Nuclear pairing studies on ^{72}Se

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Introduction

Pairing correlations are considered as the dominant many-body correlation after nuclear mean-field. Bardeen-Cooper-Schrieffer (BCS) theory, which initially explained superconductivity in solids was also developed in the case of nuclei. The thermal effect on nuclear pairing has been studied within the finite temperature BCS (FTBCS) theory. This was further extended to include the effects of angular momentum, so that it can be applied to study hot and rotating nuclei. In this work, we study the temperature and angular momemntum dependence on pairing gap of ^{72}Se and its entropy.

Theoretical Framework

The Hamiltonian of a system of nucleons interacting with the pairing force with constant pairing strength G and is rotating about z-axis written as follows [1].

$$\hat{H} = \hat{H}_P - \lambda\hat{N} - \gamma\hat{M} \tag{1}$$

here $\hat{H}_P$ is the well-known pairing Hamiltonian, can be written as

$$\hat{H}_P = \sum_k \epsilon_k(A_k + A_{-k}) - G\sum_{kk'} P_k^\dagger P_{k'} \tag{2}$$

$$A_{\pm k} = a_{\pm k}^\dagger a_{\pm k}, P_k^\dagger = a_k^\dagger a_{-k}^\dagger\ . \tag{3}$$

Where $\hat{N}$ is the number of particles, $\hat{M}$ is the projection of the total angular momentum on a laboratory-fixed z-axis.

$$\hat{N} = \sum_k(A_k + A_{-k}), \hat{M} = \sum_k m_k(A_k - A_{-k}) \tag{4}$$

Here k is used to label the single-particle states and m_k is the single-particle spin projections. λ and γ are chemical potential and angular velocity and also are the two Lagrange multipliers which is to be determined later on.

The grand potential after Bogloliubov transformation and diagonalisation of hamiltonian can be written as

$$\begin{aligned}\Omega = &-\beta\sum_k(\epsilon_k - \lambda - E_k)\\ &+\sum_k \ln[1+\exp(-\beta(E_k - \gamma m_k))]\\ &+\sum_k \ln[1+\exp(-\beta(E_k + \gamma m_k))] - \beta\tfrac{\Delta^2}{G}\ .\end{aligned} \tag{5}$$

Where E_k is the quasiparticle energy and β the statistical temperature in MeV.

$$E_k = \sqrt{(\epsilon_k - \lambda)^2 + \Delta^2} \tag{6}$$

The standard choice for the gap parameter (Δ) is the value that minimizes the grand potential (Ω), so by minimizing Ω we get the FTBCS gap equation.

$$\begin{aligned}\tfrac{2}{G} = \textstyle\sum_k \tfrac{1}{2E_k}\Big[&[\tanh\tfrac{\beta}{2}(E_k - \gamma m_k)\\ &+\tanh\tfrac{\beta}{2}(E_k + \gamma m_k)\Big]\end{aligned} \tag{7}$$

$$\begin{aligned}N = \textstyle\sum_k\Big[1 - \tfrac{(e_k-\lambda)}{2E_k}\Big(&\tanh\tfrac{\beta}{2}(E_k - \gamma m_k)\\ &+\tanh\tfrac{\beta}{2}(E_k + \gamma m_k)\Big)\Big]\end{aligned} \tag{8}$$

$$\begin{aligned}M = \textstyle\sum_k m_k\Big[&\tfrac{1}{1-exp\beta(E_k-\gamma m_k)}\\ &-\tfrac{1}{1-exp\beta(E_k+\gamma m_k)}\Big]\end{aligned} \tag{9}$$

Results

The single particle energies and spin states are generated at $T = 0$ within the de-

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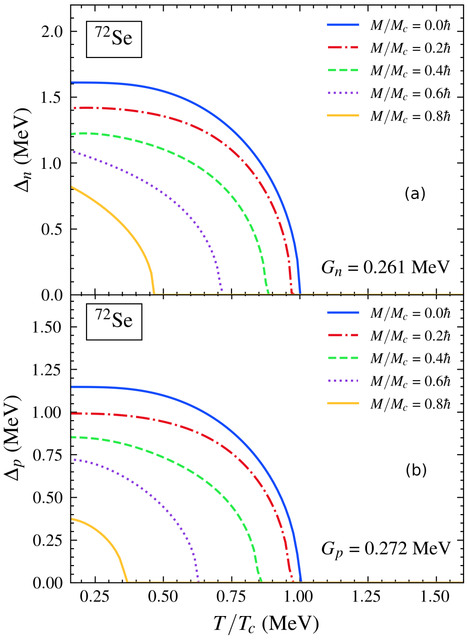

FIG. 1: Pairing gap as a function of T at various M obtained within the FTBCS for (a) neutrons and (b) protons in ^{72}Se using $G_n = 0.261$ MeV and $G_p = 0.272$ MeV.

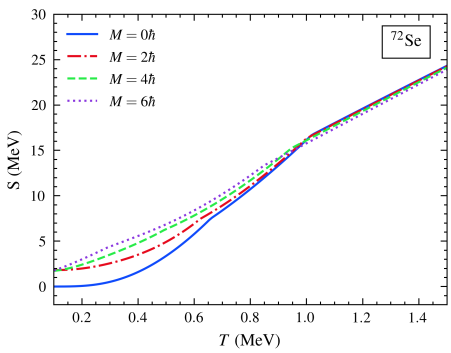

FIG. 2: Entropy as a function of T at different values of angular momentum M within the FTBCS model.

formed Wood-Saxon potential using WS-BETA code [2], where the deformation parameters are taken from FRDM 2012 [3]. In Fig. 1, the thermal effect of neutron and proton pairing gap is studied by numerically solving the non-linear coupled equations (7) to (9) for ^{72}Se at various M. The values of T_c (at $M = 0$) and M_c (at $T = 0$) are found equal to 0.91 MeV and $12\hbar$ for neutron and 0.66 MeV and $8\hbar$ for proton respectively. The pairing gaps decreses with increase in the temperature.

In Fig.2, the entropy of the total system is plotted as a function of T for various M. The effect of nuclear pairing can be seen at low temperature $T < T_c$ and also this effect reduces as M approches M_c. At $T > T_c(M = 0)$ the angular momentum has insignificant effect on entropy. The effect is maximum at $T = 0$ and $M = 0$.

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