Coulomb and nuclear breakup at low energies and the scaling law

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The effect of the coupling to the breakup channel on the complete fusion of weakly-bound, and especially, halo nuclei, has been under great scrutiny both experimentally and theoretically. It seems that this coupling hinders the fusion at energies above the barrier, and enhances the tunneling-dominated fusion below the barrier. Owing to the importance of the breakup channel at these low energies, we make an effort to understand its cross section, and the relative importance of its Coulomb and the nuclear components. In particular, we investigate the dependence of these components on the mass number of the target nucleus. We rely on a recent study of this topic, especially with regards to the dependence on the target mass, made at higher energies cite1. According to this study, the nuclear breakup cross section behaves at a given value of the bombarding energy, E_{Lab} as,

$$\sigma_N^{BU} = P_1 + P_2 A_T^{1/3}, \tag{1}$$

where the parameters P_1 and P_2 depend on the projectile, the structure of the target and the bombarding energy. Detailed CDCC calculation confirmed very well the above "scaling law" for normal weakly-bound projectiles, while less so in the case of halo nuclei, such as ^{11}Be. We have extended the above study to near barrier energies [2], and as a result of the important effect of the tunneling, the above scaling law is modified by fixing not the bombarding energy, but rather its ration to the height of the Coulomb barrier, E_{Lab}/V_B, such that

$$\sigma_N^{BU} = \overline{P}_1 + \overline{P}_2 A_T^{1/3}. \tag{2}$$

In Fig. 1 we show the nuclear breakup cross section of ^{6}Li as a function of $A_T^{1/3}$ at $E_{CM}/V_B = 0.84$, 1.00, and 1.07. The general behavior resembles the high energy results of Ref. [1], for the normal, non-halo, weakly-bound nucleus ^{7}Be. In fact the almost straight lines

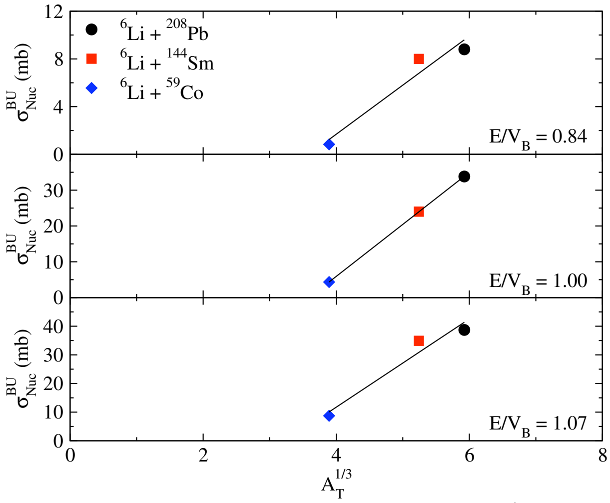

FIG. 1: Scaling of nuclear breakup cross sections as a function of $A_T^{1/3}$ at energies close to the Coulomb barrier.

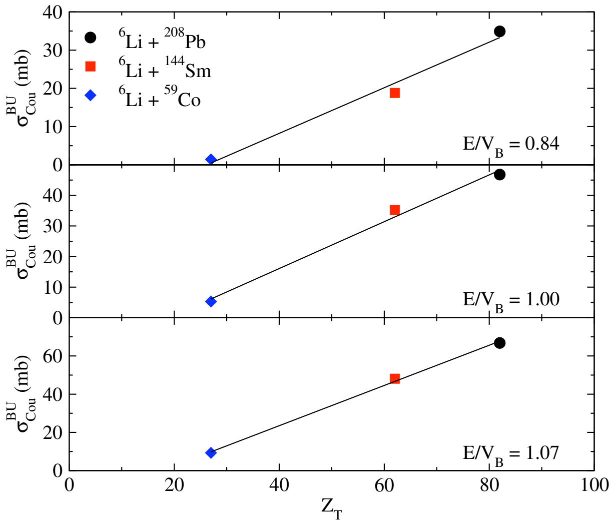

FIG. 2: Scaling of the Coulomb breakup cross sections as a function of Z_T for the same systems as in Fig. 1, for three energies close to the Coulomb barrier.

that represents the curves for $E_{CM}/V_B = 0.84$, 1.00, and 1.07 are fitted with P_1 = -14.76, -62.60, -49.89 *mb*, and P_2 = 4.11, 16.94, 15.41 *mb*, respectively. The rather large and negative values of P_1 are presumably traced to barrier penetration effects, which limits the use of the geometrical picture behind the scaling law. On the other hand, at above the barrier energies the values of P_2, which supply the slopes of the curves, are practically equal. Accordingly, the modified scaling law presented here, should supply a useful and easy way to estimate the nuclear breakup cross section at other energies close to the barrier, and for other target nuclei.

One can also derive a scaling law for the Coulomb breakup cross section. Since the matrix-elements for Coulomb breakup coupling are proportional to Z$_T$, the cross section should scale with Z$_T^2$. Thus, plotting the Coulomb breakup cross section as a function of the energy normalised with respect to V$_B$, which is roughly proportional to Z$_T$, one should get a linear dependence. This is illustrated in Fig. 2, where we show σ^{BU}_{Cou} for the different systems studied here as functions of E/V_B.

The above findings about the breakup cross section of weakly-bound nuclei at low energies, should be valuable in assessing their importance in the general study of fusion reactions at near barrier energies [2].

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[1] M.S. Hussein *et al.*, Phys. Lett. **B 640**, 91 (2006).

[2] D.R. Otomar *et al.*, submitted for publication in Phys. Rev. C (2012).