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THE UNIVERSAL FERMI INTERACTION AND THE CAPTURE OF MUONS IN HYDROGEN

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THE theory of the universal Fermi interaction with (V-A) coupling proposed by Marshak and Sudarshan[1] and by Feynman and Gell-Mann[2] is supported by all existing experimental evidence on β decay. To explain the equality of the Fermi β-decay constant and the constant for the μ decay, Feynman and Gell-Mann have put forward the hypothesis of a conserved vector current in the weak interactions. This hypothesis leads to the appearance of an anomalous magnetic-moment effect in the β decay ("β magnetism"). Calculations of the effect have been made by Gell-Mann and others[3-5] and have apparently already received experimental confirmation in β decay.[6]

The latest experimental data show that the probability of the β decay or (μ, ν) decay of hyperons is apparently considerably smaller than that given by the universal (V-A) theory.[7] But even if these data are confirmed and we are forced to abandon the universal interaction including the hyperons, nevertheless the universal interaction between (p, n), (e, ν), and (μ, ν) will remain an extremely probable hypothesis.

Since it already seems that the β decay and the decay of the μ meson can be explained within the framework of the (V-A) theory, it is of particular interest to examine the process of μ capture and test the idea of the universal (V-A) interaction in this case.

In the present note we present expressions for the probability of the capture, the angular distribution, and the polarization of the emerging neutrons in the case of capture of polarized μ^- mesons by protons, based on the assumption of the universal (V-A) coupling with conserved vector current as proposed by Gell-Mann and Feynman.

The capture probability and the angular distribution are (in units $\hbar = c = 1$):

$$w = (2\pi)^{-2}(\pi a_\mu^3)^{-1}2^{-1}G^2 I\,[1+\alpha P\,(\mathbf{n}\cdot\mathbf{s})]\,p^2\,d\Omega,$$

$$I = 1 + 3\lambda^2 + \beta(1+\lambda^2) + \beta\mu(2\lambda + \beta\mu/2),$$

$$I\alpha = 1 - \lambda^2 + \beta(1+\lambda^2) - \beta\mu(2\lambda + \beta\mu/2).$$

The total probability for capture is

$$\tau^{-1} = 2^{-1}G^2\pi^{-2}a_\mu^{-3}p^2 I.$$

The polarization $\langle\sigma_n\rangle$ of the neutrons is given by the formula

$$I\,[1+\alpha P(\mathbf{n}\cdot\mathbf{s})]\,\langle\sigma_n\rangle = [a + b\,(\mathbf{n}\cdot\mathbf{s})]\,\mathbf{n} + c\mathbf{s},$$

$$a = -2\,[\lambda(\lambda+1) + \beta\lambda + \beta\mu(\lambda + \beta\mu/4)],$$

$$b = -\beta P\,[\lambda(\lambda+1) - \mu(1 + \lambda + \beta\mu/2)],$$

$$c = 2P(\lambda - 1)\,[\lambda + \beta(\lambda+\mu)/2].$$

Here we have used the notations: $p\mathbf{n}$ is the momentum of the neutron, and $P\mathbf{s}$ is the polarization of the μ meson ($\mathbf{n}$ and $\mathbf{s}$ are unit vectors); $\lambda = -C_A/C_V$, $\beta = p/M$; $G \equiv 2^{1/2}C_V$ is the universal coupling constant; M is the nucleon mass; $\mu = \mu_p - \mu_n$ is the difference of the magnetic moments of the proton and neutron; $a_\mu = (m_\mu e^2)^{-1}$ is the radius of the mesonic K orbit in hydrogen.

Terms of the order $(v/c)^2$ have been neglected in the calculation (v is the speed of the neutron). In addition it has been assumed that in the pseudovector coupling the higher moments do not give an additional renormalization. A numerical computation (taking $G = (1.01 \pm 0.01) \times 10^{-5} M^{-2}$, $\mu = 4.7$, $\lambda = 1.24$, $\beta = 0.1$) shows that the effect of the anomalous magnetic moment increases the total probability of capture by ≈ 17 percent, and the angular correlation coefficient by a factor of about 2.4; the polarization of the neutrons is changed only slightly as compared with the results of the ordinary theory. At present calculations are being carried out on the capture of mesons by nuclei according to the Feynman — Gell-Mann theory. It can be expected that in this case also the correction introduced by the anomalous magnetic moment will be large.

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ON THE SPECTRUM OF THE ELECTRON-PHOTON COMPONENT OF EXTENSIVE AIR SHOWERS

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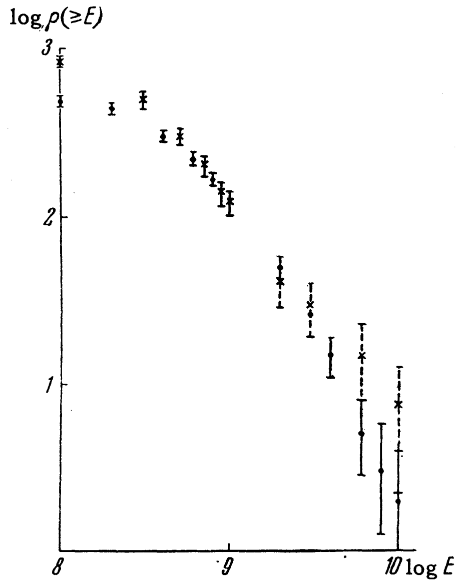
An experiment was carried out in 1958 in Moscow in an attempt to explain the discrepancies observed in our earlier experiments.[1,2]

In these experiments we studied the electron-photon component of extensive atmospheric showers (EAS), and in particular the fraction of high-energy electrons and photons near the shower axis. A cloud chamber with lead plates was used for that purpose.[3] The energy of electrons and photons was determined from the number of particles in the cascade showers produced by them in the lead plates.

The energy spectra obtained for the region $< 10^9$ ev in references 1 and 2 were different. In addition, the fraction of high-energy electrons and photons $\rho\,(\geq 10^9)/\rho\,(> 0)$ at 0 to 3 m from the shower axis amounted to $(1.85 \mp 0.25)\,\%$ according to reference 1 and to $\geq 10\%$ according to reference 2. Several reasons for the discrepancy were indicated:[1] (a) difference in shower sizes, (b) different transition effects in the roof above the apparatus, and (c) large errors in the axis location by means of the hodoscope in reference 1.

An additional experiment was carried out at sea level to study the problem, using the same cloud chamber. The selection method[4] made it possible to record EAS, the axes of which fell in 70% of the cases at a distance 0 to 3 m from the chamber. The mean shower size was $\sim 3 \times 10^4$ particles. Such showers were studied in reference 1 with best statistics. A total of 385 showers were recorded during 400 hours of operation.



Integral energy spectra of the electron-photon component. The ordinate represents $\log \rho\,(\geq E)$, where $\rho(\geq E)$ is proportional to the density of electrons and photons per 1 m² in one shower. The abscissa represents log E, where E is the energy in ev, ×) data of reference 1 in the range 0 to 3 m, •) data of the present experiment for all distances (70% of the showers in the range 0 to 3 m). The spectra are normalized at $E = 10^9$ ev.

As the result of the measurements we obtained the integral energy spectrum of the electron-photon component shown in the figure. The spectrum obtained in reference 1 for distances 0 to 3 m is included for a comparison. It can be seen that the spectra are different below 10^9 ev.

The fraction of high-energy electrons and photons was defined, as in the earlier experiments, as the ratio of the density of electrons and photons with $E \geq 10^9$ measured in the cloud chamber, to