^{136}Xe(d,^{3}He) reaction for the formation of deeply bound pionic atoms

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Deeply bound pionic atoms have attracted much attention since they would provide valuable information on the behavior of "real" pions in the interior of the nucleus [1]. Recently, deeply bound pionic states were found experimentally for the first time in (d,^{3}He) reactions on ^{206,208}Pb [2, 3]. The observed spectrum showed an excellent agreement with our calculation made before the experiment [4]. In the reaction on ^{208}Pb, the peak structure in the observed cross section was attributed to the pionic $2p$ state contribution. In the reaction on ^{206}Pb, pionic $1s$ state was seen as an isolated peak, which was expected to correspond to $[1s \otimes p_{3/2}^{-1}]$ and $[1s \otimes f_{5/2}^{-1}]$ configurations based on the theoretical prediction [5]. The agreement between theoretical results and data provides a strong confidence on the predictability of the theoretical model used. Hence, we have good theoretical and experimental tools at present and we can study the spectroscopies of deeply bound pionic states precisely using them.

In order to observe the $1s$ pionic state as the largest peak in the spectrum, we use heavy nuclei with s neutron states in the valence major shell. In these cases, we can expect to populate the $[1s \otimes s_{1/2}^{-1}]$ configuration largely as quasi substitutional states under the recoilless condition.

We evaluate ^{136}Xe(d,^{3}He) reaction cross section using our model [4, 5]. We calculate the effective numbers N_{eff} for the (d,^{3}He) reaction on a ^{136}Xe target at T_d = 500 MeV for various pionic states with $3s_{1/2}, 2d_{3/2}, 2d_{5/2}, 1g_{9/2}$, and $1h_{11/2}$ neutron-hole states. In order to incorporate the realistic excitation levels and strengths of ^{135}Xe, we use experimental excitation energies and spectroscopic factors obtained from ^{136}Xe(d,^{3}He)^{135}Xe reaction [6, 7, 8]. We have also evaluated negative pion quasifree production contribution [9]. We assumed 5μb/MeV/sr as structureless background

Calculated results are shown in Fig. 1, where the negative pion production threshold with the ground state of ^{135}Xe corresponds to Q = -140.843 MeV. A prominent peak is seen around Q = -137 MeV. This peak is dominated by the contribution of $[1s \otimes s_{1/2}^{-1}]$ component ($\geq$ 90 %).

In summary we have calculated the excitation spectrum of the ^{136}Xe(d,^{3}He) reaciotns at T_d = 500 MeV in order to observe the deepest pionic $1s$ state. We have shown that the contributions from the pionic $1s$ state can be seen as an isolated peak with the feasible experimental energy resolution. This peak mainly consists of the $[1s \otimes s_{1/2}^{-1}]$ cofiguration. We believe that this theoretical work motivates further experimental efforts to develop the physics of pionic atom spectroscopy.

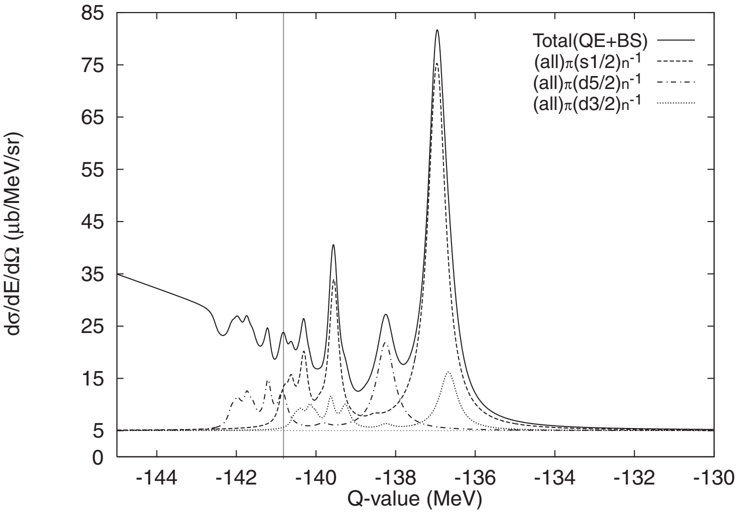

Figure 1: Calculated forward cross section of ^{136}Xe(d,^{3}He) reaction at T_d = 500 MeV with 200 keV experimental resolution. Dashed line shows the contributions from the neutron $s_{1/2}$ state, and dotted line those from the neutron $d_{5/2}$ state. A vertical line shows the negative pion production threshold with the ground state of ^{135}Xe.

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