Reaction dynamics for the systems \(^{11}\text{Be} + ^{209}\text{Bi}\) and \(^{17}\text{F} + ^{208}\text{Pb}\) at energies around the Coulomb barrier

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INTRODUCTION

The reaction dynamics at energies around the Coulomb barrier for the systems \(^{11}\text{Be} + ^{209}\text{Bi}\) and \(^{17}\text{F} + ^{208}\text{Pb}\) has been extensively investigated by our Italian-Japanese collaboration \([1]\). Both nuclei are radioactive and very loosely bound, but with a different type of valence nucleons: \(^{11}\text{Be}\) has a binding energy \(S_n\) of 501 keV and an additional \(n\)-halo structure, whereas \(^{17}\text{F}\) is bound by \(S_n = 601\) keV and its first excited state at 493 keV has a well known \(p\)-halo structure. The related physics case is the following: what are the signatures of these features on the reaction dynamics at near-barrier energies? Do these two different types of valence nucleons produce similar or rather opposite effects? Do they mainly influence the reaction cross section rather than the fusion probability?

EXPERIMENTS

We have recently measured the scattering process for the system \(^{11}\text{Be} + ^{209}\text{Bi}\) at 40, 42, 44, 46, 48 MeV \([2]\) and the scattering and exclusive breakup \((^{17}\text{F} \rightarrow ^{16}\text{O} + p)\) for the reaction \(^{17}\text{F} + ^{208}\text{Pb}\) at 85 MeV \([3]\). The former system was studied at RIKEN (Japan), while the latter at LNL. The \(^{11}\text{Be}\) secondary beam was produced via in-flight fragmentation of a high-intensity \(^{13}\text{C}\) primary beam and subsequently separated with the RIPS spectrometer \([4]\). The \(^{17}\text{F}\) radioactive beam was produced via the two-body reaction \(^{1}\text{H}_2\left(^{17}\text{O},^{17}\text{F}\right)n\) and then selected employing the EXOTIC facility \([5]\). For both systems the elastically and inelastically scattered particles and the breakup fragments were detected with the eight telescopes which constitute the EXODET array \([6]\). The readout electronics of this setup is based on ASIC chips and the telescope are arranged into a compact configuration around the target ensuring a solid angle coverage of \(\sim 70\%\) of \(4\pi\) sr.

Fig. 1 shows one example of the results recently obtained for the system \(^{17}\text{F} + ^{208}\text{Pb}\). The upper panel displays an exclusive breakup spectrum, i.e. \(^{16}\text{O}\) particles in coincidence with protons, compared with the scattering events recorded in the same detectors (bottom panel). One can clearly see that at subbarrier energies, the exclusive breakup probability is very small compared to that for the elastic scattering process. Additional details concerning the experimental set up, secondary beam quality, data analysis, can be found in Refs. \([2,3]\).

FIG. 1. \(^{17}\text{F} + ^{208}\text{Pb}\) at 85 MeV beam energy. Upper panel: \(^{16}\text{O}\) ions in coincidence with protons (events collected from two forward telescopes). Lower panel: \(^{17}\text{F}\) scattering events in the angular range \(35^\circ - 42^\circ\).

FIG. 2. Ratio to Rutherford for the differential cross section with relative optical model fit for \(^{17}\text{F}\) ions scattered from a \(^{208}\text{Pb}\) target at 85 MeV beam energy.

Fig. 2 shows the elastic scattering differential cross section at 85 MeV \((E_{cm}/V_b = 0.90)\). The small deviation from the pure Rutherford scattering points out a very
small absorption. These data are still somehow preliminary since the data collected from two of the four telescopes located at backward angles were discarded (50\% of the statistics) due to apparent non physical results. This point is still under consideration.

DISCUSSION

![Graph: Reaction and fusion cross sections for the system $^{11}$Be + $^{209}$Bi](image)

**FIG. 3.** Reaction and fusion cross sections for the system $^{11}$Be + $^{209}$Bi.

![Graph: Reaction, fusion, inclusive and exclusive breakup cross sections for the system $^{17}$F + $^{208}$Pb](image)

**FIG. 4.** Reaction, fusion, inclusive and exclusive breakup cross sections for the system $^{17}$F + $^{208}$Pb.

Figs. 3 and 4 compare the experimental data existing for the reaction, fusion, exclusive and inclusive breakup cross sections for the systems $^{11}$Be + $^{209}$Bi and $^{17}$F + $^{208}$Pb at near-barrier energies. Fig. 3 shows that for $^{11}$Be the reaction cross section is larger than the fusion one. This behavior is somehow expected since the small binding energy of the valence neutron should consistently increase the breakup probability. Within the large experimental uncertainty, a similar trend can be observed also for the reaction $^{17}$F + $^{208}$Pb, but only at the lowest energy point, well below the Coulomb barrier. At the higher energies the reaction and fusion cross sections are nearly identical. The small exclusive breakup cross section measured in this energy range is compatible with these results. The different behavior between $^{11}$Be and $^{17}$F, which are almost equally loosely bound, could be ascribed to the different role played by the valence nucleons. In fact the $^{17}$F valence proton has to overcome a Coulomb barrier and a centrifugal barrier higher than the $^{11}$Be valence neutron.

![Graph: Reduced reaction cross sections for light weakly bound nuclei compared with those measured for stable well bound projectiles](image)

**FIG. 5.** Reduced reaction cross sections induced by light weakly bound nuclei compared with those measured for stable well bound projectiles. The reduction has been done according to the procedure described in Ref. 7.

In fig. 5 we finally plot the reduced reaction cross sections for several reactions induced by light weakly bound nuclei on high-Z spherical targets ($^{208}$Pb and $^{209}$Bi) compared with those measured for well bound projectiles, namely: $^{4,6}$He, $^{10,11}$Be and $^{17,19}$F. The reaction $^{18}$O + $^{208}$Pb has also been plotted as an additional reference system. The reduction has been done according to the procedure described in Ref. [7] and takes into account the geometrical size of the projectiles and the different Coulomb barrier heights for different systems. We notice a large difference between the tightly bound $^4$He and the $^6$He halo nucleus, while the reaction cross sections turn out to be rather similar for two beryllium isotopes (the two lowest $^{10}$Be energy points [8] strongly deviate from the systematics and should be remeasured). Finally there is an unexpected enhancement for the $^{19}$F induced reaction with respect to weakly bound $^{17}$F. This outcome is somehow surprising and deserves further theoretical and experimental work.

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