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NOTE TO EDITORS: This release is for use only on or after July 1, to coincide with the publication of the July 1 issue of Physical Review Letters, in which will appear the scientific paper announcing this discovery.

NEW TYPE OF NEUTRINO DISCOVERED IN COLUMBIA-BROOKHAVEN EXPERIMENT

Upton, New York, July 1, 1962 -- The Department of Physics of Columbia University in collaboration with Brookhaven National Laboratory announces the discovery that there exists in nature two different types of neutrinos. A group of physicists from the two institutions, working at Brookhaven's new 33-Bev Alternating Gradient Synchrotron (AGS) have succeeded in observing collisions of high energy neutrinos with nuclei.

The neutrino appears in various nuclear reactions as an elementary particle of zero mass and zero electric charge. The Columbia-Brookhaven experiment indicates that in fact two quite independent particles of this type exist; one connection with mu-mesons and one connected with electrons. The neutrino experiment is the first to study the so-called "weak" force at high energies and was made feasible by the availability of the very high energy particle accelerators such as the Brookhaven AGS.

The research team that has demonstrated this dichotomy among the neutrinos includes Professors L. Lederman, M. Schwartz and J. Steinberger of the Physics Department of Columbia University; Dr. G. Danby of Brookhaven National Laboratory; and J-M. Gaillard, K. Goulianos and N. Mistry of Columbia.

Financial support for the experiment came from the U. S. Atomic Energy Commission; Professors Schwartz and Steinberger are Alfred P. Sloan Fellows.

In order to observe fifty neutrino interactions, it was necessary to pass 100 trillion neutrinos through a 10-ton detector. The particles produced by the neutrino collisions are made to leave a trail of sparks along their path. The detector is preceded by a 42-foot steel wall (of old battleship armor plate) to screen out all other particles. The neutrinos were of the type known to be associated with mu-mesons. The experiment showed that these neutrinos were not able to produce electrons. The experimenters concluded that they must therefore differ from the neutrino-type of particle associated with electrons.

I. SUMMARY

The neutrino has been a most elusive particle since it was first proposed by W. Pauli some 30 years ago. Its original purpose was to account for an apparent violation of energy conservation in the spontaneous decay of some nuclei. When a nucleus underwent such a decay (called beta-decay) an electron (or a positron) was emitted. The total energy visible after decay did not amount to the energy present before decay. A careful study of these decays showed that it was possible to retain this conservation law if an uncharged particle of zero mass were emitted in the decay, in addition to the electron (or positron). By convention the particle that came along with the electron was called the anti-neutrino while the particle that came along with the positron was called the neutrino. It has since been shown that the neutrino and anti-neutrino are different particles and their assignment to positron and electron, respectively, always holds in beta-decay. The reason for the elusiveness of the neutrino (or anti-neutrino) lies in the nature of their interactions with other elementary particles. Whereas two protons will interact with each other whenever they are within a distance from each other of the order of their radii, the same does not hold for a neutrino and a proton. Neutrinos participate only in what are called the weak interactions. This means, for example, that a neutrino from a typical beta-decay can pass on the average through $\sim 10^{14}$ miles of lead before interacting. This makes its detection a formidable chore, and it was only in 1955 that C. Cowan and F. Reines of Los Alamos were first able to observe the effects of such an interaction. (They actually observed the interactions of anti-neutrinos which came from spontaneous decay of the free neutron.)

Some fifteen years ago, the pi-meson (called pion) was first observed and was found to decay spontaneously into a mu-meson (called muon) and an unseen particle. Careful observation of the decay of the positive pion led to the establishment that the unseen particle that came along with the positive muon had all the properties of the neutrino. Similarly, the unseen particle that accompanied the negative muon in the decay of the negative pion had all the properties of the anti-neutrino. Consequently, it was assumed that these particles were the same as were present in beta-decay.

One of the most interesting characteristics of the weak interactions is the following: Whenever a muon is involved in a weak interaction, so is a neutrino (or an anti-neutrino). The same holds true for the electron. For example, if either an electron or a negative muon is absorbed by a nucleus in such an interaction, a neutrino is emitted. In this sense, both electrons and muons seem to be explicitly coupled to neutrinos in the weak interactions.

In recent years, the question of the non-identity of the neutrino coupled to the muon and the neutrino coupled to the electron has been raised. One of the most straightforward tests for this possibility is the following: Take a sample of neutrinos (or anti-neutrinos) that are guaranteed to be coupled to muons. (For example, the neutrinos from the normal decay of the pion.) Let them impinge in sufficient number on a target. If they are the same as the neutrinos involved in beta-decay, then they should produce as many electrons as they produce muons. If they are different, then they can in principle produce only muons. A comparison of the number of electrons produced with the number of muons produced will yield the desired information.

The Columbia-Brookhaven group has just completed such an experiment. Its feasibility arises because high energy neutrinos interact more strongly than low energy neutrinos. Indeed, a neutrino with an energy of one billion electron volts will pass through only 10^8 miles of lead on the average before interaction. This means that if one can put 10^7 neutrinos per second through a 10-ton detector, one should see about one neutrino interaction per day.

The Brookhaven experiment proceeded as follows: Pions produced by the AGS were allowed to travel about 70 feet before striking a shielding wall. About 10% of these pions decay during this interval. The shielding wall that is placed in the way is 42 feet thick and consists of about 5000 tons of iron (old battleship deck plate). This wall is thick enough to stop all particles except neutrinos (which hardly notice the existence of the wall). On the other side of the wall, in a well-shielded room, is a 10-ton spark chamber. This is an instrument that will show a trail of sparks along the path of a charged particle traveling within it. A neutrino interaction would be signified by either a muon or an electron starting within the chamber.

The aim of the experiment was to detect these neutrino-induced tracks, which should occur several times per day, and note how often they corresponded to electrons being produced against how often they corresponded to muons being produced.

Since the beginning of the year, 100 trillion neutrinos have been allowed to pass through the chamber. Fifty of these neutrinos have interacted in the chamber, making energetic events. Of these, 29 show only a single energetic muon being produced, while the remainder show muons being produced along with other particles. In no case was a single energetic electron produced. This demonstrates that the neutrinos arising from the decay of the pion are different from those involved in beta-decay. It is thus no longer adequate to speak of a neutrino--it must be labeled as either a muon-type neutrino or an electron-type neutrino.

II. HISTORY

A. Radioactivity of Atoms and Particles

It has long been known that certain atoms undergo spontaneous disintegrations. Cobalt-60 is commonly known as an example of such a radioactive atom. These unstable atoms emit radiation in the form of electrons. Detailed studies of these processes have uncovered two important facts: (1) the force responsible for this instability is extremely weak compared to other forces known to be important in the structure of matter; and (2) that in order to preserve the laws of conservation of energy, another particle must be assumed to be emitted along with the electron, one that escaped detection in the careful early studies. This second particle, postulated some 30 years ago by W. Pauli and now called a neutrino, was known to be electrically neutral and of zero mass.* The years of subsequent experimentation confirmed this brilliant hypothesis; the neutrino, elusive and mysterious, was accepted as a full-fledged member of the family of elementary particles.

*In ordinary radioactivity both negatively charged electrons and positively charged positrons are emitted. The electron is accompanied by an anti-neutrino, the positron by a neutrino.

The advent of large accelerators ("atom-smashers") constructed since the war facilitated a tremendous advance in the understanding of the basic structure of matter. Deep penetrations of the nucleus by high-energy atomic projectiles led to the discovery of many new particles and to an easy familiarity with such previously known sub-atomic bits as the pi-meson (pion) and the mu-meson (muon). One important fact gradually became clear; most of the new particles were "radioactive", most eventually disintegrated. In the case of the most familiar of the mesons, the mu-meson, an electron was again emitted in the decay process. . . . and something else. This time, detailed analysis indicated that the "something else" required to maintain the energy balance had to be two small, neutral and almost massless particles. These seemed to have the same properties as the neutrinos invented earlier. The pi-meson, in its disintegration, emitted a particle which was soon identified as the mu-meson and again, a "neutrino-like" object was required to satisfy the conservation laws.

B. Theory of the Weak Force

A detailed theory of the radioactivity of atoms and particles was gradually evolved. This theory succeeded in correlating many of the facts known about these unstable atoms and particles after the discovery, in 1957, of the failure of parity conservation.* It was based on an exciting postulate; that the same weak force was responsible for all the weakly unstable particles. However, the theory was in some ways superficial and not accepted, even by the originators, as completely satisfying. There remained certain unexplained facts; many reactions that should have been generated by this weak force were not observed, in spite of painstaking experiments in many laboratories. An example of one such non-observed reaction was the conversion of a mu-meson into an electron and a gamma-ray (quantum of light energy), written as $\mu \rightarrow e + \gamma$.

C. Muon Decay Crisis

In the fall of 1959, there began discussions at Columbia (and certainly in other laboratories throughout the world) of the need for further exploration

*This period saw a major refinement in the theory of the neutrino itself.

of this weak force at higher energies where the strength of the force was supposed to increase. In particular, Columbia theoreticians Professors G. Feinberg and T. D. Lee (working with C. N. Yang of the Institute for Advanced Study) considered the absence of the mu-electron-gamma reaction as a "crisis".

The crisis arises as follows: Whenever a muon is involved in a weak interaction, so is a neutrino (or an anti-neutrino). The same holds true for the electron. For example, if either an electron or a negative muon is absorbed in a nucleus as a result of such an interaction, then a neutrino is emitted. In the above sense, both electrons and muons seem to be explicitly coupled to neutrinos by the weak force. The difficulty arises in that calculations have shown that if the muon and the electron were both connected with the same type of neutrino, then one might expect that a muon should spontaneously decay some fraction of the time into an electron and a gamma-ray. Indeed, it was expected that this should happen once for every ten thousand normal decays. However, experiments have been performed during which 100 million muons were observed to decay. The electron-gamma type was never seen. Several physicists noted that a "natural" way out of the difficulty was to break the chain connecting the muon to the electron through the neutrino by supposing that the neutrino involved with muon reactions was a <u>different particle</u> from the neutrino connected with electrons. If this were true, the muon would never convert into an electron and a gamma-ray.

The experiment that has just been completed was designed to study both problems--to find a way of observing the weak force at the higher energies made available by the recently completed AGS machine, and to test a possible solution to the mu-electron-gamma crisis.

III. THE EXPERIMENT

To carry out their observations, the Columbia-Brookhaven team used the radiation of pi-mesons produced by the bombardment of beryllium nuclei by 15-billion-electron-volt protons accelerated by the huge AGS. About 10% of these pions disintegrate during their transit (at almost the velocity of light) from the machine toward the detector. The resulting mu-mesons and neutrinos continue roughly in the same direction and participate in the high energy originally invested in the pi-meson. The idea of the experiment was to detect the neutrinos--and to thus measure the weak force between these neutrinos and the ordinary matter of the detector.

A. Why Use Neutrinos?

The reason for selecting neutrinos had earlier been set forth independently by Professors M. Schwartz of Columbia and B. Pontecorvo in Moscow. They noted that of all the known particles, only neutrinos were subject to the weak force alone and to no other force. Mu-mesons are electrically charged and the enormously stronger electrical force would mask the small effects of the weak force. Similar arguments applied to all other particles. Being untouched by ordinary forces, the neutrino can slip through enormous quantities of dense matter without suffering collisions. It would take a lead shield one light year thick to be reasonably sure of stopping a neutrino from Cobalt-60. This makes the detection a formidable chore and it was only in 1955 that F. Reines and C. Cowan of Los Alamos were first able to observe the direct collisions of neutrinos. (They used the enormous flux of anti-neutrinos from a nuclear reactor at Hanford.)

B. Expected Rate

The situation at the AGS was considerably different. At higher energies the weak force was supposed to become stronger, the neutrino more reactive. In the Brookhaven experiment, a shield of lead only 100 million miles thick would have a reasonable chance of stopping a one-billion-electron-volt neutrino. However, the number of neutrinos generated per second was relatively small. Calculations showed that, for each ton of detector, one of two neutrino collisions would take place per ten days, with the AGS machine running 24 hours per day at maximum intensity.

The aim of the experiment was to detect these neutrino-induced tracks.

C. Shielding

To screen the detector against all particles other than neutrinos, an enormous shield containing 5000 tons of steel (obsolete battleship armor provided by the U. S. Navy) was erected near the AGS. The front wall was 42 feet thick. Buried in this shield was a small room containing the detector--a 10-ton aluminum spark chamber.

D. The Spark Chamber Detector

The spark chamber, a relatively new tool of nuclear physics, consists of 90 aluminum plates, each 4 foot square and 1 inch thick. These are spaced about 1/2 inch apart and the intervening space filled with neon gas. Interspersed among these plates are sensitive electronic counters. Surrounding most of the apparatus, which stands 10 feet high by 6 feet long by 4 feet wide, is a protective screen of additional counters to warn against cosmic rays.

Radiation--in the form of an electrically charged particle--disturbs the atoms of neon in the gas of the spark chamber. The electronic counters also detect the presence of this radiation, and, if the cosmic ray counters are quiet, this signals the sudden application of high voltage between successive pairs of the spark chamber plates. This causes an electrical spark to strike wherever the gas has been disturbed. Thus, the path of the particle that generated the disturbance is rendered visible via the familiar red light of glowing neon. The sparks are photographed by automatic cameras. The neutrino, in its collision with the nucleus of the aluminum atom, will project forth charged particles. These are the tracks sought.

E. <u>Construction and Support</u>

The equipment took two years to build. The effort was divided between the Columbia laboratory, Nevis, at Irvington-on-Hudson, New York, and Brookhaven. Brookhaven National Laboratory is operated by Associated Universities, Inc. under contract with the U. S. Atomic Energy Commission, which supported the neutrino search with a special grant. The Nevis Laboratories are part of the Columbia Physics Department, and are supported by both the Atomic Energy Commission and the Office of Naval Research.

F. <u>The Run</u>

Since the beginning of the year, the equipment has been exposed to radiation from the AGS. The intensity of this radiation was being continuously improved by the accelerator scientists under Drs. Kenneth Green, Ernest Courant, Hildred Blewett and John Blewett. By June, the total number of neutrinos estimated to have passed through the detector reached the 100-trillion mark. Several times per day, the automatic cameras changed film, indicating the possibility of an "event". When the film was analyzed, over 50 such events were recognized.

G. Crucial Check

Detailed studies of the tracks added to the conviction that these had all the properties required of neutrino reactions. There remained a crucial check. Suppose there were some kind of background simulating neutrino events? The neutrinos had to be "turned off" but not the background. This was approximated by moving 4 feet of steel from the main shielding wall up close to the target where the pions are generated. Thus, the pions would be largely destroyed before having time to decay into muons and neutrinos. The film resulting from this kind of operation was examined with great anxiety by the experimenters. This anxiety increased dangerously when a clear neutrino-type "event" was found. It was not until all the film was studied that it became clear that the background check was successful; a few events were expected due to the short time still left to the pions in their flight from the target to the steel. The reduction in rate was correct, and added to the proof that the neutrino from pion-decay had now in fact been observed.

H. The Results

The collision probability was indeed observed to be 100,000 times higher at the AGS energies than at the energies typical of Cobalt-60 or the nuclear reactor. Not only this, but in every case in which it was possible to identify the results of the neutrino collisions, mu-mesons were produced. Not a single energetic electron was observed. The conclusion was clear--the neutrinos made in the Columbia-Brookhaven experiment, that is, made together with muons via the decay of the pion, were incapable of making electrons. These must then be different particles from the neutrinos that are coupled with electrons. It is no longer adequate to speak of a neutrino--it must be labeled as either a muon-type neutrino or an electron-type neutrino.

IV. SIGNIFICANCE

It is generally agreed that the present experiment represents the beginning of a new field of research. Neutrino experiments or facilities are being planned for the 25-Bev Proton Synchrotron operated by the European Center for Nuclear Research (CERN) in Geneva, and for all of the large accelerators now under construction in the United States and the Soviet Union. The capability for doing such research is an important factor in proposals for super-high energy accelerators (1000 Bev) now under intensive discussion. Why all the interest? There are several reasons. The weak force (the official name for the theory is Universal Fermi Interaction, after E. Fermi who proposed the original version in 1934) has a theoretical form which may be valid down to distances as small as 10^{-16} cm. This length is 1000 times smaller than the radius of the proton (the smallest particle whose size has been measured). There is great interest in examining whether or not the theory requires modification before such lengths are reached. The basic goal toward which another decisive step has now been taken, is a complete understanding of the behavior of this force. Somewhat more speculative is the light that may be shed on the general problem of the structure of fundamental particles. The proliferation of so-called "elementary particles" has raised disturbing questions as to where the underlying simplicity, which all scientists hope for, is to be found. One striking example is just in the two particles, the muon and the electron. The properties of these particles have been very precisely measured. They differ in only one way: the muon is 200 times more massive than the electron. This dichotomy in structure is a problem that has troubled physicists increasingly over the past five years. Now, the problem, by no means solved, is viewed in a new context. The muon and its neutrino have to be considered together as a kind of pair, to be contrasted with the electron and its neutrino. The muon-type pair always appears together in weak reactions, as does the electron-type pair. They are separate and the nature of this "separateness" is unknown. The muon-electron problem is thus sharpened, a fact that can only improve the hope of eventual solution.

V. VITAE

The scientists who carried out the neutrino experiment are: From the Department of Physics of Columbia University, Professors Leon M. Lederman, 39; Melvin Schwartz,* 29; Jack Steinberger,* 40; Research Physicist Jean-Marc Gaillard, 28, (French AEC exchange visitor from SACLAY, France); Graduate Research Assistants Konstantin Goulianos, 26, (Fulbright Travel Fellow from Salonica, Greece) and Nariman Mistry, 24, (Bombay, India); from Brookhaven National Laboratory, Associate Physicist Dr. Gordon Danby, 32.

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