Residual Interaction Effects in Deeply Bound Pionic States

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Deeply bound pionic states, which had been predicted by Toki *et al.* [1], were discovered in the ^{208}Pb (d, ^{3}He) reaction at GSI very recently [2, 3]. In the experiment, we can observe binding energies and widths of the pionic states as resonance peaks of ejected ^{3}He spectrum. Binding energies of the deeply bound pionic 1s and 2p states are deduced from the data and determined to be B.E.(1s)=7.1 $\pm$ 0.2MeV and B.E.(2p)=5.31 $\pm$ 0.09MeV [4]. These values indicate that the effective pion mass increases by 19.3 $\pm$ 2.7 MeV at the center of the ^{207}Pb [4].

So far, all theoretical calculations and analyses of the data postulate that the configuration mixing of the neutron-hole and pion-particle state due to the residual interaction is small. In this report, we study the residual interaction effects in the deeply bound pionic states in ^{207}Pb. Since the π-^{207}Pb states are particle (pion) - hole (neutron) states, we need to evaluate the effects of the residual interaction to the binding energies and widths of the atomic states in order to extract the precise information on the pion-nucleus interaction from data.

We use the S-wave pion-nucleon interaction as the residual interaction which is written as;

$$V_S(\vec{r}) = -\frac{2\pi}{m_\pi}[b_0 + b_1\vec{t}\cdot\vec{\tau}]\delta^3(\vec{r}), \tag{1}$$

where m_π is the pion mass. Interaction strength is fixed to be b_0=-0.0283m_π^{-1} and b_1=-0.12m_π^{-1} [5]. Matrix elements of this interaction is expressed as follows;

$$\begin{aligned} < (\ell'_\pi \otimes j_\beta^{-1})^J | V_S | (\ell_\pi \otimes j_\alpha^{-1})^J > \;=\; & -\frac{2\pi}{m_\pi}\frac{b_0+b_1}{4\pi}(-1)^{J+j_\alpha+j_\beta+\ell_\beta+\ell_\alpha-\frac{1}{2}} \\ \times\; & \sqrt{(2j_\alpha+1)(2j_\beta+1)(2\ell_\alpha+1)(2\ell_\beta+1)(2\ell'_\pi+1)(2\ell_\pi+1)} \\ \times\; & [\int_0^\infty drr^2 R^*_{\ell_\beta}(r)R_{\ell_\alpha}(r)R_{\ell'_\pi}(r)R_{\ell_\pi}(r)] \\ \times\; & \sum_L \left\{ \begin{array}{ccc} \ell'_\pi & j_\beta & J \\ j_\alpha & \ell_\pi & L \end{array} \right\} \left\{ \begin{array}{ccc} \ell_\alpha & j_\alpha & \frac{1}{2} \\ j_\beta & \ell_\beta & L \end{array} \right\} \\ \times\; & (\ell_\beta 0 \ell_\alpha 0|L0)(\ell_\pi 0 \ell'_\pi 0|L0). \end{aligned} \tag{2}$$

We include $p_{1/2}^{-1}$, $f_{5/2}^{-1}$, $p_{3/2}^{-1}$, $i_{13/2}^{-1}$ for neutron-hole states and $1s$, $2s$, $2p$, $3s$, $3p$, $3d$ for pion-particle states. Hole wavefunctions are calculated using a potential of Woods-Saxon form obtained in ref. [6]. Pion wavefunctions are calculated using a standard optical potential in ref. [5]

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In Table. 1 we show the preliminary results. We choose four combinations of the particle-hole states, $|\ell_\pi \otimes j_n^{-1}> = |1s_\pi \otimes p_{3/2}^{-1}>$, $|1s_\pi \otimes f_{5/2}^{-1}>$, $|2p_\pi \otimes p_{1/2}^{-1}>$, and $|2p_\pi \otimes p_{3/2}^{-1}>$, which make dominant contributions to the formation cross sections. We show the complex energy shifts in unit of [keV] in the Table. We find that the energy shifts due to the residual interaction are less than 20 [keV]. We also find that the configuration mixing probabilities are small and less than 0.2%.

In conclusion, we have evaluated the residual interaction effects in deeply bound pionic states on heavy nucleus with one neutron-hole, ^{207}Pb. We show preliminary results. We find that the both energy shifts and configuration mixing effects are small. We will report comprehensive results soon [7].

Table 1 Complex energy shifts of deeply bound pionic states due to the residual interaction.

$1s_\pi \otimes p_{3/2}^{-1}$	J=3/2		
ΔE [keV]	14.3 + 2.6 i		
$1s_\pi \otimes f_{5/2}^{-1}$	J=5/2		
ΔE [keV]	14.1 + 3.5 i		
$2p_\pi \otimes p_{1/2}^{-1}$	J=3/2	J=1/2	
ΔE [keV]	8.8 + 2.9 i	8.8 + 2.9 i	
$2p_\pi \otimes p_{3/2}^{-1}$	J=5/2	J=3/2	J=1/2
ΔE [keV]	10.2 + 3.6 i	1.8 + 0.7 i	17.2 + 6.1 i

References

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