Influence of thermodynamic pairing on entropy and heat capacity of ^{94}Mo

J. Dhivya Saranya[1], S. Prasanna Kumari[1], N. Boomadevi[1], S. Selvaraj[2], and *T. R. Rajasekaran[1]

[1]*Department of Physics, Manonmaniam Sundaranar University, Tirunelveli - 627012, INDIA*
[2]*Department of Physics, The M.D.T Hindu College, Tirunelveli - 627010, INDIA*
** email: trrajasekaran@gmail.com*

Introduction

A challenging goal in nuclear physics is to deduce the thermodynamical quantities as functions of excitation energy. These quantities depend on statistical properties in the nuclear many-body system and may reveal phase transition. The density of levels as a function of excitation energy is the starting point to extract quantities such as entropy, heat capacity and temperature. Recently a good deal of attention has been devoted to the investigation of nuclear pairing correlations and phase transition. For larger systems, the phase transition was explained by the Bardeen – Cooper – Schrieffer (BCS) mean – field theory. In our former work [1], we have investigated the nuclear specific heat as a function of temperature and angular momentum for seven even – even 2s – 1d shell nuclei (small system) to confirms the phase transition by using statistical theory of hot rotating nuclei (STHR). The nuclear specific heat is one of the crucial tools to study the existence of phase transition. For the complete understanding of the nature of phase transition a probe is primarily established on the nuclear specific heat with pairing correlation in statistical approach. A signature of such a phase transition would be the S shape of the heat capacity as a function of temperature. It has been argued that the S shapes are a fingerprint of the superfluid – to – normal phase transition, because such S shapes occur if continuity is taken between heat capacity in the superfluid phase and that in the normal fluid phase.

Formalism

Statistical descriptions of finite nuclear systems are generally based on grand canonical ensemble averages. The theoretical framework of the statistical theory of hot rotating nuclei (STHR) is used for two cases: i) without pairing correlations, ii) with pairing correlations [2].

The Fermi gas nuclear level density at an internal excitation energy U is obtained using the formula,

$$\rho(E) = \eta \frac{\mathrm{EXP}^{(2\sqrt{aU})}}{12\sqrt{2}a^{1/4}U^{5/4}\sigma_I}. \qquad (1)$$

where, η is the normalization constant. a is the single particle level density parameter and σ_I is the spin cut-off parameter. The internal excitation energy U of the residual nucleus is given by,

$$U = E^* - E_{rot} - S_N - E_n. \qquad (2)$$

The quantities $E^*$is the total excitation energy, S_N is the neutron separation energy, E_n is the outgoing neutron energy. Rotational energy E_{rot} is given by,

$$E_{rot} = E(M, T) - E(0, T). \qquad (3)$$

Ericson formula of level density is given by,

$$\rho(E) = \frac{1}{16}\left(\frac{\pi^2}{a}\right)^{1/4} E^{-5/4}\exp(2\sqrt{aE}) \qquad (4)$$

Specific heat can also be calculated from entropy S and total energy E, defined as,

$$C_V = \frac{\partial E}{\partial T} \quad \text{and} \quad C_V = T.\frac{\partial S}{\partial T} \qquad (5)$$

Results and discussion:

In this work, we consider ^{94}Mo for numerical calculations. For these calculations,

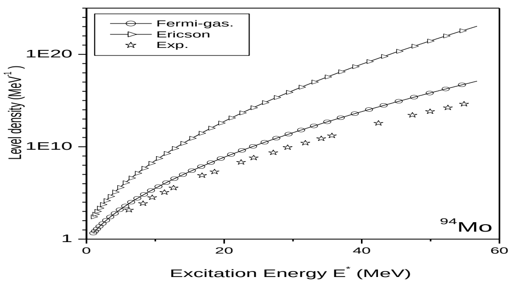

Fig. 1 Level density as a function of excitation energy

we use the deformed Nilsson harmonic-oscillator potential to generate single particle energies upto N=11 levels which are found to be sufficient for the range of temperature.

From fig.1 we see that, the calculated Fermi-gas level density is found to be in good agreement with the experimental [3] Fermi-gas back-shifted level density. The discrepancy between Ericson and experimental results seems to be large and increase with excitation energy for ^{94}Mo nucleus.

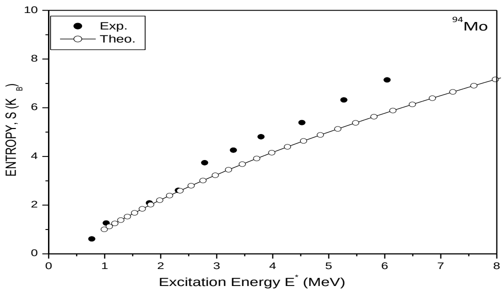

Fig. 2 Entropy as a function of temperature

From the fig.2, it is obvious that the calculated entropy agrees with the experimental data [3] at low excitation energy for the nucleus ^{94}Mo.

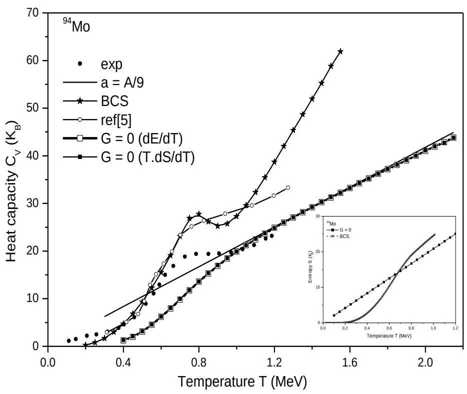

Fig. 3 Total heat capacity (filled stars) as a function of temperature for ^{94}Mo. Experimental data (closed circles) are taken from [4]. The BCS results [5] (open circles) are also shown for comparison. The solid line denotes the Fermi gas values with the level density parameter a = A/9. Open and closed squares give the result for independent – particle model, i.e., for G = 0

The calculated heat capacities as a function of temperature are shown in fig. 3, where the experimental heat capacities [4] and BCS [5] calculations are also plotted for comparison. There is no noticeable change or peak in the specific heat curve due to the without pairing correlation (G = 0). Also it exhibits a very gradual shape transition in the whole range of temperature considered. The inclusion of pairing dramatically changes the situation in the nucleus, where definite peak in the specific heat around T ≈ 0.7 – 0.9 MeV that indicating a pairing phase transition. Although the calculated heat capacities are larger than the corresponding experimental values at low temperature, there is a similarity in the shape of the predicted heat capacity and the observed S-shaped heat capacity for ^{94}Mo. The results with and without pairing term track each other at high temperatures, indicating that pairing is essentially thermally destroyed by approximately T = 1 MeV. The insert fig.3 shows the presence of S-shape in the entropy as a function of temperature. Hence we have demonstrated that S-shape specific heat capacity as the breaking of cooper pairs and phase transition from superfluid to normal nuclear matter. In addition, we have shown that the S-shape in the entropy as other signatures of the phase transition.

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