core<sup>[9]</sup>. The capture transforms this nucleus in an excited state, allowing one occurring decay with emission of gamma additional rays, this is, in addition to those arising from ionization. The whole process lasts around 5 ms. Therefore, detection, by Reynes<sup>[6]</sup> and Cowan, of light signals spaced by 5 ms, beyond the light due to ionization, confirms the presence of neutrinos, including the reaction rate provided by the Fermi's theory<sup>[5]</sup>.

### Final considerations

According to scholars of the subject, the study of neutrinos will help in understanding the origins of the universe. According to speculations, trillions of neutrinos pass through the Earth every

day, but without a trace. It is believed that initially neutrinos were created during the Big Bang and are now generated by nuclear reactions in the sun, or in the generation of a Supernova. The problem with experiments involving neutrinos is that they are difficult to detect and measure. In general, detectors are huge steel tanks at deep mines in various parts of the world, and even one in the South Pole, under hundreds of meters of ice. For example, the bottom of a zinc mine in Kamioka, 200 km from Tokyo, the device called Super Kamiokande works, a stainless steel tank, 40 meters tall and 36 in diameter, containing 47.2 million liters of ultra-purified water and surrounded by 11,146 light amplifiers. It is the largest the neutrino detector ever built. The device is supervised by over 100 physicists arising from Japanese and American institutions. According to agency information FRANCE PRESS<sup>[8]</sup>, an underground observatory of subatomic particles was built inside a huge ice cube with a kilometer long on each side, IceCube, at the South Pole. The construction of this large neutrino observatory took a decade of work in the Antarctic tundra and helped scientists study space particles in the search for dark matter, invisible material that comprises most of the mass of the universe. Situated 1,400 meters below the surface, the observatory consists of a network of over 5,000 optical sensors, each about the size of a basketball, suspended by cables, aiming to detect emitted blue light when an occasional neutrino collides with an ice atom.

### References

1. Asimov I. The neutrino, Ghost particle of the atom – Doubleday & Company, Inc., Garden City, New York, 1966.
2. Bethe HA, Peierls RE. *Nature*, 1934; 133:532.
3. Bohr N, *Nature*, julho. Letters to the Editor, 1936.
4. Bush GL, Silvidi Ae. *The Atom*, a simplified description – Barnes & Noble, Inc. New York, 1964, 76-79.
5. Dirac PAM. *Nature* Fevereiro. 1936, 298-99.
6. Ellis CD, wooster WA. *Nature*, Abril de, 1927, 563-64.
7. Fermi E, Zeits F, *Physik*. 1934, 161-177.
8. France Press. Cubo de gelo gigante na Antártica, disponível em <http://www1.folha.uol.com.br/ciencia/850204-cubo-de-gelo-gigante-na-antartica-ajudara-na-busca-por-materia-escura.shtml>, acessado em, 2014.
9. Fisher A, Neutrino. A partícula fantasma, available in <http://galileu.globo.com/edic/87/universo1.htm>, access in, 2014.
10. Gamow G, Schoenberg E. *Phys. Rev.*, 1941; 59:539-547,
11. Harvard Project Physic. partículas elementares (unidade suplementar A) por Haven Whiteside Federal City College– Projeto Física, tradução de Maria Teresa S.B.G.O. Ramos pela Fundação Calouste Gulbenkian – Lisboa, 1987, 49.
12. Kaplan I. *Física Nuclear*, 2a edição, 317 – 354 – Aguilar, SA De Ediciones, Madrid, 1962; 728.
13. Katz L, Penfold AS. *Rev. Mod. Phys.* n.1, 1952; 24:28-44.
14. Kurie. Richardson and Paxton, *Phys. Rev.*, 1936; 49:368-381.
15. Majorana E. *Nuovo Cimento*, 1937; 14:171-184.
16. Marinelli, Brinckerhoff Hine E. *Rev. Mod. Phys.*, 1947; 19(1):25-28.
17. Natale AE, Guzzo M. Neutrinos partículas onipresentes, *Ciência Hoje*, 1999; 147:75.

18. Reines F, Cowan CL *et al.* Science n.3212, 1956; 124:103-104.
19. Reines F, Cowan CL. Neutrino, Nature, 1956; 178:446-449.
20. Schrödinger E. Nuovo Cimento, n.1, 1958; 9:163-169.
21. Shankland, Robert S. Physical Review, janeiro, 1936; 49:8-13.
22. Uhlenbeck E, Konopinski. On the Fermi Theory of Radioactivity Phys Rev, 1935, 48.
23. Yang CN, Tiomno. Phys. Rev., 1950; 79(3):495-498.
24. The Nobel Prize in Physics. Available in [http://www.nobelprize.org/nobel\\_prizes/physics/laureates/2015/](http://www.nobelprize.org/nobel_prizes/physics/laureates/2015/), access in, 2015.