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POLARIZATION OF THE μ^+ MESON CURRENT AT SEA LEVEL

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THE violation of the law of parity conservation in weak interactions is known to lead to the longitudinal polarization of the μ meson in the $\pi \rightarrow \mu$ decay in the center-of-mass system. The μ mesons observed at sea level are produced in the decay of π mesons in flight. A current of μ mesons with energy E_μ is generated by π mesons in a certain energy interval ΔE_π. Since the energy spectrum of the π mesons in the atmosphere decreases fast with the energy $(\sim E^{1-\gamma_\pi})$, there will be an excess of μ mesons flying, in the center-of-mass system, into the forward hemisphere relative to the direction of motion of the π mesons, i.e., the μ-meson current will be polarized. The degree of polarization of the the μ mesons was theoretically determined by Gol'dman (reference 1).* It is given by the expression

$$\eta = \frac{1}{v} - \frac{\gamma}{\gamma - 1}\frac{1-v}{v}\left[1 - \left(\frac{1-v}{1+v}\right)\quad\right] \Big/ \left[1 - \left(\frac{1-v}{1+v}\right)^{\gamma}\right], \quad (1)$$

where v is the velocity of the μ meson in the center-of-mass system, measured in units of c; γ is a parameter characterizing the energy spectrum of the particles which generate the μ mesons. It was further shown[1,2] that the depolarization due to scattering of the μ meson before it comes to rest is negligibly small. The polarization of the μ mesons can be determined by studying the asymmetry in the electron emission in the $\mu \rightarrow e$ decay.

In the two-component theory of the neutrino, this asymmetry is determined by the formula of Lee, Yang, and Landau:

$$W(\varepsilon, \theta)\, d\varepsilon\, d\Omega = \frac{\varepsilon^2}{2\pi}\left[(3 - 2\varepsilon) + \xi\eta(2\varepsilon - 1)\cos\theta\right] d\varepsilon\, d\Omega, \quad (2)$$

where ϵ is the energy of the positron in units of the maximal energy, ξ is a theoretical parameter which is close to unity and depends on the coupling constants, η is the degree of polarization, and θ is the angle between the polarization vector of the μ meson and the direction of emission of the electron.

The present note is devoted to the experimental determination of the degree of polarization of the cosmic μ^+ mesons at sea level. The measured quantity is the relative yield of decay positrons emitted into the upper hemisphere in the decay of the μ^+ meson as it comes to rest. The $\mu \rightarrow e$ decays were observed in a large rectangular Wilson chamber containing 9 copper plates each 4 mm thick. The presence of 550 g/cm^2 of material on top of the chamber determined the momentum of the μ mesons decaying in the chamber as $p_\mu \gtrsim 1.2$ Bev/c. In total, 202 meson decays were observed. In 122 events the positron was emitted into the upper hemisphere and in 80 events, into the lower hemisphere. The relative number of decays in which the positron was emitted into the upper hemisphere is thus $\beta_{Cu} = 0.604 \pm 0.034$,† which corresponds to a degree of polarization $\eta = 0.98^{+0.02}_{-0.32}$. To ascertain that no coarse systematic errors were incurred which might lead to an asymmetry, a control experiment was run in which the copper plates in the chamber were replaced by iron plates, which were so magnetized in the horizontal direction as to depolarize the μ mesons completely. In this experiment the relative number of decays with the positron emitted into the upper hemisphere was $\beta_{Fe} = 0.516 \pm 0.052$, which is in good agreement with an isotropic distribution $\beta = 0.5$.

Theoretical calculations[1] of the degree of polarization of the μ mesons produced by π mesons give the value $\eta = 0.3$. The experimental result is therefore not in agreement with the theoretical value. It also contradicts the experimental value $\eta = 0.19 \pm 0.06$ of Clark and Hersil.[4]

This discrepancy may be due to statistical fluctuations, which have a probability of $\sim 1\%$. If further investigations confirm the results of our experiment, one may be led to the assumption that the μ mesons within the considered range of momenta are produced in the atmosphere not only on account of the $\pi \rightarrow \mu$ decay. In our experiment we studied the polarization of μ mesons with momenta $\gtrsim 1.2$ Bev/c at sea level. Muons with these momenta are mainly produced at heights of several kilometers and have momenta of 4 — 5 Bev/c at the moment of their creation. The $K_{\mu 2}$ decay, which makes up 60% of all K decays, may play an essential role in the production of μ mesons with such momenta. The μ mesons in the $K_{\mu 2}$ decay are practically completely polarized, if the energy spectrum of the K mesons in the atmosphere falls off with the energy corresponding to a parameter value $\gamma \geq 2$ (reference 1). For satisfactory agreement with experiment it is sufficient to assume that, at energies of ~ 10 Bev, the number of K mesons amounts to 20% of that of the π mesons. The disagreement with the results of reference 4 is then explained by submitting that the μ mesons whose polarization was measured in reference 4 had significantly lower momenta (~ 2 Bev/c at the moment of creation), to which the contribution from the $K_{\mu 2}$ decay is small.

In this way it is possible to obtain information about the mechanism of the production of μ mesons of high energy by investigating the dependence of the degree of polarization on the μ meson energy.

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*Hayakawa made a similar calculation.[2]

†In the calculation of the transmission coefficient of the positrons in the plates and of the number of positrons exiting into the upper hemisphere, we used the Wilson's[3] theoretical energy-range and scattering-range relations.

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THERMODYNAMIC PROPERTIES OF A DEGENERATE PLASMA

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USING the diagram technique developed by Matsubara[1] for statistical Green's functions in quantum statistical mechanics, we have calculated the interaction correction for the thermodynamic potential of a completely ionized degenerate plasma in the case in which the electron plasma is a Fermi gas while the nuclei form a Boltzmann gas.

The calculation is carried out under the assumption that the mean scattering amplitude in the Coulomb field $e^2/\overline{E}$ is small, compared to the mean distance between particles $R : e^2/R\overline{E} \equiv \alpha \ll 1$. We consider the case in which the chemical potential of the electrons μ and the temperature T are of the same order of magnitude; in this case the mean energy $\overline{E}$ is of the same order of magnitude as the temperature T. We may note that under these conditions the plasma is highly compressed; from the inequality

$$e^2/T \sim e^2/\mu \sim e^2/(\hbar^2/mR^2) \ll R$$

it follows that R, the mean distance between particles is much smaller than the Bohr radius: $R \ll \hbar^2/me^2$.

If these conditions are satisfied the thermodynamic potential Ω is expanded in terms of the small parameter α and with accuracy to terms of order $\alpha^{3/2}$ is given by the expression:

$$\Omega = \Omega_0 - \int V_q n_p^e n_{p+q}^e d\mathbf{p} d\mathbf{q} - \frac{2}{3} \sqrt{\pi} e^3 \left(2 \frac{\partial n_e}{\partial \mu_e} + \frac{\partial n_i}{\partial \mu_i} \right)^{3/2},$$

$$n_p = [1 + \exp(p^2/2m - \mu)/T]^{-1}, \quad n = \int n_p d\mathbf{p}. \quad (1)$$

Here Ω_0 is the thermodynamic potential of an ideal gas of electrons and nuclei, $V_q = 4\pi e^2/q^2$ is the Fourier component of the potential of the Coulomb interaction $e^2/|\mathbf{x}|$, μ_e and μ_i are the chemical potentials for the electrons and for the nuclei.

The second term in Eq. (1) represents the ex-