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HEAVY ION PHYSICS

Fusion cross sections for the ^{6,7}Li+^{27}Al, ^{9}Be+^{27}Al systems

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Abstract. We present the results of total fusion cross sections measurements for the $^{6,7}Li$ + ^{27}Al, ^{9}Be + ^{27}Al, systems at energies above and below the Coulomb barrier ($0.8V_b \leq E \leq 2.0V_b$). The experimental evidence at the measured energy regime show that the total fusion cross sections of ^{6}Li and ^{9}Be with a light mass target are not affected by the break-up process. The elastic break up cross sections for the ^{6}Li + ^{27}Al system were also measured and the results are being presented in this issue. The data for the ^{7}Li + ^{27}Al system are still being analyzed and therefore these results should be considered preliminary.

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1. Introduction

The break up mechanism of loosely bound nuclei and its influence on the fusion cross section has become a subject of interest, during the last years. An exhaustive and comprehensive review of this topic was already given by P.R.S.Gomes in this conference [1] (see also [2]) and therefore will not be treated in this contribution. The motivation of this work was to study the influence of the breakup of weakly bound projectiles on the same target nucleus. The systems using $^{6,7}Li$ as projectiles

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on ^{27}Al target, were already measured at energies well above the Coulomb barrier [3]. This time our measurements comprise projectile energies above, around and below the Coulomb barrier.

2. Experimental setup

Beams of $^{6,7}Li$ and ^{9}Be were supplied by the Tandar accelerator at Buenos Aires. In order to count and to identify the evaporation residues, the time of flight (TOF) technique was used. The detector system is an improved version of that used and described in [3] but now, using a second μ-Channel Plate (MCP-time zero detector) as a stop detector. In this way, the residual energy measurement is completely independent of the time measurement in an attempt to avoid low-energy-cuts in the energy-time coincidence spectra. The relevant characteristics of the systems are: time resolution (FWHM)= 1.5 ns, energy resolution (FWHM)=1.7% and counting-efficiency ranging (15-20)% and (35-55)% for projectile-like and fusion-evaporation residues, respectively. A typical two-dimensional energy vs. time spectrum obtained for the $^{6}Li + ^{27}Al$ system at 24 MeV bombarding energy and at θ_{Lab}=12° , is shown in Figure 1. Note that our detection system is able to separate evaporation residues coming from the fusion of the projectile and target, from that stemming from those originated in the fusion of ^{6}Li on the target contaminant ^{16}O.

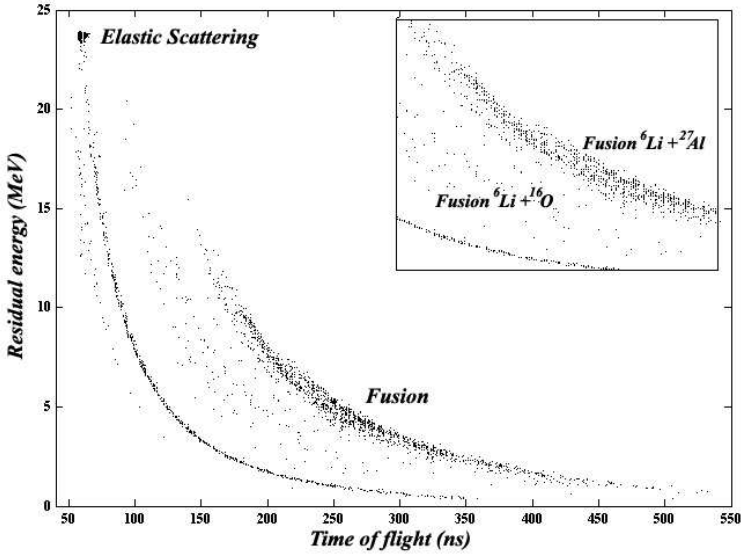

Fig. 1: Two dimensional residual energy vs. time of flight spectrum obtained for the $^{6}Li + ^{27}$Al system, at E_{Lab}=24MeV and at θ_{Lab}=12°.

From this spectrum (and the additional ones obtained at different projectile ener-

gies and scattering angles) it is possible, using a suitable procedure to correct for energy degradation in the carbon foils of the MCP's, to convert the spectrum in a one-dimensional histogram of masses that later can be compared with theoretical predictions using the evaporation code PACE [4]. Finally, it is easy to recognize those events produced in the fusion of the projectile and the target.

3. Experimental results

A usual procedure that helps to get confidence of the data in this type of experiments is to compare the experimental values deduced for the barrier radius R_b and the barrier height V_b with those obtained, for instance, from the systematic of reference [5]. Figure 2 shows the total fusion cross section vs. the inverse of the center of mass projectile energy for the three systems. The straight lines represent the minimum square fit to the data, from which (by extrapolation) one can get the experimental barrier height V_b and the experimental barrier radius R_b. The values obtained for the extrapolation are given in Table I. Within the experimental errors one can see that the agreement between values obtained for the systems using ^{9}Be and ^{6}Li as projectiles, is quite reasonable. This is not the case for that using ^{7}Li projectile, the values are far from the systematic, mainly the experimental barrier height derived in this work. Our suspicious fall on the cross sections data from 0.06 1/MeV to 0.10 1/MeV which are questionable, probably because of a bad estimate of the evaporation residues efficiency of the detection system, due to the energy degradation produced in the very thick carbon foils of both MCP's used in the experimental runs to study the ^{7}Li + ^{27}Al.

Table 1: Experimental values of Barrier height (V_b) and Barrier radius (R_b) obtained from the plots of Fig. 2 are compared with the systematic values from Kovar [5].

System	R_bExp. (fm)	R_bSyst. (fm)	V_bExp (MeV)	V_bSyst. (MeV)
$^{9}Be+^{27}Al$	8.6 ± 0.3	8.4	8.4 ± 0.4	8.1
$^{6}Li+^{27}Al$	7.8 ± 0.3	7.4	7.0 ± 0.5	6.2
$^{7}Li+^{27}Al$	8.9 ± 0.3	7.7	8.9 ± 0.5	6.0

To study possible breakup effects on fusion excitation functions, different systems may be compared in the same plot. In Figure 3, following the prescription of "reducing procedure" described in [6], we compare the reduced fusion excitation functions induced by three distinct weakly bound nuclei and one considered tightly bound nucleus on the same light mass target.
The enhancement or suppression of fusion cross sections when weakly bound nuclei are present and different breakup threshold energies are involved can be investigated in this way. We use for comparison the reduced total fusion cross sections of the ^{16}O

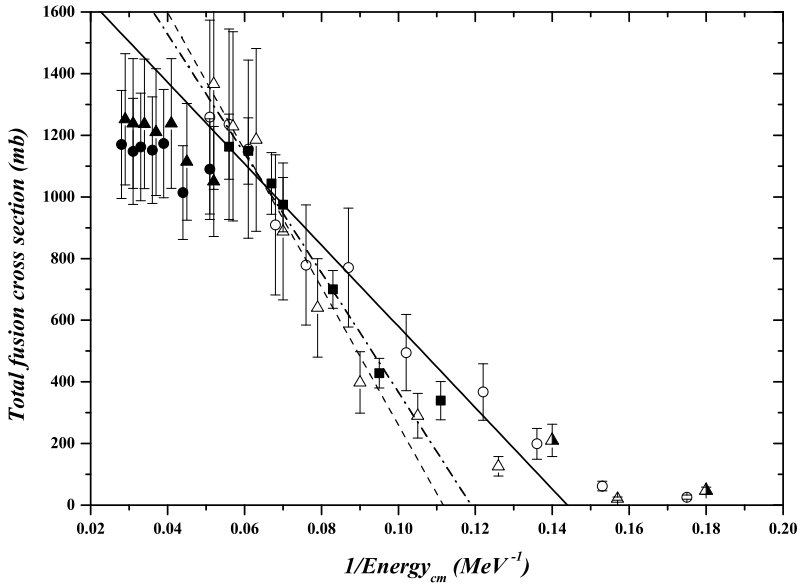

Fig. 2: Total fusion cross sections for the measured systems as a function of the inverse of the centre of mass energy. The full and open circles correspond to ^{6}Li + ^{27}Al, full, half-full and open triangles correspond to ^{7}Li + ^{27}Al, and full squares correspond to ^{9}Be + ^{27}Al.

+ ^{27}Al system [7] in which ^{16}O is considered a tightly bound nucleus. Total fusion cross sections are only slightly larger for the ^{9}Be + ^{27}Al system, and reasonably similar for ^{6}Li + ^{27}Al comparing with the total fusion cross sections of the tightly bound system. The data for the ^{7}Li + ^{27}Al system seems to be suppressed, but because of the problems already mentioned we do not to want to draw definite conclusions for these data. We have already said that we suspect of a possible efficiency deficit, but of course this has to be confirmed. One should note the two experimental points obtained for this last system (half-full triangles in Fig. 3), measured in the same experiment performed for the ^{6}Li + ^{27}Al fusion cross section measurements. They seem to follow the same tendency as ^{6}Li and ^{16}O projectiles.

The experimental results were also compared with theoretical predictions performed using the SPP (Sao Paulo Potential) bare potential [8]. It is important to note that there is not free parameter in this potential. The comparison is shown in Figure 4. One can see that a reasonable agreement for the fusion cross sections of the systems ^{6}Li + ^{27}Al and ^{9}Be + ^{27}Al is obtained. The theoretical predictions for the other system ^{7}Li + ^{27}Al are relatively far from the experimental data but no further conclusions can be extracted for the data and further data analysis is required.

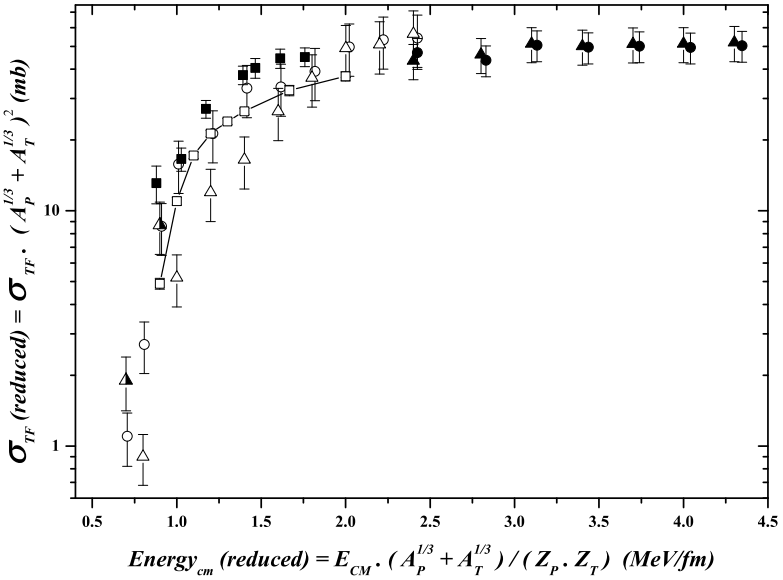

Fig. 3: Reduced total fusion cross sections as a function of the reduced centre of mass energy. The full and open circles correspond to $^{6}Li + {}^{27}Al$ system, the full squares correspond to $^{9}Be + {}^{27}Al$ system and the full, half-full and open triangles correspond to $^{7}Li + {}^{27}Al$ system. For comparison the total fusion cross sections for the $^{16}O + {}^{27}Al$ [7] system are included (open squares joined by a line).

4. Conclusions

Using the Time of flight technique, we have measured total fusion cross sections for the following systems: $^{6,7}Li + {}^{27}Al$ and $^{9}Be + {}^{27}Al$ at energies around and below the Coulomb barrier. The similar behavior of the fusion cross sections for the two systems using ^{6}Li and ^{9}Be, which are considered weakly bound projectiles compared with the fusion cross section of the ^{16}O, considered as tightly bound projectile, would indicate no evidence of the influence of breakup on the fusion cross sections for those systems. The different total fusion cross sections behavior shown for the $^{7}Li + {}^{27}$Al system at energies below the Coulomb barrier is still under analysis. Although the experimental results for this system suggest a suppression, we thought that the cause could be associated with the energy degradation of the fusion evaporation residues in the thick MCP's C-foil used in the experiment, which in turn could produce a low-energy-threshold cut-off reducing the efficiency for those events. The second important point that one can deduce from these experiments is that: specific experiments designed to carefully measure the efficiency of the time of flight system and the influence of the MCP's C-foils thickness are strictly necessary to be carried out.

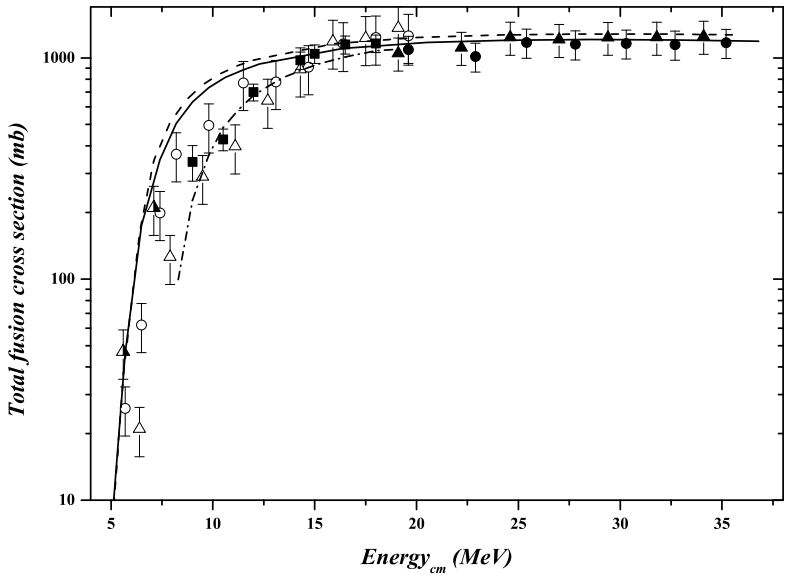

Fig. 4: Total fusion cross sections for the measured systems vs. the centre of mass energy. The full and open circles correspond to ^{6}Li + ^{27}Al system (above and below the Coulomb barrier, respectively), the full squares correspond to ^{9}Be + ^{27}Al system, and the full, half-full and open triangles correspond to ^{7}Li + ^{27}Al system (above and below the Coulomb barrier, respectively). The results of the SPP calculations for ^{6}Li, (dahsed line), ^{7}Li (full line), and ^{9}Be (dash-dotted line) are included.

Notes

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