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NUCLEAR ORIENTATION IN RADIATIVE K CAPTURE

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As is well known, the nucleus becomes oriented as a consequence of parity nonconservation in beta decay. For the case of an allowed beta-transition of a nonoriented nucleus, the average value $\langle \mathbf{J} \rangle$ of the angular momentum of the daughter nucleus is given by

$$\langle \mathbf{J} \rangle = {}^1\!/_3 (j+1)\zeta \mathbf{v}, \qquad (1)$$

where j is the angular momentum of the daughter nucleus, $c\mathbf{v}$ is the velocity of the β electron (the neutrino direction is not observed), and ζ is the coefficient in the formula

$$w = 1 + \zeta \mathbf{v}\cdot\langle \mathbf{J} \rangle / j,$$

which describes the electron angular distribution for decays of oriented nuclei.[1-3] This orientation is responsible for effects in the electromagnetic transitions of the daughter nucleus such as the circular polarization of photons,[3] and the polarization of conversion electrons.[4]

An analogous orientation of the nucleus also takes place in radiative orbital electron capture $e + p \rightarrow n + \nu + \gamma$ (see reference 5). The nuclear orientation is given in this case by Eq. (1), in which $c\mathbf{v}$ is the photon velocity and ζ is the coefficient that appears in positron emission.

To prove this premise, let us consider the matrix element $V_{m_1 m}$ for radiative K capture with the nucleus going from the state $j_1 m_1$ into jm. Accurate to within an overall multiplicative factor, we have

$$V_{m_1 m} = (jm \mid O_i \mid j_1 m_1)\,(\bar{u}_\nu(q)\, O_i\, (\hat{p} - \hat{k} + im)\,\hat{e} u_e(p)),$$

where $(jm \mid O_i \mid j_1 m_1)$ is the nuclear matrix element, $u_\nu(q)$ is the amplitude of a neutrino with four-momentum q, $u_e(p)$ is the electron amplitude, e is the polarization vector of the photon, and k is its four-momentum. The polarization density matrix of the daughter nucleus is of the following form (accurate up to an overall multiplicative factor):

$$\rho_{mm'} = \sum_{m_1} (jm \mid O_i \mid j_1 m_1)\,(jm' \mid O_j \mid j_1 m_1)^* \,\mathrm{Sp}\, Q, \qquad (2)$$

$$\mathrm{Sp}\, Q = \mathrm{Sp}\, \{(\hat{p} + im)\,\hat{e}\,(\hat{p} - \hat{k} + im)\,\bar{O}_j \hat{q} O_i\,(\hat{p} - \hat{k} + im)\,\hat{e}\},$$

where $\bar{O}_j = \gamma_4 O_j^{\dagger} \gamma_4$. Since for K capture $\hat{p} = \gamma_4 p_4$, hence

$$\mathrm{Sp}\, Q = \mathrm{Sp}\, \hat{k} \bar{O}_j \hat{q} O_i. \qquad (3)$$

In the case of positron emission $\rho_{mm'}$ is also of the form (2) and

$$\mathrm{Sp}\, Q = (\hat{p}_+ + im)\bar{O}_j \hat{q} O_i, \qquad (4)$$

where p_+ is the positron four-momentum. For an extremely relativistic positron ($m = 0$, $p_+^2 = k^2 = 0$) Eq. (4) goes over into (3), thus proving Eq. (1) with $\mathbf{v}$ equal to the photon velocity. (We have here the same relationship as in the formulas for photon polarization.[6])

At first sight it may seem peculiar that the pseudovector $\langle \mathbf{J} \rangle$ is proportional to the vector representing the photon momentum since photon emission proceeds through a parity conserving mechanism. In actuality, the nucleus becomes polarized because the virtual electron can be absorbed by the nucleus only in a state with a definite polarization, namely in the direction of its momentum, which in turn is opposite to the direction of the momentum of the emitted photon.

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