Final-state effects in the electromagnetic breakup of exotic nuclei

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Exotic nuclei have been studied extensively in recent years by electromagnetic excitation with the help of the Coulomb breakup method. These unstable nuclei are weakly bound and the excitation process readily leads to a breakup of the projectile into fragments at intermediate to high beam energies. Electromagnetic transitions to the continuum with large strength at low energies are observed. For a recent review see Ref. [1].

Experiments are usually analyzed in first order theories with simple structure models. However, the effects of the final-state interaction (FSI) between the fragments and between target and fragments have to be assessed in order to obtain reliable information from experimental data. The final state of the breakup process with at least three particles is a complicated system. Various theoretical methods have been developed to study final-state effects.

The FSI between target and fragments destroys the simple factorization of the cross section into contributions from nuclear structure and the excitation process in first-order theories. Higher-order effects from the target-fragment interaction can be included in the semiclassical approach by extending time-dependent perturbation theory to higher orders or by applying the sudden approximation The most general approach is studying the time evolution of the projectile system by coupled-channel calculations or by solving the time-dependent Schrödinger equation (dynamical calculation).

A prime example is the well-studied breakup of the halo nucleus ^{8}B into a proton and ^{7}Be with a very small proton separation energy $S_p = 0.137$ MeV. E1-E2 interference leads to a marked asymmetry of longitudinal momentum distributions at low beam energies. Higher-order effects that were considered in a dynamical calculation reduce this asymmetry and require an increased E2 strength as compared to a simple potential model in order to describe the experimentally observed asymmetry [2]. The Coulomb breakup of ^{8}B was also used as an indirect method to extract the astrophysical S factor $S_{17}(E)$ of the radiative capture reaction ^{7}Be(p,γ)^{8}B [3]. Higher-order effects of the target-fragment interaction lead to a reduction of the dissociation cross section. High projectile energies and large impact parameters reduce the effect considerably. A dependence of the S factor on the fragment-fragment FSI is also found in this case. It affects the extrapolation of measured $S_{17}(E)$ values to zero energy [3]. The FSI is also relevant for the ANC method where the zero-energy S factor is calculated theoretically using ground-state asymptotic normalization coefficients that were experimentally determined from transfer or nucleon-removal reactions [4]. The sensitivity of the zero-energy S factor on the potential strength increases with S_p.

For neutron+core nuclei the dependence of the final-state effects on characteristic quantities of the system is found from simple but realistic models that can be solved analytically [5]. Matrix elements for electric multipole transitions to the continuum are determined by the asymptotics of the wave functions in the initial and final state. The reduced transition probability exhibits a characteristic universal shape when expressed in terms of the relevant parameters. The effective-range expansion of the phase shifts motivates the introduction of reduced scattering lengths in order to include effects of the fragment-fragment interaction in the model [6].

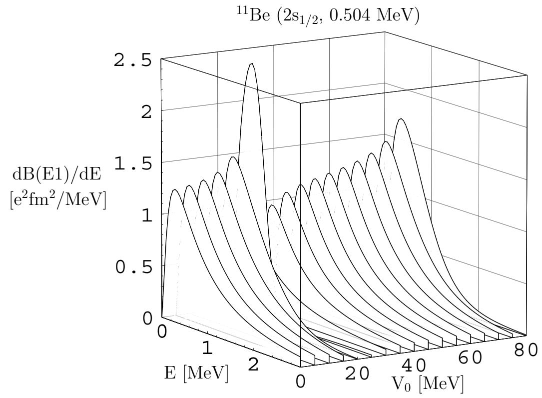

Figure 1: Reduced transition probability $dB(E1)/dE$ for the breakup of ^{11}Be into ^{10}Be+neutron for various depths V_0 of the nuclear potential (of Woods-Saxon shape) in the final state.

An increase of the strength of the FSI between the fragments from zero to realistic values leads to a significant variation of the shape of the reduced transition probability. These results are corroborated in more realistic calculations with simple potential models for n+core systems (see Fig. 1 for the case of ^{11}Be with a $2s_{1/2}$ neutron and a separation energy of $S_n = 0.504$ MeV in the ground state). The sensitivity of the transition probability on the fragment-fragment FSI increases with the neutron separation energy. For n-halo nuclei with small neutron separation energy plane-wave calculations neglecting the fragment-fragment interaction give similar results like calculations with realistic values of the potential.

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