Upper Limit on the Neutrino Magnetic Moment*

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A liquid scintillation detector and neutrinos from a fission reactor were employed to set a new upper limit of 10^{-7} Bohr magnetons for the neutrino magnetic moment.

IF a neutrino possesses a magnetic moment, then on passing through matter it will undergo elastic collisions with atomic electrons. The cross section $\sigma(W)dW$ (cm^2) for the target electrons to appear in an energy range dW at energy W as a result of such a process has been calculated by Bethe[1] to be

$$\sigma(W)dW=Af^2\frac{1}{1+W}\left(1-\frac{W}{E}\right)\frac{dW}{W}, \tag{1}$$

where A = classical electron area (2.5×10^{-25} cm^2) obtained by taking $r_0=e^2/mc^2$, E = energy of the incident neutrino in units of the electron rest energy (mc^2 units), W = target electron energy (in mc^2 units) resulting from collision ($W\gg$ ionization potential), and f = neutrino magnetic moment in Bohr magnetons (Bm). The rest energy of the neutrino is taken to be negligible compared to the incident neutrino energy.[2]

On the basis of Bethe's theory, Nahmias[3] has shown experimentally that $f<2\times10^{-4}$ Bm, corresponding to a cross section less than 10^{-30} cm^2 per "air atom" for neutrinos from radium. Barrett,[4] in an experiment similar to that of Nahmias, but using tritium, obtained an upper limit of 4×10^{-34} cm^2/electron, corresponding to $f<10^{-5}$.

Houtermans and Thirring,[5] using data of Kulp and Tyron[6] and assuming that the sun provides a flux at the earth of 6×10^{10} neutrinos/cm^2 sec, deduce the neutrino collision cross section to be $<8\times10^{-34}$ cm^2/"air atom," giving $f<2\times10^{-6}$ Bm. Crane[7] rules out cross sections down to 10^{-36} cm^2 on the basis of geophysical arguments, with the result that $f<2\times10^{-7}$ Bm.

In the course of an experiment to measure backgrounds for use in an improved version of the free neutrino experiment,[8] data were collected which permit the setting of a new upper limit on the neutrino magnetic moment.

The neutrinos from the reactor were incident on a liquid scintillation detector which provided electrons as targets for the neutrinos. In this detector the liquid is viewed by several 5-in. DuMont photomultiplier tubes. The counting rate difference due to the reactor in the 0.44–2 Mev energy range was 30($\pm$4) counts/sec. In order to obtain an upper limit on the neutrino-electron interaction via a neutrino magnetic moment, we attribute this difference to the neutrino. The detection efficiency for electrons in this energy range is very nearly unity. We assume, perhaps conservatively, that the mean energy of the fission neutrinos is 2 Mev. Integrating Eq. (1) from the upper limit E to a lower limit W_0, we obtain a cross section for these recoil electron energies,

$$\sigma=Af^2\ln\left[\frac{E}{W_0}\left\{\frac{1+W_0}{1+E}\right\}^{(1+1/E)}\right]. \tag{2}$$

Inserting the energy limits $E=4$, $W_0=0.86$, and the value of A, we find

$$\sigma=7.5\times10^{-26}f^2\ (\text{cm}^2). \tag{3}$$

Combining this equation with numbers for the estimated net reactor neutrino flux, the upper limit on the observed difference in counting rate, and the number of target electrons, we obtain $f<10^{-7}$ Bm. This result is $\sim10^3$ short of the theoretical estimate,[5] $f_{\text{th}}\sim10^{-10}$ Bm, based on the virtual dissociation of the neutrino into neutron, antiproton, and electron.

The data obtained can also be used to establish an upper limit on the electron-neutrino interaction without specifying the origin of the interaction. Table I gives upper limits to the cross section for the scattering of fission neutrinos by electrons resulting in an electron energy in the ranges cited. It seems likely that a further reduction in this interaction cross section will be made incidental to the improved neutrino experiment mentioned above.

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TABLE I. Upper limit on electron neutrino interaction for fission neutrinos resulting in the production of electrons with energies above those listed.

Minimum energy in units of mc^2	$\sigma\times10^{40}$ (cm^2)
0.45	14
0.9	6
1.3	3
1.7	2

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