Shape transitions in the hot rotating nucleus ^{148}Nd

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Introduction

Since the pioneering work of Newton and his coworkers [1] a great effort has been devoted to the investigation of phase transitions in hot rotating nuclei. The fact that the phase transition to deformed shapes causes a splitting of the giant resonance has been well known for many years and it is used to study the shape changes as a function of angular momentum or temperature by means of the fine structure of the GDR. A very simple understanding of the universal features of shape transitions in nuclei as a function of the angular momentum and temperature is given by Levit et al. [2]. Recently, investigations on the phase transition in finite nuclei have created new attention among physicists, but many questions are still open. One of the interesting questions which arise in the finite-temperature description of the nuclei is whether or not phase transition really does occur. There are many theoretical and experimental evidences for the occurrence of phase transition in finite nuclear systems.

In the present investigations we have observed the following:

i) A phase transition from the superfluid state to normal nuclear matter for temperature $T \approx 0.6$MeV, and angular momentum $M > 20\hbar$ when pairing correlations are important.

ii) A shape transition from prolate collective to oblate non-collective beyond temperature $T \approx 0.6$MeV and angular momentum $M > 30\hbar$.

iii) The influence of pairing and structural changes on the level density parameter at high angular-momentum states and high excitation energies for the nucleus ^{148}Nd on the basis of statistical theory of hot rotating nuclei (STHR).

Formalism:

The logarithm of the grand partition function for the Z protons of the superfluid nuclei at a temperature T, using the BCS formulation is given by

$$ln\, Q_{BCS} = -\beta \sum_k[\epsilon_k^z - \mu_Z - E_k^Z] + \sum_k \ln\{1 + \exp[-\beta(E_k^z - \lambda m_k^z)]\} - \beta\Delta_Z^2/G_Z \quad (1)$$

where $E_k^Z = [(\epsilon_k^Z - \mu_Z)^2 + \Delta_Z^2]^{1/2}$ are the proton quasiparticle energies. G_Z is the pairing strength and Δ_Z is the gap parameter. The quantity β is the reciprocal of the temperature (β=1/T) and μ_Z is the proton chemical potential. The particle number equations for protons, the equation for the angular momentum M and for the energy E are,

$$Z_{BCS} = \frac{\partial \ln Q_{BCS}}{\partial \mu_Z};\ M_{BCS}^Z = \frac{\partial \ln Q_{BCS}}{\partial \lambda};\ E_{BCS}^Z = \frac{-\partial \ln Q_{BCS}}{\partial \beta}; \quad (2)$$

The gap parameter Δ_Z is obtained as a function of β, λ, and μ_Z by solving the gap equation

$$\sum_k \frac{1}{2E_k^Z}\left[\tanh\frac{\beta}{2}(E_k^Z - \lambda m_k^Z)\right] = \frac{2}{G_Z} \quad (3)$$

The entropy is then determined as

$$S_{BCS}^Z = \sum_k \ln\{1 + \exp[-\beta(E_k^Z - \lambda m_k^Z)]\} + \beta\sum_k \frac{E_k^Z - \lambda m_k^Z}{1 + exp\, \beta(E_k^Z - \lambda m_k^Z)} \quad (4)$$

A similar set of equations for neutrons also exists. The level density parameter a^{BCS} is given by,

$$a^{BCS} = S_{BCS}^2/4E_{BCS}^*. \quad (5)$$

Results and discussion:

The results obtained for the nucleus ^{148}Nd using the theoretical framework of STHR described in this section. Figures 1(a-d) illustrate the hodograph of the deepest energy minima of the nucleus is shown. The equilibrium shape of the system is determined by minimizing the free energy with respect to the deformation parameters ε, γ at finite angular momentum M and temperature T and it is denoted by a dot in these figures. It is observed from fig. 1(a and b) that the nucleus is found to be prolate (ε = 0.2, $\gamma = -120^0$) for the angular momentum range M = 0 to 20ħ, triaxial (ε = 0.3,

$\gamma = -140^0$ and $\varepsilon = 0.3$, $\gamma = -160^0$) for M = 21 to 35ħ and finally reaches the oblate shape for M = 36 to 60ħ ($\varepsilon = 0.3$, $\gamma = -180°$). A similar behaviour is exhibited by the nucleus for two other different temperatures T = 0.6 and 1.0MeV and it is shown in figs. 1(c and d). Thus the shape transitions occur from prolate collective to oblate non-collective rotation with increasing angular momentum.

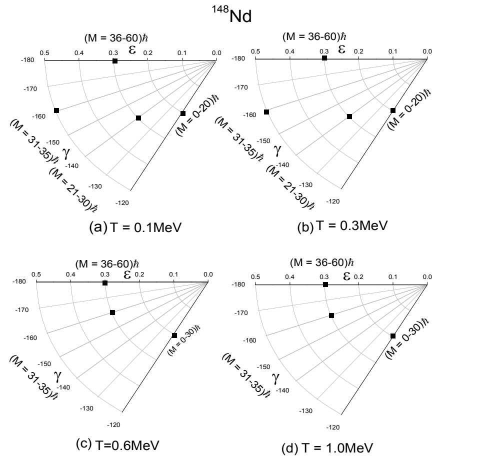

Fig.1: The shape evaluation of ^{148}Nd at different temperatures 'T'.

Results of the level density parameter 'a' without pairing correlations are illustrated in fig.2.

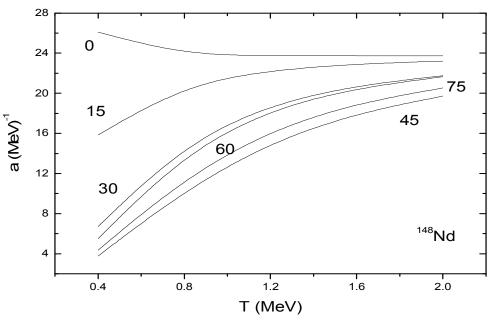

Fig. 2: Level density parameter 'a' versus temperature 'T'.

A significant effect of rotation on the level density parameter is observed at very low temperatures. At these temperatures where the contribution of shell structure dominates, the level density parameter varies for different angular momentum states of the nucleus. The nucleons start to behave like a degenerate system at T = 1.0MeV when the shell corrections vanish. In the present case the temperature T = 1.0MeV, at which the shell correction collapses, may be treated as a critical temperature T_C, where the system behaves like a degenerate Fermi gas represented by a constant level density parameter of the order of A/8. For T > 1.0MeV the level density parameter 'a' shows a linear behaviour for all the angular momentum considered. The level density parameter with pairing correlations for temperature T with different angular momenta is shown in fig. 3.

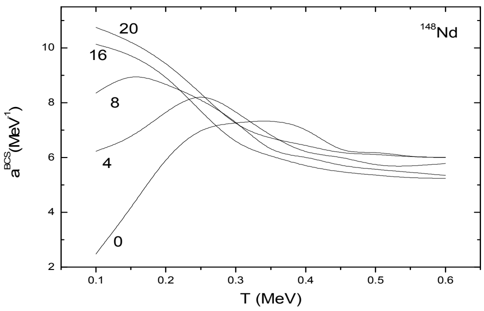

Fig. 3: Level density parameter a^{BCS} versus temperature 'T'.

The noticeable decrease in the values of a^{BCS} for all 'M' may also be due to the smearing out of the occupational probability of the nucleons at the Fermi surface and the exclusion of quadrupole interaction [3].

The role of pairing has significant effects on the parameters evaluated in this study. The empirical relation a_{BCS} = A/10 could not be reproduced by the investigation on the level density parameter in the presence of pairing using BCS formalism.

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