Dineutron and effective pairing forces in momentum space

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The spatial two-neutron correlation, called dineutron correlation, is one of the unique features around the neutron drip line. The dineutron correlation has been discussed extensively in light-mass nuclei such as ^{11}Li,[1,2] but it is considered to be a universal phenomenon over all mass-number regions.[3]

We propose a new effective pairing force by focusing on the spatial structure of a neutron pair. First, we discuss the necessity by performing a three-body model calculation with the density-dependent zero-range force (DD $\delta(\boldsymbol{r})$-force),[1,2] $V_\delta(\boldsymbol{r}_1, \boldsymbol{r}_2) = V^{(0)}\{1 - \eta[\rho(\boldsymbol{r}_1)/\rho_0]\}\,\delta(\boldsymbol{r}_1 - \boldsymbol{r}_2)$. The DD $\delta(\boldsymbol{r})$-force is widely used in nuclear structure calculations.[1-3] It must be supplemented with a cutoff in the two-particle spectrum, $\varepsilon_1 + \varepsilon_2 \le E_{\rm cut}$. The parameters $V^{(0)}$ and η are adjusted for each $E_{\rm cut}$ so as to reproduce the properties of low-energy neutron-neutron (nn) scattering and the two-neutron energy E_{2n} of finite nuclei. The parameter $\rho_0 = 0.16$ fm^{-3} is the saturation density.

In Fig. 1, the root-mean-square (rms) values $k_{\rm rel}$ and $q_{\rm cm}$ of the relative and center of mass (cm) momenta of paired neutrons in ^{11}Li and ^{12}Be are shown. $k_{\rm rel}$ converges, while $q_{\rm cm}$ diverges as a function of $E_{\rm cut}$ owing to undesirable coupling to high-momentum components of single-particle states in the continuum.

In order to overcome the difficulties, we consider a new effective pairing force in momentum space (k space) that has a non-local separable form (k-SEP force), $V_{\rm SEP} = -\frac{1}{2\pi^2}V_k^{(0)} g(\boldsymbol{k})g(\boldsymbol{k}')h(\boldsymbol{q})h(\boldsymbol{q}')$. Here, the Yamaguchi-type form factor $g(\boldsymbol{k}) = 1/(\boldsymbol{k}^2 + \Lambda^2)$ and the Gaussian distribution $h(\boldsymbol{q}) = (\sqrt{\pi}q_0)^{-3}e^{-\boldsymbol{q}^2/q_0^2}$ for the relative momentum $\boldsymbol{k}$ and the cm momentum $\boldsymbol{q}$ of paired neutrons are adopted. The parameters $V_k^{(0)}$ and Λ are fixed so as to reproduce the properties of low-energy nn scattering.[4] The parameter q_0 is fixed by the two-neutron energy E_{2n} of finite nuclei.

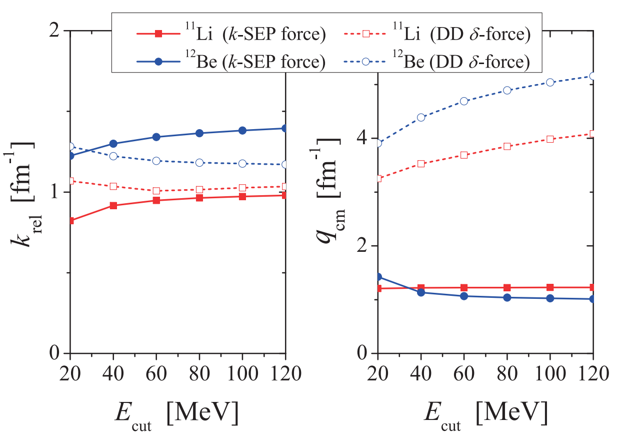

Fig. 1. Relative momentum $k_{\rm rel}$ and cm momentum $q_{\rm cm}$ of the neutron pair in ^{11}Li and ^{12}Be. The results using the k-SEP force and the DD $\delta(\boldsymbol{r})$-force are shown.

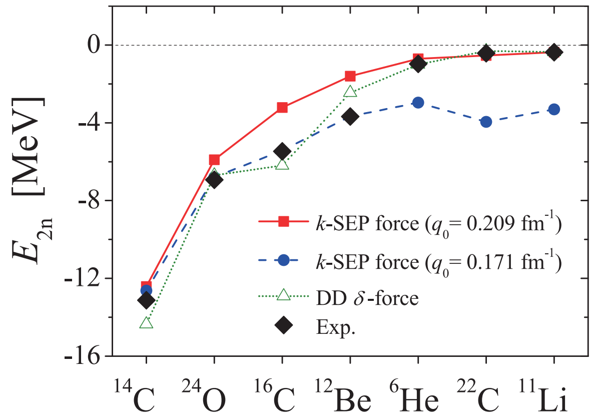

Fig. 2. Two-neutron energies E_{2n} obtained with the k-SEP force ($q_0 = 0.209$ and 0.171fm^{-1}) and the DD $\delta(\boldsymbol{r})$-force with fixed $E_{cut} = 40$ MeV and $\eta = 0.849$, in comparison with the experimental data.

The $k_{\rm rel}$ and $q_{\rm cm}$ obtained with the k-SEP force are shown in Fig. 1. They converge well above $E_{\rm cut} = 100$ MeV. Here, the parameter $q_0 = 0.209$ fm^{-1} (0.171 fm^{-1}) is used for ^{11}Li (^{12}Be). The small cm momentum $q_{\rm cm}$ indicates that the pairing correlation occurs only around the nuclear surface region in real space. The relative momentum $k_{\rm rel}$ in ^{12}Be becomes larger than that in Borromean ^{11}Li owing to the high-momentum component in the bound $1p_{1/2}$ state.

The two-neutron energies E_{2n} of three-body systems can be classified into two categories as shown in Fig. 2. The Borromean nuclei (^{6}He, ^{22}C, ^{11}Li) are well described with $q_0 = 0.209$ fm^{-1}, while $q_0 = 0.171$ fm^{-1} for non Borromean nuclei. Because the parameter q_0 introduces a cutoff for correlations in the opening angle θ_k between $\boldsymbol{k}_1$ and $\boldsymbol{k}_2$ as $\cos\theta_k \lesssim q_0^2/(2k_1k_2)$ in $h(\boldsymbol{q})$, the pairing correlations have a more collective nature in calculation with a larger q_0.

In conclusion, we proposed a new effective pairing force that describes well the structure of the neutron pair. It is also easily utilizable in various frameworks such as the density functional theory in k space.[5]

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References

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