Dineutron correlation and large quadrupole collectivity in deformed Mg isotopes near neutron drip line

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Dineutron correlation is one of the exotic features in nuclei near the neutron drip line. The pair excitation into continuum states plays a key role in creating the strong spatial correlation between two neutrons. Dineutron correlation is considered to be a universal phenomenon around the drip line but the experimental evidence is still under intense debate except for light mass nuclei. In this study, we discuss low-lying quadruple excitations in deformed Mg isotopes to clarify the continuum effects in pairing correlation, which could suggest the presence of dineutron correlation.

First, we solve the Hartree-Fock-Bogoliubov (HFB) equation with Skyrme energy density functional (EDF). We demonstrate the result using the SkM* EDF but the UNEDF0 EDF draws the same conclusion. The pairing correlation is active for single-particle states whose energy ε satisfies $\varepsilon < \lambda + E^{(+)}_{\rm pair}$. Here, λ is the chemical potential and $E^{(+)}_{\rm pair} = 10$ MeV is used. The predicted neutron drip line nucleus is ^{44}Mg with neutron chemical potential $\lambda_n = -0.15$ MeV. The quadrupole deformations of ^{34,36,38,40,42,44}Mg are $\beta_2 = 0.35$, 0.30, 0.28, 0.28, 0.21, and 0.15, and the neutron pairing gaps are $\Delta_n = 1.21$, 1.20, 1.17, 0.98, 1.05, and 1.00 MeV respectively.

On top of the HFB states, we solve the quasiparticle random phase approximation (QRPA) equation in the matrix form.[1)] Figure 1 shows the $K^\pi = 0^+$ isoscalar quadrupole transition strength $B(Q^{\rm IS}2; E_\nu) = |\langle\nu| r^2 Y_{20} |0\rangle|^2$ to the excited state $|\nu\rangle$ at excitation energy E_ν in ^{40,42,44}Mg. The QRPA excitation is generated by the coherent superposition of excitations of both particle-hole and particle-particle types. The transition strengths without the dynamical pairing effects, *i.e.*, QRPA calculation ignoring the residual pairing interactions, are also shown.

It should be noted that the transition strength of low-lying states significantly reduces when the dynamical pairing effect is ignored. This excitation mode is induced by the fluctuation of neutron-pair occupation in Nilsson orbits with different spatial shapes. For example, the prolate-type orbits [310]1/2 and [301]1/2, and the oblate-type orbit [303]7/2 are the main contributors around ^{40}Mg.

Figure 2 shows the summation of strength $S_{\rm IS2}(6\ \text{MeV}) = \sum_{0<E_\nu<6\ \text{MeV}} B(Q^{\rm IS}2; E_\nu)$. In ^{34,36}Mg, the typical model size for stable nuclei, $E^{(+)}_{\rm pair} = 4$ MeV, gives reasonable results. The effect of continuum states above $E^{(+)}_{\rm pair} = 4$ MeV becomes gradually sizable as it approaches the drip line. $S_{\rm IS2}(6\ \text{MeV})$ converges with $E^{(+)}_{\rm pair} = 10$ MeV. It should be noted that the single-particle state with $\varepsilon \approx 10$ MeV has a wave number $k \approx 0.27$ fm^{-1} and the spatial size $\Delta x \approx 1/k \approx 3.7$ fm corresponds to the diameter of a dineutron predicted around ^{40}Mg.[2)]

Figure 2 also shows the $S_{\rm IS2}(6$ MeV) of RPA and QRPA ignoring the dynamical pairing correlation. These two results coincide with each other except for ^{44}Mg. $S_{\rm IS2}(6$ MeV) increases by 38.9% when static pairing correlation is added in ^{44}Mg. This is due to an additional particle-hole configuration from the resonant state [321]1/2 to resonant state [301]1/2.

In conclusion, the coupling to continuum states in pairing correlation enhances the low-lying transition strengths of $K^\pi = 0^+$ isoscalar quadruple excitations in Mg isotopes near the neutron drip line. This suggests the presence of dineutron correlations.

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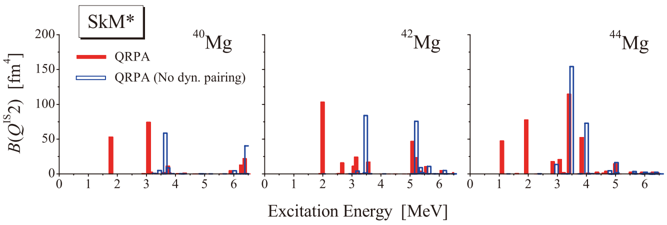

Fig. 1. $K^\pi = 0^+$ isoscalar quadrupole transition strengths with $E^{(+)}_{\rm pair} = 10$ MeV in ^{40,42,44}Mg. QRPA strengths ignoring the dynamical pairing effect are compared.

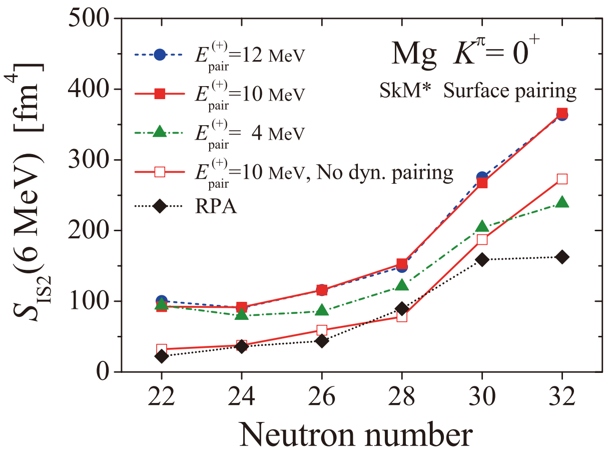

Fig. 2. Summation of strength $S_{\rm IS2}(6$ MeV) in neutron-rich Mg isotopes are shown. Effects of continuum states and pairing correlation are investigated.

References

1) M. Yamagami *et al.*, RIKEN Accel. Prog. Rep. **50**, 92 (2017).
2) M. Yamagami *et al.*, Phy. Rev. C **77**, 064319 (2008).