ANGULAR DISTRIBUTION OF RECOIL NUCLEI IN THE REACTION $\mu^- + He^3 \to H^3 + \nu$

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A formula for the angular distribution of tritium nuclei produced in the capture of partially polarized μ^- mesons by He^3 nuclei is derived taking hyperfine structure into account. The dependence of the asymmetry coefficient on the constant describing the induced pseudoscalar interaction is investigated.

ONE of the fundamental questions in the investigation of the capture of μ^- mesons by nuclei is the determination of the constants describing the interaction responsible for this process. The available experimental data are compatible with values of the constants lying within very wide limits [1]. The determination of the constants from the partial transition probabilities is made difficult by a lack of knowledge of exact nuclear wave functions, while the interpretation of data on μ^- capture by nuclei accompanied by the emission of neutrons is even more complicated. Therefore, of considerable interest are such effects as the asymmetry of angular distribution and the polarization of recoil nuclei in partial transitions. Calculations relating to these effects are in many cases almost independent of the nuclear model used [2]. Moreover, their characteristics contain combinations of constants which are different from those appearing in the probabilities and which are critical with respect to the constant of the induced pseudoscalar interaction.

Of particular interest is the investigation of the asymmetry of angular distribution of recoil nuclei in the reaction

$$\mu^- + He^3 \to H^3 + \nu, \tag{1}$$

since here the ranges of H^3 are sufficiently great to be experimentally observed. The angular distribution of tritium nuclei produced as a result of the capture of partially polarized μ^--mesons in the reaction (1) has the form

$$dw/d\Omega \sim (1 + \alpha \mathbf{P}_\mu \cos\theta), \tag{2}$$

where θ is the angle between $\mathbf{P}_\mu$ and the direction of recoil, and $\mathbf{P}_\mu$ is the polarization vector of the μ^--meson which it would have in the triplet state in the absence of spin-spin interaction. This quantity is simply related to the average value of the spin vector $\mathbf{F}$ for the mesic atom in the triplet state:

$$\mathbf{P}_\mu = \tfrac{3}{2}\langle \mathbf{F}\rangle_t. \tag{3}$$

The expression for α in terms of the nuclear matrix elements and the interaction constants has the same form for all nuclear transitions $\frac{1}{2} \to \frac{1}{2}$ without a change in parity. By utilizing the Hamiltonian for the weak V-A interaction [3] and taking into account the induced pseudoscalar, the "weak magnetism" and the relativistic corrections $\sim q/2M$, the following formula for α has been obtained:

$$\alpha = \frac{2}{3}\,\frac{w_+(H+T)^2}{w_+\{[H + {}^1/_3 T - {}^1/_3\sqrt{2}R]^2 + {}^4/_9[\sqrt{2}T + R]^2\} + w_-[H - T + \sqrt{2}R]^2}\,. \tag{4}$$

Here

$$H = C_V(1 + q/2M)\sqrt{3}\,[000] - C_V\sqrt{{}^1/_3}\,M^{-1}[110p],$$
$$T = [C_A + (C_A - C_P)\,q/2M]\sqrt{{}^1/_3}\{[101] + \sqrt{2}\,[121]\} + C_A\sqrt{3}\,M^{-1}[011p],$$
$$R = [C_A - C_V(1 + \mu_p - \mu_n)\,q/2M]\sqrt{{}^1/_3}\{[121] - \sqrt{2}\,[101]\} + C_V M^{-1}[111p], \tag{5}$$

w_+ and w_- are the probabilities for finding the mesic atom in the triplet and the singlet states respectively.

The nuclear matrix elements [000] and others are defined in the same way as in the paper of Morita and Fujii [3] and we have assumed

$$[kvu] = [kvu\pm]. \tag{6}$$

The evaluation of the nuclear matrix element appearing in α requires that we know the wave functions for He^3 and H^3. However, this difficulty may be avoided if we make use only of the fact that the wave function for these nuclei contains only a small admixture of the D-state[4]:

$$\psi = \sqrt{1-\varepsilon^2}\,|^{22}S_{1/2}\rangle + \varepsilon\,|^{24}D_{1/2}\rangle, \qquad (7)$$

where $\epsilon^2 \approx 0.04$.

The contribution made by the D-state can turn out to be significant only because of the $S \rightleftarrows D$ transitions. However, in the basic matrix elements such interference effects are absent. They occur only in [121] and [011p], which are themselves smaller than the basic matrix elements by one or two orders of magnitude. Therefore, taking the D-state into account yields corrections not greater than $\sim \epsilon^2$.

If we neglect these corrections, then without utilizing the explicit form for the radial wave function we can easily obtain

$$[101] = -3\,[000], \quad [011\,p] = \sqrt{1/3}\,[110p],$$
$$M^{-1}\,[011p] = (q/2\,M)\,[000],$$
$$[121] = [111\,p] = 0. \qquad (8)$$

Since all the nuclear matrix elements can be expressed in terms of one of them, the asymmetry coefficient turns out to be independent of them:

$$\alpha = \frac{2}{3}\,\frac{w_+(G_V - G_A + G_P)^2}{w_+\{(G_V - G_A + 1/3\,G_P)^2 + 8/9\,G_P^2\} + w_-(G_V + 3G_A - G_P)^2}\,; \qquad (9)$$

$$G_V = C_V, \quad G_A = C_A - C_V\,(1+\mu_p-\mu_n)\,q/2M,$$
$$G_P = [C_P - C_V\,(1+\mu_p-\mu_n)]\,q/2M. \qquad (10)$$

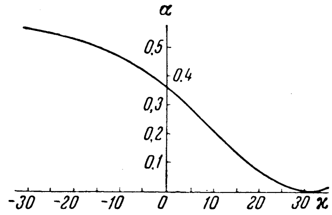
In the case that the populations of the hyperfine structure levels for the mesic atom have their statistical values ($w_+ = 3/4$, $w_- = 1/4$) we obtain

$$\alpha = \frac{1}{2}\,\frac{(G_V - G_A + G_P)^2}{G_V^2 + 3G_A^2 + G_P^2 - 2G_A G_P}\,. \qquad (11)$$

The dependence of α on $\kappa = C_P/C_A$ calculated in accordance with formula (11) is shown in the diagram for $C_A = -1.24\,C_V$.

For He^3 a possible value[5] is $P_\mu \sim 0.1$ so that the effective asymmetry coefficient αP_μ apparently turns out to be too small to be measured experimentally.

However, there exists a possibility for considerable increase in αP_μ as a result of utilizing polarized He^3 nuclei[1)]. If the target nuclei are polarized in the same direction as the μ^- mesons, the quantity P_μ can be increased severalfold. Moreover, the numerical value of α will also be increased due to the decrease in the probability of formation of singlet states. As a result αP_μ will attain a value which can be measured experimentally.



Dependence of the asymmetry coefficient α on $\kappa = C_P/C_A$ for $C_A = -1.24C_V$ taking "weak magnetism" into account.

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[1)]In this case in the angular distribution formula (2) there will appear an additional term $\beta P_2(\cos\theta)$ which will not alter the "forward-backward" asymmetry.

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