Title
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EFFECTS OF THE OCTUPOLE VIBRATION ON THE REACTIONS

$^{207}\text{Pb}(t,p)^{209}\text{Pb}$ AND $^{209}\text{Pb}(p,t)^{207}\text{Pb}$

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September 1969

ABSTRACT

The effects of particle-vibration coupling on the reaction $^{207}\text{Pb}(t,p)^{209}\text{Pb}$ and its inverse reaction are estimated. It is found that the effects are generally small although they are not negligible for some final states.
The purpose of the present note is to estimate the effects of the octupole core polarization on the reaction $^{207}\text{Pb}(t,p)^{209}\text{Pb}$ and the inverse reaction. Riedel et al.\(^1\) analyzed the reaction $^{207}\text{Pb}(t,p)^{209}\text{Pb}$ assuming pure configurations both for the target and final nuclei, and compared the calculated cross sections with the experimental results. Their relative cross section to the first excited state ($i_{11/2}$) of $^{209}\text{Pb}$ agrees well with the experiment, but the one to the second excited state ($j_{15/2}$) is smaller than the experiment, i.e. $\sigma_{\text{exp}} / \sigma_{\text{theo}} \approx 1.4$. The alpha decay phenomenon has a similar characteristic as the two nucleon transfer reaction. The relative alpha intensities from the isomeric state of $^{211}\text{Po}$ was analyzed by Zeh and Mang.\(^2\)

The relative decay rate to the $i_{13/2}^{-1}$ state of the daughter nucleus $^{207}\text{Pb}$ calculated by them is very much smaller than the experiment. Recently, Mottelson\(^3\) has discussed phenomena in which the coupling of a single particle state to the collective octupole vibration in $^{208}\text{Pb}$ plays an important role. According to his lecture, the single neutron $g_{9/2}$, $j_{15/2}$ and $i_{13/2}^{-1}$ states are described as:

\[
|9/2\rangle = 0.96 |g_{9/2}\rangle + 0.27 (j_{15/2}, 3-)9/2\rangle \\
|15/2\rangle = 0.82 |j_{15/2}\rangle - 0.57 (g_{9/2}, 3-)15/2\rangle \\
|13/2\rangle = 0.95 |i_{13/2}^{-1}\rangle - 0.30 (f_{7/2}, 3-)13/2\rangle
\]

If we neglect small admixtures which involves the spin flip, other states are expected to be rather pure single neutron states. In order to see if the disagreements reported in Refs. 1 and 2 are due to the neglect of the octupole core polarization in their calculations, we intend to estimate the effect on the reaction $^{207}\text{Pb}(t,p)^{209}\text{Pb}$ and its inverse reaction.
For a simplicity, the effect of the inelastic processes in the transfer reactions will be neglected in the present note.

As is well known, the octupole vibrational state is described mainly by a linear combination of many one particle-one hole configurations. Neglecting the blocking effect, we used True's wave function $^4$ for the 3- state of $^{208}$Pb in the present work. If both the target and residual nuclei are expressed by a type of the wave function mentioned above, four kinds of transfer processes are possible. Let us consider $^{209}$Pb(p,t)$^{207}$Pb reaction in which the final nucleus is in $13/2^+$ state, as an example. In this case, the four processes are described as

- **Process A**: $|5_{9/2}\rangle \rightarrow |l_{13/2}\rangle$
- **Process B**: $|5_{9/2}\rangle \rightarrow |(f_{7/2}^{-1}, 3-)_{13/2}\rangle$
- **Process C**: $|(J_{15/2}, 3-)_{9/2}\rangle \rightarrow |l_{13/2}\rangle$
- **Process D**: $|(J_{15/2}, 3-)_{9/2}\rangle \rightarrow |(f_{7/2}^{-1}, 3-)_{13/2}\rangle$

and are illustrated in Fig. 1

Structure amplitudes for the two neutron transfer reactions have been calculated based on the harmonic oscillator wave function and tabulated in Ref. 5. We used those values for oscillator constant $\nu = 0.165$, and calculated the projected wave functions which are to be used in the DWBA calculation. Figure 2 shows the projected wave function for the above example with the angular momentum transfer $L = 2$. Dotted and solid curves represent the projected wave functions with and without the core polarization, respectively. In this case the change of the projected wave function is quite large, but for the most other cases the changes due to the core polarization are very small. To get a rough idea of the change in cross section, we tried
the DWBA calculations, taking the incident particle energies equal to 20 MeV. Optical parameters are taken from Ref. 6 and 7. In Table I, the ratios of the calculated cross sections with and without the core polarization are displayed. Enhancement factors are rather small, because the only particular configurations (particle or hole state is specified) in the 3- state wave function can contribute to the transfer reaction. There are uncertainties connected with the wave functions of the target and residual nuclei, the parameter values of triton and proton optical potentials and the use of a harmonic oscillator wave function. However, we may conclude that changes of the two nucleon transfer reaction cross sections due to the octupole core polarization will be generally within 20%, and they depend on the final states. In the cases for which final states are \( j_{15/2} \) and \( i_{13/2}^{-1} \) states, the changes of the cross sections are larger compared with other cases. The reason is that some of the new two neutron configurations which are picked up in processes (B) and (C) in Fig. 1 have larger overlap with the triton wave function than the original ones in the type (A). For the \( i_{13/2}^{-1} \) final state, the original two neutron configuration is \( g_{9/2} \cdot i_{13/2}^{-1} \), and one of the new configuration is \( f_{7/2} \cdot p_{3/2}^{-1} \). The latter has much larger overlap than the former with a triton, and the admixture of \( p_{3/2}^{-1} \cdot g_{9/2} \) configuration in the 3- state wave function is rather large. Finally we could say also that the octupole core polarization acts to reduce the disagreements reported in Ref. 1 and 2.

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REFERENCES AND FOOTNOTES

* Work performed under the auspices of the U. S. Atomic Energy Commission.
† On leave from Japan Atomic Energy Research Institute, Tokai-mura, Japan.

4. W. W. True, Phys. Rev., to be published. We are especially grateful to Professor W. True for making available his unpublished wave function for 208\(^{8}\)Pb.
Table I. Ratio of the calculated cross sections with and without the core polarization. Incident energies are taken to be 20 MeV for both reactions.

<table>
<thead>
<tr>
<th>Final State</th>
<th>L</th>
<th>( \sigma \text{(with c.p.)} )</th>
<th>( \sigma \text{(without c.p.)} )</th>
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<td>( \pi_9/2 )</td>
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<td>1.01</td>
<td></td>
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<tr>
<td>( \iota_{11/2} )</td>
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<td>1.00</td>
<td></td>
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<tr>
<td>( \zeta_{15/2} )</td>
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<td>1.09</td>
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<table>
<thead>
<tr>
<th>Final State</th>
<th>L</th>
<th>( \sigma \text{(with c.p.)} )</th>
<th>( \sigma \text{(without c.p.)} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \pi_{1/2} )</td>
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<tr>
<td>( \iota_{5/2} )</td>
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<tr>
<td>( \pi_{3/2} )</td>
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<tr>
<td>( \iota_{3/2} )</td>
<td>2</td>
<td>1.17</td>
<td></td>
</tr>
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</table>

10 did not calculate
FIGURE CAPTIONS

Fig. 1. Four contributions to the reaction $^{209}$Pb(p,t)$^{207}$Pb in which the final nucleus is in $13/2^+$ state. The hatched line, the solid circle and the dotted circle represents the Fermi level, a particle-hole configuration in the 3- state wave function and the two neutrons which are to be picked up in the reaction, respectively.

Fig. 2. The projected wave function for $^{209}$Pb(p,t)$^{207}$Pb reaction in which the final nucleus is in $13/2^+$ state. Dotted and solid curves represent the projected wave functions with and without the octupole core polarization, respectively.
Fig. 1
Fig. 2

Projected wave function (arbitrary units)

$L = 2$

$\frac{1}{23}_2^1$ state

8 fm

R
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