Role of large quadrupole deformation in the Borromean nucleus ^{19}B

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The Borromean nucleus ^{19}B shows different and mysterious aspects depending on the experimental probe. Recent measurement of the low-energy $E1$ strength[1)] suggests that two valence neutrons have large s-wave component. The large distance between the ^{17}B core and the halo-neutron pair of $R_{c\text{-}2n} = 5.75 \pm 0.11 \pm 0.21$ fm was observed. However, the observed matter radius of $R_m = 3.11(13)$ $(\approx 1.17 \times 19^{1/3})$ fm in ^{19}B[2)] shows no increase, which suggests the absence of neutron halo, compared to $R_m = 2.99(9)$ $(\approx 1.16 \times 17^{1/3})$ fm in ^{17}B.[2)] The d-wave dominance in ^{19}B was suggested by a correlation analysis between the matter radius and the two-neutron separation energy.[3)]

I demonstrate that these experimental results can be consistently understood by considering large quadrupole deformation. For this purpose, I perform an analysis using a seven-body model consisting of a deformed core of ^{13}B and six valence neutrons.

The Woods-Saxon (WS) potential with axial quadrupole deformation is employed for the core-neutron potential. The pairing correlation is considered in the Hartree-Fock-Bogoliubov method using the contact force $v_{nn}(\mathbf{r}, \mathbf{r}') = V_0 F(\mathbf{r}) \delta(\mathbf{r} - \mathbf{r}')$. The density dependence is represented by the form factor $F(\mathbf{r}) = 1 - f(r) + \beta R_{pair}[\frac{d}{dr} f(r)] Y_{20}(\hat{\mathbf{r}})$ with $f(r) = [1 + \exp((r - R_{pair})/a)]^{-1}$. β is a quadrupole-deformation parameter, and R_{pair} determines the region where the pairing correlation occurs. With large R_{pair}, neutron pairs are formed far away from the core, resulting in large $R_{c\text{-}2n}$ and R_m.

Figure 1 shows the relationship between $R_{c\text{-}2n}$ and R_m obtained by varying R_{pair}. $R_{c\text{-}2n} = 5.75$ fm is obtained with $R_{pair} \approx 3.8$ fm, regardless of β. The results of $\beta = 0.4$, 0.6, 0.8, and 1.0 are compared with experimental values.[1,2)] The comparison reveals that the experimental values of $R_{c\text{-}2n}$ and R_m are consistently explained only when the quadrupole deformation is $0.4 \lesssim \beta \lesssim 1.0$.

This is due to the shrinkage of the subsystem ^{17}B in ^{19}B. To elucidate it, I show the neutron single-particle energies as a function of β in Fig. 2. The strength parameters of the WS potential for the $\Omega^\pi = 1/2^+$ and $5/2^+$ states are fixed by the experimental value of the s-wave scattering length $a_s = -50$ fm and the predicted d-wave resonance at 1.14 MeV, respectively (*e.g.*, see Ref. 1)). For other Ω^π states, the standard strength parameter by Bohr and Mottelson is used. Here, Ω is a spin-projection onto the symmetry axis of the quadruole deformation.

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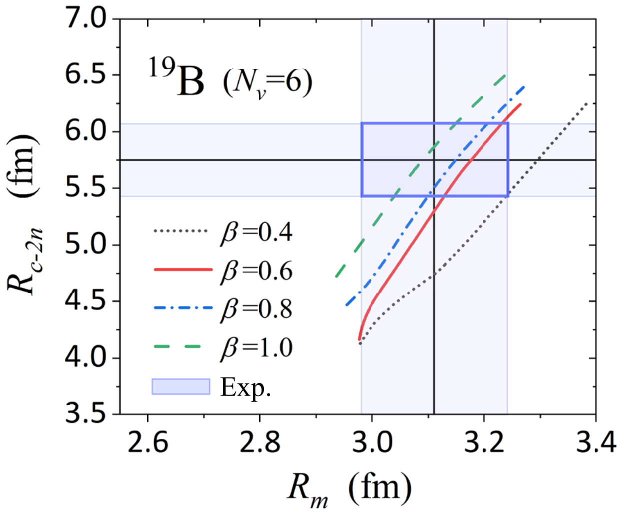

Fig. 1. Relationship between $R_{c\text{-}2n}$ and R_m obtained by varying the parameter R_{pair}. The results assuming six valence neutrons and deformations of $\beta = 0.4$, 0.6, 0.8, and 1.0 are compared with experimental values.[1,2)]

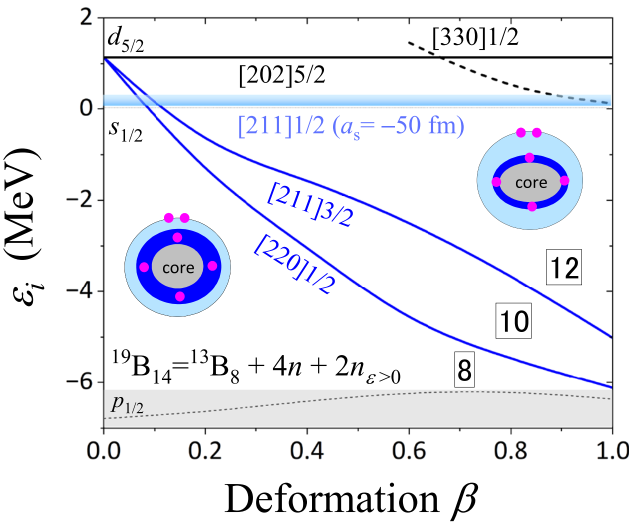

Fig. 2. Neutron single-particle energies in ^{19}B are shown as a function of deformation β. In the inserted diagram, blue (light blue) represents the neutron skin (halo).

The single-particle energies of the neutron [211]3/2 and [220]1/2 states become deeper with increasing β, and the radius of the density distribution of six valence neutrons reduces from 5.65 fm ($\beta = 0.4$) to 5.07 fm ($\beta = 1.0$) at a fixed $R_{c\text{-}2n} = 5.75$ fm.

In conclusion, large quadrupole deformation is shown to be necessary to understand the experimental values of $R_{c\text{-}2n}$ and R_m consistently. Regarding the halo-neutron pair, the present study predicts the p-wave component that is of equal magnitude to the s-wave (for example, about 20% at $\beta = 0.6$), and such large p-wave component has not been reported previously. Further researches are needed to reconcile the structure of the halo-neutron pair.

References

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