Investigations of fluctuations on phase transitions in light nuclei

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Introduction

Recently a renewed interest in the study of phase transition has emerged as an exciting topic. 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. Phase transition from superfluid to normal fluid has been investigated based on finite temperature mean field theories such as Bardeen-Cooper-Schrieffer (BCS), Hartree-Fock (HF) and Hartree-Fock-Bogliubov (HFB) formalisms. However the empirical analysis of experimental data does not predict a sudden phase transition, the reason being the neglect of fluctuations in the mean field approximations. Especially in light nuclei, quantal and statistical fluctuations are inevitable in identifying phase transitions [1].

A system at zero temperature has quantal number and spin fluctuations and at finite temperature there are statistical fluctuations in the pair gap, deformation and energy. Very recently a self consistent quasiparticle RPA shows that pairing phase transitions are indeed smoothed out with a long exponential tail that extends up to higher temperature. In the present study, we have extended our investigation of nuclear phase transitions [2] in light nuclei with the inclusion of quantal and statistical fluctuations. Calculations are executed for the fluctuations of selected observables that convey the signals for the phase transition like particle number, spin, pair gap, deformation, and energy using the finite temperature statistical theory. This theory has been used in our earlier calculations pertaining to the evaluation of single particle level density parameter, neutron separation energy and emission probability at high spins. To our knowledge, so far efforts have not yet been made to explain the effects of all these fluctuations in light nuclei hence the present work discusses them in detail.

Formalism

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

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

where 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

$$< N >= \frac{\partial \ln Q}{\partial \alpha_N}. \tag{2}$$

$$< Z >= \frac{\partial \ln Q}{\partial \alpha_Z}. \tag{3}$$

$$< M >= \frac{\partial \ln Q}{\partial \lambda}. \tag{4}$$

$$< E >= -\frac{\partial \ln Q}{\partial \beta}. \tag{5}$$

The excitation energy E^* of the system is

$$E^* = E(M, T) - E_0. \tag{6}$$

The specific heat C as a function of angular momentum M and temperature T is extracted using the equation

$$C = \frac{dE^*}{dT}. \tag{7}$$

The mean square fluctuation of any observable O is given as

$$(\delta O)^2 =< O^2 > - < O >^2. \tag{8}$$

In our calculations all the parameters like total energy, excitation energy, specific heat are evaluated as a function of angular momentum M from 0 η to 16 η, temperature T from 0 MeV to 5 MeV and deformation parameter ε 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

Phase transitions in light nuclei are explored with the inclusion of fluctuations in the relevant order parameters. The nuclear specific heat C versus temperature for M= 0 η is presented in figure 1(a) for ^{20}Ne, ^{22}Ne, ^{24}Mg and ^{28}Si. All the nuclei have a general tendency to exhibit an abrupt change in the specific heat and the peak in specific heat occurs at different temperatures for different nuclei. A small peak appears at $T \approx$ 0.5 MeV for all the four nuclei and a larger peak appears at $T \approx 2.0$ MeV for ^{22}Ne, $T \approx 2.7$ MeV for ^{20}Ne and at $T \approx 3.5$ MeV for ^{24}Mg and ^{28}Si. The shape of these curves is analogous to the one reported in Ref. [3] for all the light nuclei. Figure 1(b) illustrates the results of level density calculations with a sudden change around the critical temperature for all the nuclei. It is obvious that the abrupt change in the level density coincides with the peaks in the specific heat at the higher temperature. Thus the peaks in the specific heat in all cases are the result of a sudden increase in the many body level density around the critical temperature.

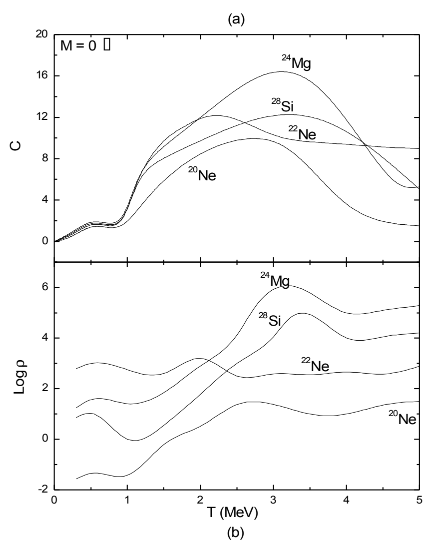

Fig. 1

For light nuclei, both quantum as well as statistical fluctuations is important. Of particular importance are the statistical fluctuations in the pair gap Δ which are prominent at finite temperature. The temperature dependence of pair gap Δ for ^{22}Ne without fluctuations is depicted in figure 2 and it shows the monotonous decrease in pair gap with increasing temperature. At one particular temperature pairing has got completely vanished representing a phase transition from paired to unpaired configuration. However, statistical fluctuations in pair gap when considered; Δ becomes non zero even at high temperature. Thus, the occurrence of pairing-phase transition is safely ruled out, since most of the pair correlations are generated by the fluctuations of the pair field, which are more established than the mean field itself. For all the nuclei considered, the effect of washing out the sharp phase transition from superfluid to normal driven by temperature is obvious and so we can conclude that there is no true phase transition and this may be due to the finiteness of space involved in the calculation.

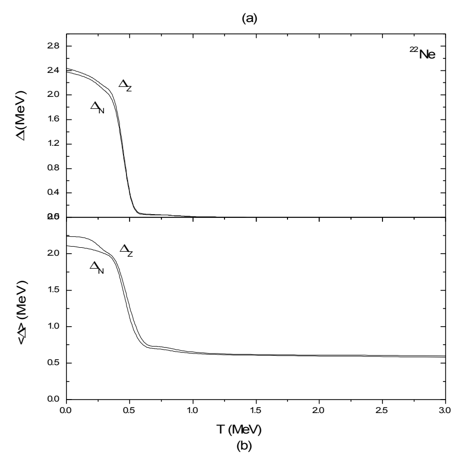

Fig. 2

Acknowledgment

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