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Nobel Prize in Physics 1988


Leon M. Lederman


Melvin Schwartz


Jack Steinberger

The Nobel Prize in Physics 1988 was awarded jointly to Leon M. Lederman, Melvin Schwartz and Jack Steinberger *"for the neutrino beam method and the demonstration of the doublet structure of the leptons through the discovery of the muon neutrino"*.

Information about winners:

Leon Lederman,
Batavia, Illinois, USA,
Melvin Schwartz,
Mountain view, California, USA
Jack Steinberger,
Geneva, Switzerland,

RESEARCH INFORMATION:

The work now rewarded was carried out in the 1960s. It led to discoveries that opened entirely new opportunities for research into the innermost structure and dynamics of matter. Two great obstacles to further progress in research into weak forces - one of nature's four basic forces - were removed by the prizewinning work. One of the obstacles was that there was previously no method for the experimental study of weak forces at high energies. The other was theoretically more fundamental, and was overcome by the three researchers' discovery that there are at least two kinds of neutrino. One belongs with the electron, the other with the muon. The muon is a relatively heavy, charged elementary particle which was discovered in cosmic radiation during the 1930s. The view, now accepted, of the paired grouping of elementary particles has its roots in the prizewinner's discovery.

Background information

Neutrinos are almost ghostlike constituents of matter. They can pass unaffected through any wall, in fact all matter is transparent to them. During the conversion of atomic nuclei at the centre of the sun, enormous quantities of neutrinos (which belong to the electron family) are produced. They pass through the whole sun virtually unhindered and stream continually from its surface in all directions. Every human being is penetrated by sun neutrinos at a rate of several billion per square centimetre per second, day and night, without leaving any noticeable trace. Neutrinos are inoffensive. They have no electrical charge and they travel at the speed of light, or nearly. Whether they are weightless or have a finite but small mass is one of today's unsolved problems.

The contribution now awarded consisted among other things of transforming the ghostly neutrino into an active tool of research. As well as in cosmic radiation, neutrinos, which belong to the muon family, can be produced in a multistep process in particle accelerators, and this is what the prizewinners utilized. Suitable accelerators exist in some few laboratories throughout the world. Since all matter is transparent to neutrinos, it is difficult to measure their action. Neutrinos are, however, not wholly inactive. In very rare cases a neutrino can score a random direct hit or, more correctly, a near-miss, on a quark, a pointlike particle within a nucleon (proton or neutron) in the nucleus of an atom or on a similarly infinitesimal electron in the outer shell of an atom. The rarity of such direct hits implies that a single neutrino of moderate energy would be able to pass unhindered through a wall of lead of a thickness measured in light-years. In neutrino experiments the rarity of the reactions is compensated for by the intensity of the neutrino beam. Even in the first experiment, the number of neutrinos was counted in hundreds of billions. The probability of a hit also increases with the energy of the neutrinos. The method of the prizewinners makes it possible to achieve very high energies, limited only by the performance of the proton accelerator. Neutrino beams can reveal the hard inner parts of a proton in a way not dissimilar to that in which X-rays reveal a person's skeleton.

When the neutrino beam method was invented by the Columbia team at the beginning of the 1960s the quark concept was still unknown, and the method has only later become important in quark research. Also of later date is the experimental discovery of an entirely new way for a neutrino to interact with an electron or a quark in which it retains its own identity after impact. The classical way of reacting implied that the neutrino was converted into an electrically charged lepton (electron or muon), and this was the reaction utilised by the prizewinners.

The prizewinners' experiment

The very first experiment using a beam of high-energy neutrinos originated in one of the daily coffee breaks at the Pupin laboratory, where faculty and research students would relax together for half an hour. In this stimulating atmosphere around Nobel Prizewinners T.D. Lee, C.N. Yang (Nobel prize for physics 1957) and others at the end of the 1950s, the need to find a feasible method of studying the effect of weak forces at high energies was discussed. Hitherto it had only been possible to study processes of radioactive decay, spontaneous processes at necessarily relatively low energies. Beams of all common particles (electrons, protons and neutrons) were discussed. While these are relatively simple to produce, they were found to be unusable for this purpose. The apparently hopeless situation suddenly changed when **Melvin Schwartz** proposed that it ought to be possible to produce and use a beam of neutrinos. During the next two years he, together with **Leon Lederman** and **Jack Steinberger**, worked on the proposal in order to achieve a sufficiently intense beam of neutrinos free from all other types of particle, and to design a detector for measuring neutrino reactions. The group at Columbia also included G. Danby, J.M. Gaillard and K. Goulianos and N. Mistry.

The neutrinos in the Columbia experiment were produced in the decay in the flight of charged pi-mesons. In a first step protons were accelerated to high velocities and directed at a target of the metal beryllium. As the next step high-velocity pi-mesons were produced in a forward-directed beam. Mesons are radioactive, and they decayed into a muon and a neutrino each when allowed to travel a path of free flight, which was set at 21 metres. In this step high-energy neutrinos were produced as a forward-directed beam, still containing quantities of leftover pi-mesons and myons which had been formed at the same time. To eliminate these unwanted particles completely from the beam, a 13.5-metre-thick wall of steel was needed. The material came from scrapped warships. The measuring device (detector) was built behind the wall, which of course was transparent to the neutrinos. So that the detector should not be entirely transparent, it was thought best to build it as a 10-ton spark chamber, then a new and fairly untested type. The detector consisted of a large number of aluminium plates with spark gaps between them. A muon or an electron produced by a neutrino in one of the aluminium plates photographed its own track as a series of sparks, using a special self-exposing device.

A burning problem had arisen at the time of the experiment regarding the measurements of muon radioactive decay. The measurement results, to which **Jack Steinberger** and Bruno Pontecorvo among others contributed, disagreed with accepted theoretical calculations. The problem was addressed by many researchers, among them G. Feinberg and T.D. Lee, as well as methodologically by Pontecorvo, and they indicated that one way out of the dilemma would be the existence of two entirely different types of neutrino.

If the neutrinos in the Columbia experiment beam were identical to the neutrinos common in beta decay, the reactions in the detector should convert the neutrino to a fast electron as often as to a fast muon. On the other hand only muons would result if there were two different kinds of neutrino. The prizewinners and their collaborators arranged their detector so that the cause of the spark tracks could be interpreted. The results showed that only muons were produced by the neutrinos in the beam, no electrons. Thus there exists a new type of neutrino that forms an intimate pair with the muon. Consequently the electron forms its own delimited family with its neutrino.

The discovery thus had immediate consequenses. Knowledge of the role of the family concept and the great importance of the method within elementary particle physics has grown during the time that has elapsed since the discovery was made. A question that is still current is whether or not small departures from strict family membership occur.

For more details please visit:

http://www.nobelprize.org/nobel_prizes/physics/laureates/1988/press.html