EVIDENCE FOR A SHAPE CHANGE OF HOT, FAST ROTATING ^{45}Sc NUCLEI FROM GDR STUDIES

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1. INTRODUCTION

At moderate temperatures ($T \geq 2$ MeV), where the pairing and shell effects vanish, the nuclear shapes are well described by the rotating liquid drop model (RLDM)[1]. The RLDM predicts that the shape of the nucleus which is spherical in its ground-state changes with increasing angular momentum L into a deformed one - oblate rotating non-collectively. With further increase of L the deformation of the oblate shape increases and at very high angular momenta ($L = L_I$) the oblate shape becomes unstable, favouring a triaxial ellipsoid and eventually strongly prolate shape rotating collectively. This transition is similar to the Jacobi instability known for fast rotating stars.

In this article I would like to present an evidence for the shape transition from oblate non-collective to triaxial, strongly deformed shapes in $^{45}Sc^*$ compound nuclei which is predicted by the RLDM to occur at critical value $L_I = 29\ \hbar$.

An information about the shape of the highly excited nucleus may be extracted from the Giant-Dipole-Resonance (GDR) strength function and the angular distribution of γ rays emitted during the statistical GDR decay.[2,3] The measured angular distribution may be presented as $W(\theta, E_\gamma) = A_0[1 + a_2(E_\gamma) \cdot P_2(cos\theta)]$, where the coefficient $a_2(E_\gamma)$ completely characterizes the angular distribution for each E_γ energy. To determine the most probable shape of the hot, fast rotating nucleus the experimental values of the average cross section $\sigma_{abs}(E_\gamma)$ for the inverse process of photoabsorption and the $a_2(E_\gamma)$ coefficient have to be compared with the results of calculations including thermal shape and orientation fluctuations [4].

2. EXPERIMENTAL DETAILS

We produced $^{45}Sc^*$ compound nuclei at four excitation energies in the range E_{xi} =50 - 90 MeV by colliding ^{18}O on ^{27}Al at projectile energies E_{lab} =44.9, 72.5, 89.4 and 109.6 MeV, using the heavy-ion beam from the University of Washington tandem liniac.[5] The corresponding grazing angular momenta are $L_0 \approx 20$, 28, 33 and 36 $\hbar$, respectively. Gamma rays were detected at θ_γ = 40-140^0 in a large shielded NaI(Tl) detector. Pulsed beams and time of flight techniques were used to separate prompt γ rays produced in the target from neutron-induced events. Our experimental technique was similar to that described previously[6].

3. RESULTS AND DISCUSSION

The measured γ-ray spectral shapes, due primarily to the decay of the GDR built on excited states, have been analysed using Cascade statistical model code to extract the average cross section $\sigma_{abs}(E_\gamma)$ for the inverse process of photoabsorption by the hot nucleus. The results are shown in Fig. 1 (top row) as the points with errors for each of the four studied reactions, labelled by the average spin and temperature appropriate for each case. The a_2 angular distribution coefficient in the center-of-mass is shown in the bottom row.

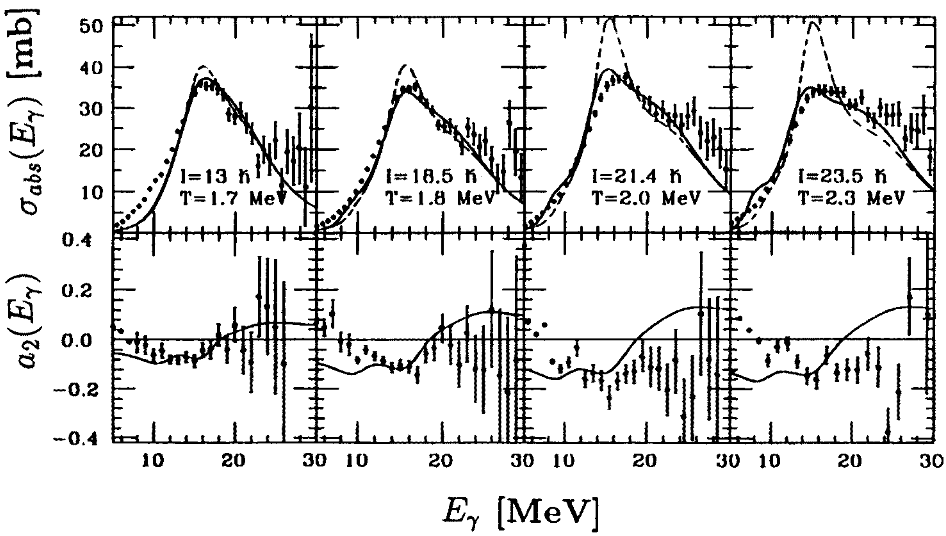

Fig. 1: Photoabsorption cross section $\sigma_{abs}(E_\gamma)$ and a_2 coefficient for $^{45}Sc^*$ at average spins and temperatures populated in reactions studied; points with errors: experimental values, lines: thermal shape and orientation fluctuation calculations. [ref.5]

The main feature of interest is the appearance of a second peak or shoulder in the $\sigma_{abs}(E_\gamma)$ at $E_\gamma \approx 25$ MeV, on the high energy side of the main GDR peak, for two higher spin cases. This indicates the presence of large spin-induced deformations $\beta \geq 0.45$ in the ensemble of decaying states.

A quantitative interpretation of the data requires a comparison with the results of thermal shape and orientation fluctuation calculations, which have been done for these cases by Alhassid and Whelan[5]. In these calculations, the nuclear potential energy is found to have an oblate minimum for angular momenta less than 29 $\hbar$.

For higher spins the minimum is triaxial, nearly prolate. The result, for spins near and above the critical value, is a very soft potential energy surface with a large equilibrium deformation. The results of thermal shape and orientation fluctuation calculations with these surfaces is shown as a solid line in Fig. 1. The calculated $\sigma_{abs}(E_\gamma)$ are in reasonable agreement with the experimental cross sections. For the higher spins, they exhibit a high-energy shoulder similar to the experimental results, but less pronounced. The shoulders in the calculations are due to the presence of large deformations in the ensemble of decaying states. The differences between the calculated and measured spectral shapes are not unreasonable, given that the deformation increases very rapidly for spins beyond the critical value and the actual spin distributions are not precisely known.

The comparison of the calculated a_2 coefficient with the experimental value may be done for $E_\gamma > 11$ MeV, below which the contribution of the daughter nuclei in the decay is significant. Calculations qualitatively reproduce the negative dip on the low energy side of the GDR peak, but fail to reproduce the sign of a_2 at higher γ-ray energies, especially for two higher spin cases. This is presently not understood. It should be noted that, in contrast to the spectrum shape, the a_2 coefficient depends on the orientation of the deformed nucleus as well as its deformation and, thus, may be in principle more difficult to understand.

In order to clarify the effect of the shape change into triaxial on the GDR spectral shapes, we have performed thermal shape fluctuation calculations with free-energy surfaces in which the triaxial shape (transition) has been removed. This has been done by constructing parabolic surfaces in which the minimum remains on the oblate axis for all spins, and the curvatures are similar to those found at zero spin. The result is shown by dashed lines in Fig. 1. The calculations clearly fail in reproducing the experimental cross sections at higher energy, demonstrating the essential role of shape transition in describing the data.

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