THE POSSIBILITY OF EXPERIMENTAL CHECK OF THE MODEL OF A NON-AXIAL ROTATOR BY STUDYING THE INFLUENCE OF THE MEDIUM ON THE ANGULAR CORRELATION OF CASCADE GAMMA RAYS

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An experiment is proposed for the purpose of checking the assumptions of the model of a non-axial rotator for even-even nuclei. The experiment is based on measurement of the attenuation factor for angular correlation of γ quanta for similar cascades in isotopes of the same element placed in identical media.

THE model of the non-axial rotator which was developed by Davydov and Filippov[1] predicts a quite marked dependence of the quadrupole moment of the nucleus Q_2 in the excited states of the rotator on the parameter γ of non-axial deformation of the nucleus.

According to this model, we have for the matrix element of the nuclear quadrupole moment operator

$$\langle\psi^*_{IM_1i}(\beta,\gamma,\theta_j)|\hat{Q}_{2\mu}|\psi_{IM_2i}(\beta,\gamma,\theta_j)\rangle = \frac{3}{4\pi}ZR_0^2\sqrt{\frac{4\pi}{5}}\beta f_{Ii}(\gamma)C^{IM_1}_{IM_22\mu},$$

$$\hat{Q}_{2\mu} = \sqrt{\frac{4\pi}{5}}\sum_{i=1}^{Z} r_i^2 Y_{2\mu}(\mathbf{n}_i); \qquad (1)$$

θ_j are the Euler angles for the orientation of the rotator; β, γ are the deformation parameters for the nucleus; $C^{::}_{::}$ are the Clebsch-Gordan coefficients. In particular, for the first and second excited states with spin $I = 2^+$, the functions $f_{Ii}(\gamma)$ are equal to

$$f_{21} = -f_{22} = -3\cos 3\gamma/\sqrt{1+8\cos^2 3\gamma}. \qquad (2)$$

Investigation of the dependence of Q_2 on γ is of interest as an experimental test of the assumptions of the non-axial rotator model. Measurement of quadrupole moments of nuclei in excited states is possible by investigating the attentuation of the angular correlation of cascade γ quanta as a result of the interaction of the quadrupole moment Q_2 in the intermediate state of the nucleus with the electric field of the source medium.[2] However, the application of this method is seriously limited by the fact that the field of the medium is not known precisely and can only be estimated crudely with difficulty. This difficulty can be eliminated if we compare the moments Q_2 of different isotopes of the same element, as determined from the attenuation of the correlation in one and the same medium. In this case, the unknown value of the field intensity (or the corresponding derivatives) and other parameters of the medium drop out of the final result for the ratio of the quadrupole moments.

Such a possibility exists in the case of the even-even isotopes of Nd, Sm, Gd, W, Os, and Pt. In this group of nuclear isotopes, according to the non-axial rotator model, as the number of neutrons is changed there occurs a change in the parameter of non-axial deformation γ from 0 to 30°. Thus, measurement of the ratio of values of Q_2 for nuclei of this group enables one to check the dependence (2).

Especially interesting is the study of the quenching of the angular correlation when we use a liquid as the source medium. In this case, as it turns out, there is no need to know exactly the lifetime of the intermediate state of the nucleus, τ, which in general enters in the result in other cases.[2]

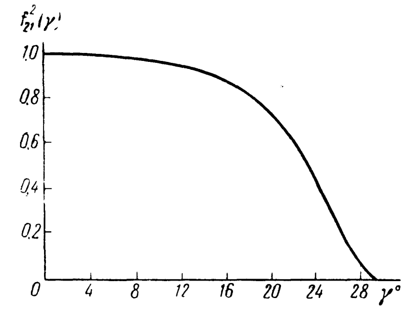
From observation of the angular correlation of the γ-γ cascade $I_i \to I_B \to I_f$,

$$W(\theta) = 1 + \sum_{\varkappa} G_{2\varkappa}A_{2\varkappa}P_{2\varkappa}(\cos\theta)$$

one determines experimentally the attenuation coefficients G_{2K}, since the A_{2K} are known exactly for a given form of cascade with known spins I_i, I_B and I_f.[2] For liquid sources under the condition that the resolving time of the apparatus is much greater than the lifetime τ of the nucleus in the intermediate state with spin I_B, we have for the coefficients G_{2K}[2]

$$G_{2\varkappa} = (1 + \lambda_{2\varkappa}\tau)^{-1}. \qquad (3)$$

Here (cf. reference 2)



$$\lambda_{2\varkappa} = \frac{3}{80}\left(\frac{eQ_2}{\hbar}\right)^2 \left\langle \frac{\partial^2 V}{\partial z^2} \right\rangle^2 \tau_c \times \frac{2\varkappa(2\varkappa+1)\,[4I_B(I_B+1) - 2\varkappa(2\varkappa+1) - 1]}{I_B^2(2I_B-1)^2}, \quad (4)$$

$< \partial^2V/\partial z^2 >^2$ is the mean square of the second derivative of the fluctuation field in the medium; τ_c is the correlation time in the liquid, Q_2 is the quadrupole moment of the nucleus in the state I_B.

Now let us compare $\lambda_{2K}\tau$ for two isotopes of the same element whose nuclei have respectively $\gamma = 0$ and $\gamma \neq 0$, i.e., let us find the ratio $(\lambda_{2K}\tau)_\gamma/(\lambda_{2K}\tau)_0$. It is assumed that the values of G_{2K} for the isotopes are measured in similar cascades $I_i \rightarrow I_B \rightarrow I_f$ in the same medium.

The probability of the γ transition for collective E2 transitions of a rotator $I_B \rightarrow I_f$ has the form:[1]

$$\frac{1}{\tau} = W(E2;\, I_B \rightarrow I_f) = \frac{3}{8\pi}\,10^{-3}\left(\frac{e^2}{\hbar c}\right)^5 Z^2 R_0^4 k^5 \beta^2 b(E2;\, I_B \rightarrow I_f)\,\frac{m_e c^2}{\hbar}. \quad (5)$$

Here R_0 is the nuclear radius in units $r_0 = 1.4 \times 10^{-13}$ cm; $r_0 = e^2/2m_e c^2$; k is the energy of the radiated quantum in units of $m_e c^2$ (0.511 Mev). The values of $b(E2;\, I_B \rightarrow I_f)$ are given in reference 1 for various transitions.

Assuming that one uses the same medium and the same type of cascade for the isotopes with $\gamma = 0$ and $\gamma \neq 0$, we obtain from (3), (4), and (5) for the ratio $(\lambda_{2K}\tau)_\gamma/(\lambda_{2K}\tau)_0$ the result

$$\frac{(\lambda_{2\varkappa}\tau)_\gamma}{(\lambda_{2\varkappa}\tau)_0} = \frac{k_0^5}{k_\gamma^5}\,\frac{[b(E2;\, I_B \rightarrow I_f)]_0}{[b(E2;\, I_B \rightarrow I_f)]_\gamma}\, f^2_{I_B}(\gamma). \quad (6)$$

Here $f_{I_B}(\gamma)$ is the function $f_{I_i}(\gamma)$ for the state I_B of the rotator [cf. (1)]; k_0 and k_γ are energies of the E2 transitions $I_B \rightarrow I_f$ for the isotopes with $\gamma = 0$ and $\gamma \neq 0$.

Of primary interest is a cascade where the intermediate level is the first excited state of the nucleus with spin $I_B = 2^+$. In this case $b(E2;\, 21 \rightarrow 0)$ varies between the limits 0.933 and 1[1], i.e., it is practically independent of γ. Thus we have

$$f^2_{21}(\gamma) = \frac{(\lambda_{2\varkappa}\tau)_\gamma k_\gamma^5}{(\lambda_{2\varkappa}\tau)_0 k_0^5} = \frac{k_\gamma^5}{k_0^5}\,\frac{[(1-G_{2\varkappa})/G_{2\varkappa}]_\gamma}{[(1-G_{2\varkappa})/G_{2\varkappa}]_0}. \quad (7)$$

The function $f^2_{21}(\gamma)$ is shown in the figure. The right side of (7) can easily be measured experimentally, while γ is known from the ratio of the energies of the first and second excited states of the nucleus which have spins 2^+.[1] Thus there is the possibility for checking the dependence of $Q_2(\gamma)$ in the model of the non-axial rotator.

[1] A. S. Davydov and G. F. Filippov, JETP **35**, 440 (1958), Soviet Phys. JETP **8**, 303 (1959).

[2] A. Abragam and R. V. Pound, Phys. Rev. **92**, 943 (1953). R. M. Steffen, Advances in Phys. **4**, 293 (1955).

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251