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An Upper Limit for the Cross Section for Scattering of Neutrinos by Hydrogen

E. O. WOLLAN
Clinton Laboratories, Oak Ridge, Tennessee

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An upper limit of about 2.0×10^{-30} cm^2 for the cross section for scattering of neutrinos by hydrogen has been determined. The experiment consisted in an attempt to measure the ionization in hydrogen in the vicinity of the Clinton pile under as nearly ideal shielding conditions as possible. The fact that the ion current in the hydrogen-filled chamber could not be measured and the known sensitivity of the instrument were used to deduce the above-mentioned upper limit to the cross section. One reason for making this determination was to rule out the possibility of neutrinos constituting a health hazard in the vicinity of a high flux pile.

SINCE chain reacting piles constitute very powerful sources of radioactivity, they are presumably also very strong sources of neutrinos. This fact made it logical to consider in the early days of the Plutonium Project whether or not neutrinos could constitute a radiation hazard problem. Wigner considered this problem in a Project Report "On the Available Information Concerning the Interaction of Neutrinos with Matter," June 2, 1943. He pointed out that the only type of interaction of neutrinos with matter for which a cross section can be even approximately calculated is that of the inverse beta-decay. This is the process by which a stable nucleus (A, Z) is converted into one of the nuclei $(A, Z+1)$ or $(A, Z-1)$. Both these processes require energy, and this energy must be furnished by the neutrino. The cross section calculated for this process is in the neighborhood of 10^{-42} cm^2.

In addition to the inverse beta-decay process there is, however, also the process of elastic scattering of neutrinos by electrons or by heavy particles. It is possible at present only to set a theoretical upper limit to the cross section for the scattering process, and the actual cross section may differ from this by a large amount. Wigner showed that from neutrinos of a few Mev one can expect ionization to occur only in the case of hydrogen, because for heavier nuclei (even helium) the velocity imparted to the recoiling nucleus is insufficient to separate it from its electrons. Nahmias[1] tried to observe the ionization in air produced by the neutrinos emitted by a source of radium heavily shielded against gamma-rays. The negative results from these experiments made it possible to set an upper limit of 10^{-31} cm^2 to the interaction of neutrinos with electrons. So fas as the cross section for interaction of neutrinos with nuclei is concerned, no conclusions can be drawn from Nahmias' results.

It became possible in connection with some measurements made at the time of the start-up of the Clinton pile (October, 1943) to set an upper limit of about 2.0×10^{-30} cm^2 for the neutrino-hydrogen scattering cross section. The experiment from which these results were obtained had to do with determining the efficiency for neutron absorption of the shield material to be used in the Hanford piles.* A pair of balanced ionization chambers was used in these measurements. One of these chambers was filled with CH_4 at about 11 atmosphere pressure and the other with argon at a pressure just sufficient to give an equal response to gamma-rays. When these chambers have opposite collecting potentials applied to them and are connected together to an electrometer, the apparatus measures the difference in ionization produced in them. Although the apparatus was built for measuring neutrons it will measure any radiation for which the ratio of ionization in CH_4 and argon is different from that for gamma-rays.

Since the scattering of neutrinos by hydrogen should produce ionization in that gas, the

[1] M. E. Nahmias, Proc. Camb. Phil. Soc. **31**, 99 (1935).

* This experiment was carried out by K. Z. Morgan, H. M. Parker, and E. O. Wollan.

measurements at Clinton permit one to set an upper limit to the cross section for neutrino-hydrogen scattering. One would expect the cross section for the scattering of neutrinos by other nuclei to be of the same order of magnitude although it would not lead equally readily to ionization.

The sensitivity of the above apparatus for neutrons was determined with a Ra-Be source (at a voltage sensitivity of the electrometer of 160 div/volt) to be 1 neutron per cm^2 sec.$=0.032$ div/sec., or making use of the voltage sensitivity one has that 1 neutron per cm^2 sec.$=2\times 10^{-4}$ volt/sec. The electrical capacity of the system being about 4×10^{-11} farad, this gives the current response of the instrument for 1 neutron per cm^2 sec.$=8\times 10^{-15}$ ampere or 5×10^4 ion pairs per second formed in the chamber.

For the measurements of the neutron activity through the shield the pile was operated at constant power for several minutes. The electrometer showed no measurable deflection during this time but wandered very slightly some of the time in one direction and some of the time in the opposite direction. An analysis of the readings showed a maximum rate of drift corresponding to that which would be produced by about ± 0.25 neutron per cm^2 sec. If the rate of drift had been four times this amount (i.e., corresponding to 1, neutron per cm^2 sec. or 5×10^4 ion pairs per sec. in the chamber) the deflection rate would certainly have been measurable. On this basis then if the neutrino-hydrogen scattering cross section were of such magnitude that the ionization by neutrinos reached a value of 5×10^4 ion pairs per sec. in the chamber, a measurable current would have been observed.

An upper limit to the neutrino-hydrogen cross section can be calculated from these results, on the assumption that about two pile neutrinos per fission will have sufficient energy to produce on the average about $\frac{1}{4}$ ion pair per neutrino-hydrogen scattering event.

If F=number of fissions per sec. at operation power, d=distance from center of pile to chamber, n=number of atoms of hydrogen in the chamber, and σ=neutrino-hydrogen scattering cross section, then the ionization, I, produced in the chamber will be

$$I=\tfrac{1}{4}(2Fn\sigma/4\pi d^2)$$

or

$$\sigma_{\text{upper limit}}=(8\pi d^2/Fn)\times I_{\text{upper limit}}.$$

The ion chambers had a volume of about 2000 cm^3, and one of them was filled with CH_4 at a pressure of 11 atmospheres. F and d are not given for security reasons.

On the basis of $I_{\text{upper limit}}=5\times 10^4$ ion pairs per sec. the following value of the upper limit for neutron-hydrogen scattering cross section was obtained.

$$\sigma_{\text{upper limit}}\cong 2\times 10^{-30}\ \text{cm}^2.$$

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