Role of Fluctuations in the Shape Transitions of Hot Rotating Nuclei

V. Selvam [1] and P.Rekha [2]

[1]Department of Physics, R.D. Govt. Arts College, Sivagangai-630 561, INDIA.
[2]Department of Physical Sciences, James College of Education, Karungal, Kanyakumari-629 157, INDIA.

Introduction

The investigation of structural transitions as a function of both angular momentum and temperature has been among one of the fascinating aspects of highly excited nuclei in recent years. One of the main prospect of using recently developed multi detector arrays is the more accurate study of shape transitions in hot rotating nuclei. The experimental analysis of giant dipole resonance (GDR) built on excited states has started to yield information about the shape transitions that takes place in nuclei under extreme conditions of spin and temperature. The light and medium mass nuclei are of special interest in the study of structural changes of nuclei at high excitation energy and large angular momentum.

To study the shapes of hot rotating nuclei, mean field theories such as the microscopic Hartree-Fock Bogoliubov cranking theory [1] and Landau theory [2] have to be used. Appart from these, the more appropriate Mottelson – Nilsson [3] and Nilsson – Strutinsky [4] approaches can also be used for studying hot rotating nuclei. The purpose of this work is to study the shape evolutions in ^{120}Sn nucleus as a function of spin and temperature including the most important thermal fluctuations. In the first phase of this work, the cranked Nilsson Strutinsky method with tuning to fixed spins [4] is used to obtain the shape and deformation for the considered nuclei. Then extended Landau theory of shape transitions [4] is used to study the shape variations due to thermal fluctuations.

Theoretical Formalism

In the case of hot rotating nuclei the equilibrium state is the state which minimizes the free energy and is computed using Strutinsky pescription as,

$$F(T,I;\beta,\gamma) = E(T,I;\beta,\gamma) - TS - E_s + E_{RLDM} \qquad (1)$$

where E_s is the Strutinsky smoothed energy for extracting shell correction and E_{RLDM} is the rotating liquid drop energy given by

$$E_{RLDM} = E_{LDM} - \frac{1}{2} J_{rig}\,\omega^2 + \hbar\,\omega I_s \qquad (2)$$

For finite temperature, one should also consider thermal fluctuations which create shapes different from the most probable shape obtained by minimizing the free energy.

According to the extended Landau model, the free energy F(T, β,γ) at any spin I can be expanded to the sixth order in β as

$$F(T, \beta, \gamma) = F_0 + F_2 \beta^2 + F_3 \beta^3 \cos3\gamma + F_4 \beta^4 + F_5 \beta^5 \cos3\gamma + F_6^{(1)} \beta^6 + F_6^{(2)} \beta^6 \cos^2 3\gamma + \qquad (3)$$

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 ^{120}Sn nucleus. Then the angular momentum is brought in within the cranking approach. Up to second order in cranking frequency ω the free energy is given by

$$F(T,\omega; \beta,\gamma) = F(T, \omega = 0; \beta,\gamma) - (½)\, J_{zz}(T, \beta, \gamma)\, \omega^2 \qquad (4)$$

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

$$J_{zz}(T, \beta,\gamma) = J_0 + J_1 \beta \cos \gamma + J_2^{(1)} \beta^2 + J_2^{(3)} \beta^2 \sin^2 \gamma + J_3^{(1)} \beta^3 \cos3 \gamma + J_3^{(2)} \beta^3 \cos \gamma + J_4^{(1)} \beta^4 + J_4^{(2)} \beta^4 \cos 3\gamma \cos \gamma + J_4^{(3)} \beta^4 \sin^2 \gamma + \ldots \qquad (5)$$

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

The probability for a given shape to occur is

$$P(\beta,\gamma,T,I) \propto \exp[-F(\beta,\gamma,T,I)/T] \quad (6)$$

For a given spin and temperature, consider, an ensemble of nuclei with this distribution of deformations. The ensemble average of β and γ are

$$\overline{\beta} = \langle\beta\rangle = \frac{\int \beta\, P(\beta,\gamma)\, \beta^4 |\sin 3\gamma|\, d\beta\, d\gamma}{\int P(\beta,\gamma)\, \beta^4 |\sin 3\gamma|\, d\beta\, d\gamma} \quad (7)$$

Similarly, the ensemble average of γ is,

$$\overline{\gamma} = \langle\gamma\rangle = \frac{\int \gamma\, P(\beta,\gamma)\, \beta^4 |\sin 3\gamma|\, d\beta\, d\gamma}{\int P(\beta,\gamma)\, \beta^4 |\sin 3\gamma|\, d\beta\, d\gamma} \quad (8)$$

where $\beta^4 |\sin 3\gamma|\, d\beta\, d\gamma$ is the Bohr rotation- vibration volume element in the infinitesimal area for polar coordinates β and γ.

Results and Discussion

The aim of this work is to study the shape evolutions in hot rotating ^{120}Sn nucleus using cranked Nilsson Strutinsky method including the most important thermal fluctuations. We performed calculations taking $\gamma = -120^0$ to -180^0 and $\beta = 0.0$ to 0.8 and spin I = 0 to $40\hbar$ for different temperatures. The resulting free energy surfaces are then least square fitted with those of extended Landau theory to extract the respective Landau constants. Then the averaged values of β and γ are evaluated by using equations (7) & (8) to obtain the shape variations with thermal fluctuations.

Figures 1 and 2 show the sample results of shape transitions obtained as a function of spin at temperatures T = 1.5 MeV and T = 2.5 MeV respectively for the case of ^{120}Sn. The shape evolutions obtained with spin at different temperatures without thermal fluctuations using Strutinsky method is also presented for comparison. It is noted from figures 1 &2 that when thermal fluctuations are not included, a sharp shape transition from spherical to oblate is obtained as a function of spin. But when thermal fluctuations are included, these sharp shape transitions then turn into triaxial shapes with γ fascinating between -160^0 and -140^0, which is clearly seen.

The authors are grateful to Prof.G.Shanmugam for his valuable suggestions.

References

[1]K.Sugawara Tenabe et al. Nucl. Phys. **A357**, 45(1981)

[2]Y.Alhassid et al. Nucl. Phys. **A469**, 205(1987)

3]G.Shanmugam and M.Thiagasundaram, Phys. Rev. **C39**, 1623(1989)

[4]G.Shanmugam and V.Selvam, Phys. Rev **C62**, 014302(2000)

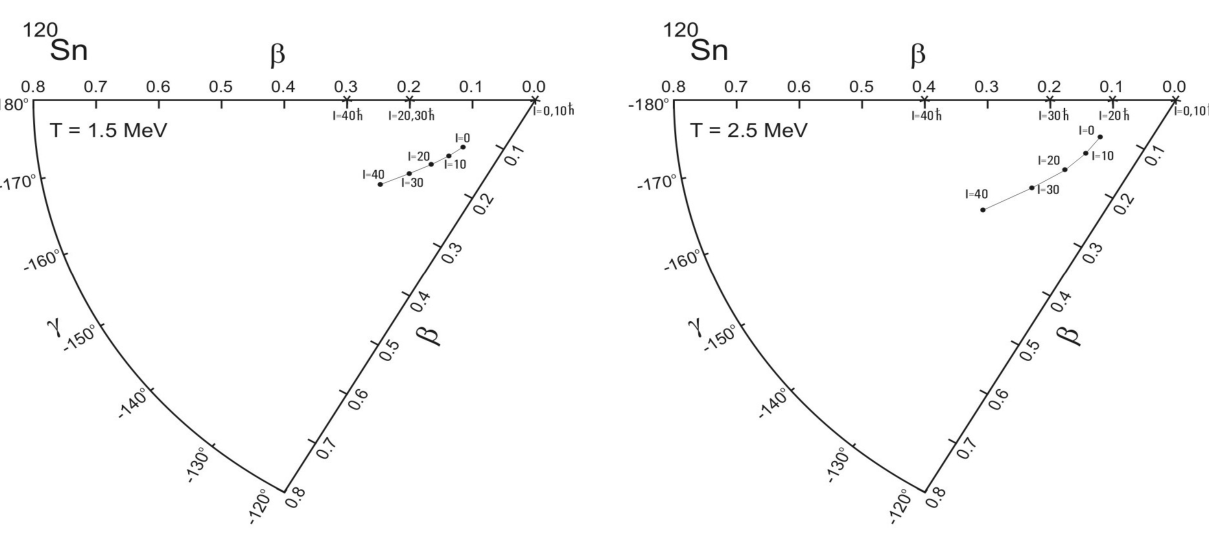

Fig. 1&2