Search for an Intermediate Boson*

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(Received 29 October 1963)

In an experiment to observe the possible effects of an intermediate boson, the cross section for elastic electron-proton scattering was measured at 135° in the laboratory system for incident electron energies from 150 to 850 MeV. This energy range was covered in steps of 0.7% with an energy analyzed electron beam 1% wide. The presence of the intermediate boson would have produced an enhancement in the cross section of from 50 to 500% at the resonance energy. The cross section at each energy was measured to a statistical precision of 3%. No resonant peak was observed in this energy range. The conclusion is that there is no evidence for such a boson of mass less than 3080 m_e.

THE results of elastic electron-proton scattering are presently in extremely good agreement with electromagnetic theory and the cross section may be consistently fit by the well-known Rosenbluth formula. However, the electromagnetic interaction is not the only possible force between the electron and proton since weak interaction processes are also present. Normally, the weak interaction would be negligible compared with the electromagnetic, but under certain conditions the weak interaction term could become resonant in character and dominate the electromagnetic contribution to the scattering.

A specific model for such a resonance was first postulated by Kinoshita[1] from the intermediate boson hypothesis of Tanikawa and Watanabe.[2] Kinoshita's model showed that the intermediate boson of Tanikawa and Watanabe would produce a resonance in the total cross section for neutrino production of muons from the reaction

$$\nu_\mu + n \rightarrow B \rightarrow \mu^- + p\,,$$

and that the existence of the boson could be demonstrated by the enhancement in the number of muons produced by neutrinos in the correct energy range.

The results of Cowan[3,4] on the number of muons produced by cosmic-ray neutrinos, although statistically weak, seem to support the model of Kinoshita. As a result of this, Astbury and Crowe[5] used the Berkeley 184-in. cyclotron as a source of neutrinos, and detected muons produced in a heavily shielded sodium iodide crystal. Their results enabled a lower limit of $2130 m_e$ to be put on the mass of the boson, but could neither affirm nor reject the theory because of the low energy of the neutrinos produced by the cyclotron.

As was pointed out by Kinoshita,[1] the same boson would produce a resonance in the reaction

$$\begin{aligned} e^- + p \rightarrow B &\rightarrow e^- + p \\ &\searrow \nu_e + n\,. \end{aligned}$$

The energy of the resonance is directly related to the mass of the boson through the relation

$$E_0 = (m_B^2 - m_n^2)/2m_n\,, \tag{1}$$

where m_B, m_n are the boson and nucleon masses in MeV. In order that the boson reproduce the shape of the β-decay spectrum, its mass should be greater than $\sim 2300\, m_e$.

By adapting the formalism of Ref. 1 to the case of electron scattering, the total cross section at resonance is found to be

$$\sigma_{\text{res}} = [\pi m_B^2 (\hbar c)^2 / (m_B^2 - m_n^2)^2]\text{cm}^2 \tag{2}$$

in the proton rest system.

However, since the resonance has a width of ~ 100 eV, the resonant cross section is reduced by the ratio of the width of the resonance to the energy spread of the incident electrons. With an energy-analyzed incident beam 1% wide, the observed cross section becomes

$$\sigma_{\text{obs}} = [g^2 \times 50 (\hbar c)^2 / (m_B^2 - m_n^2)]\text{cm}^2 \tag{3}$$

with $g^2/4\pi = 6.4 \times 10^{-7}$ corresponding to the usual Fermi coupling constant.

The resonant scattering is isotropic in the center-of-mass system, and so the expected differential cross section was obtained from the expression

$$\left(\frac{d\sigma}{d\omega}\right)_{\text{obs}} = \frac{\sigma_{\text{obs}}}{4\pi}\left(\frac{d\sigma}{d\omega}\right)_{\text{lab}} \Big/ \left(\frac{d\sigma}{d\omega}\right)_{\text{c.m.}}. \tag{4}$$

An experiment to look for the effect of the boson was carried out using the Stanford Mark III linear accelerator. The apparatus used was a 44-in. radius 90° mag-

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* Supported in part by the joint program of the U. S. Office of Naval Research, The U. S. Atomic Energy Commission and the U. S. Air Force Office of Scientific Research.

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netic spectrometer with 0.2% resolution. The beam of electrons was momentum analyzed and a 1% wide band was incident on a liquid hydrogen target placed at the focal point of the spectrometer. To ensure a square energy spectrum, the accelerator was detuned to give a 2%-wide intrinsic spectrum and the central 1% was selected by energy slits. Elastically scattered electrons were accepted at 135±1.5°, momentum analyzed by the spectrometer and detected by a three-counter telescope placed at the image plane.

The full momentum acceptance of the spectrometer was 7.5% and so the telescope accepted the whole elastic peak including most of the radiative tail. To ensure the same conditions for each run as the incident electron energy was varied, a scintillation counter ladder placed in front of the counter telescope sampled the momentum distribution of the elastic peak in thirteen ½% channels and enabled a check to be made on the positioning of the peak during each run.

During the experiment, the incident electron energy E_i was varied in steps of 0.7% from 850 to 150 MeV. The spectrometer magnet current was adjusted in corresponding steps to keep the elastic peak centered on the counter telescope.

At each energy the threefold coincidence rate was measured by scaling the output of a fast coincidence circuit with a 100-Mc/sec scaler. The momentum spectrum from the ½% channels was gated by the threefold coincidence and displayed on thirteen scalers whose readouts were photographed by a Polaroid Land Camera. The presence of the resonance would show up as a large enhancement in the counting rate in at least one and possibility two experimental points. Approximately 1000 counts were obtained at each point. The integrated electron beam current was recorded by a secondary emission monitor, which was periodically calibrated against a Faraday cup. The beam intensity was adjusted during the experiment to maintain a constant counting rate in order to eliminate systematic dead-time variations.

As a double check against the possibility of missing such a narrow resonance, the whole procedure was repeated in a second running period. The results of both runs were identical. Figure 1 shows the results of the second run where the points are the raw numbers normalized to a constant integrated current from the secondary emission monitor.

The solid line is the prediction of Eq. (4) and gives the expected number of counts at resonance, from the weak interaction only, as a function of boson mass. Thus, the presence of the boson would produce a deviation of one or two experimental points from the smooth curve representing agreement with electromagnetic theory. The magnitude of the deviation should equal the ordinate of the solid line at the resonance energy.

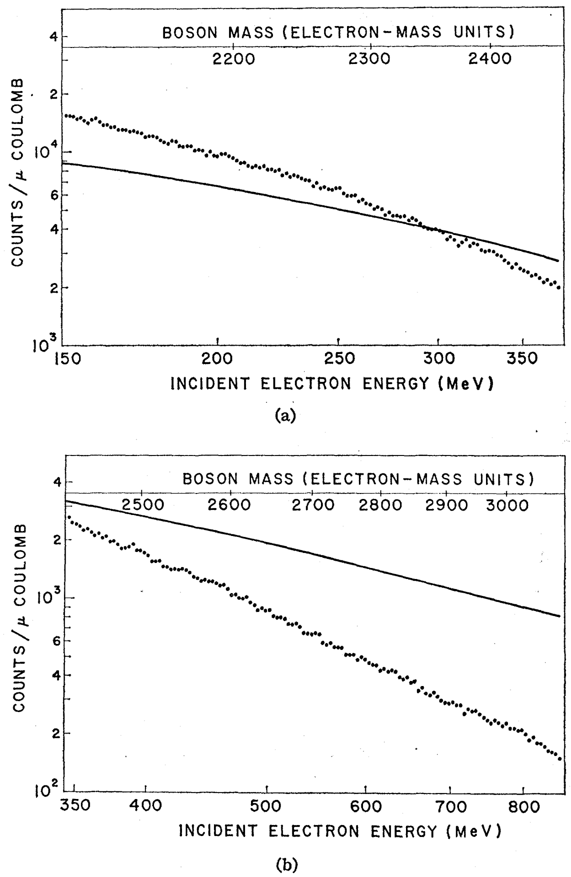

FIG. 1. (a) and (b). Results as a function of incident electron energy. The experimental points all have 3% statistical error. The solid line is the prediction of Eq. (4) as a function of boson mass.

As can be readily seen by inspection of Fig. 1, there was no evidence for such a deviation in the range of boson masses:

$$2110m_e \leq m_B \leq 3080m_e.$$

Kinoshita[1] states that certain variants of the theory could be found which cannot be disproved by one negative experiment alone. Since we have found no evidence for the resonance in the electron-proton scattering experiment, an extension of the experiment of Astbury and Crowe to higher neutrino energies or an improvement in the statistical data from cosmic-ray neutrinos should finally reject this hypothesis.

ACKNOWLEDGMENTS

The authors would like to thank A. Astbury for helpful discussions and communication of results prior to publication. We are indebted to D. Lundquist, H. Lynch, and J. Wong for help in taking data.