Deformation effect in Borromean nucleus ^{19}B†

M. Yamagami*1

The Borromean nucleus ^{19}B has been a subject of debate because of its two seemingly contradictory properties: the dominance of the d-wave in the two valence neutrons ($2n$), as suggested by a matter radius of 3.11(13) fm ($\approx 1.17 \times 19^{1/3}$ fm);[1)] and halo formation with a significant s-wave contribution, as indicated by a low-lying $B(E1)$ distribution. An analysis of the $B(E1)$ distribution also revealed a large core-$2n$ distance, estimated to be $r_{c\text{-}2n} = 5.75 \pm 0.11 \pm 0.21$ fm.[2)]

To consistently interpret these experimental data, I performed calculations using a deformed-core plus multi-neutron model. The core-n potential is represented by the Woods-Saxon potential with quadrupole deformation β. Pairing correlations are included by using the Hartree-Fock-Bogoliubov method. A contact pairing force, $v_{nn}(\mathbf{r}, \mathbf{r}') = v_{nn}^{(0)} F(\mathbf{r}) \delta(\mathbf{r} - \mathbf{r}')$, was employed with the form factor:

$$F(\mathbf{r}) = 1 - f(r) + \beta R_{\text{pair}} \left[\tfrac{d}{dr} f(r)\right] Y_{20}(\hat{\mathbf{r}}),$$

where $f(r) = 1/\{1 + \exp[(r - R_{\text{pair}})/a]\}$. $R_{\text{pair}}^{(\text{cut})}$ and $v_{nn}^{(0)}$ are determined to satisfy $r_{c\text{-}2n} = 5.75$ fm and the $2n$ separation energy of $S_{2n} = 0.5$ MeV in ^{19}B.[2)]

I demonstrated that the experimental values of the matter radius and the core-$2n$ distance can be consistently explained by considering a largely deformed ^{13}B core plus $6n$ structure. With $r_{c\text{-}2n} = 5.75$ fm and the matter radius of the ^{13}B core kept fixed, the matter radius of ^{19}B is overestimated for small β (*e.g.*, 3.40 fm for $\beta = 0.2$). However, as β increases, the matter radius decreases and aligns with the experimental value (*e.g.*, 3.18 fm for $\beta = 0.6$).

The mechanism is as follows: As shown in Fig. 1, the energies of the bound [211]3/2 and [220]1/2 states deepen with increasing deformation. Consequently, the neutron skin becomes thinner, resulting in a reduction of the matter radius. This analysis indicates that ^{19}B consists of three distinct spatial layers: the neutron-halo layer, neutron-skin layer, and ^{13}B core. The deformation dependence of the neutron-skin layer plays a critical role in suppressing the enhancement of the matter radius due to the neutron halo.

The mixing of positive and negative parity orbits is an important element in understanding the spatial structure of the dineutron, where deformation effects can lead to significant changes. As shown in Fig. 2, both the s- and p-wave contributions are predicted to be approximately 20% for deformations of $\beta = 0.2$ to 0.6. At larger deformations, while the s-wave contribution remains at approximately 20%, the p-wave component increases and reaches 32.1% owing to the influence of the [330]1/2 resonant state (see Fig. 1).

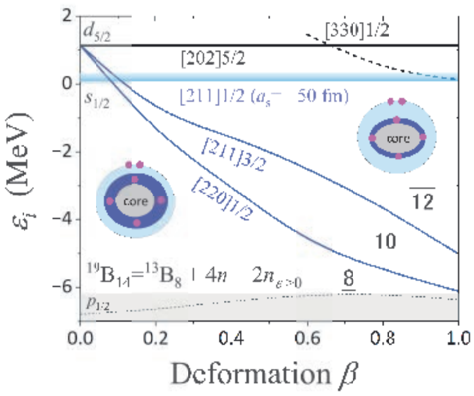

Fig. 1. Neutron single-particle energies in ^{19}B as a function of deformation β. $n_{\varepsilon>0}$ denotes the contribution from unbound neutrons. In the inserted diagrams, the blue (light blue) region represents the neutron skin (halo).

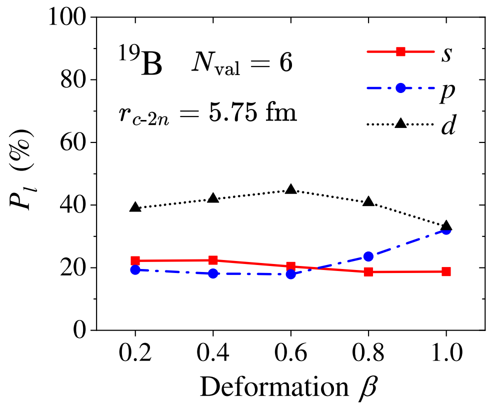

Fig. 2. Fraction of partial-wave components in the dineutron as a function of deformation β. $r_{c\text{-}2n} = 5.75$ fm and valence-neutron number $N_{\text{val}} = 6$ are fixed.

By contrast, an analysis based on the spherical-core plus $2n$ model estimated the s-wave contribution to be 35%.[2)] The remaining partial-wave components are primarily d-wave components, along with a minor p-wave components.

The partial-wave components extracted from the $B(E1)$ distribution still have large uncertainties. The deformation effects might improve the reproduction of the $B(E1)$ distribution. Efforts are currently underway to enhance the analysis for deformed Borromean nuclei by extending the deformed-core plus multi-neutron model.

References

1) T. Suzuki *et al.*, Nucl. Phys. A **658**, 313 (1999).
2) K. J. Cook *et al.*, Phys. Rev. Lett. **124**, 212503 (2020).

† Condensed from the article in Phys. Rev. C **110**, 044312 (2024)

*1 Department of Computer Science and Engineering, University of Aizu

DOI:10.34448/RIKEN.APR.58-045