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Asymptotic and near-target direct breakup of ^{6}Li and ^{7}Li

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Background: ^{6,7}Li and ^{9}Be are weakly bound against breakup into their cluster constituents. Breakup location is important for determining the role of breakup in above-barrier complete fusion suppression. Recent works have pointed out that experimental observables can be used to separate near-target and asymptotic breakup.
Purpose: Our purpose is to distinguish near-target and asymptotic direct breakup of ^{6,7}Li in reactions with nuclei in different mass regions.
Method: Charged particle coincidence measurements are carried out with pulsed ^{6,7}Li beams on ^{58}Ni and ^{64}Zn targets at sub-barrier energies and compared with previous measurements using ^{208}Pb and ^{209}Bi targets. A detector array providing a large angular coverage is used, along with time-of-flight information to give definitive particle identification of the direct breakup fragments.
Results: In interactions of ^{6}Li with ^{58}Ni and ^{64}Zn, direct breakup occurs only asymptotically far away from the target. However, in interactions with ^{208}Pb and ^{209}Bi, near-target breakup occurs in addition to asymptotic breakup. Direct breakup of ^{7}Li into α-t is not observed in interactions with ^{58}Ni and ^{64}Zn. However, near-target dominated direct breakup was observed in measurements with ^{208}Pb and ^{209}Bi. A modified version of the Monte Carlo classical trajectory model code PLATYPUS, which explicitly takes into account lifetimes associated with unbound states, is used to simulate sub-barrier breakup reactions.
Conclusions: Near-target breakup in interactions with ^{6,7}Li is an important mechanism only for the heavy targets ^{208}Pb and ^{209}Bi. There is insignificant near-target direct breakup of ^{6}Li and no direct breakup of ^{7}Li in reactions with ^{58}Ni and ^{64}Zn. Therefore, direct breakup is unlikely to suppress the above-barrier fusion cross section in reactions of ^{6,7}Li with ^{58}Ni and ^{64}Zn nuclei.

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I. INTRODUCTION

Collisions involving weakly bound stable and unstable nuclei are interesting from the perspective of understanding both nuclear structure and nuclear reactions. Information has been obtained on clusters in nuclei [1–3], the effect of breakup on other reaction observables [4–17], and nuclear structure near drip lines [18,19]. In astrophysics, direct Coulomb breakup has been used to probe radiative capture reactions at low energies [20–23]. Here, our interest lies in the effect of breakup on fusion cross sections.

Breakup prior to reaching the fusion barrier is thought to be one reason for the observed ∼30% suppression of above-barrier complete fusion cross sections for reactions of ^{6,7}Li and ^{9}Be with heavy target nuclei [4–7,24–26]. Such a suppression is not observed [24,26] in reactions with well-bound nuclei (where breakup should be negligible) forming the same compound system. A smaller suppression of complete fusion has been reported in measurements for reactions of ^{6}Li with ^{64}Ni [27], ^{96}Zr [9], and ^{9}Be with ^{89}Y [28]. Complete fusion measurements are, however, sparse for light and medium-mass nuclei, since separation of complete and incomplete fusion products is difficult. This is because charged particle evaporation from a light compound nucleus is much more significant than that in heavier nuclei. The same reaction product can thus be formed by charged particle evaporation after complete fusion and by incomplete fusion, where only part of the charge of the projectile is captured. For this reason, the extracted complete and incomplete fusion cross sections are often reliant on estimates of charged particle evaporation probabilities from statistical models. This has precluded a systematic understanding of complete fusion suppression from fusion measurements alone, as well as the relationship between above-barrier complete fusion suppression and breakup.

An alternate approach towards this goal has been developed in recent years [29–31], in which breakup mechanisms are studied in detail at sub-barrier energies [7,32]. The charged fragment absorption leading to incomplete fusion is minimal at sub-barrier energies, thus allowing a clearer understanding to be developed. Coincident measurements of charged particles resulting from breakup of the projectile-like nucleus, measured at a range of sub-barrier energies and angles, allows determination of breakup probabilities as a function of the

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