tion. In addition, an investigation of the polarization of nuclei in various alloys may yield information on the magnetic properties of the atoms in these alloys.

The authors express their deep gratitude to E. K. Zavoĭskiĭ for interest in the work and for much valuable advice, and to L. V. Groshev for a review of the results.

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Translated by J. G. Adashko
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DEPOLARIZATION OF μ^- MESONS IN THE FORMATION OF μ-MESIC ATOMS

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Submitted to JETP editor December 7, 1958

J. Exptl. Theoret. Phys. (U.S.S.R.) **36**, 645-646 (February, 1959)

In the formation of μ-mesic atoms, the μ^- mesons initially fall into highly excited states. Therefore, during the cascade transitions into the ground state, the mesic atom, on the average, passes through a large number of intermediate states. At lower levels, the inequality

$$\Delta_{nl} \gg \Gamma_{nl}, \tag{1}$$

is valid, where Δ_{nl} is the distance between fine-structure levels with the quantum numbers n and l, but different j ($j = l \pm \frac{1}{2}$), and Γ_{nl} is the width of the corresponding level and is equal to the sum of the radiative width and the width with respect to Auger transitions (the greater Z, the greater the values of n for which condition 1 is satisfied). Physically, inequality (1) signifies that the time during which the μ-mesic atom remains at a given level is considerably greater than the time required for a change of the μ-meson spin under the action of the field of the nucleus. This leads to depolarization of the μ^- mesons, if they were initially polarized. Below, we will estimate the degree of polarization of the μ^- mesons falling into the K shell of the mesic atom. In order not to complicate the question by the necessity of taking hyperfine structure into account, we limit ourselves to the considerations of μ-mesic atoms formed with nuclei of zero spin.

Considering radiative or Auger transitions between levels for which Eq. (1) is satisfied, and remembering that these transitions are essentially dipole transitions, we obtain the following relation between the average values of $\sigma = 2\mathbf{s}$ ($\mathbf{s}$ is the spin operator of the μ^--meson), $\bar{\sigma}_1$ and $\bar{\sigma}_2$, in the initial and final states:

$$\bar{\sigma}_2 = \beta\bar{\sigma}_1, \tag{2}$$

where

$$\beta = \frac{[j_2(j_2+1) - l_2(l_2+1) + {}^3/_4][j_1(j_1+1) + j_2(j_2+1) - 2]}{[j_1(j_1+1) - l_1(l_1+1) + {}^3/_4]2j_2(j_2+1)}. \tag{3}$$

The bar over σ signifies that the average is taken firstly over states with given nlj and μ (μ is the projection of j), and secondly over all μ for given nlj.

Let us now consider some excited level of the μ-mesic atom with sufficiently large quantum numbers $n_0 l_0 j_0$, for which condition (1) is still satisfied. Let $\bar{\sigma}_0$ be the average value of σ at this level. The successive application of Eqs. (2) and (3) to the cascade transition from the given level to the K shell leads to a relation between the average values of the spin in the K shell and $\bar{\sigma}_0$ with a definite set of intermediate states passed through by the μ-mesic atom. Averaging over the various possible cascades by using the formulas for the probabilities of radiative[1] and Auger transitions,[2,3] we obtain

$$\bar{\sigma}_K = \beta_K \bar{\sigma}_0. \tag{4}$$

for $\bar{\sigma}_K$, the average value of σ in the K shell.

Analysis of the result thus obtained indicates that if n_0 and l_0 are large and $j_0 = l_0 + \frac{1}{2}$, then for all practical purposes, $\beta_K \approx 1$. But if under the same conditions $j_0 = l_0 - \frac{1}{2}$, then $\beta_K = 0$.[4]

Initially, in the formation of a mesic atom, the μ^- mesons fall into states with large n ($n \approx 14, 15$) and large l. In these excited states, the sign of inequality (1) is reversed, owing to Auger transitions. Therefore, depolarization does not occur in these states. It does not begin until the μ^- meson falls to a level at which Eq. (1) holds. This makes it possible to evaluate $\bar{\sigma}_0$ in the following way: at the instant at which the polarized μ^- meson drops into the level with the quantum numbers $n_0 l_0$, the wave function has the form

$$\Psi_0 = \sum_m a_m \chi_{1/2}\, \varphi_{n_0 l_0 m} = \sum_{m j_0} a_m C^{j_0 m + 1/2}_{l_0 m, 1/2 1/2}\, \Phi_{n_0 l_0 j_0 m + 1/2}. \tag{5}$$

where $\varphi_{n_0 l_0 m}$ is the wave function of the mesic atom without taking spin into account, $\chi_{1/2}$ is the spin function of the μ^- meson polarized along the z axis, $\Phi_{n_0 l_0 j_0 m+\frac{1}{2}}$ is the wave function of the mesic atom with the quantum numbers $n_0 l_0 j_0$, and finally, $\mu_0 = m + \frac{1}{2}$. For $t > 0$,

$$\Psi = \sum_{mj_0} a_m C^{j_0 m+1/2}_{l_0 m, 1/2 1/2} \Phi_{n_0 l_0 j_0 m+1/2} \exp(-iE_{n_0 l_0 j_0} t/\hbar). \quad (6)$$

In view of Eq. (1), the states with $j_0 = l_0 + \frac{1}{2}$ and $j_0 = l_0 - \frac{1}{2}$ must be considered independently. Considering that all values of m are equally probable, it is not hard to find that for given n_0 and $l_0 \gg 1$, the probability of falling into states with $j_0 = l_0 + \frac{1}{2}$ and $j_0 = l_0 - \frac{1}{2}$ is equal to $\frac{1}{2}$. Here, the average value $\bar{\sigma}_z$ in each of these states (for $l_0 \gg 1$) is equal to $1/3$. From states with $j_0 = l_0 + \frac{1}{2}$, the μ mesons reach the K shell, retaining the value of $\bar{\sigma}_z$ ($\beta_K \approx 1$) equal to $1/3$. But from states with $j_0 = l_0 - \frac{1}{2}$, the μ^- mesons, in dropping into the K shell, are almost completely depolarized ($\beta \approx 0$). Consequently, the average value of σ_z, i.e., the degree of polarization of the μ^- mesons in the K shell, must be equal to $1/6 \approx 17\%$. This agrees approximately with the experimentally-observed value.[5,6]

I would like to express my sincere thanks to S. S. Gershteĭn, V. N. Gribov, and A. Z. Dolginov for their interest in the work and for useful discussions.

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Translated by D. Lieberman
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ON $\mu^+\mu^-$ ANNIHILATION AND THE DECAY OF NEUTRAL MESONS

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Submitted to JETP editor December 10, 1958

J. Exptl. Theoret. Phys. (U.S.S.R.) **36**, 646-647 (February, 1959)

By analogy with e^+e^- annihilation (see reference 1), it can be expected that the $\mu^+\mu^-$ "atom" will yield two quanta in the para-state and three quanta in the ortho-state.

Berestetskii and Pomeranchuk[2] have pointed out the possibility of the direct transformation of an e^+e^- pair into $\mu^+\mu^-$ through one virtual quantum.* Considering the inverse process, we come to the conclusion that in addition to $\mu^+\mu^-$ annihilation with emission of quanta, the transformation of $\mu^+\mu^-$ into an e^+e^- pair is also possible. This process is of the same order with respect to $e^2/\hbar c$ as two-quantum annihilation.

It is easy to convince oneself that the transformation of $\mu^+\mu^-$ into e^+e^- in this order cannot occur in the para-state. On the other hand, in the ortho-state of $\mu^+\mu^-$, the transformation into e^+e^- proceeds with a probability three times smaller than the probability of two-quantum annihilation of the para-state. Thus, the probability of the transformation of ortho-$\mu^+\mu^-$ into e^+e^- is approximately 400 times greater than the probability of the three-quantum annihilation of ortho-$\mu^+\mu^-$.

The pseudoscalar neutral meson π^0 is similar (see reference 3) to the para-state of $\mu^+\mu^-$ or e^+e^-; the decay of π^0 into two quanta conforms to this analogy. The ortho-state of $\mu^+\mu^-$ would be similar to a neutral odd-parity meson with spin 1. As is clear from what has been presented above, such a meson would decay not into three quanta, but directly into an e^+e^- pair, with a lifetime of the order of the lifetime of the π^0 (compare reference 4).

Careful measurements of e^+e^- pairs during energetic collisions of cosmic particles with nuclei were performed[5,6] in connection with measurements of the lifetime of the π^0. The results of these measurements apparently rule out the existence of a nuclearly-active neutral meson with spin 1, because the number of e^+e^- pairs produced in the vicinity of the collision agrees with Dalitz's calculation[7] of the relative probability of the process $w(\pi^0 = \gamma + e^+ + e^-)$ namely $w(\pi^0 = 2\gamma) = 1/80$.