Structural changes in Hot Rotating Transitional Nuclei

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Introduction

The possibility of heating a nucleus to a finite temperature opens a new direction in the study of nuclear structure. The experimental analysis of giant dipole resonance (GDR) built on excited states have started to yield information about the shape transitions that takes place in such nuclei. This is also well known now that GDR cross section curves are not that clear as we expect in rotating nuclei, because in hot rotating nuclei, thermal fluctuations may make the GDR curves a little complicated to interpret. Due to the finite number of degrees of freedom it is necessary to include thermal shape fluctuations in order to obtain good fits to experimental observables such as the giant dipole resonance built on hot nuclei. The main theoretical methods used to describe hot nuclei are taken from statistical mechanics. The Landau theory [1] offers a natural frame work in which these fluctuations are introduced.

Many of the earlier calculations used the Landau theory in limited form with expansion of the free energy upto fourth power of β for the study of shape transitions in hot rotating light and medium mass nuclei [2,3]. The quality of Landau theory applied to medium and heavy mass nuclei when the free energy is expanded up to fourth power of β is not as good for lower temperatures and higher spins [4]. Hence in heavy nuclei, at medium temperatures ($T \leq 1.5$ MeV), it is necessary to extend the Landau free energy upto sixth order of β and temperature and spin dependent moment of inertia must be used in the calculations. We have applied this extended form of Landau theory to study the shape evolutions of hot rotating transitional nuclei, especially for the isotope of Neodymium such as ^{146}Nd.

Details of calculation

As developed recently [5] the free energy at any spin I can be expanded to the sixth order in β as ;

$$F(T, \beta, \gamma) = F_0 + F_2 \beta^2 + F_3 \beta^3 \cos 3\gamma + F_4 \beta^4 + F_5 \beta^5 \cos 3\gamma + F_6^{(1)} \beta^6 + F_6^{(2)} \beta^6 \cos^2 3\gamma + \ldots (1)$$

Here F_0, F_2,… are temperature dependent Landau parameters. These expansion coefficients are determined by least square fit to the Strutinsky calculation results in the Neodymium isotopes. Then the angular momentum is brought in within the cranking approach. The free energy for fixed spin is obtained under Legendre transformation and is given by

$$F(T,I; \beta,\gamma) = F(T,I=0; \beta,\gamma) + I^2/(2J_{zz}(T,\beta,\gamma)) \quad (2)$$

where, the temperature dependent moment of inertia with respect to the body fixed z- axis is given by

$$J_{zz}(T, \beta,\gamma) = J_0 + J_1 \beta \cos \gamma + J_2^{(1)} \beta^2 + J_2^{(3)} \beta^2 \sin^2 \gamma + J_3^{(1)} \beta^3 \cos 3\gamma + J_3^{(2)} \beta^3 \cos \gamma + J_4^{(1)} \beta^4 + J_4^{(2)} \beta^4 \cos 3\gamma \cos \gamma + J_4^{(3)} \beta^4 \sin^2 \gamma + \ldots (3)$$

The temperature-dependent moment of inertia is given by

$$J(A,\beta;T,I) = J_{rig}(A,\beta)[1 - g\left(\frac{\beta\hbar\omega_0}{2\Delta(T,I)}\right)]\ldots(4)$$

where $g(x) = \frac{\ln[x\sqrt{1+x^2}]}{x\sqrt{1+x^2}}$ evaluated separately for neutrons and protons. The gap parameter $\Delta(T,I)$ occurring in the expression is obtained by solving the temperature-dependent coupled equations within the BCS formalism [6].

The temperature dependent gap equation is given by

$$\frac{2}{G} = \Sigma_\mu \frac{\tanh(E_\mu/2T)}{E_\mu} \qquad \ldots.(5)$$

The parameters J_0,J_1…… are also determined by a fitting procedure.

For a given spin and temperature, the ensemble average of β and γ gives the averaged β and γ.

Results and Discussion

In the present work we have made an attempt to study the shape evolutions of hot rotating Neodymium isotopes using the extended Landau model with thermal fluctuations. The Landau constants are evaluated by least square fitting with the free energy surfaces obtained by the finite temperature version of the cranked Nilsson Strutinsky method. The sample results of shape transitions obtained as a function of spin at temperatures 0.25, 0.5, 1.0 & 2.0 MeV respectively with thermal fluctuations using the extended Landau model for the case of ^{146}Nd are given in the table. It is noted from the table that at T = 0.25 MeV, the nuclei undergo a shape transition from nearly prolate to nearly oblate as a function of spin and then to more triaxial at higher spins. In the transition, the deformation increases with spin. Almost the same trend, but increased deformations are obtained as a function of spin at other temperatures also for the same nuclei. It is noted from the table that, the sharp shape transitions are not obtained in the presence of thermal fluctuations. This proves the fact that averaging by all possible shapes always yields triaxial shape.

TABLE: The shape transitions obtained as a function of spin &temperatures with thermal fluctuations for the case of ^{146}Nd

T / I(ħ)	0.25 MeV		0.5 MeV		1.0 MeV		2.0 MeV	
	<β>	<γ>	<β>	<γ>	<β>	<γ>	<β>	<γ>
10	0.0931	-122.15°	0.0909	-135.17°	0.0885	-136.81°	0.0984	-145.54°
20	0.0943	-124.36°	0.0912	-136.52°	0.0906	-137.32°	0.1027	-147.62°
30	0.1862	-168.28°	0.1838	-163.36°	0.2017	-161.26°	0.2162	-160.17°
40	0.2913	-164.32°	0.3163	-159.35°	0.3220	-160.18°	0.3416	-159.86°
50	0.4018	-158.61°	0.4338	-155.67°	0.4413	-160.07°	0.4669	-159.95°
60	0.5246	-153.24°	0.5675	-149.83°	0.5804	-159.17°	0.5915	-158.82°

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