THE STUDY OF THE ASYMMETRY IN THE DECAY OF NEGATIVE MUONS IN A NUCLEAR EMULSION

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Submitted to JETP editor May 28, 1960

J. Exptl. Theoret. Phys. (U.S.S.R.) **39**, 1198-1200 (November, 1960)

The spatial asymmetry of electrons from the $\mu^- \to e^-$ decay in NIKFI-R emulsions was studied in an 11-koe and in zero field. It is shown that no asymmetry can be observed in either of the cases in a total of approximately 10^4 decay events.

In the first experiment by Lederman et al.,[1] which was performed by electronic methods and which demonstrated the parity nonconservation in $\pi \to \mu \to e$ decay, it was shown that the coefficient of asymmetry for negatively-charged muons stopped in graphite is approximately six or seven times less than for positive muons, and its value is $a \approx -0.05$. The mechanism by which the negative muons can be so greatly depolarized was considered by Shmushkevich[2] and Dzhrbashyan,[3] who showed that in cascade transitions in mesic atoms the negative muons lose the greater part of their polarization, and retain only 15–17% of the initial polarization on the K shell of the mesic atom, where they decay. This result is in agreement with the experimental data obtained by Ignatenko et al.[4] If the nucleus of the mesic atom has a magnetic moment, then the interaction between the magnetic moments of the nucleus and the negative muon will cause even this residual part of the polarization to be lost, and it can no longer be restored in ordinary magnetic fields obtainable under laboratory conditions. However, if the nucleus has no spin (such nuclei are the C^{12} and O^{16}, which make up the main part of the gelatine in emulsions), then the additional depolarization on the K shell will be due only to the interaction of the magnetic moment of the negative muon with the magnetic field of the electron shell, and such a depolarization can be destroyed by ordinary magnetic fields, similar to what takes place in muonium. Actually, the energy of interaction between the magnetic moments of the negative muon and of the peripheral electron can be only less than the energy of interaction of the hyperfine structure in muonium, since the electron has an effective quantum number greater than unity. Consequently, a field of approximately 10^4 oe, which is sufficient for the annihilation of the depolarization of positive muons, should be sufficient also for the annihilation of this depolarization mechanism.

With these considerations in mind, along with the thought that the presence of a measurable polarization of the negative muons stopped in nuclear emulsion would permit investigation of asymmetry in many secondary processes connected with the capture of negative muons by the light nuclei of the emulsion, we undertook a measurement of the asymmetry coefficient in $\mu^- \to e^-$ decay in a nuclear emulsion without a magnetic field ($H < 0.1$ oe), and in a strong magnetic field ($H = 11$ koe) directed along the axis of a negative-meson beam.*

The NIKFI-R emulsions were exposed in the synchrocyclotron of the Joint Institute for Nuclear Research to a negative-muon beam first slowed down by copper filters in such a way that the negative muons were stopped in the first 3 or 4 cm of emulsion.

The initial polarization of the negative-muon beam was not measured, and apparently cannot differ greatly from the initial polarization of the positive muon beam, which amounts to 0.81 ± 0.11 according to Mukhin, Ozerov, and Pontecorvo.[5]

In measurements of the asymmetry coefficient, the initial direction was taken to be the direction of the negative-muon beam, about which the decay electrons have a distribution of the form $1 + a \cos \vartheta$. To measure the value of a, the observers noted the emission of the decay electrons in the angular intervals $\vartheta = (0 \pm 45)°$ (forward) and $(180 \pm 45)°$ (backward).† A total of 9279 decays were observed without the magnetic field and 3403 decays were observed in the 11-koe

*This field was produced by an iron-free solenoid, graciously furnished by A. E. Ignatenko.

†All the μ–e decays more than 50μ away from the glass or the surface of the emulsion were registered.

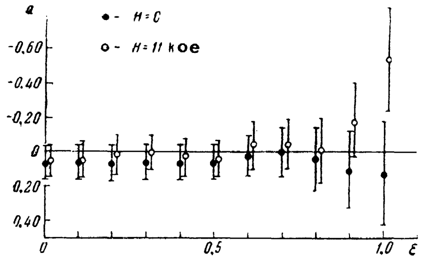
field. The conditions and results of the measurement are as follows:

Magnetic field H	$\leqslant 10^{-1}$ oe	11 koe
Number of decays forward	4580	1707
Number of decays backward	4699	1696
Asymmetry coefficient	+0.02 ± 0.017	0.00 ± 0.025
Number of observers	6	14
Agreement (by the χ^2 test)	$\chi^2 \sim 8$	$\chi^2 \sim 25$

It follows from these data that within the indicated statistical errors we observed neither noticeable asymmetry nor an effect of the magnetic field on this asymmetry. The positive sign of the asymmetry for H = 0 may be the result of a small systematic measurement error. It should be noted that in the case of μ^- decays the danger of systematic errors is considerably higher than for μ^+ decays. Actually, in the latter case practically each stoppage of the positive muon is accompanied by the appearance of a decay electron (thus, in 99442 decays of positive muons no decay electron was observed in only 20 cases). The stoppings of the negative muons are approximately equally distributed among the light (C, N, O) and heavy (Ag, Br) components of the emulsion, and consequently approximately half of all the stoppings in the emulsion occur without the appearance of a decay electron. This contributes to the occurrence of systematic scanning errors, connected, for example, with the different efficiency of observing decay electrons in different parts of the field of view of the microscope.

In connection with the possibility of subjective systematic errors of the observers, we have analyzed the agreement between the date of 14 individual observers, using the usual χ^2 criterion. The data above indicate that the results obtained by individual observers, particularly in the case H = 0, are in sufficiently good agreement with each other.

Further measurements consisted of attempting to detect a spatial asymmetry at the end of the decay-electron spectrum, where the asymmetry coefficient is approximately three times greater than the asymmetry coefficient averaged over the entire spectrum.[6] For this purpose we selected 612 flat electron tracks (306 decays each for H = 0 and H = 11 koe), in which the energy could be measured by the multiple-scattering method, and measured the energy distributions of these electrons by means of a semi-automatic scattering measuring apparatus, as well as the angles ϑ between the directions of these tracks and the direction of the negative-muon beam.



Coefficient of asymmetry a for electrons with energy greater than a given value (ε).

The procedure of these measurements and the criterion for selecting the tracks were in complete agreement with those indicated in earlier works.[6,7] The results are shown in the figure. The values of the asymmetry coefficient shown in the graph have been calculated from the average value of $\overline{\cos \vartheta}$ using the formula

$$a = 2\overline{\cos \vartheta} \pm 1.57/\sqrt{N},$$

for N is the number of electrons with energy greater than a given energy ϵ. The energy dependence thus obtained for the asymmetry coefficient points, in agreement with the data given above, to the absence of noticeable asymmetry. A striking fact is that at H = 11 koe a certain increase in the average value of a is observed at the end of the spectrum. The statistical significance of this increase, which does not exceed one and a half times the standard error, is however very small.

The measurements performed make it therefore possible to state that our experiments show practically no asymmetry effect in the decay of negative muons in the NIKFI-R nuclear emulsion, independently of the presence of an external magnetic field. This makes it almost impossible to observe by the emulsion method such secondary effects connected with the polarization of negative muons as the asymmetry of emission of protons from stars produced upon absorption of negative muons by a nucleus, or the asymmetry of emission of the electrons from β-active recoil nuclei formed in such an absorption.

The authors are grateful to N. V. Rabin and E. A. Pesotskaya for participating in the measurements of the decay-electron spectrum.

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Translated by J. G. Adashko
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