Proton-neutron pairing vibrations in ^{40}Ca: Precursory soft mode of the isoscalar spin-triplet pairing condensation[†]

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The pairing correlation plays a central role in low-energy nuclear phenomena. The correlation is so strong that the fluctuations of the pairing gap around its zero equilibrium value develop in nuclei near the closed shell, and the systems get deformed eventually in gauge space when more nucleons are added. The collective pairing vibration emerging in the closed-shell nuclei is thus associated with the occurrence of the pairing condensation.

It is in the isovector and spin-singlet $(T=1, S=0)$ channel that the pairing correlation has been extensively studied. With the advent of the radioactive-isotope beam technology, heavy proton-rich nuclei along the $N=Z$ line have received considerable attention. The isoscalar and spin-triplet $(T=0, S=1)$ pairing correlation is expected to be visible in $N \sim Z$ nuclei because the shell structures around the Fermi levels of both neutrons and protons are similar to each other and the spatial overlap between the neutron and proton single-particle wave functions would be large to form a proton-neutron (*pn*) Cooper pair[1)]. Because of the strongly attractive *pn* interaction in the $^3S_1$ channel, the possible $T=0$ pairing condensate has been discussed theoretically in heavy $N \sim Z$ nuclei[2–4)].

I investigate the possibility of a collective $T=0$ *pn*-pairing vibrational mode in the "normal" phase where the $T=0$ pairing gaps are zero. The *pn* pair excitations are described microscopically based on the nuclear energy-density functional (EDF) method. More precisely, the *pn*-pairing vibrational modes are obtained out of the solutions of the *pn* particle-particle random-phase approximation (ppRPA) equation, and are described as elementary modes of excitation generated by two-body interactions acting between a proton and a neutron. Then, I show that the strongly collective $T=0$ *pn*-pairing vibrational mode emerges when the interaction is switched on.

Figure 1 shows the strength distributions for the monopole $(L=0)$ *pn*-pair-addition and removal transfer $|\langle Z\pm1, N\pm1; \lambda|\hat{P}^\dagger_{T,S}(\hat{P}_{T,S})|Z,N\rangle|^2$ as functions of the RPA frequency ω_λ in ^{40}Ca. In the present calculation, the SGII interaction is used for the particle-hole (ph) channel. For the pp channel, the density-dependent contact interactions are employed. The pairing strength in the $T=1$ channel is fixed as $V_0^{(T=1)} = -390$ MeV fm^3. The pairing strength in the $T=0$ channel is given as $V_0^{(T=0)} = f \times V_0^{(T=1)}$. Factor f is changed to see the effect of the interaction in the $T=0$ channel.

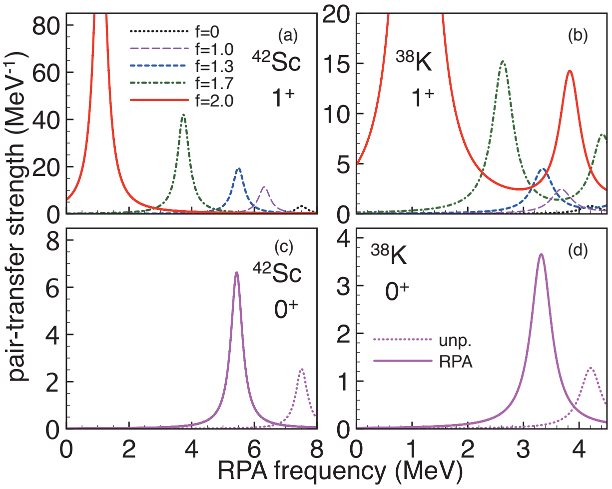

Fig. 1. Monopole *pn* pair-addition strengths of ^{40}Ca → ^{42}Sc and pair-removal strengths of ^{40}Ca → ^{38}K in the $J^\pi = 1^+, T=0$ [(a), (b)] and $J^\pi = 0^+, T=1$ [(c), (d)] states smeared with a width of 0.1 MeV. For the $(J,T)=(1,0)$ channel, the strengths obtained with factors $f = 0, 1.0, 1.3, 1.7$, and 2.0 are shown. For the $(J,T)=(0,1)$ channel, the unperturbed single-particle transition strengths are also shown by a dotted line.

It is clearly visible that the RPA frequency of the $T=0$ *pn*-pairing vibrational mode becomes lower on increasing the pairing strength f. The pairing collectivity generated is sensitive to the shell structure as well as to the interactions. The critical strength is found to be $f_c = 2.04$. A rapid lowering of the RPA frequency seen here indicates the occurrence of true vacuum giving the $T=0$ pairing gaps $\boldsymbol{\Delta} \equiv \langle \hat{P}_{T=0,S=1}\rangle \neq 0$ in the limit of the strong pairing interaction $f > f_c$. Another direct measure of the collectivity is the *pn* transfer strength. One can also see an exponential enhancement in the transition strengths when approaching the critical strength f_c. Therefore the 1^+ state in ^{38}K and ^{42}Sc can be considered as a precursory soft mode of the $T=0$, $S=1$ pairing condensation.

References

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