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Collective excitations induced by pairing anti-halo effect

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Abstract. We emphasize a special interplay of loosely-bound neutrons with small orbital angular momentum ℓ and self-consistent pairing correlations for low-lying collective vibrational excitations in neutron drip line nuclei. Change of the spatial structure in quasiparticle wave functions by self-consistent pairing correlations leads to the broad localization of two-quasiparticle states with low-ℓ neutrons. We show that the broad localization can cause the enhancement of the low-lying collectivity. By performing HFB plus quasiparticle random phase approximation (QRPA) calculation for the first 2^+ states in neutron rich Ni isotopes, the unique role of self-consistent pairing correlations is examined. Finally we make a comment on deformation effects for low-lying vibrational excitations in neutron drip line nuclei.

PACS. 21.10.Re Collective levels – 21.60.Ev Collective models – 21.60.Jz Hartree-Fock and random-phase approximations

1 Introduction

Vibrational excitations are microscopically represented by coherent superposition of two-quasiparticle states (or one-particle–one-hole ($1p$-$1h$) states in closed shell nuclei), and the spatial localization of two-quasiparticle states is one of the important conditions to produce correlations among them.

In stable nuclei, because tightly-bound states are mainly involved in the low-lying vibrational excitations, the two-quasiparticle states spatially concentrate around the surface region. In neutron drip line region, by contrast, the contributing single-particle states are loosely-bound states, resonant states and non-resonant continuum states. Because the two-quasiparticle states among them have a rich variety of spatial structures, we may expect qualitatively new aspects of low-lying vibrational excitations in neutron drip line nuclei.

In the present study we analyze the spatial structure of the two-quasiparticle states involving loosely-bound and resonant states of low-ℓ neutrons. We emphasize the unique role of self-consistent pairing correlations for their induced spatial localization, the broad localization, and the possible enhancement of low-lying collectivity in neutron drip line nuclei.

2 Spatial structure of two-quasiparticle states

We examine the spatial structure of the neutron quadrupole two-quasiparticle states in ^{86}Ni, that is the neutron drip line nucleus within Hartree-Fock (HF) calculation with Skyrme SLy4 force. In this section we solve the simplified Hartree-Fock-Bogoliubov (HFB) equation in coordinate space [1,2]. For the mean field, the spherical Woods-Saxon potential with $V_{\rm WS} = -41.4\,$MeV and $R_{\rm WS} = 5.5\,$fm are used. These parameters simulate the neutron shell structure in ^{86}Ni. The calculated neutron single-particle states around the Fermi level of $3s_{1/2}$ ($\varepsilon_h = -0.50\,$MeV) are $2d_{5/2}$ ($\varepsilon_h = -1.77\,$MeV), resonant $d_{3/2}$ ($\varepsilon_p \approx 0.14\,$MeV), and resonant $g_{7/2}$ ($\varepsilon_p \approx 0.98\,$MeV). The index h (p) represents all necessary quantum numbers to specify the hole (particle) state.

The spatial distribution of the particle-hole component of the two-quasiparticle state with a hole part $v_{lj}(E_{lj,n}, r)$ and a particle part $u_{l'j'}(E_{l'j',n'}, r)$ [1,2] is defined by

$$F_{uv}^{(L)}(r) \equiv \{r u_{l'j'}(E_{l'j',n'}, r)\} r^L \{r v_{lj}(E_{lj,n}, r)\}/N_{uv}\,. \quad (1)$$

The normalization factor, $N_{uv} = u_{l'j',n'} v_{lj,n}$, is introduced, and the coefficient $u_{l'j',n'}$ ($v_{lj,n}$) is the norm of the wave function $u_{l'j'}(E_{l'j',n'}, r)$ ($v_{lj}(E_{lj,n}, r)$). L is the multipolarity of the transition, and monopole transitions are taken into account with $L = 2$. $E_{lj,n}$ is the quasiparticle energy. In our analysis the continuum states are discretized by imposing the box boundary condition with a box radius $R_{box} = 75\,$fm. The distribution without pairing, $F_{ph}^{(L)}(r)$, is similarly defined [1,2].

In fig. 1 the spatial distribution of the low-lying neutron quadrupole $1p$-$1h$ excitations without pairing of the configurations; (a) $3s_{1/2} \to$ resonant $d_{3/2}$, (b) $2d_{5/2} \to$ resonant $d_{3/2}$, and (c) $2d_{5/2} \to$ resonant $g_{7/2}$, are shown. They are localized around the surface region, and the correlations among them can cause some collectivity. However the configuration (a) only has the sizable component outside the surface that cannot correlate with the other $1p$-$1h$ states. Therefore the first 2^+ state, that is a discrete

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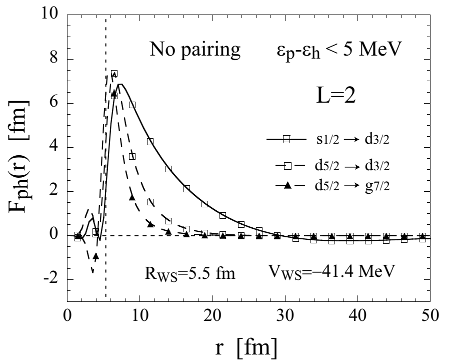

Fig. 1. The spatial distribution of the neutron quadrupole $1p$-$1h$ states with $\varepsilon_p - \varepsilon_h < 5\,\text{MeV}$ in ^{86}Ni.

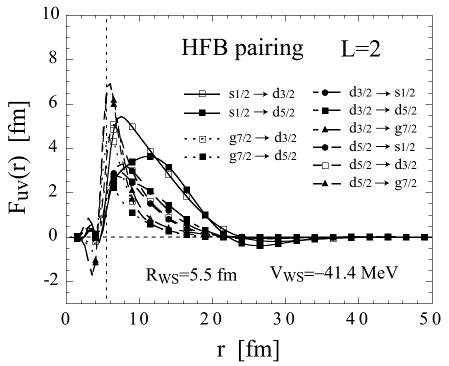

Fig. 2. The spatial distribution of the neutron quadrupole two-quasiparticle states among the low-lying resonant $s_{1/2}$, $d_{3/2}$, $d_{5/2}$, and $g_{7/2}$ states in ^{86}Ni.

solution in RPA, behaves as a single-particle like excitation with the dominant component of (a) [1,2].

Pairing correlation is one of the important ingredients in low-lying collective vibrational excitations. By taking into account pairing correlation, as known in stable nuclei, not only the particle-hole channel but also the particle-particle and hole-hole channels participate in vibrational excitations, and help to increase the collectivity. In addition, self-consistent pairing correlations have unique effects that change the spatial structure of quasiparticle wave functions in loosely-bound nuclei; namely "the pairing anti-halo effect" in the lower component $v_{lj}(r)$ [3], and "the broadening effect" in the upper component $u_{lj}(r)$ [2]. These effects are more prominent in lower-ℓ neutrons.

In fig. 2 the spatial distributions of the two-quasiparticle states among the neutron low-lying resonant $s_{1/2}$, $d_{3/2}$, $d_{5/2}$, and $g_{7/2}$ states are shown. The quasiparticle wave functions at the lowest resonant peak energy are adopted for the plot. The distributions involving the s and d states have sizeable components around the spatially extended region, $10\,\text{fm} < r < 20\,\text{fm}$, in addition to the surface region where the localization is achieved in stable nuclei. We call such spatially extended but localized distribution "the broad localization". On the other hand the two-quasiparticle states with the $g_{7/2}$ state concentrate only around the surface region. The broad localization among low-ℓ neutrons can have the large transition

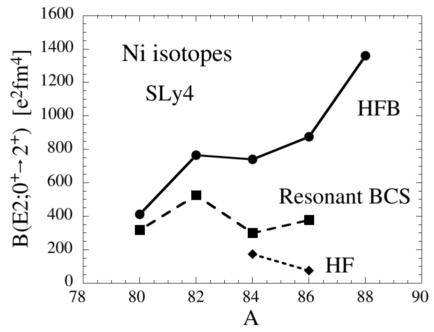

Fig. 3. The $B(E2, 0_1^+ \to 2_1^+)$ values of the first 2^+ states in neutron rich Ni isotopes calculated by HFB plus QRPA, resonant BCS plus QRPA, and RPA with Skyrme SLy4 force.

matrix elements, and may cause the enhancement of the low-lying collectivity in neutron drip line nuclei [2].

3 HFB plus QRPA calculations

By performing HFB plus QRPA calculation with Skyrme SLy4 force, we investigate the first 2^+ states in neutron rich Ni isotopes. In fig. 3 the $B(E2, 0_1^+ \to 2_1^+)$ values of the first 2^+ states up to ^{88}Ni are shown. These states are discrete solutions below the threshold energies. For comparison the results by resonant BCS plus QRPA and RPA are also shown. As approaching the neutron drip line, the $B(E2)$ values increase in HFB plus QRPA, on the other hand, decrease in resonant BCS plus QRPA, and much smaller in RPA. The broad localization is realized only in HFB, and causes the qualitative difference of the low-lying excitations [1,2].

4 Roles of quadrupole deformation

Finally we briefly mention the effects of quadrupole deformation. Because of the breaking of the rotational symmetry and the mixing of isoscalar and isovector modes in deformed neutron drip line nuclei, the low-lying negative parity excitations with $K^\pi = 0^-, 1^-$ are conjectured to behave like collective soft dipole modes with pear ($Y_{10} + Y_{30}$ mixed) or banana ($Y_{11} + Y_{31}$ mixed) shape vibration. The possibility of the strong collectivity enhancement by the interplay of self-consistent pairing correlations and loosely-bound low-Ω neutrons, where Ω is the component of one-particle angular momentum along the symmetry axis, is discussed.

References

1. M. Yamagami, in *Proceedings of the Fifth Japan-China Joint Nuclear Physics Symposium*, edited by Y. Gono, N. Ikeda, K. Ogata (Kyushu University, Fukuoka, 2004) p. 218, preprint nucl-th/0404030.
2. M. Yamagami, submitted to Phys. Rev. C, preprint nucl-th/0504059.
3. K. Bennaceur *et al.*, Phys. Lett. B **496**, 154 (2000).