On the fusion probabilities of halo nuclei

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Introduction

The availability of radio-active nuclear beams at several laboratories have made it possible to study the fusion of nuclei with interesting properties. The nuclei of our interest are weakly bound nuclei especially halo nuclei, which have small separation energies, large extended density distributions and narrow momentum distribution of the last neutron(s). A halo nucleus with its radius appreciably larger than that predicted by the liquid drop model, has a long tail associated with its neutron-density distribution. The seperation energy of the the last nucleon(s) is extremely small *i.e.* less than 1 MeV as compared with the 6-8 MeV in stable nuclei. A number of studies have been carried out in the recent past to study the role of halo structure in reaction dynamics at intermediate energies. These studies revealed that nuclear halo structure increases the fragmentation multiplicity and weakens the momentum dissipation in the lower beam energy region. Our interest is to see the effect of extended radii of neutron-halo projectiles on barrier heights and fusion probabilities at low incident energies.

Methodology

The systematic studies for a large number of fusion reactions in Refs. [1] showed that among various versions of proximity based potentials, Aage Winther (AW) 95, Bass 80 and Proximity 2010 are able to reproduce the experimental data within ±10% on average. We study the fusion of halo projectiles especially ^{6}He (two neutron halo) and ^{11}Be (one neutron halo) with heavy target (^{209}Bi) using these proximity based potentials. The interaction potential $V_N(R)$ between two colliding surfaces as given in [1] is

$$V_N = 4\pi\gamma b\overline{C}\Phi\Big(\frac{R - C_1 - C_2}{b}\Big)MeV, \qquad (1)$$

where $\overline{C}$ $(= (C_1C_2)/(C_1 + C_2\ ))$, b and R are the reduced radius, surface width and central separation, respectively. Here C is the central radius and Φ is the universal function. By adding Coulomb potential to nuclear potential, one can compute total potential V(R) and hence barrier positions R_B and heights V_B. The method used for calculating fusion cross-sections is mentioned in Ref.[1].

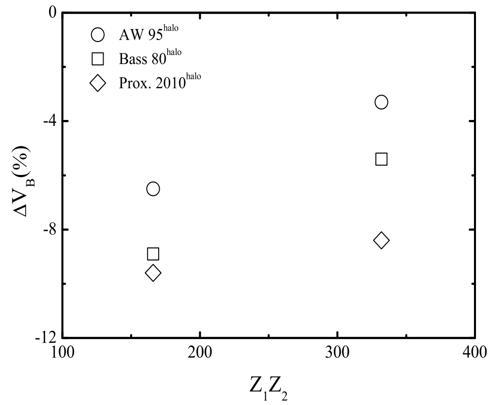

FIG. 1: The percentage decrease $\triangle V_B$ (%) in fusion barrier heights as a function of the product of the charges of colliding pairs Z_1Z_2.The reactions under consideration are ^{6}He+^{209}Bi and ^{11}Be+^{209}Bi.

Results and Discussions

In order to consider the extended matter distribution of these special nuclei, the nuclei radii borrowed from cross section measurements [2] are included in these poten-

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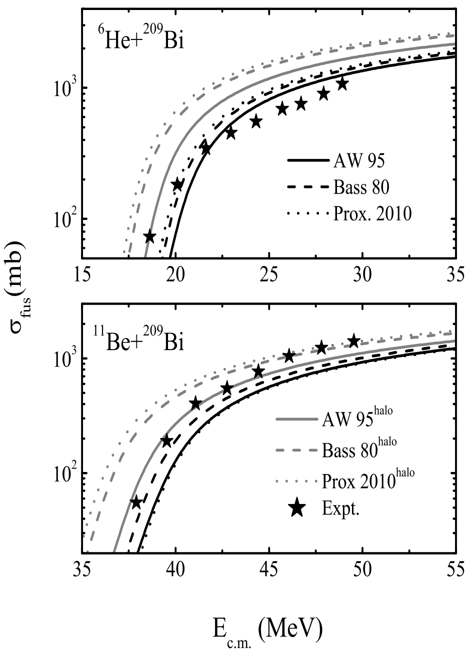

FIG. 2: The fusion cross sections for the reactions of ^{6}He+^{209}Bi and ^{11}Be+^{209}Bi are displayed as a function of center of mass energies. The experimental data for the reactions of ^{6}He+^{209}Bi and ^{11}Be+^{209}Bi is taken from Aguilera 2012 [3] and Signorini 1998[4] respectively.

TABLE I: The calculated matter radii of various halo nuclei and those from cross-section measurements.

Nucleus	AW 95	Bass 80	Prox. 2010	Expt.
^{6}He	2.09	2.01	1.78	2.71
^{11}Be	2.58	2.45	2.08	2.90

tials. From Table 1, we can find a large difference between calculated matter radii and those from experimental measurements.

In Fig. 1, we present the percentage decrease in barrier heights on including the measured radii in case of AW 95, Bass 80 and Proximity 2010. This percentage decrease in barrier heights is given by

$$\triangle V_B(\%) = \left(\frac{V_B^{halo} - V_B}{V_B}\right) \times 100, \quad (2)$$

here V_B^{halo} represents the barrier heights calculated by including measured radii in above mentioned potentials. From this Fig. we see that the percentage decrease in barrier heights on including the extended (measured) radii in case of AW 95, Bass 80 and Proximity 2010 are within 7%, 9% and 10% respectively. Therefore, it is evident that on considering the effect of halo structure, Coulomb barrier is appreciably reduced in both these cases. In Fig. 2, we observe enhancement at below barrier energies. In order to see the effect of extended sizes of these halo nuclei on fusion probabilities, we include the extended matter radii (experimental measurements) in above mentioned proximity potentials. Our results overpredict the experimental data at all energies, showing that the extended sizes of neutron halos is not contributing to the fusion process. The below barrier enhancement may be due to Coulomb polarization, which favours the valence neutrons residing in the region between the core and the target. As these valence neutrons are closer to the target, their probability of being transferred to the target is more.

Acknowledgments

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