The neutrino and the Nobel prize in physics 2015

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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 Kajuta 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 [24] 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 [24] 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 [24] 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) [1], 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 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 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.

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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) \cite{1}, 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)\cite{11}. 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) \cite{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 \cite{12} which makes references to the work of Meitnar and Orthman (1930) among the countless publications referenced \cite{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) \cite{6}, Richardson and Paxton (1936), Marinelli, Brinkhoff and Hine (1947) \cite{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 Ezner, (cited Schrödinger 1958)\cite{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) \cite{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) \cite{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 Tubingen 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) \cite{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 (Emax), offering an average value about (1/3) Emax, as indicated by several experimental works, such as Meitnar 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 \cite{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)\(^\text{[10]}\),
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 \(^\text{[20]}\) 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 \(^\text{[2]}\), 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 \(^\text{[13]}\) 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) \(^\text{[17]}\) 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 \(^\text{[9]}\). 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 Reines \(^\text{[6]}\) 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 \(^\text{[8]}\).

**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 \(^\text{[8]}\), 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.

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