ANGULAR DISTRIBUTION OF POSITRONS IN $\pi^+ - \mu^+ - e^+$ DECAY IN PROPANE

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IT is known that if parity conservation is violated in the μ–e decay, the angular distribution of the decay electrons can be approximated by a function of the form[1,2]

$$dN \sim \left(1 + \frac{\lambda}{3}\cos\vartheta\right) d\Omega = (1 + a\cos\vartheta)\, d\Omega, \qquad (1)$$

where ϑ is the angle between the direction of motion of the electron (within the range of the solid angle $d\Omega$) and the direction of the μ-meson spin. The experimental angular distributions, obtained by several authors, have a form close to that of the function $(1 + A\cos\vartheta)\, d\Omega$, although the coefficient A is found to be different for various substances.

Actually, in the experiment we measure the angular distribution relative to the direction of motion of the μ mesons, since polarization of μ mesons along their momentum takes place in the π–μ decay. However, a fraction of the μ mesons have the orientation of their spins changed before decaying. The difference in degree of disorientation in different substances is responsible for the variations in value of A and does not permit identification of A with the coefficient a in Eq. (1). A statistically reliable number of measurements of A in various substances must be compiled in order to determine a and to clarify the disorientation mechanism of the μ mesons.

We have studied the angular distribution in π^+–μ^+–e^+ decay in propane. This is valuable, too, considering the usefulness of propane (widely utilized in bubble chambers) for measurements of angular correlations of events of similar nature as in the μ–e decay.

The experimental setup is shown in Fig. 1. A $7.2 \times 6.5 \times 16$ cm bubble chamber[3] was irradiated by a 175-Mev π^+-meson beam in the synchrocyclotron of the Joint Institute for Nuclear Research. π^+ mesons, formed in a polyethylene target, decayed in the chamber after having been taken out through a collimator and slowed down by a copper absorber. During the measurements, the chamber was inside a magnetic screen, which reduced the external magnetic field to 1 oersted.

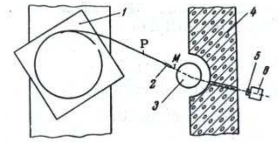

FIG. 1. Setup of the chamber at the accelerator: 1 – vacuum chamber of the accelerator, 2 – target, 3 – deflecting magnet, 4 – shielding, 5 – absorber, 6 – chamber, P – proton beam, M – π^+ mesons.

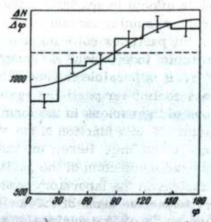

FIG. 2. Electron angular distribution in $\pi^+ - \mu^+ - e^+$ decay. φ is the projection of the spatial angle between the initial directions of the e^+ and μ^+ momenta onto the plane of the camera film.

In all, we have obtained 8,000 photographs in which we found 6,670 π^+–μ^+–e^+ decays. Not included in this number are decays for which the end of the μ^+ track was closer than 3 mm from the chamber walls. For such borderline cases the probability of observing an electron emitted in the direction of motion of the μ^+ meson could be smaller than if it were emitted backwards.

We have measured the angular distribution of the projection of the spatial angle onto the plane of the camera film. If one assumes an isotropic distribution of the μ^+ mesons in the decay, the function (1) is transformed to read in terms of the plane angle φ as follows:

$$dN \sim [1 + (a\pi^2/16)\cos\varphi]\, d\varphi. \qquad (2)$$

The experimental angular distribution of the decay electrons is shown in Fig. 2. The distribution is satisfactorily approximated by a function of the form (2) (solid line; dotted line represents an isotropic distribution). The ratio of the number of electrons emitted into the angular interval $90 - 180°$ to the number of electrons emitted into the interval $0 - 90°$, relative to the direction of the projection of the initial momentum of the μ^+ mesons, is 1.19. This corresponds to a coefficient $A = -0.22 \pm 0.03$ in the expression $(1 + A\cos\vartheta)$ for the distribution of spatial angles.

As mentioned above, the measured coefficient A is not equal to the coefficient a of Eq. (1). If one denotes by γ the degree of quenching of the μ^+ mesons at the instant of decay, then $A = a \times (1 - \gamma)$. Assuming, as Chadwick et al.[4] do, no disorientation of μ^+ mesons in hydrogen, and using for the determination of $\gamma(C_3H_8)$ the data of Swanson et al.,[5] we find $\gamma(C_3H_8) = 0.33 \pm 0.10$; hence $a = 0.33 \pm 0.06$ and $\lambda = 0.99 \pm 0.18$. The analogous value of λ found by Chadwick et al. from the data in G-5 emulsions equals 0.85 ± 0.18.

We take this opportunity to express our gratitude to Professor V. P. Dzhelepov for making it possible for us to perform this experiment at the synchrocyclotron.

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ENERGY DEPENDENCE OF ANGULAR CORRELATION IN $\mu^- - e^-$ DECAY

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ACCORDING to the two-component neutrino theory[1,2] the angular asymmetry in the μ–e decay depends strongly on the electron energy. If ϵ stands for the ratio of the electron energy to the maximum energy in the μ–e decay, then the angular distribution is described by the function

$$dN = N(a + b\lambda\cos\vartheta)\, d\epsilon\, d\cos\vartheta, \qquad (1)$$

where ϑ is the angle between the momentum direction of the decay electron and the μ-meson spin; λ is a theoretical parameter;

$$a = 2\epsilon^2(3 - 2\epsilon); \quad b = 2\epsilon^2(2\epsilon - 1).$$

Several authors, in particular Vaisenberg and Smirnitskii[3,4] have analyzed the angular distribution of positrons of various energies in the π^+–μ^+–e^+ decay and found an increase with energy of the "backward-forward" asymmetry. We have studied the angular correlation in the decay of negative μ mesons, which decayed in an emulsion.

A stack of NIKFI-R photoemulsion 10 cm in diameter and 400μ thick was irradiated by a negative μ-meson beam from the synchrocyclotron of the Joint Institute for Nuclear Research. The μ^- mesons were formed from the decay of 350-Mev π^- mesons and were then separated from other particles by a carbon absorber 90 cm thick. The emulsion chamber was surrounded by a thick layer of iron, which screened it from the stray field of the accelerator.

The geometry of the experiment was such that μ^- mesons of energy close to maximum were registered in the emulsion. The momentum direction of such μ^- mesons changes only slightly in going from the coordinate system in which the π^- meson is at rest to the laboratory coordinate system. For this reason, the μ^--meson beam was considered polarized.

In the scanning of separate emulsion layers tracks of long-range μ^- mesons with decay electrons were noted.

Altogether 630 cases of μ^-–e^- decays were analyzed in which μ^- mesons stopped at a distance of not less than 50μ from any of the emulsion surfaces. In 135 cases of μ^-–e^- decays, an estimate of the electron energy was made when the electron track length was more than 500μ. 83 electrons had a track length of over 1 mm.

The electron energy was measured by the multiple-scattering method; the error in the energy determination ranged from 30 to 18%, depending on the electron track length.

In order to compare the experiment with formula (1) and the consequences resulting from it, it was necessary to measure the angle ϑ, which in our case was taken to be the same as the angle between the direction of the electron motion and the axis of the μ^--meson beam.

In 135 cases of μ^-–e^- decays, 64 electrons were emitted forwards (i.e., $0 \le \vartheta \le 90°$) and 71 electrons were emitted backwards (i.e., $90° \le \vartheta \le 180°$). This circumstance may serve as an indication that the spin direction of the μ^- meson,

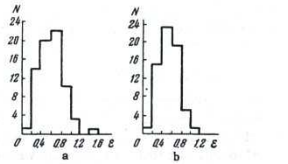

FIG. 1 Electron energy spectra: a – electrons emitted backwards, b – electrons emitted forwards.

at least for some particles, keeps its initial direction in the emulsion up to the instant of decay.

In Fig. 1 the energy spectrum is shown separately for the electrons emitted forwards and backwards. Here the number of electrons N is plotted against the ratio ϵ of the electron energy to the maximum energy E_{max} = 55 Mev.

Angles	Direction	Electron Number	Theoretical ratio ($\lambda = -1$)
0–20° 160–180°	forward backward	3 9	1 : 2.6
0–60° 120–180°	forward backward	11 19	1 : 2
60–90° 90–120°	forward backward	8 13	1 : 1.2

For energies $\epsilon > 0.6$ the "forward-backward" electron ratio was 25 : 36. In the low energy region ($\epsilon < 0.6$), 39 particles were emitted forwards and 35 backwards. The observed change in sign of the asymmetry for fast and slow electrons is in qualitative agreement with formula (1).

In addition, we have studied the asymmetry in various angular intervals. The table gives the ratio of "forward-backward" electrons for various angular intervals in the energy region > 35 Mev.

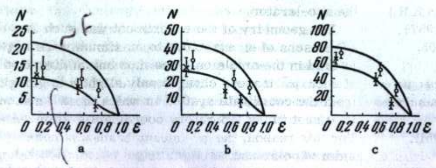

FIG. 2. Electron energy spectra in various angular intervals: a) 0 – 20° and 160° – 180°, b) 0 – 45° and 135° – 180°, c) 0 – 90° and 90° – 180°; o – backward emitted electrons, × – forward emitted electrons.

In Fig. 2 the energy spectra in various angular intervals are compared with theoretical curves. The upper curve is for electrons emitted backwards, and the lower curve for electrons emitted forwards. The slight disagreement between the experimental points and the expected distribution is, apparently, due to a partial depolarization of the μ^- mesons before decaying.

From the above given analysis of the angular correlation in the $\mu^- - e^-$ decay one can see a qualitative agreement with the two-component neutrino theory. Unfortunately, the accumulated statistics are not sufficient for quantitative conclusions.

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SCATTERING OF NEUTRINOS BY ELECTRONS

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IMPROVEMENTS in experimental techniques have made it possible to determine cross sections on the order of $10^{-44} - 10^{-45}$ cm^2 in reactions dealing with the absorption of neutrinos by protons or Cl^{37} (see Refs. 1 and 2), and have led to the hope that these experiments will be repeated in the near future for the purpose of measuring the scattering of neutrinos by electrons. Up to now, experiments carried out to determine the magnetic moment of the neutrino have led to negative results. According to Ref. 3, σ_μ, the cross section for ν–e scattering, is less than 7.5×10^{-46} cm^2/electron, which leads to a value of μ, the magnetic moment of the neutrino, of less than $10^{-7} \mu_B$ (μ_B is the Bohr magneton). On the other hand, theoretical estimates of Thirring and Houtermans[4] yield $\mu \sim 10^{-10} \mu_B$.

The purpose of the present note is to show the possibility of ν–e scattering through a direct 4-fermion interaction $\bar{e}e\nu\bar{\nu}$. The cross section for such scattering may be of the same order of magnitude as σ_μ and can even exceed it. If the incident neutrino has energy E, and the recoil electron has energy W (in units of mc^2), the scattering cross section has the form

$$d\sigma_E(W) = \frac{m^2}{8\pi\hbar^4}\frac{dW}{E^2}\{|g_S|^2(W^2+WE)+g_P^2W^2 + 2|g_V|^2[W^2-W(2E+1)+2E^2] + 2|g_A|^2[W^2-W(2E-1)+2E^2] + 2|g_T|^2[W^2-W(4E+1)+4E^2] + 2\mathrm{Re}(2g_Vg_A^* + g_Sg_T^* + g_Pg_T^*)(W^2-WE)\}. \quad (1)$$

The total effective cross section

$$\sigma_f = \int_0^\infty \rho(E)\,dE \int_0^{2E^2/(2E+1)} d\sigma_E(W) \quad (2)$$

is obtained by averaging over the energy distribution of the incident neutrinos $\rho(E)$. Assuming as in Ref. 5 that $\rho(E) \sim \exp[-E^2/2(\Delta E)^2]$ we find for $\Delta E = 3.8$

$$\sigma_f = 0.05\,(m^2/\hbar^4)\,g^2,$$
$$g^2 = |g_S|^2 + 0.5|g_P|^2 + 5|g_V|^2 + 6|g_A|^2 + 9|g_T|^2 - 2.5\,\mathrm{Re}(2g_Vg_A^* + g_Sg_T^* + g_Pg_T^*). \quad (3)$$

If one assumes the usual value of the universal Fermi interaction constant $g = 3 \times 10^{-49}$ erg-cm^3, then

$$\sigma_f = 3.5 \cdot 10^{-45}\ \mathrm{cm}^2. \quad (4)$$

This value is 5 times larger than the cross section $\sigma_\mu \sim 7.5 \times 10^{-46}$ cm^2, corresponding to $\mu \sim 10^{-10} \times \mu_B$.

An interaction of this type may generally also take place in the scattering of a neutrino by a nucleon. Formula (1) may be used as above to obtain a cross section of the same order of magnitude, however, it is practically impossible to observe ν–n and ν–p scattering because of the small recoil energy of the nucleons.

Nonconservation of parity leads to modifying (1) and (3) as follows:

$$g_ig_j^* \to g_ig_j^* + g_i'g_j'^* - \eta(g_ig_j'^* + g_i'g_j^*),$$

where η is the longitudinal polarization of the neutrino beam.

In conclusion, the author wishes to thank I. M. Shmushkevich, V. N. Gribov, and I. T. Diatlov for discussion of this analysis.

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