FROM THE CURRENT LITERATURE

The discovery of neutral currents

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At the present time neutral currents in the weak interaction are the object of active experimental searches. This is due to the fact that a number of theoretical models of the weak interaction predict the existence of these currents. In particular, we refer to the unified theories of weak and electromagnetic interactions, in which weak neutral currents serve to make these theories renormalizable like ordinary quantum electrodynamics.

Let us recall that the standard scheme of the universal weak interaction originates from the fact that all weak interactions arise in the interaction of four charged currents: two lepton currents ($\bar{e}\nu e$, $\bar{\mu}\nu_\mu$) and two hadron currents, one of which conserves strangeness and the other changes it by unity (in the quark model they have the forms $\bar{p}n$ and $\bar{p}\lambda$, respectively). For example, the interaction of $\bar{e}\nu$ and and $\bar{\mu}\nu$ currents gives muon decay, of $\bar{e}\nu$ and $\bar{p}n$—nuclear β decay, and of $\bar{p}\lambda$ and $\bar{p}n$—nonleptonic strange-particle decays. The neutral currents which we are discussing have the form $\bar{e}e$, $\bar{\mu}\mu$, $\bar{\nu}\nu$, $\bar{e}\mu$ for leptons and $\bar{p}p$, $\bar{n}n$, $\bar{\lambda}\lambda$, $\bar{n}\lambda$ for hadrons. On July 23, 1973, Hasert et al.[1] reported to Physics Letters the apparent observation at CERN in the Gargamelle bubble chamber of interaction of the current $\bar{\nu}_\mu\nu_\mu$ with a strangeness-conserving neutral hadron current (it is some superposition of the currents $\bar{p}p$, $\bar{n}n$, and $\bar{\lambda}\lambda$). The authors of this report are 55 physicists representing 7 institutes of West Germany, Belgium, Switzerland, France, Italy, and England.

The Gargamelle bubble chamber has the form of a cylinder 4.8 m long and 1.85 m in diameter, filled with Freon (CF_3Br). The high density of Freon (1500 kg/m^3) and the presence in it of bromine ($Z = 35$) has the result that in it both the nuclear mean free path ($L = 60$ cm) and the radiation length ($x_0 = 11$ cm) are small in comparison with the chamber dimensions. The chamber is in a magnetic field of 20 kG and is operated in the CERN neutrino beam. Up to 1973, more than 700 000 photographs have been obtained in it.

The neutral currents were observed in analysis of 83 000 photographs taken in the neutrino beam and 207 000 photographs taken in the antineutrino beam. In the fiducial volume of 3 m^3, events of two types were observed:

1) ordinary neutrino events due to charged currents (CC), in which ν (or $\bar{\nu}$), colliding with a nucleon, is converted to a muon and in the process produces some number of hadrons:

$$\nu/\bar{\nu} + N \to \mu^- \mu^+ + \text{hadrons}\,(\text{CC}), \qquad (1)$$

2) neutrino events due to neutral currents (NC):

$$\nu/\bar{\nu} + N \to \nu/\bar{\nu} + \text{hadrons}\,(\text{NC}). \qquad (2)$$

For ν, 102 NC events and 428 CC events were observed, and for $\bar{\nu}$—64 NC events and 148 CC events.

On the basis of these data, the authors give for the ratio of the number of NC and CC events the following values:

$$(\text{NC/CC})_\nu = 0.21 \pm 0.03, \quad (\text{NC/CC})_{\bar{\nu}} = 0.45 \pm 0.09.$$

Thus, the cross sections for processes in which ν and $\bar{\nu}$, exciting nucleons, do not produce charged leptons are not much smaller than the cross sections for ordinary processes with charged leptons in the final state. The main problem in proving that events without muons in the final state are actually due to the NC reaction lies in the possible background: of course $\nu/\bar{\nu}$ are not visible either in the initial state or the final state. The main background processes which are discussed in most detail by the authors are reactions induced by fast neutrons:

$$n + N \to \text{hadrons}. \qquad (3)$$

In this case the main source of energetic neutrons is reactions of the CC type in the shield surrounding the chamber. In order to reduce this background, only those NC and CC events were selected in which the total energy carried away by hadrons was at least 1 GeV. According to the calculations made by the authors, neither the number of events of the type NC nor their uniform distribution over the chamber volume can be explained by reaction (3). Because of the small mean free path of the neutrons, the distribution of type (3) events should be nonuniform (they were mainly near the chamber walls), and the expected number of type (3) events is substantially smaller than the observed number of NC events. The authors also discuss other possibilities: penetrating particles (other than ν and $\bar{\nu}$) produced directly in the target, and production by the neutrino beam of heavy unstable leptons which rapidly decay without emission of muons. Serious objections exist to these possibilities, but the authors do not consider them finally excluded.

In Gargamelle among 375 000 ν photographs and 360 000 $\bar{\nu}$ photographs the same ground (51 authors) observed one event which is interpreted by them as the reaction[2]

$$\bar{\nu}_\mu + e \to \bar{\nu}_\mu + e. \qquad (4)$$

This type of elastic scattering by an electron of a muonic antineutrino (and neutrino) is forbidden according to the theory in which there are only charged currents, but is predicted by theories in which neutral currents exist; it arises from interaction of two neutral currents ($\bar{\nu}_\mu\nu_\mu$) and ($\bar{e}e$). The expected background in this case is estimated by the authors as 0.03 ± 0.02 event. Of course, from one event, which appears in the chamber as a single electron emitted in the direction of the $\bar{\nu}$ beam with an energy 385 ± 100 MeV, it is impossible to conclude that reaction (4) has been observed. In order to find several more events, several million photographs are necessary.

The discovery of neutral currents in neutrino experiments could turn out to be a striking confirmation of the unified model of weak and electromagnetic interactions proposed by Weinberg[3] at the end of 1967. At the same time this model and its various modifications (see the review by A. I. Vaĭnshteĭn and I. B. Khriplovich, which will be published in Uspekhi Fizicheskikh Nauk in the first half of 1974) predict not only neutral currents but also other no less substantial changes in the present picture of elementary particles. In particular, according to these theories there should exist the so-called intermediate bosons (charged $W^{\pm}$ and neutral Z^0) with masses of several tens of GeV. In the Weinberg model, for example $m_{W^{\pm}} \geq 37$ GeV, $M_{Z^0} \geq 74$ GeV.

Further, these models contain additional, experimentally as yet unobserved hadrons (so-called hypercharged particles, charmed particles, or colored particles). The existence of such particles is postulated in these models in order to explain the fact that decays of the types $K^+ \to \pi^+ e^+ e^-$, $K^+ \to \pi^+ \nu\bar{\nu}$, which could occur if there were a neutral strange current (of the type $\bar{n}\lambda$), are according to experiment suppressed by hundreds of thousands of times (and the decay $K_L^0 \to \mu^+\mu^-$ even by hundreds of millions of times) in comparison with similar decays occurring under the action of charged currents. In a number of models the existence is predicted also of heavy leptons, charged and neutral, with masses of the order of 1 GeV and higher.

Neutral currents could exist even without relation to unified theories of weak and electromagnetic interactions, for example, as the dynamical manifestation of such conserved quantities as baryon, lepton, or muon charge.

To return now to results obtained in Gargamelle, it must be emphasized that a final conviction that neutral currents have been discovered can exist only after these results have been confirmed by other workers.

At the International Symposium on Electron and Photon Interactions, held at Bonn on August 27–31, 1973, a rapporteur's talk was given by Mallet on neutral currents. In this report additional data were presented which were obtained in the accelerators at Batavia and Argonne. In Batavia the ratio $(NC/CC)_\nu$ turned out to be 0.3 ± 0.1 (a counter experiment). At Argonne in the 12-foot hydrogen bubble chamber it was found that the ratio $(\nu p \to \nu\Delta^+)/(\nu p \to \mu^-\Delta^{++})$ was of order 0.23 ± 0.17. These results are in qualitative agreement with the results obtained at CERN.

[1] F. J. Hasert and S. Kabe, et al. (55 authors), Phys. Lett. B46, 138 (1973).
[2] F. J. Hasert and H. Faissner, et al., (51 authors), Phys. Lett. B46, 121 (1973).
[3] S. Weinberg, Phys. Rev. Lett. 19, 1264 (1967); A. Salam, Proc. of the 8th Nobel Symposium, Stockholm, 1968, p. 367.

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