Neutron and proton system chemical potential in static path approximation of ^{56}Fe

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Introduction

Recently lots of effort has been made to describe level density and thermodynamic quantities of nuclei with microscopic models. For example BCS model based on the Bardeen-Cooper-Schrieffer theory [1-4].

The static-path approximation (SPA) is a useful treatment to evaluate the partition function and therefore thermodynamic quantities and level density in finite systems such as nuclei. In recent theoretical approaches, also small-amplitude fluctuations around the static path have been taken into account. These fluctuations give corrections to the partition function. The static-path plus random-phase approximation (SPA+RPA) method with taking thermal fluctuations to account gives excellent agreement with exact results [5]. In small systems with fixed particle number, the canonical partition function should be employed. In this work we have used number-parity projected SPA [6] partition function to calculate chemical potential of neutrons and protons system in ^{56}Fe. The results have been compared with BCS and mean value BCS (MVBCS[7]) results.

Method

We start from a monopole pairing Hamiltonian:

$$H = \sum_{\tau,k} \varepsilon_{k,\tau}\left(c^{\dagger}_{k,\tau}\, c_{k,\tau} + c^{\dagger}_{\bar{k},\tau}\, c_{\bar{k},\tau}\right) - \sum_{\tau} G_{\tau}\, P^{\dagger}_{\tau} P_{\tau} \qquad (1)$$

Where $\tau = n, p$ and $\bar{k}$ denotes the time reversed state.

$\varepsilon_{k,\tau}$ is a single-particle energy and P_{τ} is the pairing operator.

In SPA+RPA approach based on Hubbard-Stratonovich transformation, the number-parity projected partition function is given by [8]:

$$Z = \prod_{\tau} \frac{2}{G_{\tau} T} \int_{0}^{\infty} d\Delta_{\tau}\, \Delta_{\tau}\, e^{\frac{-\Delta_{\tau}^{2}}{G_{\tau} T}} Z_{\tau}(\Delta)\, C^{\tau}_{RPA} \qquad (2)$$

here

$$Z_{\tau}(\Delta) = \prod_{k} 2e^{-\frac{\gamma_{k,\tau}}{\mathrm{T}}} \cosh^{2}\left(\frac{1}{2\mathrm{T}}\lambda_{k,\tau}\right) \times \left[1 + \sigma \prod_{\acute{k}} tanh^{2}\left(\frac{\lambda_{k,\tau}}{\mathrm{T}}\right)\right] \qquad (3)$$

Where $\lambda_{k,\tau} = \sqrt{\varepsilon'^{\,2}_{k,\tau} + \Delta_{\tau}^{\,2}}$ is quasiparticle energies, $\varepsilon'_{k,\tau} = \varepsilon_{k,\tau} - \mu_{\tau} - \frac{G_{\tau}}{2}$ and $\gamma_{k,\tau} = \varepsilon_{k,\tau} - \mu_{\tau} - \lambda_{k,\tau}$. σ denotes even or odd number parity. With $C^{\tau}_{RPA} = 1$, eq. (2) reduces to the partition function in SPA approach.

Chemical potential of neutrons and protons system in nuclei can be deduced with the use of conservation of particle number of nucleons:

$$N = T\frac{\partial ln Z_{SPA}}{\partial \mu} \qquad (4)$$

Conservation of particle number condition can be applied to the partition functions in BCS and MVBCS and chemical potential can be deduced in these approaches too.

Results

Chemical potential of neutrons and protons system in ^{56}Fe have been extracted in static path approximation. Calculated chemical potentials are shown in Fig.1 as a function of temperature.

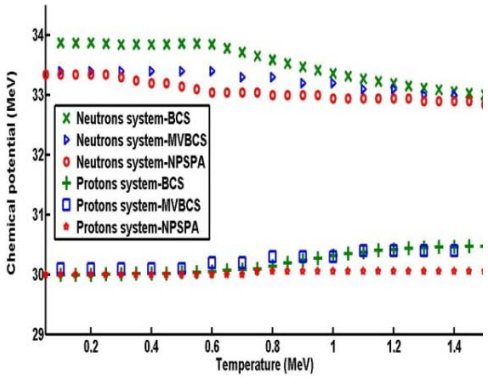

Fig. 1 Plot of chemical potential of nucleons system in ^{56}Fe, calculated in NP-SPA along with corresponding values calculated in other microscopic models.

Also corresponding Chemical potentials are calculated in BCS model and MBCS model that use mean value, instead of most probable value for gap parameter. The results are shown in Fig.1 for comparison.

References

[1] J. Bardeen, L. N. Cooper & J. R. Scheriffer, Phys. Rev, 108, 1175 (1957) .
[2] R. Razavi, Phys. Rev. C 88, 014316 (2013).
[3] R. Razavi et al., Nucl. Phys. A 930, 57 (2014).
[4] R. Razavi et al., Indian Journal of Pure and Applied Physics, 50,706 (2012).
[5] K. Kaneko, M. Hesegawa, et al., Phys. Rev. C74, 024325 (2006).
[6] R. Rossignoli et al., Phys. Rev. Lett. 80, 1853 (1998).
[7] R. Razavi and V. Dehghani, Int. J. Mod. Phys. E 23, 1450015 (2014).
[8] K. Kaneko etal., Phys. Rev. C **76**, 064306 (2007).