CORRELATION BETWEEN THE DIRECTION OF AN INTERNAL BREMSSTRAHLUNG QUANTUM AND CIRCULAR POLARIZATION OF A GAMMA QUANTUM EMITTED BY AN EXCITED NUCLEUS AFTER K CAPTURE

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The correlation between the γ quantum from radiative K capture and the circularly-polarized γ quantum from an excited nucleus is studied. A general formula is derived for the correlation and for its dependence on the spins of the initial, excited, and final states of the nuclei.

It is well known that along with ordinary K capture one observes radiative K capture, which is frequently called internal bremsstrahlung, in which a continuous spectrum of γ quanta, up to the maximum energy W_0, is produced. If the nucleus is produced here in the excited state, circular polarization of the γ quantum of the excited nucleus can be observed in the direction of emission of the bremsstrahlung γ quantum. This offers an interesting possibility of determining the spin of excited states of nuclei formed in K capture.

In the case of electronic β decay, the spins of the excited nuclei can be determined by studying the correlation of the electrons and the circular polarization of the γ quantum of the excited nucleus.[1]

The correlation considered by us occurs unconditionally only if parity is not conserved in K capture. It is not necessary here to measure the energy of the bremsstrahlung quantum. This finds its expression in the fact that the considered correlation is of the form

$$W(\theta) \approx 1 + A\tau\cos\theta, \qquad (1)$$

where θ is the angle between the directions of the two γ quanta, and τ equals +1 or −1 respectively for right- and left-handed polarized γ quanta.

Let us dwell briefly on a derivation of this formula for the case of the A, V variant of the β interaction.

The matrix element for radiation K capture is:

$$R = \sqrt{4\pi / 2k_0}\,(ge / 2mk_0)\,\Phi(0)\,\{\bar{\nu}\Lambda\hat{k}\hat{\varepsilon} e\}; \qquad (2)$$

$\Phi(0)$ is the wave function of the K electron in the nuclear region, ϵ is the polarization vector of the bremsstrahlung γ quantum, k and k_0 are respectively the momentum and energy of bremsstrahlung γ quantum, and Λ is the matrix of the β interaction:

$$\Lambda = (\psi_f \,|\, 1 \,|\, \psi_i)\,\gamma_0 (C_V^* - iC_V^{'*}\gamma_5) - i(\psi_f \,|\, \sigma_\alpha \,|\, \psi_i)\,(C_A^* + iC_A^{'*}\gamma_5)\,\gamma_\alpha\gamma_5. \qquad (3)$$

We have to find the density matrix ρ_R for the radiation K capture, and then multiply it by the density matrix ρ_γ for the γ transition $J_f \rightarrow J_{ff}$.

The density matrix ρ_R of the radiative K capture is

$$(\rho_R)_{M_f M_f'} \sim \sum_{s_\nu,\, s_l} (J_f M_f \,|\, H_R \,|\, J_i M_i)\,(J_f M_f' \,|\, H_R \,|\, J_i M_i)^*, \qquad (4)$$

$$H_R = \bar{\nu}\Lambda\hat{k}\hat{\varepsilon}e. \qquad (5)$$

The summation extends over the spins of the emitted neutrino and the captured electron. M_f is the magnetic quantum number of the excited nucleus, J_i is the initial spin of the nucleus, J_f is the spin of the excited state, and J_{ff} is the spin of the final nucleus after emission of the γ quantum.

We shall not perform a complete calculation of ρ_R, and will write the result for the interference term (between A and V) of the ρ_R matrix. This term equals

$$-2mk_0\, 4q_0 M_F (C_V^* C_A' + C_A C_V'^*)\,(J_f M_f' \,|\, \sigma_\alpha \,|\, J_i M_i)^*\, k_\alpha \delta(M_f, M_i) - 2mk_0\, 4q_0 M_F^* (C_V C_A'^* + C_A^* C_V') \times (J_f M_f \,|\, \sigma_\alpha \,|\, J_i M_i)\, k_\alpha \delta(M_f', M_i); \qquad (6)$$

M_F is the Fermi matrix element.

A similar result is obtained when calculating the matrix ρ for positron β decay, but k_α is replaced by the corresponding positron momentum component p_α. This pertains also to other terms of the density matrix ρ.

Starting with the above we can write an expression for the coefficient A in (1), using the results of Alder, Stech, and Winther[2] on β-γ correlation.

Here the electron momentum must be replaced by the bremsstrahlung γ-quantum momentum, and since $k/k_0 = 1$, A is independent of the energy of the bremsstrahlung γ quantum:

$$A = \frac{\frac{1}{2\sqrt{3}}\left[\sum_{\lambda,\lambda'} \delta_\lambda \delta_{\lambda'} F_1(\lambda, \lambda', J_{ff}, J_f)\right]\left\{\frac{J_f(J_f+1) - J_i(J_i+1) + 2}{[J_f(J_f+1)]^{1/2}} |M_{GT}|^2 (C_A C_A'^* + C_A' C_A^*) + 4M_F M_{GT} \operatorname{Re}(C_V C_A'^* + C_V' C_A^*)\right\}}{\left\{|M_F|^2 (|C_V|^2 + |C_V'|^2) + |M_{GT}|^2 (|C_A|^2 + |C_A'|^2)\right\} \sum_\lambda \delta_\lambda^2} \qquad (7)$$

By way of an interesting example, let us consider the K capture

$$\begin{array}{l} Be^7 \rightarrow Li^{7*} + \nu + \gamma_{brem.} \\ \quad\quad\quad \downarrow \\ \quad\quad Li^7 + \gamma \end{array}$$

There are two possibilities, $3/2 \xrightarrow{\beta} 1/2 \xrightarrow{\gamma} 3/2$ or $3/2 \xrightarrow{\beta} 3/2 \xrightarrow{\gamma} 3/2$. The excited state, in all probability, emits a quadrupole γ quantum, i.e., $\lambda = \lambda' = 2$.

In the first case of a pure Gamow-Teller transition (for the 2-component neutrino and real C_V and C_A), $A = 1/6$. In the second case

$$A = -0.13 \frac{(4/\sqrt{15})\, C_A^2 |M_{GT}|^2 + 4M_F M_{GT} C_V C_A}{G_V^2 M_F^2 + C_A^2 M_{GT}^2}$$

$$x = M_F C_V / M_{GT} C_A.$$

$$= -0.13 \frac{1.03 + 4x}{1 + x^2}, \qquad (8)$$

In the second case A is close to $1/6$ and is positive only when $x \sim -1$. The contribution of the interference terms is quite large here.

Thus, an investigation of the correlation of the γ quantum of radiative K capture and of a circularly-polarized γ quantum of an excited nucleus can yield interesting information on the spin of the excited state, or else, if J_f is known, it yields data on the role of the interference terms in the β interaction. The correlation considered is analogous in many respects to the β-γ correlation.

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[1] F. Boehm and A. H. Wapstra, Phys. Rev. **106**, 1364 (1957).

[2] Alder, Stech, and Winther, Phys. Rev. **107**, 728 (1957).

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