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:

$$\begin{pmatrix} u_{lj}(r) \\ v_{lj}(r) \end{pmatrix} \to \begin{pmatrix} \cos\delta_{lj} j_l(k_1 r) - \sin\delta_{lj} n_l(k_1 r) \\ D h_l^{(1)}(\kappa_2 r) \end{pmatrix}, \quad (1)$$

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

We consider the (^{46}Si+n) system. According to several HFB calculations, ^{46}Si is a neutron drip-line nucleus of Si isotopes. We assume that this nucleus has a spherical shape. Note that ^{46}Si has a weakly bound $2p$ 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 $\bar{\Delta}$ 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 $\bar{\Delta}$. 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 $\bar{\Delta}$. 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

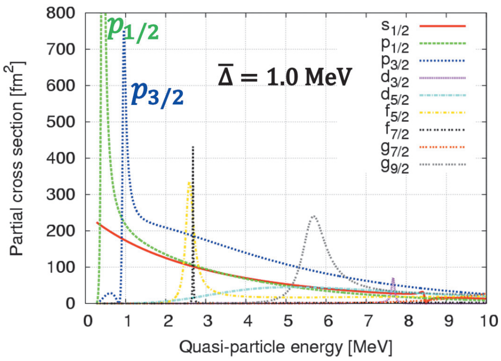

Fig. 1. Partial cross section with $\bar{\Delta} = 1.0$MeV.

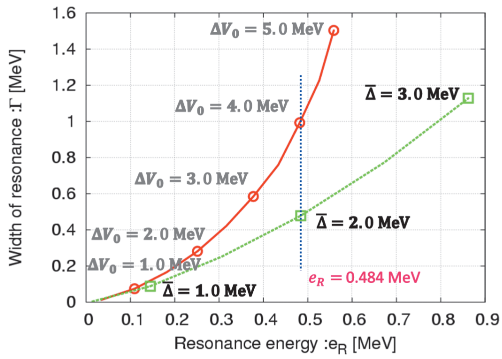

Fig. 2. Comparison of results of resonance width.

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