Pairing correlation and quasi-particle resonances in neutron drip-line nuclei

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In neutron drip-line nuclei, which have an extremely shallow Fermi surface, the pairing correlation is expected to influence low-energy scattering and resonances of a neutron. An interesting phenomenon predicted in the theory of superfluid nuclei is quasi-particle resonance.\(^1\)\(^-\)\(^3\) A scattering neutron can couple to a hole state by creating a Cooper pair and thus resulting in a narrow resonance. The quasi-particle resonance has also been studied for neutron drip-line nuclei.\(^4\)\(^-\)\(^6\) As neutron drip-line nuclei are expected to provide better opportunities for observation of quasi-particle resonance, we study these drip-line nuclei to clarify the properties of quasi-particle resonance. In the present study, we focus on the influence of the pairing on the resonance width.

We use the coordinate space Hartree-Fock-Bogoliubov (cHFB) equation\(^7\) to describe the scattering wave function of a neutron under the pairing effect. We solve the cHFB equation such that the quasi-particle wave function satisfies the scattering boundary condition:

\[
\begin{pmatrix}
  u_{lj}(r) \\
  v_{lj}(r)
\end{pmatrix}
\rightarrow
\begin{pmatrix}
  \cos \delta_{lj} H_l(k_1 r) - \sin \delta_{lj} n_l(k_1 r) \\
  D_h^{(1)}(\kappa_2 r)
\end{pmatrix},
\]

where \(k_1 = \sqrt{2m(\lambda + E)/\hbar}\), \(\kappa_2 = \sqrt{-2m(\lambda - E)/\hbar}\). Here, \(m\), \(\lambda\) and \(E\) are the mass of neutron, Fermi energy and quasi-particle energy, respectively. Next, we calculate the phase shift \(\delta_{lj}\) and the elastic cross section.

We consider the \((^{46}\text{Si} + n)\) system. According to several HFB calculations, \(^{46}\text{Si}\) is a neutron drip-line nucleus of Si isotopes. We assume that this nucleus has a spherical shape. Note that \(^{46}\text{Si}\) has a weakly bound \(2p_{1/2}\) orbit. We use the Woods-Saxon potential as the nuclear potential, and the pair potential is also assumed to have the Woods-Saxon shape. The averaged pairing gap \(\Delta\) is a strength of the pair potential.

Fig.1 shows the calculated partial cross section. Narrow low-lying peaks seen in \(p_{1/2}\) and \(p_{3/2}\) are the quasi-particle resonances. These peaks disappear if we switch off the pairing as they are originally weakly bound \(2p_{1/2}\) and \(2p_{3/2}\) orbits in the Woods-Saxon potential. In order to analyze the effect of pairing on the resonance width, we calculate the width of the \(p_{1/2}\) resonance for various pairing strengths \(\Delta\). We extract the resonance width and resonance energy from the phase shift using a fitting method. The green line in Fig 2 shows the relation between the resonance width and the resonance energy for various values of \(\Delta\). As the pairing strength increases, both the resonance width and the resonance energy increase. For comparison, we plot the width vs. energy relation for the single-particle potential resonance of the \(2p_{1/2}\) state (red line in Fig.2), which is obtained by varying the depth of the Woods-Saxon potential \(V_0\). If we compare these two results at the same resonance energy, we find that the width of quasi-particle resonance is narrower than the width of single-particle potential resonance. We conclude that the pairing has an effect of reducing the resonance width.

![Fig. 1. Partial cross section with \(\Delta = 1.0\) MeV.](image)

![Fig. 2. Comparison of results of resonance width.](image)

References
2) A. Bulgac: nucl-th/9907088.

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