pair production, with inclusion of the spin states of the particles, we find

$$\sigma = (\pi/8)(e^2/\hbar c)^2\{(1+s_-s_+)(1+ll')F_1 + (1-s_-s_+)(1-ll')F_2 - (1+s_-s_+)F_3 + s_-s_+(1-ll')F_4 + (s_-+s_+)(l+l')F_5\}, \quad (3)$$

where

$$F_1 = 2k/K^3 + {}^1/_2(k^2/K^4 - 1/K^2)q,$$
$$F_2 = -k/K^3 + {}^1/_2(1/K^2 + k^2/K^4)q,$$
$$F_3 = k(3k_0^2 + 2k^2)/K^5 + (k^4/2K^6 + k^2/K^4 - 3/2K^2)q,$$
$$F_4 = (3k_0^2 + 2k^2)/kK^3 + (k^2/2K^4 + 1/K^2 - 3/2k^2)q,$$
$$F_5 = k^2/K^4 + qkk_0^2/2K^5,$$
$$q = \ln(K+k)/(K-k), \quad K = \sqrt{k^2 + k_0^2}.$$

Here $p_- = p_+ = \hbar k$ is the momentum of the electron (positron); $k_0 = m_0c/\hbar$ corresponds to the rest mass of the electron; $s_\pm = \pm 1$, with $s_- = 1$ (or $s_+ = 1$) for the state of the electron (or positron) with right-handed polarization, and $s_- = -1$ (or $s_+ = -1$) for the state of left-handed polarization.

From Eq. (3) it follows that: 1) in the collision of two right-handed ($l = l' = 1$) or two left-handed ($l = l' = -1$) quanta there can be production of an electron and positron with right-handed ($s_- = s_+ = 1$) or with left-handed ($s_- = s_+ = -1$) longitudinal polarization, the probabilities being different for the two polarizations. In such collisions, however, there cannot be production of an electron with right-handed ($s_- = 1$) and a positron with left-handed ($s_+ = -1$) polarization, or vice versa ($s_- = -1$, $s_+ = 1$), since the cross-section σ for this is zero. 2) In the collision of two quanta, one with right-handed ($l = 1$) and the other with left-handed ($l = -1$) polarization (or vice versa, $l = -1$, $l' = 1$) there can be production of: a) an electron and positron with right-handed ($s_- = s_+ = 1$) or with left-handed ($s_- = s_+ = -1$) polarization, the probabilities for the two results being equal; or b) an electron with right-handed ($s_- = 1$) and a positron with left-handed ($s_+ = -1$) polarization, or vice versa ($s_- = -1$, $s_+ = 1$), with equal probabilities.

In the ultrarelativistic case (κ and $k \gg K_0$) the expression (3) goes over into the following:

$$\sigma = \frac{\pi}{4}\left(\frac{e^2}{c\hbar}\right)^2\frac{1}{k^2}\left\{(1+s_-s_+)ll' + (1-ll')\left[s_-s_+ - (1-s_-s_+)\left(\frac{1}{2} - \ln\frac{2k}{k_0}\right)\right] + \frac{1}{2}(s_-+s_+)(l+l')\right\}. \quad (4)$$

The analysis given above can also be carried through for Eq. (4).

By averaging Eq. (3) over the polarizations of the quanta and summing over the spin states of the electron and positron, we get the cross-section for pair production by the collision of two unpolarized quanta:

$$\sigma_0 = \frac{\pi}{2}\left(\frac{e^2}{\hbar c}\right)^2 \times\left\{\frac{k}{K^3} - \frac{k(2k^2+3k_0^2)}{K^5} + \left(\frac{3}{2K^2} - \frac{k^4}{2K^6}\right)\ln\frac{K+k}{K-k}\right\}. \quad (5)$$

In conclusion we express our gratitude to Professor A. A. Sokolov for his constant interest in this work and for valuable comments.

[1] De Wire, Jackson, and Littauer, Phys. Rev. **110**, 1208 (1958).
[2] P. C. Stein and K. C. Rogers, Phys. Rev. **100**, 1209 (1958).
[3] Goldhaber, Grodzins, and Sunyar, Phys. Rev. **109**, 1015 (1958).
[4] H. Schopper, Phil. Mag. **2**, 710 (1957).
[5] A. A. Sokolov and D. D. Ivanenko, Квантовая теория поля, (The Quantum Theory of Fields), Part 1, GITTL 1952.
[6] B. K. Kerimov and I. M. Nadzhafov, Izv. Akad. Nauk SSSR, Ser. Fiz. **22**, 886 (1958), Columbia Tech. Transl., p. 879.

Translated by W. H. Furry
256

ON THE MECHANISM OF THE LEPTONIC DECAY OF HYPERONS

V. V. TUROVTSEV

Institute of Nuclear Physics, Moscow State University

Submitted to JETP editor January 13, 1959

J. Exptl. Theoret. Phys. (U.S.S.R.) **36**, 1326-1327 (April, 1959)

THE best confirmation of the universal V-A interaction[1] is now coming from nuclear β-decay experiments and from the study of the branching ratios for the different decay modes of the π meson.[2] This interaction also explains to a certain degree the equality of the probabilities for the K_{e3} and $K_{\mu3}$ decays and the absence of the K_{e2} decay.[3] However, in the calculation of the leptonic decay rates of the Σ^- and Λ^0 hyperons,[4] (which, admittedly, were obtained without account of the form factor and the renormalization constant), the V-A interaction leads to values for these rates which are too high in comparison with the upper limits set by experiment. Taking account of the form factor with an accuracy including the first two terms in its expansion in powers of $(p/M)^2$ lowers the rate of, e.g., the $\Sigma^- \to p + e + \nu$ decay by a factor of 2.5 (reference 5). In the leptonic decays of the hyperons, therefore, either the unknown form factor plays an important role, or the decay mechanism is different from the four-fermion V-A interaction.

In the present note we consider the decay of a hyperon at rest into leptons via a virtual K meson whose spin is assumed to be zero (this should lead to a lower decay rate than that obtained with the local four-fermion interaction). We calculate the ratio, R, of the energy spectrum of the nucleons for the $Y \to n + \mu + \nu$ decay (a) and the corresponding spectrum for the $Y \to n + e + \nu$ decay (b). The experimental determination of R for the purpose of identifying the decay mechanism is, of course, much more difficult than the determination of the ratio of the decay rates. On the other hand, neither the absolute values of rates of the decays (a) and (b), nor their ratio can be computed exactly.

Without recourse to perturbation theory, we can write the matrix element for the decay process in the form

$$M = f(\varepsilon)(\bar{u}_n G \Gamma u_\nu)(\bar{u}_\mu \Gamma (g + g'\gamma_5) u_\nu) \qquad (1)$$

(the indices specifying the parity of the K meson are omitted), where Γ is either 1 or γ_5, and $f(\epsilon)$ is some unknown function of the nucleon energy, which also depends on G and the masses M_Y, M_n, M_K, m_π, but not on either m_e or m_μ; G and g, g′ are the strong and weak coupling constants, where $gfG \to g_S$ (or g_P) for $M_K \to \infty$. These expressions for M correspond to the S and P variants of the theory of the four-fermion interaction. According to (1), we obtain for the energy dependent (i.e., the nucleon energy) decay rate

$$dW/d\varepsilon = \text{const}\cdot|f|^2\sqrt{\varepsilon^2-1}$$
$$(\varepsilon_{max}-\varepsilon)^2(\varepsilon \pm 1)/(1 + M_Y^2 - 2M_Y\varepsilon), \qquad (2)$$

$\epsilon_{max} = (M_Y^2 - m^2 + 1)/2M_Y$ is the maximal energy of the nucleon in units of $M_n c^2$. The signs ± refer to a scalar and pseudoscalar virtual meson, respectively. It is seen from (2) that the ratio R is independent of the parity of the meson and of the factor f. It is connected with the analogous ratio F, obtained from the V-A variant without account of the energy form factor and the renormalization constant, in the following way:

$$F = R\left[m_\mu^2 + M_Y\left(1 - \frac{M_Y(\varepsilon^2-1)}{3(M_Y-\varepsilon)(M_Y\varepsilon-1)}\right)\right]$$
$$\times\left[m_e^2 + M_Y\left(1 - \frac{M_Y(\varepsilon^2-1)}{3(M_Y-\varepsilon)(M_Y\varepsilon-1)}\right)\right]^{-1} \equiv RH(\varepsilon), \qquad (3)$$

ϵ_{max}^{μ} and ϵ_{max}^{e} are the maximal energies of the leptons for the decays (a) and (b), respectively. We note that the factor $H(\epsilon)$, which determines the deviation of R from F near the upper limit of the energy spectrum of the nucleons, reaches the values ~2.5, ~2.0, and ~2.6 for the leptonic decays of the Λ^0, Σ^-, and Ξ^- hyperons, and is close to unity at the beginning of the spectrum.

In conclusion I thank I. S. Shapiro for suggesting the topic of the present note and for interest in this work.

[1] R. P. Feynman and M. Gell-Mann, Phys. Rev. **109**, 193 (1958). E. C. G. Sudarshan and R. E. Marshak, Phys. Rev. **109**, 1890 (1958).

[2] Fazzini, Fidecaro, Merrison, Paul, and Tollestrup, Phys. Rev. Lett. **1**, 247 (1958). Impeduglia, Plano, Prodell, Samios, Schwartz, and Steinberger, Phys. Rev. Lett. **1**, 249 (1958).

[3] I. Yu. Kobzarev and I. E. Tamm, J. Exptl. Theoret. Phys. (U.S.S.R.) **34**, 899 (1958); Soviet Phys. JETP **7**, 622 (1958).

[4] V. M. Shekhter, J. Exptl. Theoret. Phys. (U.S.S.R.) **35**, 458 (1958); Soviet Phys. JETP **8**, 316 (1959).

[5] A. Sirlin, Phys. Rev. **111**, 337 (1958).

Translated by R. Lipperheide
257

ASYMMETRY OF ANGULAR DISTRIBUTION OF $\mu^+ \to e^+$ DECAY ELECTRONS IN A 27,000 GAUSS MAGNETIC FIELD

C. A. ALI-ZADE, I. I. GUREVICH, Yu. P. DOBRETSOV, B. A. NIKOL'SKIĬ, and L. V. SURKOVA

Submitted to JETP editor February 1, 1959

J. Exptl. Theoret. Phys. (U.S.S.R.) **36**, 1327-1329 (April, 1959)

It is known that the angular distribution of $\mu \to e$ decay electrons is given by

$$4\pi dN/do = 1 - a\cos\theta, \qquad a = \lambda P/3 = a_0 P, \qquad (1)$$

where $\lambda = 3a_0 = -\cos(V, A)$ determines the rela-