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HELICITY OF ANTINEUTRINOS EMITTED BY NUCLEI*

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The helicity of antineutrinos emitted in nuclear transitions has been measured by determining the circular polarization of gamma rays emitted by a gaseous source of Hg^{203} and resonantly scattered by Tl^{203} nuclei. The antineutrinos and electrons preceding these gamma rays are known to travel approximately opposite to the gamma quanta. The helicity of neutrinos emitted following electron capture has been remeasured using the same apparatus.

The helicity of neutrinos involved in nuclear processes was determined by Goldhaber, Grodzins, and Sunyar.[1] Although a similar direct determination of the helicity of antineutrinos has never been made, there is experimental evidence suggesting that the antineutrino has helicity $\Theta_{\overline{\nu}} = +1$,[2] in agreement with the two-component theory of the neutrino.[3-5] It has recently been shown by this author that the practical difficulties in determining the helicity of the antineutrino through a method parallel to that employed by Goldhaber, Grodzins, and Sunyar can be overcome through the proper choice of an isotope for the experiment.[6]

If the total kinetic energy of the antineutrino and the electron is nearly equal to the gamma-transition energy, the gamma ray can be resonantly scattered by the daughter nucleus only if, in general, both the preceding leptons traveled in directions approximately opposite to the gamma quantum. The circular polarization of the resonance-scattered gamma rays can be approximately given to be[6,7] $P = -A(\overline{v}/c - \Theta_{\overline{\nu}})$, where A represents the beta-gamma circular-polarization angular-correlation coefficient, $\overline{v}$ is the average speed of electrons in the beta spectrum, and $\Theta_{\overline{\nu}}$ is the helicity of the antineutrinos. In actual practice, the circular polarization tends to be less, due to the direction and velocity distribution of the antineutrinos and electrons that precede the resonance-scattered gamma rays. Moreover, uncertainties in P may arise due to lack of information on the beta-neutrino angular correlation.

A gaseous source of Hg^{203} at a pressure of about 0.1 atm is used in the experiment. Hg^{203} decays with a 47-day half-life, by beta emission of maximum kinetic energy 208 keV followed by gamma rays of 279-keV energy. The gamma radiation is passed through a transmission-type polarimeter of average transmission length approximately 4 mean free paths, operated at magnetization cycles of 10 sec. The gain shift of the photomultiplier output due to reversal of the

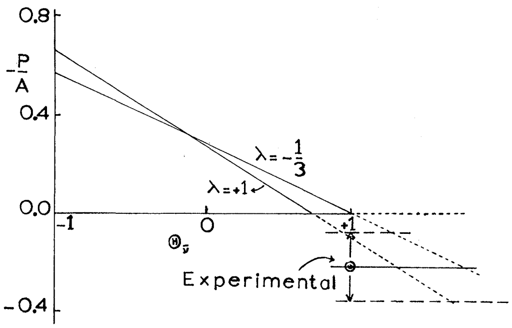

FIG. 1. Circular polarization of resonance-fluorescence gamma rays for extreme values of the beta-neutrino angular-correlation coefficient λ versus helicity of antineutrinos.

magnetic field was reduced to less than 10^{-5} by a combination of magnetic shielding and microvariation of the phototube voltage.[8] The spectra of the gamma rays scattered from a natural thallium scatterer during the periods of opposite magnetizations were separately collected in two 128-channel groups of a Nuclear Data 512-channel analyzer. Data were printed out daily, and the entire electronics corresponding to the up and down directions of the magnetic field were interchanged. The experiment was performed with three sources of around 500-mCi strength, each being used for 50 days.

Earlier measurements using the resonance-scattering apparatus employed in this experiment showed that nuclear-resonance fluorescence resulted in a 9.5% enhancement of the full-energy peak in the scattered-gamma spectrum dominated by Rayleigh scattering.[9] The degree of circular polarization of the resonance-fluorescence radiation was estimated through a computer program to be $P=-A(0.29-0.34\Theta_{\bar{\nu}})$. In this program, the beta-neutrino-gamma (circular-polarization) angular correlation was expressed as

$$W[\beta,\nu,\gamma(\tau)]=[1+A(v/c)\tau\cos\beta](1-A\Theta_{\bar{\nu}}\tau\cos\nu)$$
$$\times[1+\lambda(v/c)\cos(\beta-\nu)].$$

In this equation, β and ν represent the beta-gamma and neutrino-gamma angles, respectively, and λ the unknown beta-neutrino angular-correlation coefficient. Assuming the ξ approximation to be valid, λ is expected to be between +1 and $-\frac{1}{3}$. The effect of the cross terms is found to be less than 10%, and has only a small effect on the computation of $\Theta_{\bar{\nu}}$. The average value of A obtained from two mutally consistent measurements[10,11] is -0.19 ± 0.04.

Table I. Asymmetry between count rates in the Rayleigh-scattering plus resonance-fluorescence peak for opposite directions of the magnetic field, antiparallel and parallel to the path of gamma rays. Data were obtained for scattering from thallium and lead.

Source No.	Count rate asymmetry in 279-keV peak Thallium	Lead
1	$(2.4\pm1.8)\times10^{-4}$	
2	$(4.5\pm2.0)\times10^{-4}$	$(-0.7\pm2.9)\times10^{-4}$
3	$(-1.0\pm1.8)\times10^{-4}$	$(-2.4\pm2.1)\times10^{-4}$
Average	$(1.8\pm1.1)\times10^{-4}$	$(-1.8\pm1.7)\times10^{-4}$

The circular polarization of the resonance gamma rays was determined by this experiment to be (-4.2 ± 2.5)%, which is consistent with the helicity of the antineutrinos being +1 (Fig. 1). The circular polarization of the nonresonance background (predominantly Rayleigh-scattered radiation) was also measured, using a lead scatterer in place of the thallium scatterer, and found to be fairly consistent with the expected value, zero (see Table I). A further check on the present experiment was obtained by repeating the experiment of Goldhaber, Grodzins, and Sunyar with the present equipment by using Eu^{152} as the source and replacing the thallium scatterer by one of samarium oxide. The solid source was mounted at such a point along the axis of the apparatus that the average path length in the polarimeter iron for the Eu^{152} gamma radiation was approximately 3 mean free paths. The resonance-scattered radiation was found to have a circular polarization (-61 ± 12)%, consistent with the results obtained by the earlier experimenters, and by Marklund and Page.[12]

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SECONDARY PARTICLE PRODUCTION IN HIGH-ENERGY MUON-NUCLEON INTERACTIONS

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Secondary particles produced by muon-nucleon interactions at 10.1 GeV/c (positive) and 14.6 GeV/c (negative muons) have been identified in nuclear emulsions. The energy spectrum and angular distribution (in c.m. system) is given for pion, kaon, and proton along with their partial cross sections. Yang's hypothesis of limiting fragmentation in high-energy lepton-hadron collision is compared with our results which tend to support it.

Recently a number of experiments[1-6] have been performed studying the inelastic lepton-hadron scattering at high energies to obtain detailed information about the structure and about any fundamental constituents of hadrons. Most of the data that have been available from Stanford Linear Accelerator Center, Cambridge Electron Accelerator, Brookhaven, and Deutsches Elektronen-Synchrotron were taken where one detects only the final scattered lepton at a predetermined laboratory angle. In these experiments the arrangement was such that they did not detect the secondary particle produced in these interactions. In the present report we give our preliminary results of the measurements of the secondary particles produced in 10.1- and 14.6-GeV/c positive and negative muon-nucleon inelastic interactions, respectively. The results at 5 GeV/c were presented earlier.[7]

Two large stacks, each of 70 Ilford G-5 pellicles, were exposed to 10.1- and 14.6-GeV/c positive and negative muons, respectively, with a flux density of $5\times10^5/\mathrm{cm}^2$ at the Brookhaven alternating-gradient synchrotron. The beam was parallel to the plane of the emulsion. The pion contamination in the beams was measured[8] and the ratio of pions to muons was found to be less than 10^{-6}. We also took another precaution by placing an extra filter just before the emulsion stack so the contamination was considered to be negligible.[9] The processed emulsions were area scanned for all possible events produced by each muon beam. Using 70 pellicles from both the exposures, we observed about 7000 stars, and under very stringent selection criteria[9] discarded the background events produced either by cosmic rays or by the secondary tracks produced in other interactions. About 2500 events passed through all the required tests. All (1 +1) type[10] events were checked for coplanarity and the elastic events were removed from all calculations.

In the selected events, the grain density g_s and the product of the three-momentum and velocity $\bar{p}\beta c$ was measured for all the grey and light secondary tracks[11] with dip angles less than 30°. The grain density g_0 of the primary track was measured separately for each event in order to eliminate any error due to nonuniformity of the blob density from place to place in the emulsion stack. The blob count was performed over a length of 5000 μ for the primary and for at least 1000 μ for the secondary track. A Koristka scattering microscope, attached to which was a filar micrometer that could be read to an accuracy of 0.02 μ, was used for the measurements of $\bar{p}\beta c$. The shower particles were identified by a well-known g^*-$\bar{p}\beta c$ technique.[9,12] Whenever it was considered desirable, the secondary tracks were followed from pellicle to pellicle until they stopped in the emulsion. Thus the track-following technique gave us an independent way of identifying the secondary particles (π, K, p, and Y) uniquely and thus their energy values were determined from their ranges. The theoretical curves for $g^* = g_s/g_0$ vs $\bar{p}\beta c$ were drawn for each beam for different particles (μ, π, K, p, etc.) produced in muon-nucleon interactions. The projected and dip angles that the shower par-