Neutral currents in neutrino experiment, and light neutral intermediate boson

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To explain the presence of neutral currents in the CERN experiment and their absence in the NAL experiment, it is suggested that the carrier of the neutral currents is a vector meson with mass $m < 2$ GeV.

It was recently reported[1] that an interaction of neutral currents was observed at CERN in the neutrino reactions

$$\nu + N \to \nu + \text{hadrons} \quad (1)$$

$$\bar{\nu} + N \to \bar{\nu} + \text{hadrons} \quad (2)$$

The cross sections of reactions (1) and (2) amount to ~20 and 40% of the corresponding cross sections with production of charged leptons. On the other hand, according to preliminary data obtained in Batavia, where neutral currents were also searched for, the effect is either nonexistent or small.

It is perfectly possible that the resultant contradiction will be eliminated with further refinement of the experiment of the experimental data, and the results of the two groups will agree. Nonetheless, we wish to call attention to the existence of a simple mechanism that is capable in fact of leading to the supression of the contribution of neutral currents at high energies.

Assume that the neutral intermediate boson (C^0) has a mass on the order of several GeV, and the mass of the intermediate charged boson is large. Then the relative contribution of the neutral currents will attenuate with increasing energy, owing to the cutoff action of the boson propagator $(q^2 + m^2)^{-1}$. Since the average neutrino energy at CERN is of the order of 2 GeV and in Batavia 15 GeV, the suppression effect can be appreciable.

Quantitative estimates can be obtained by using the parton model. These estimates are given in the table for several values of the C^0 mass. If we stipulate at least a twofold suppression of the neutral currents on

s/m_C^2	0	2	4	6	10	25	100
Suppression factor	1	0.75	0.6	0.5	0.4	0.3	0.1

going from the CERN to the Batavia energy, then $m_C < 2$ GeV. The result depends somewhat on the ratio of the vector and axial coupling constants of the boson, and is given in the table for the case of pure vector coupling:

$$L_{int} = g C^{\circ}_{a} (\bar{l}\gamma_a l + x \bar{h}\gamma_a h), \tag{3}$$

where h are fundamental hadrons (quarks), l are leptons ($l = e, \mu$), $\nu_L^{e,\mu} = [(1+\gamma_5)/2]\nu^{e,\mu}$, and x characterizes the ratio of the hadronic and leptonic coupling constants.

It follows from the experimental data of[1] that

$$g^2 x \approx \frac{10^{-5}}{\sqrt{5}} \left(\frac{m_C}{m_N}\right)^2, \tag{4}$$

where we have neglected the dependence of the C-meson propagator on q^2 at the CERN energies. The latter can alter the result by not more than a factor of two, as can be readily seen from the table.

We note that the vector character of the coupling constants of the hypothetical boson seems natural if the boson is connected with spontaneously broken gauge symmetry. Then the C^0 boson can interact, for example, with a certain combination of lepton and baryon charges $(L + xB)$, and its constant would be purely vector. A more detailed analysis of Abelian gauge groups of this kind can be found in[2,3]. We note here that, within the framework of Weinberg's model,[4] the mass of the neutral vector boson, as is well known, is bounded from below, and the possibility discussed here is not realized. The generalizations of Weinberg's model[2,3] are free of such limitations. A phenomenologically closely similar model of a neutral vector boson interacting with a baryon-charge current was recently discussed also in[5].

If the C^0 interaction constant is purely vector, then the absolute values of the reactions (1) and (2) should be equal at high energies. At CERN the ratio of these cross sections is $\sim 1.3 \pm 0.3$. At the CERN energies, however, the deviations from the parton model can still be appreciable, and it would be of interest to verify this prediction in Batavia.

In the general case, the ratio of the vector and axial constants for the coupling of the C-boson with fermions can be arbitrary, and to verify the hypothesis of the mechanism of neutral currents it is necessary to perform experiments at two different (and high) values of the energy.

If the C-boson exists, then it is natural to assume that it interacts not only with neutrinos but also with charged leptons. Then C^0 can be observed in experiments on the production of lepton pairs, $a + b \to \mu^+ + \mu^- + X$. The corresponding cross section is equal to

$$\sigma(a + b \to C^{\circ}_{\hookrightarrow \mu^+\mu^-} + X) = \frac{3}{8}\frac{g^2}{\alpha^2}\frac{x^2\Gamma_{\mu\mu}}{\Gamma_{tot}} m_C \frac{d\sigma_{em}}{dq}\bigg|_{q=m_C}, \tag{5}$$

where $d\sigma_{\mathrm{em}}/dq$ is the differential cross section for the electromagnetic production of pairs with mass q, while $\Gamma_{\mu\mu}$ and Γ_{tot} are the partial and total widths of the C boson. One should expect $x^2\Gamma_{\mu\mu}/\Gamma_{\mathrm{tot}} \approx 1.5$ at $x \geq 1$.

Lederman's group obtained in their experiments[6] bounds on the vector-boson production cross section. A comparison of these results with formula (5) shows that the existence of the C boson is not excluded. In the optimal case, observation of C^0 calls for increasing the accuracy by four of five times.

Experiments are now being planned on muon pair production (for a description see, e.g., the review[7]) at Brookhaven and DESY. The sensitivity of these experiments will certainly be sufficient to observe a boson in the mass interval 1—6 GeV. These experiments would be crucial for the verification of the discussed hypothesis.

The C-boson can also be sought in the reactions

$$e^+e^- \begin{matrix} \nearrow e^+e^- \\ \searrow \mu^+\mu^- \end{matrix} \tag{6}$$

in colliding beams. For the ratio of the weak and electromagnetic contributions to the cross sections of these processes we can obtain

$$\left(\frac{d\sigma}{d\theta}\right)_{weak} \Big/ \left(\frac{d\sigma}{d\theta}\right)_{e.m.} \approx \frac{3\pi}{16\alpha}\,\frac{g^2}{4\pi\alpha}\,\frac{\Gamma_{ee}}{\Gamma_{tot}}\,\frac{2m_C}{\Delta E}\,\frac{(1+z^2)(1-z)^2}{(3+z^2)^2}, \tag{7}$$

where z is the cosine of the scattering angle and ΔE is the resolution relative to the total initial energy. It is assumed here that the initial energy equals the mass of the C boson with accuracy ΔE.

Although the predicted effect is quite large ($\sim 35\%$ at $x = 1$, $m_C = 2$ GeV, and $\Delta E = 20$ MeV), it might have escaped detection in the experiment, since the measurements were made at only several values of the initial energy (see, e.g., the review[7]).

In purely leptonic weak processes of the type $\nu_\mu e \to \nu_\mu e$, the momentum transfers are small and at a boson mass 1—4 GeV one can neglect the dependence of the propagator on q^2. The cross section depends on the value of x [see formulas (3) and (4)] and amounts to 0.2—0.4 of the cross section of the usual $(V - A)$ interaction at $x = 1$.

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