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CLUSTER MODEL FOR REACTIONS INDUCED BY WEAKLY BOUND AND/OR EXOTIC HALO NUCLEI WITH MEDIUM-MASS TARGETS

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An experimental overview of reactions induced by the stable, but weakly-bound nuclei ^{6}Li,^{7}Li and ^{9}Be, and by the exotic, halo nuclei ^{6}He,^{8}B,^{11}Be and ^{17}F on medium-mass targets, such as ^{58}Ni,^{59}Co or ^{64}Zn, is presented. Existing data on elastic scattering, total reaction cross sections, fusion, breakup and transfer channels are discussed in the framework of a CDCC approach taking into account the breakup degree of freedom.

1. Introduction

In reactions induced by weakly bound nuclei and/or by halo nuclei, the influence on the fusion process of coupling both to collective degrees of freedom and to transfer/breakup channels is a key point for the understanding of N-body systems in quantum dynamics.[1] Due to their very weak binding energies, a diffuse cloud of neutrons for ^{6}He or an extended spatial distribution for the loosely bound proton in ^{8}B would lead to larger total reaction (and fusion) cross sections at sub-barrier energies as compared to predictions of one-dimensional barrier penetration models.[1,2] This enhancement is well understood in terms of the dynamical processes arising from strong couplings to collective inelastic excitations of the target (such as "normal" quadrupole and octupole modes) and projectile (such as soft dipole resonances). However, in the case of reactions where at least one of the colliding nuclei has a sufficiently low binding energy for breakup to become a competitive process, conflicting conclusions were reported.[1–4] Recent studies with Radioactive Ion Beams (RIB) indicate that the halo nature of ^{6}He, for instance, does not enhance the fusion

probability as anticipated. Rather the prominent role of one- and two-neutron transfers in ^{6,8}He induced fusion reactions[3] was definitively demonstrated. On the other hand, the effect of non-conventional transfer/stripping processes appears to be less significant for stable weakly bound projectiles. Several experiments involving ^{9}Be, ^{7}Li, and ^{6}Li projectiles on medium-mass targets have been undertaken.[1,5–15] In this contribution, a comprehensive study of the ^{6,7}Li+^{59}Co reactions[5–15] is presented as a benchmark as illustrated by Fig. 1.

2. Experimental Results

The fusion excitation functions as measured for the ^{6,7}Li+^{59}Co reactions[5] are presented in Fig. 1 with comparisons with other lighter targets.[12–15]

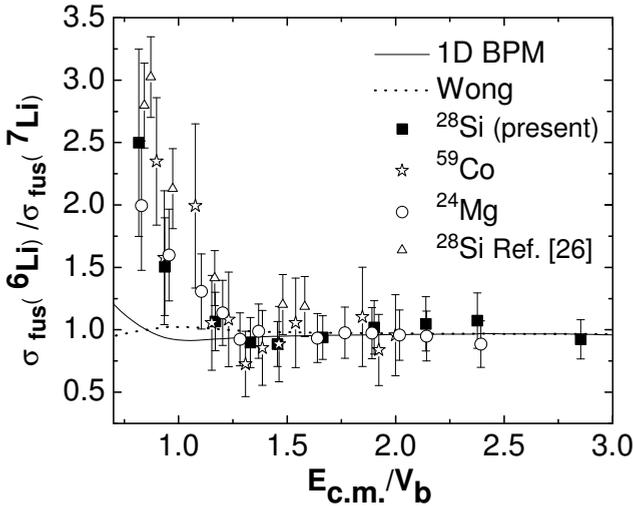Fig. 1.   Ratios of measured fusion cross sections for ^{6}Li and ^{7}Li projectiles with ^{24}Mg, ^{28}Si and ^{59}Co targets as a function of $E_{c.m.}/V_b$. The solid line gives the 1D-BPM prediction while the dotted line shows results obtained from Wong's prescription. This figure taken from Refs. 14 and 15 was originally shown for ^{6,7}Li+^{59}Co in Ref. 5.

The comparison with Continuum-Discretized Coupled-Channel (CDCC) calculations[6,7,11] indicates only a small enhancement of total fusion for the more weakly bound ^{6}Li below the Coulomb barrier, with similar cross sections for both ^{6,7}Li+^{59}Co reactions at and above the barrier. It is interesting to notice that the same conclusions have been found for both ^{24}Mg[12] and ^{28}Si[13–15] targets (see Fig. 1). This result is consistent with rather low breakup cross sections measured for the ^{6,7}Li+^{59}Co reactions even at incident energies larger than the Coulomb barrier.[8–10] However, the coupling of the breakup channel is extremely important for the CDCC analysis[7–11] of the angular distributions of the elastic scattering. Therefore, a more detailed investigation of the breakup process in the ^{6}Li+^{59}Co reaction with particle
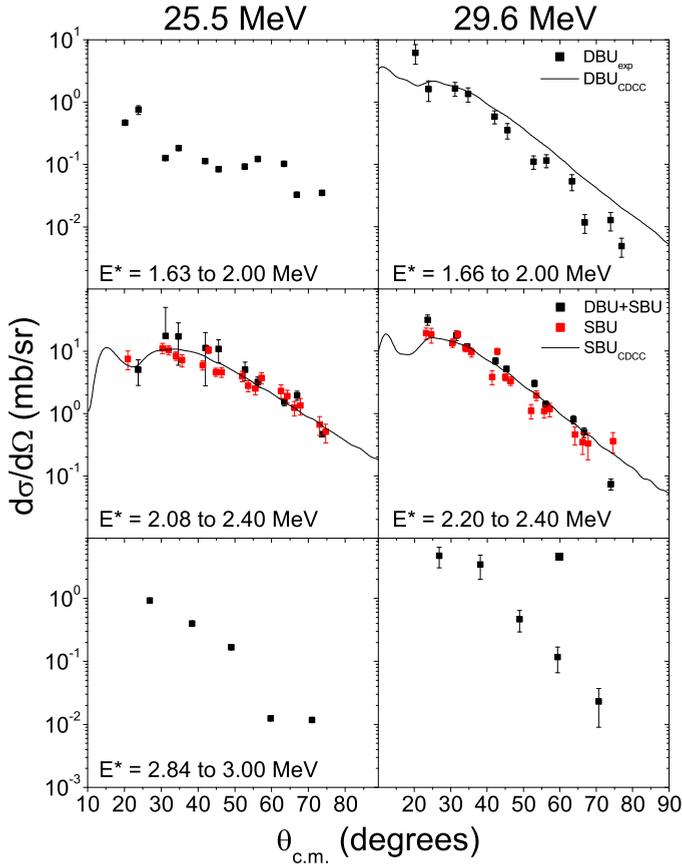
Fig. 2.   Experimental and theoretical CDCC angular distributions for the SBU and DBU projectile breakup processes (see text for details) obtained at $E_{lab} = 25.5$ MeV and 29.6 MeV for ^{6}Li+^{59}Co. The chosen experimental continuum excitation energy ranges are given.

techniques has also been proposed to discuss the interplay of fusion and breakup processes.[8–11] Coincidence data compared to three-body kinematics calculations[9,10] reveals a way how to disentangle the contributions of breakup, incomplete fusion and/or transfer-reemission processes.

3. Discussion and Conclusions

Fig. 2 displays experimental (full rectangles) and theoretical angular distributions (solid lines) for the sequential (SBU[8]) and direct (DBU[9–11]) projectile breakup processes at the two indicated bombarding energies for the ^{6}Li+^{59}Co reaction. In the CDCC calculations[7,11] the $\alpha+d$ binning scheme has been appropriately altered to accord exactly with the measured continuum excitation energy ranges. For this reaction it has not been necessary to use the sophisticated four-body CDCC frame-

work proposed by M. Rodriguez-Gallardo in this conference.[16] The CDCC cross sections are in agreement with the experimental ones, both in shapes and magnitudes within the uncertainties. The relative contributions of the ^{6}Li SBU and DBU to the incomplete fusion/transfer process has been discussed earlier[9–11] by considering the corresponding lifetimes obtained by using a semi-classical approach.[9,10] We concluded that the flux diverted from complete fusion to incomplete fusion would arise essentially from DBU processes via high-lying continuum (non-resonant) sates of ^{6}Li; this is due to the fact that both the SBU mechanism and the low-lying DBU processes from low-lying resonant ^{6}Li states occur at large internuclear distances.[10] Work is in progress to study incomplete fusion for ^{6}Li+^{59}Co within a newly developed 3-dimensional classical trajectory model.[17,18]

As far as exotic halo projectiles are concerned we have initiated a systematic study of ^{8}B and ^{7}Be induced reactions[2] with an improved CDCC method.[7] As compared to ^{7}Be+^{58}Ni (similar to ^{6,7}Li+^{58,64}Ni) the CDCC analysis of ^{8}B+^{58}Ni reaction while exhibiting a large breakup cross section (consistent with the systematics[19,20]) is rather surprising as regards to the consequent weak coupling effect found to be particularly small on the near-barrier elastic scattering.[2] A full understanding of the reaction dynamics involving couplings to the breakup and nucleon-transfer channels will need high-intensity RIB and precise measurements of elastic scattering, fusion and yields leading to the breakup itself.

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