Role of triaxiality in deformed halo nuclei

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K. Uzawa, K. Hagino, and K. Yoshida, Phys. Rev. C 104, L011303 (2021).
Introduction: neutron halo

- Spatially extended weakly bound neutron
- Large rms radius and narrow momentum distribution
- With $l \geq 2$, centrifugal barrier suppresses halo formation (s or p-wave only !)

\[
\psi_n(r) \sim \exp \left( -\sqrt{2mS_n/\hbar^2} r \right)
\]

($S_n$: neutron binding energy)
Deformation and neutron halo

- Symmetry breaking by nuclear deformation mixes angular momentum $j$ and $l$
- $\Omega(=j_z)$ is a good quantum number with axial symmetry

$$|\phi_{n,\Omega}\rangle = \sum_{j,l} R_{n,j,l}(r) |(l, 1/2)j, \Omega\rangle$$

$\Rightarrow \Omega^\pi = \frac{1^+}{2}, \frac{1^-}{2}, \frac{3^-}{2}$ orbitals are halo candidates

$$|\Omega^\pi = \frac{1^+}{2}\rangle = \alpha |1d_{5/2,1/2}\rangle + \beta |2s_{1/2,\Omega=1/2}\rangle$$

$$|\Omega^\pi = \frac{3^+}{2}\rangle = \alpha |1d_{5/2,3/2}\rangle + \cdots$$

→ halo
An example of deformed halo

$^{37}_{25}\text{Mg}$ is a good example of deformed halo

At $\beta_2 = 0$, valence orbital corresponds to $f_{7/2}$ and does not become halo

Deformation and Symmetry Breaking extend the region of halo nuclei!

M. Takechi et al., Phys. Rev. C 90, 061305 (2014).
Extension to the triaxial deformation

Previous Researches assumed axial deformation only

\((\gamma = 0^\circ \text{ or } 60^\circ)\)

✓ Does triaxiality play a role in halo nuclei?

- **Spherical:** s or p wave only
- **Axial:** \(\Omega^\pi = \frac{1^\pm}{2}, \frac{3^-}{2}\) only
- **Triaxial:** all orbitals

\(\beta\) prolate \((\gamma = 0^\circ)\)

\(\gamma\) oblate \((\gamma = 60^\circ)\)

\(\gamma\) triaxial
\( \Omega(= j_z) \) is not already good quantum number

\[ \Rightarrow \text{s.p. orbital } |\phi_n\rangle \text{ is superposition of } |n, \Omega\rangle \text{ (}n\text{ is principal quantum number)} \]

\[ |\phi_n\rangle = \sum_\Omega c_\Omega |n, \Omega\rangle, \quad \Omega \text{ mixing} \]

\( |\phi_n\rangle \) always has \( \Omega^\pi = \frac{1^+}{2}, \frac{1^-}{2}, \text{ or } \frac{3^+}{2} \) component and possibly forms halo

\[ |\Omega = \frac{5^+}{2}\rangle \Rightarrow |\phi > = c_1|\Omega = \frac{5^+}{2}\rangle + c_2|\Omega = \frac{3^+}{2}\rangle + c_3|\Omega = \frac{1^+}{2}\rangle \cdots \]

Axial \hspace{1cm} \text{Triaxial} \hspace{1cm} \text{halo}
Case of $N = 43$

Apply 3D Woods-Saxon potential calculation to $N = 43$ orbital

$N = 43$ nuclei are not halo nuclei with axial deformation

$$\begin{align*} \text{prolate} \Rightarrow \Omega^{\pi} = \frac{3^+}{2}, \quad \text{oblate} \Rightarrow \Omega^{\pi} = \frac{7^+}{2} \end{align*}$$

3D mesh, $0 \leq x, y, z \leq 22.05$ fm
$P_s$ : fraction of s-wave component of the N=43 orbital

Fix $\beta = 0.3$ and vary $\gamma$ and $V_0$ (potential depth)

Axial ($\gamma = 0^\circ$ or $60^\circ$) : $P_s = 0$

Triaxial ($\gamma = 20^\circ, 30^\circ, 40^\circ$) : $P_s \neq 0$

$P_s$ greatly increases with $S_n \to 0$

“s-wave dominance”
$P_s$ : fraction of s-wave component of N=43 orbital

Fix $\beta = 0.3$ and vary $\gamma$ and $V_0$ (potential depth)

$\sqrt{\langle r^2 \rangle}$ also drastically increases
(triaxial deformation only)

$N = 43$ nuclei are candidate of triaxial halo

The same is true for $Z=43$. 

![Graph showing the relationship between single particle energy and rms radius.](c)
One neutron halo of $^{19}\text{C}$

✓ $^{18}\text{C}$ is a possibly triaxially deformed nucleus

✓ $^{19}\text{C}$ is a well developed one-halo nucleus ($S_n = 160 \pm 110$ keV)

⇒ Possibility that $^{19}\text{C}$ is triaxially deformed halo (Core and valence neutron is well separated)

Covariant DFT (+Angular Momentum Projection)

AMD(Antisymmetrized Molecular Dynamics)

J. M. Yao et al., Phys. Rev. C 84, 024306 (2011).

Y. Kanada-En’yo, Phys. Rev. C 71, 014310 (2005).
Apply W.S. potential to N=13 orbital of 19C 
\( \beta = 0.343, 0^\circ \leq \gamma \leq 60^\circ, V_0 \) is varied

\[
\left( \text{prolate} \Rightarrow \Omega^\pi = \frac{1^+}{2}, \text{oblate} \Rightarrow \Omega^\pi = \frac{3^+}{2} \right)
\]

With \( \gamma = 0^\circ \), rms radius is overestimated
With \( \gamma = 60^\circ \), underestimated

Triaxiality modify halo component
Summary

- Triaxial deformation causes $\Omega$ mixing and enlarges the region of halo nuclei
- For 43rd neutron, triaxial deformation is essential for halo formation
- With triaxiality, $\sqrt{\langle r^2 \rangle}$ and $S_n$ of 19C are reproduced consistently

Future Work

- Calculation based on Density Functional Theory
  ⇒ Beijing group’s work: arXiv:2212.05703
- Experimental study of medium-mass neutron-rich nuclei