Phase transitions and shape deformations in high spin nuclei

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Introduction

In recent years a renewed interest in the investigation of phase transition has emerged as an exciting area [1]. It is really a fascinating and still open question whether phase transitions do exist in finite systems of nuclei at finite temperature and signature of these transitions remains regardless of fluctuations. This thesis is devoted to the study of the microscopic aspects of phase transitions and shape deformations especially the interplay between spherical, deformed and superdeformed shapes.

In order to study the phase transitions in detail, a statistical theory has been modified incorporating temperature, deformation, angular momentum, collective and non collective rotational degrees of freedom, shell effects and pairing correlations. The basic ingredient to the statistical theory is a suitable shell model level scheme and has used cranked Nilsson Strutinsky (CNS) formalism. Pairing-phase transitions from superfluid to normal state and shape-phase transitions such as deformed to spherical shape, prolate to oblate shapes with increasing temperature and angular momentum are observed. The interplay of various degrees of freedom and their influence on the behavior of nuclei that are of current interests are studied with particular focus to level density, level density parameter, nucleon separation energies and nuclear specific heat to explore these transitions in detail.

Formalism

The grand canonical partition function for a hot rotating nucleus is given by [2]

$$Q(\alpha_Z,\alpha_N,\beta,\lambda)=\sum_i \exp(-\beta E_i+\alpha_Z Z_i+\alpha_N N_i+\lambda M_i) \qquad (1)$$

with respect to the Lagrangian multipliers $\alpha_Z,\alpha_N,\beta,\lambda$ conserve the proton number, neutron number, total energy for a given temperature T = 1/β and angular momentum M along the space fixed z axis and are fixed by the following equations given in terms of single particle energies

$$<N>=\sum_i \left[1+\exp\left(-\alpha_N+\lambda m_i^N+\beta\varepsilon_i^N\right)\right]^{-1}, \qquad (2)$$

$$<Z>=\sum_i \left[1+\exp\left(-\alpha_Z+\lambda m_i^Z+\beta\varepsilon_i^Z\right)\right]^{-1}, \qquad (3)$$

$$<M>=\sum_i n_i^N m_i^N+\sum_i n_i^Z m_i^Z \ , \qquad (4)$$

$$<E>=\sum_i n_i^N \varepsilon_i^N+\sum_i n_i^Z \varepsilon_i^Z \ . \qquad (5)$$

The excitation energy E^* of the system is

$$E^* = E(M, T) - E_0. \qquad (6)$$

The free energy of the system is given as

$$F = E - TS\ . \qquad (7)$$

The specific heat is given as

$$C = \frac{dE^*}{dT}. \qquad (8)$$

The mean square fluctuation of any observable O is given as

$$(\delta O)^2 =< O^2 > - < O >^2. \qquad (9)$$

Calculations are carried out for all the parameters like total energy, excitation energy, specific heat as a function of angular momentum M from 0 η to 16 η, temperature T from 0 MeV to 5 MeV and deformation parameter β from -0.6 to +0.6 (in steps of 0.1). The most probable values are obtained after minimizing the free energy.

Results and discussions

(i) Phase transitions

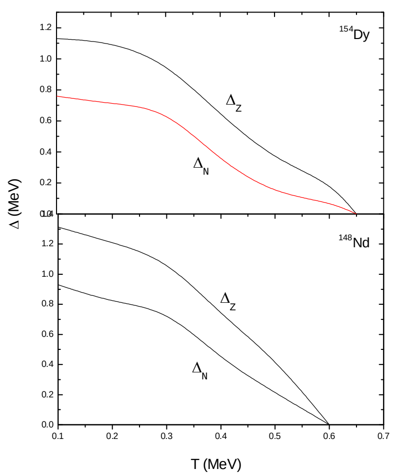
The main intention of this thesis is to study the correlation between pairing and phase transition on the one hand and thermal effects of shape deformation on the other hand with their ability to describe phase transitions.

In these investigations, the following were observed:

a) A pairing-phase transition from superfluid state to normal nuclear matter for temperature T ≈ 0.6 MeV, and angular momentum M > 20 ħ.

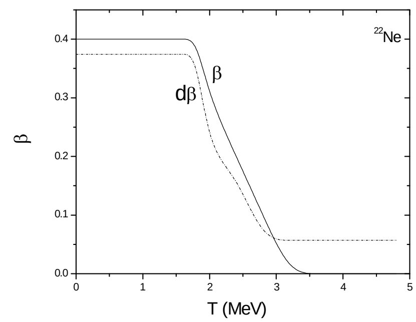
b) A shape-phase transition from prolate collective to oblate noncollective beyond temperature T ≈ 0.6 MeV and angular momentum M > 30 ħ.

c) The influence of pairing correlations and structural changes on the parameters such as level density parameter and nucleon separation energy at high angular momentum states and high excitation energies for hot rotating nuclei like ^{154}Dy.



(ii) Effects of fluctuations

Investigations on thermal evolution of pairing-phase transition and shape-phase transition in nuclei are made as a function of pair gap, deformation, temperature and shape-phase transition in nuclei are made as a function of pair gap, deformation, temperature and angular momentum using a finite temperature statistical approach with main emphasis to fluctuations The occurrence of a peak structure in the specific heat predicted as signatures of the pairing-phase and shape-phase transitions are reviewed including all the quantal and statistical fluctuations and it is found that they are not actually true phase transitions and it is only an artifact of the mean field models. Since quantal fluctuations in particle number and spin, statistical fluctuations in pair gap, deformation degrees of freedom and energy when incorporated, it wash out the pairing-phase transition and smooth out the shape-phase transition.



(iii) Superdeformation

Theoretical investigations on SD bands are also carried out in different mass regions and the general features of SD bands in those regions are investigated exhaustively. Total energy surfaces (TES) have also been generated with main emphasis to shape coexistence. Spectacular instances of coexistence of different shapes within the same nucleus are obtained and have found clear explanations for the existence of different shapes and of the evolution of these minima [3].

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References

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