CONTRIBUTION OF ELECTRONIC INTERMEDIATE STATES TO DECAY IN $0^+ \to 0^+$ TRANSITIONS

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Simultaneous emissions or absorptions of several photons are higher-order processes. It is difficult to observe them in nuclear trantions because of the very small transition probabilities. In experiments on $\gamma\gamma$ decay, transitions are chosen in which single-photon emission is strongly retarded (high multipolarity transitions) or strictly forbidden ($0 \to 0$ transitions). Four first excited 0^+ states are known (^{16}O, ^{40}Ca, ^{72}Ge, and ^{90}Zr), and the $0^+ \to 0^+$ transitions of these states to the ground states are very favourable. In two of them, $\gamma\gamma$ decay was recently observed [1,2,3].

In previous theories of $\gamma\gamma$ decay, nuclear intermediate states were considered in the calculation of transition probabilities [4,5]. Comparison of experimental and theoretical results was not satisfactory. Insufficient knowledge of the structure of nuclear states involved in the decay is an explanation of the disagreement.

In this paper, an alternative possibility is considered, suggested by Ilakovac and Ljubičić [6], in which $\gamma\gamma$ decay proceeds via electronic intermediate states, leading to the same final states. A general diagram for the emission of any number of photons via electronic intermediate states is shown in Fig. 1, where ψ_i and ψ_f represent the initial and final state of the electron, respectively, ϕ_1 and ϕ_2 the initial and final state of the nucleus $(0^+,0^+)$, respectively, and ω the transition energy. The amplitude of this diagram is equal to

$$S_{if} = -2\pi i\alpha\ \delta(E) \int d\vec{x}\ d\vec{z}\ J_\mu(\vec{z})\ \frac{e^{i\omega|\vec{z}-\vec{x}|}}{|\vec{z}-\vec{x}|}\ j_\mu(\vec{x},\vec{A})\ , \qquad (1)$$

where $\alpha = 1/137$, J_μ and j_μ are the electromagnetic currents of the nucleus and the electron, respectively. When the spherical symmetry and the equation of continuity of the electronic current are taken into account, we obtain

$$S_{if} = 2\pi i\alpha\delta(E)\int d\vec{x}\, d\vec{z}\; \phi_2^*(\vec{z})\; \phi_1(\vec{z})\frac{1}{|\vec{z}-\vec{x}|}\; j_o(\vec{x},\vec{A}) \qquad (2)$$

The integral is different from zero only for $|\vec{x}| \leq |\vec{z}|$, i.e., only the space inside the nucleus contributes to the transition probability [7]. If the electronic current inside the nucleus is assumed constant, $j_o(\vec{x}=0,\vec{A})=\text{const}$, then

$$S_{if} = -2\pi i\delta(E)\, j_o(\vec{x}=0,\vec{A})\,\frac{2\pi}{3}\,\alpha\int d\vec{z}\;\phi_2^*(\vec{z})\,z^2\phi_1(\vec{z})\;, \qquad (3)$$

where

$$j_o(\vec{x},\vec{A}) = \int d\vec{y}\; d\vec{u} \ldots \overline{\psi}_f(\vec{y})A(\vec{y})S(\vec{y},\vec{u})\ldots\gamma_o\psi_i(\vec{x})\;. \qquad (4)$$

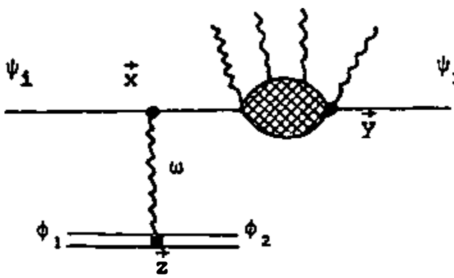

Fig. 1

General diagram for the emission of several photons via nuclear intermediate states in a nuclear transition.

Equation (3) is a generalization of the expressions for electron conversion and internal pair production in $0 \to 0$ transitions.

Lowest-order diagrams for $\gamma\gamma$ emission via electronic intermediate states are shown in Fig. 2. When K electrons are considered, we obtain by applying the impulse approximation [8]

$$j_o(\vec{x}) = \frac{i^2}{V}\,\frac{e^2}{\sqrt{2k_1 2k_2}}\int d\vec{k}\, z^*\phi(\vec{k})\,\vec{e}_1^*\vec{\alpha}S(\vec{q})\,\gamma_o\,\vec{e}_2^*\vec{\alpha}S(\vec{p})\,e^{-i\vec{p}\vec{x}}\psi(x)\,z \qquad (5)$$

where $\psi(\vec{x})$ and $\phi(\vec{k})$ are the Schrödinger wave function and its Fourier transform for a K electron, z is the spin wave function, $\vec{e}_1$ and $\vec{e}_2$ are the linear polarization vectors of emitted photons, k_1 and k_2 their energies, and $\vec{p}$ and $\vec{q}$ are given by conservation of momentum.

In the approximation $k_1, k_2 >> Z\alpha m$ and $\omega >> m$, it is possible to calculate the currents (5) for all diagrams in Fig. 2.

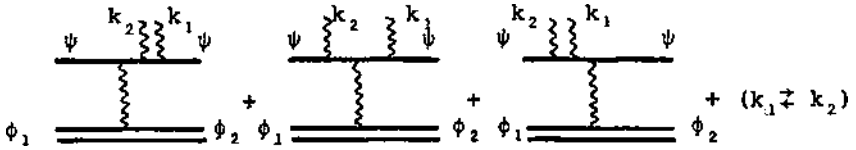

Fig. 2

Diagrams for $\gamma\gamma$ decay

The final result for the transition probability of $\gamma\gamma$ emission via a K electron, $W_{\gamma\gamma}$, divided by the K-electron conversion transition probability, W_K, is

$$\frac{W_{\gamma\gamma}}{W_K} = \alpha^2 \frac{(Z\alpha)^3}{\pi} \frac{1}{6} \left(\frac{\omega}{m}\right) . \qquad (7)$$

Comparison of this result with the ratio of the experimental values shows that it is too small by several orders of magnitude. We conclude that electronic intermediate states give a negligible contribution to $\gamma\gamma$ decay.

References

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