Quasiparticle excitations in high-frequency rotation of nuclei

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We calculate the energies of quasiparticle excitations at the levels $j = 13/2$ for high rotation frequencies. The calculations confirm the presence of zero-gap excitations in the rotational spectra of rare-earth nuclei.

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In[1], qualitative estimates were presented to show that the main cause of the appearance of the frequency anomaly (FA) or of the inverse inflection of the moment of inertia in the rotation spectra of atomic nuclei is the restructuring of the wave function of the nucleus, due to the suppression, at large frequencies, of two-particle excitations, as the principal component of the ground (yrast) state. In a coordinate system connected with the rotating nucleus, this phenomenon looks like the appearance, at a certain frequency, of zero-gap quasiparticle excitations, i.e., excitations not separated by an energy gap from the vacuum state.[2]

We present in this article the results of numerical calculations of the energies of quasiparticle excitations as functions of the rotation frequency for a nucleon angular momentum $j=13/2$, a deformation $\beta=0.20$, a pair-correlation $\Delta_0=1$ MeV, and different positions of the Fermi surface, corresponding to different nuclei in the rare-earth region. The energies ϵ_λ of the single-particle levels were taken from the Nilsson scheme, and the parameters β and Δ_0 correspond to the mean values of these quantities for rare-earth nuclei having a frequency anomaly. The quasiparticle energies E_λ were calculated from the equations for the coefficients u_λ and v_λ of the Bogolyubov canonical transformation[3] in the rotation field

$$(E_\lambda + \epsilon_\lambda)v_\lambda - \omega j_{\lambda\lambda'} v_{\lambda'} - \Delta u_\lambda = 0,$$
$$(E_\lambda - \epsilon_\lambda)u_\lambda - \omega j_{\lambda\lambda'} u_{\lambda'} - \Delta v_\lambda = 0, \qquad (1)$$

where ϵ_λ is the level energy reckoned from the Fermi surface, and ω is the rotation frequency directed along the x axis. The results of the calculations for the lowest energy of the quasi-particles as functions of the rotation frequency are given in Fig. 1. The different curves correspond to different positions of the Fermi surface, as indicated in Fig. 1 on the right.

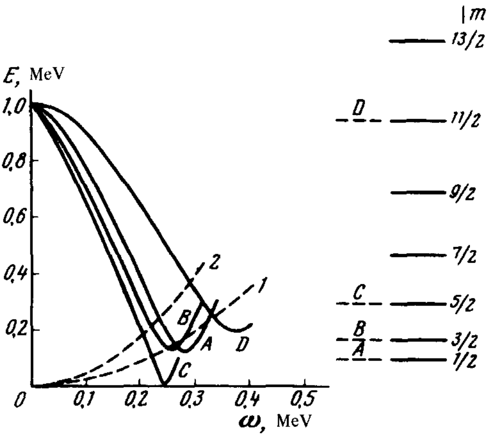

FIG. 1. Lower energies of quasiparticle excitations for different positions of the Fermi surface, as functions of the rotation frequency of the nucleus. The quantity ΔE_{rot} is shown dashed (for two different values of J^*).

The quasiparticle excitation energies E_λ in the frequency region $\omega \approx 0.25$—0.3 MeV are very close to zero, and even vanish for certain positions of the Fermi surface. The real excitation energy of the nucleus is the difference between the rotation energies E^*_{rot} and E^0_{rot} of the core of the nucleus with and without the excited quasiparticles E_1 and E_2, respectively, i.e., $E = E^*_{rot} - E^0_{rot} + E_1 + E_2$. For not very large angular momenta, we can assume that $E^0_{rot} \approx I(I+1)/2J_0$ and $E^*_{rot} = I(I+1)/2I^*$, where J_0 and J^* are the corresponding moments of inertia. By virtue of the blocking effect $J^* > J_0$ and the difference between the rotation energies, at a given I, is always negative

$$\Delta E_{rot} = E^*_{rot} - E^0_{rot} = -\frac{J_0\omega^2}{2}\left(1 - \frac{J_0}{J^*}\right) < 0. \qquad (2)$$

The value of J_0 is well known from both theoretical and experimental data. For the rare-earth region $J_0 \approx 15$—30 MeV^{-1}. We have

$$1 - \frac{J_0}{J^*} \approx \frac{\delta\Delta}{\Delta_0}\,\frac{J_n}{J^*} \approx \frac{1}{2\rho_0\Delta_0} \approx 0.2,$$

where ρ_0 is the level density on the Fermi surface. [4] In Fig. 1 the quantity $|\Delta E_{rot}|$ is shown by the dashed curve for $J_0 = 22$ MeV^{-1} (Dy^{156}) and two values of J^*, namely $1 - J_0/{}^*J = 0.2$ (a) and $1 - J_0/J^* = 0.4$ (b). At the point $\omega = \omega_{cr}$, when $E_1 + E_2 = |\Delta E_{rot}|$, the excitation energy vanishes and the two-quasiparticle excitation becomes lower in energy than the vacuum excitation, this being in fact the cause of the frequency anomaly.

The calculated frequency ω_{cr} lies in the interval 0.25—0.3 MeV and is close to the experimentally observed one.

Detailed calculations of all the excitation energies for different nucleon shells, deformations, values of Δ, and positions of the Fermi surface will be published subsequently.

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