ON TRANSITIONS BETWEEN HYPERFINE STRUCTURE LEVELS IN MU-MESIC ATOMS

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The possibility of an experimental verification of the existence of transitions between hyperfine structure levels in mesic atoms is considered. A convenient method, in the case of mesic atoms possessing nuclear spins $J > 1/2$, is shown to be the measurement of the precession frequency of the mesic atoms.

THE question of the existence of transitions between the hyperfine structure levels is of great interest in the investigation of the effects of the hyperfine structure in μ-mesic atoms. In fact, a theoretical analysis of these effects, which manifest themselves in the capture of polarized mesons,[1-3] is always carried out for the case of isolated mesic atoms. Actually, however, an experimental verification of the predictions of the theory is possible only when the mesic atoms are produced and stopped in the medium Yet the presence of the medium can complicate the situation. Thus, for example, while the hyperfine structure states with $F = J + 1/2$ and $F = J - 1/2$ form in the case of isolated atoms an incoherent mixture, transitions can occur between them in certain cases in a medium. In particular, in liquid hydrogen one observes the phenomenon of meson "jump" from one proton to another with simultaneous transition into the lower hfs state.[4-6] Attention was called in references 7 and 8 to the need of accounting for the influence of the medium on the hfs effects on other substances. For example, two types of transitions are possible in metals, accompanied either by conversion on the conduction electrons or by magnetic dipole radiation. The expressions for the probabilities of the corresponding transitions w_k and w_p have the following form:[7]

$$w_k \approx 10\left(\frac{1}{137}\right)^6 Z\left(\frac{m_e}{m_\mu}\right)^3 \frac{m_\mu c^2}{\hbar}, \qquad (1)$$

$$w_p \approx 10\left(\frac{1}{137}\right)^{13} Z_{eff}{}^9\left(\frac{m_\mu}{m_p}\right)^3 \frac{m_\mu c^2}{\hbar}. \qquad (2)$$

It is obvious that if the medium is not a metal, there will be no transitions of type w_k.

In this article we shall touch upon the question of experimental verification of the existence of the transitions. One of the methods,[8] proposed for the detection of transitions, consists of investigating the curvature K of the μ^--meson decay curve. Thus, with the A-V interaction universal and in the presence of transitions in metals having nuclear magnetic moment $\mu_N > 0$ and $Z \geq 13$, the value of K should be negative if the meson capture takes place by a separate "super-shell" proton of the nucleus. The preliminary results of an experiment[8] with aluminum have shown that $K < 0$. However, the results of this experiment alone cannot be interpreted uniquely in favor of the existence of transitions, since there is no direct experimental proof at present of the universality of interaction in the process $\mu^- + p = n + \nu$, or of the assumption that meson capture in aluminum is on the "super-shell" proton of the nucleus. Yet a direct detection of the transitions would add to the arguments in favor of interpreting such experiments to mean that in the process $\mu^- + p = n + \nu$ the constants of the A and V interactions have different signs.[8] We wish to call attention in the present paper to one possibility of direct experimental verification of the existence of transitions, consisting of a study of the polarization of mesons in mesic atoms of a definite type. The suggestion consists essentially of the following. Estimates of the values of w_k and w_p with the aid of formulas (1) and (2) for different values of Z show that w_p (whose value at small Z in many orders of magnitude smaller than Λ, the total meson-absorption probability) becomes of the same order of magnitude as Λ when $Z_{eff} \geq 30$. As regards w_k, it becomes equal to Λ even at small Z. Thus, for aluminum[7] $w_k = 4 \times 10^5$ sec^{-1}, $w_p = 1 \times 10^3$ sec^{-1}, and $\Lambda = 1.2 \times 10^6$ sec^{-1}.

It is obvious that the existence of transitions will also affect the magnitude of the polarization of mesons in mesic atoms of metals, as well as of non-metals with $Z_{eff} \geq 30$. Therefore the polarization in sostances having different properties but the same values of nuclear spin J may be different. A measure of the transition probability will be the difference between the value of the polarization, obtained experimentally, and that calculated[2] for isolated mesic atoms.

It would seem best to use for the proposed experiments substances with $J = 1/2$ and $\mu_N > 0$. Actually, such mesic atoms can be produced in states $F = 1$ and $F = 0$. In the case of the lower state $F = 0$, the mesons become depolarized. The upper state $F = 1$ "remembers" the spin direction (no depolarization takes place). Each of the states is characterized by its own value of g, the gyromagnetic ratio. If the polarization is determined by measuring the asymmetry of the decay electrons,[9] the curve for the precession of the spins of the mesic nuclei in a magnetic field, observed in this case, will be very simple, corresponding to either $F = 1$ or $F = 0$. In addition, since the degree of polarization P of a meson on the K shell, averaged over two hfs states, is[2]

$$P = \frac{1}{6} P_0 [1 + 2/(2J + 1)^2]$$

(here P_0 is the degree of polarization of the meson beam), the value of P will be greatest for substances with $J = 1/2$. Unfortunately, experiments with such substances cannot be performed in practice. The point is that among the substances with $J \neq 0$ and small Z, in which the quantities w_k and Λ are comparable, there are no metals with $J = 1/2$. One might think that phosphorus and silver would be "accessible" and convenient objects of investigation. True, both substances have $J = 1/2$ and differ greatly in their properties, silver being a metal and phosphorus not. In the case of phosphorus, therefore, the investigated transitions will play an insignificant role,[6] owing to the small values of w_k and w_p, whereas for silver they will play the predominant role. However, results of experiments with phosphorus and silver cannot be interpreted uniquely. The reason is that in mesic nuclei of silver, with $\mu_N < 0$, the transitions will be from the state $F = 0$ to the state $F = 1$. Consequently, in the case of phosphorus and silver, the experimentally expected precession curves will belong to mesic nuclei which are only in the state $F = 1$, and consequently the value of polarization will be the same.

It becomes possible to observe the transitions if substances with $J > 1/2$ are used and the precession frequency of the mesic nuclei is measured in the experiment instead of the polarization. Actually, in this case the precession curve observed experimentally[6] in the absence of transitions will be complex, namely a superposition of spin precessions mesic nuclei in two hfs states with $F \neq 0$. In the presence of transitions the curve will be simple, corresponding to the spin precessions of mesic nuclei in the lower state only. As is well known,[10] at small values of the polarization P the precession frequencies can be measured with greater accuracy than the values of P.[11] In the method proposed above, it is best to use substances with equal values of $J > 1/2$, but with different signs of μ_N, such as lithium and beryllium. In the presence of transitions, such mesic nuclei, being in the lower state, will precess with different frequencies in spite of having equal values of J. It must be noted that the foregoing discussions hold only when w_k and w_p are sufficiently large compared with Λ and with the probability of the $\mu - e$ decay. We are now carrying out experiments with such nuclei for the purpose of detecting the transitions.

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