flux density $\bar{\rho}$ in the showers. The measured partial coefficients of the barometric effect, in percent per millibar of pressure variation, are given below for different densities $\bar{\rho}$ (particles/ $m^2$).

| | $\bar{\rho}$ | Under 60 g/cm$^2$ | Under 2.5 g/cm$^2$ |
|---|---|---|---|
| $A_3 = C_3 - C_6$ | 15 | | $-0.55\pm0.05$ |
| $C_3$ | 26 | $-0.68\pm0.07$ | $-0.58\pm0.04$ |
| $C_4$ | 50 | $-0.76\pm0.11$ | |
| $C_6$ | 53 | | $-0.70\pm0.05$ |
| $C_8$ | 100 | | $-0.73\pm0.07$ |

Assuming that $\bar{\rho}$ equals the particle flux density in recorded showers at a certain distance from shower axis, and using the energy estimate given by Greisen,[1] it is possible to estimate the mean energy of the primary particles initiating the showers. We found that the energies are $1 \times 10$ and $2 \times 10^{15}$ ev for coincidences $C_3$ and $C_6$ respectively.

The observed increase of the barometric effect with energy can be explained on the lines of the theory proposed recently by Nikol'skii, Vavilov, and Batov.[2]

The author would like to thank S. I. Nikol'skii for a discussion of the work and to N. N. Efimov, N. P. Emel'ianov, and T. F. Panfilova for help in reducing the data.

[1] K. Greisen, Progr. in Cosmic Ray Physics **3**, 1-141 (1956).

[2] Nikol'skii, Vavilov, and Batov, Dokl. Akad. Nauk. SSSR 111, 71 (1956), Soviet Phys. "Doklady" **1**, 625 (1956).

Translated by H. Kasha
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## *A CONTRIBUTION TO NEUTRINO THEORY*

V. V. CHAVCHANIDZE and M. E. PEREL' MAN

Submitted to JETP editor December 24, 1957

J. Exptl. Theoret. Phys. (U.S.S.R.) **35**, 296-297 (July, 1958)

WE show in the present article that all the experimental results which can be explained by a two-component neutrino theory[1] can also be explained without introducing a longitudinal (asymmetric) neutrino. We suggest replacing this longitudinal-neutrino assumption by the assumption that in $\beta$, $\mu$, and $\pi$ decays there is emitted a quantum mechanical mixture of two light neutral Dirac particles of opposite parity, each being the antiparticle of the other, and for this purpose we introduce a possible new particle-antiparticle conjugation rule.

We shall, for simplicity, consider only $\beta$ decay, given by a Hamiltonian of the form

$$H = \sum_{i=1}^{5} c_i (\bar{\psi}_n O_i \psi_p)(\bar{\psi}_e O_i \Phi). \tag{1}$$

Before the work of Lee and Yang[2] the symbol $\Phi$ stood either for $\psi_\nu$ or $\psi_{\bar{\nu}}$, which is equivalent to postulating the possibility of experimentally differentiating between $\nu$ and $\bar{\nu}$. The possibility that a quantum mixture $\nu \pm \bar{\nu}$ may be emitted was not considered, i.e., the number of leptons assumed to be conserved. In the two-component theory, however, we write

$$\Phi \to \Phi^{(\pm)} = (1 \mp \gamma_5)\psi_\nu/\sqrt{2} = (\psi_\nu \mp \gamma_5 \psi_\nu)/\sqrt{2}. \tag{2}$$

Let us write, to be specific, $\psi_\nu = \psi_{+\uparrow}$ (the explicit form for the solutions to the Dirac equation are given by Schiff;[3] we write everywhere $E = E_+ = -E_-$). Then

$$\gamma_5 \psi_{+\uparrow} = \begin{pmatrix} 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & -1 \\ -1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \end{pmatrix} \begin{pmatrix} -p_z/E \\ -(p_x + ip_y)/E \\ 1 \\ 0 \end{pmatrix} e^{i(pr-Et)}$$

$$= \begin{pmatrix} -1 \\ 0 \\ p_z/E \\ (p_x + ip_y)/E \end{pmatrix} e^{i(pr-Et)} = -\psi_{-\uparrow}(-E).$$

Our hypothesis is equivalent to the assumption that

$$\psi_{\bar{\nu}}(E) = \psi_-(-E) = -\gamma_5 \psi_+(E) \tag{3}$$

behaves like the wave function of $\bar{\nu}$, while $\psi_\nu = \psi_+(E)$ is the wave function of $\nu$.

Usually the wave function of a particle and an antiparticle (such as, for instance, the electron and positron) are related by

$$\psi_n = C\psi_-^*(-\mathbf{p}). \tag{4}$$

This relation is necessary, and is the only possible one because in the negative-frequency equation

$$[\boldsymbol{\alpha} \cdot (\mathbf{p} - e\mathbf{A}) + \beta m + eA_0 + E]\psi_- = 0$$

it is necessary, on going over to the antiparticle equation

$$[\boldsymbol{\alpha} \cdot (\mathbf{p} + e\mathbf{A}) + \beta m - eA_0 - E]\psi_n = 0,$$

to change the sign of both the energy and the charge.

Because of its zero mass, however, the neutrino does not participate in electromagnetic interactions, and therefore the transition from $[\boldsymbol{\alpha}\cdot\mathbf{p}+E]\,\psi_{-}(E)=0$ to the anti-particle equation $[\boldsymbol{\alpha}\cdot\mathbf{p}-E]\,\psi_{\overline{\nu}}(E)=0$ is possible only with the aid of (3).

It is not evident that (3) must be true also for the neutrino (see Gell-Mann and Pais[4]). In particular, the C matrix is necessary to interchange the large and small components of a bispinor so that the wave function of a real antiparticle will be different from zero even in the nonrelativistic limit. For a neutrino, however, such a matrix is not necessary.

Thus assuming (3), we find that a Hamiltonian of the form of (1), where

$$\Phi^{(\pm)}=(\psi_\nu\pm\psi_{\overline{\nu}})/\sqrt{2}$$

[which is equivalent, from the analytic point of view, to (2)] gives the same cross sections for decay as does the two-component theory. In this way, the reason for the asymmetry in decay is not assumed due the properties of one of the particles, but to nonconservation of the lepton charge nonconserving in the interaction itself. At the same time it is seen that only mixtures of the form $\nu+\overline{\nu}$ or $\nu-\overline{\nu}$ have a definite type of interaction* (which means that it is just these which are emitted in $\beta$, $\mu$, and $\pi$ decays). The selectivity of the interaction lies in the choice of the phase factor of the emitted mixture.

We note that with our approach it is possible, though less preferable, to take mixtures of $\nu$ and $\overline{\nu}$ with different statistical weights in the form

$$\Phi=a\psi_\nu+b\psi_{\overline{\nu}}, \tag{6}$$

which would correspond to the more general assumption[2] that

$$\Phi=(1+\lambda\gamma_5)\,\psi_\nu. \tag{7}$$

It should be noted that the difference between the analytical expressions obtained from our approach and from the two-component theory will become evident if one finds "analyzers" (nuclei or particles) capable of absorbing from a mixture those Dirac particles which in themselves conserve parity (compare with Pontecorvo[5]). According to Landau[1] such "analyzers" cannot exist, since the longitudinal neutrino will not reduce to any particle with other properties.

In conclusion the authors consider it their duty to thank Professor V. I. Mamasakhlisov for valuable discussion and interest in the work.

*The situation is then similar to that for neutral K mesons.[4]

[1] L. D. Landau, J. Exptl. Theoret. Phys. (U.S.S.R.) **32**, 405 (1957), Soviet Phys. JETP **5**, 336 (1957); T. D. Lee and C. N. Yang, Phys. Rev. **105**, 1671 (1957); A. Salam, Nuovo cimento **5**, 299 (1957).

[2] T. D. Lee and C. N. Yang, Phys. Rev. **104**, 254 (1956).

[3] L. Schiff, Quantum Mechanics, McGraw-Hill, N. Y., 1955, p. 315.

[4] M. Gell-Mann and A. Pais, Phys. Rev. **97**, 1387 (1955).

[5] B. M. Pontecorvo, J. Exptl. Theoret. Phys. (U.S.S.R.) **34**, 247 (1958), Soviet Phys. JETP **7**, 172 (1958).

Translated by E. J. Saletan
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## *THE STATISTICAL WEIGHTS OF $K^+$ AND $K^-$ MESONS PRODUCED IN PION-NUCLEON COLLISIONS*

E. K. MIKHUL

Joint Institute for Nuclear Research

Submitted to JETP editor April 8, 1958

J. Exptl. Theoret. Phys. (U.S.S.R.) **35**, 298-299 (July, 1958)

By projecting the isotopic space of the initial pion-nucleon system in the subspaces of the individual strange particles, we find the probability of production of one or more strange particles of particular signs of charge. For the statistical weight of the particles produced, independent of the charge, we have used the data of reference 1.

We furthermore take into account the fact that a number of pions may be produced together with the strange particles,[2] and also that isobaric states may exist.[3]

In this way we have calculated the statistical weights on two sets of assumptions: those of Schwinger and Gell-Mann[4] about a global interaction of pions with baryons, which we denote by $W_1$; and that in which it is assumed that the interaction of pions with K, $\Lambda$, $\Sigma$, and $\Xi$ particles is much smaller than that with nucleons, which we denote by $W_2$.

In particular, for pions of energy 5 Bev we find the following values for the statistical weights on