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Measurement of Li+Sn fusion excitation functions around the Coulomb barrier using an improved activation technique

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Abstract. Fusion excitation functions have been measured for the ^{6}Li+^{120}Sn and ^{7}Li+^{119}Sn systems at energies around the Coulomb barrier, to investigate the effects of neutron transfer and breakup on the fusion process. At energies above the barrier, a suppression of the complete fusion excitation function with respect to the prediction of the 1D - Barrier Penetration Model has been observed, in both cases. At energies below the Coulomb barrier, no significant difference between the two excitation function, imputable to the different neutron transfer Q-values of the two systems has been observed.

1 Introduction

The effects of direct processes, such as neutron transfer and breakup, on fusion, in reactions induced by weakly bound nuclei, are important topics of current interest.
Concerning the neutron transfer, a lot of theoretical and experimental studies have been done to investigate on the possible presence of the sub-barrier fusion cross section enhancement on the neutron transfer Q-value. Experimentally, some signatures suggest that the presence of positive Q-values for neutron transfer enhances the fusion cross sections at sub-barrier energies (see e.g. [5, 6]). These experimental results are in agreement with what suggested in [7] and [8]. Beckerman et al. [7] proposed that the transfer of nucleon(s) with positive Q values can produce an increase of the kinetic energy favoring fusion. Based on this idea of the additional energy increase due to the positive Q-value neutron transfer, Zagrebaev [8] proposed a simplified semi-classical model to describe the effects of sequential neutron transfers in an approximate way, which can explain the observed sub-barrier fusion enhancement with respect to the 1D - Barrier Penetration Model (1D-BPM). Recently, new experimental results [9, 10] have shown that the presence of positive Q-value channels is not necessarily correlated with an enhancement of the sub-barrier fusion cross section. Moreover, Sargsyan et al. [11] presented a theoretical model suggesting that the neutron transfers influence the sub-barrier capture through the changes of deformation of the colliding nuclei.
Concerning the role of the breakup on the fusion process, there is a general qualitative understanding

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that in reactions on heavy targets (Z > 62), due to the strong breakup channel eventually followed by incomplete fusion,one has a suppression of the complete fusion (CF) above the barrier [1–3]. In particular, it has been observed that the lower is the breakup threshold of the projectile the higher is the CF suppression. Intuitively, one could expect that the breakup probability, and thus the suppression of the CF, might depend on the atomic number of the target due to the Coulomb field. Actually, for heavy targets the CF cross-section reduction seems to be independent from the Z of the target. In reactions on medium and light mass targets the CF cross-section seems not to be affected by the breakup process and no reduction was observed within the experimental uncertainties (see as example [4]). Despite many measurements, using weakly bound projectiles, have been done, the relationship between the amount of the complete fusion suppression and the Z of the target is still not clear.
In order to give further contribution to these studies, we measured the ^{6}Li+^{120}Sn and ^{7}Li+^{119}Sn fusion excitation functions at energies around the Coulomb barrier. By comparing the fusion excitation function for the two systems below the barrier, we wish to look for possible effects that could be attributed to the different neutron transfer Q-values. In fact, both reactions lead to the same compound nucleus (^{126}I) and are characterized by different Q-values for one- and two- neutrons transfer. Moreover, these measurements can help to investigate the complete fusion suppression above the barrier in a new target mass range.

2 Experimental technique

The ^{6}Li+^{120}Sn and ^{7}Li+^{119}Sn measurements were performed at the Laboratori Nazionali del Sud in Catania, using the beams delivered by the Tandem van de Graaff accelerator. As in similar experiments [12–15], we measured the fusion excitation functions by using an activation technique, based on the off-line detection of the atomic X-rays emitted after the electron capture decay of the evaporation residues (ER) produced in the reaction. This technique is particularly useful when measuring at energies close and below the Coulomb barrier since at these energies the largest fraction of ER does not have enough energy to leave the target and to be detected directly. The activation technique consists of two steps: the target activation and the measurement of the characteristic X-rays. During the first step, a target and a catcher, placed behind it, are directly irradiated with the beam. The catcher is used to stop the fraction of ER emerging from the target. After the irradiation time, the target and its catcher are placed in front of a Si(Li) detector to measure the emitted X-rays. For the present experiments, we irradiated stacks of targets (i.e. an ensemble of targets), instead of a single target with the respective catcher. In principle, the stack setup is particularly suitable in experiments where the fusion cross-section is measured at energies below the barrier or with low-intensity radioactive beams, because it allows a significant reduction of the beam time needed to perform the experiment. Even if our beams were stable, we used this setup since we were interested in it to better understand the limits and problems related with this technique. In fact, despite of a lot of measurements have been done by using this technique (see as examples [16–18]), its drawbacks are usually not discussed in detail and taken into account in the determination of the fusion excitation function. For a correct determination of the fusion excitation function with the stack technique, it should be considered the energy dependence of the fusion cross-section, the energy distribution inside the target and the possible target non-uniformity. We improved this technique by developing a procedure for taking into account all these factors.
In the left side of figure 1 a typical X-ray spectrum measured off-line is shown. It is possible to distinguish the K_{α} and K_{β} X-ray emission of Iodine, the only element which could be produced after complete fusion, and of Sb, produced in the incomplete fusion of deuteron or triton with the target. From X-ray energies one can identify different elements; the contribution of different isotopes can be

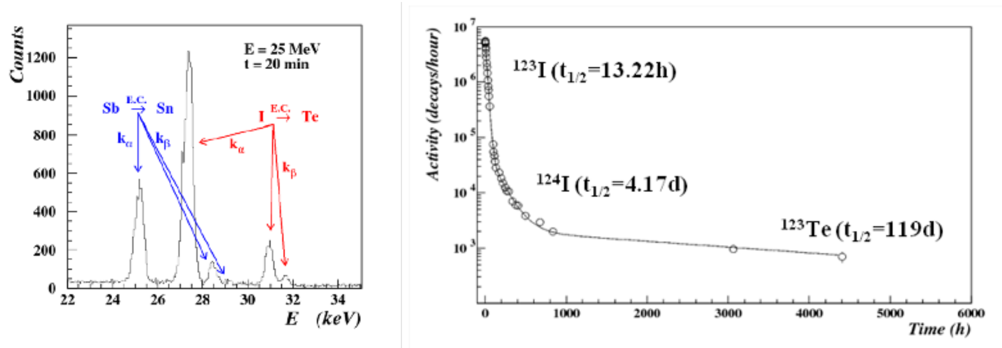

Figure 1. (Left side) X-ray spectrum measured off-line, 20 minutes after the end of the irradiation, for the reaction ^{6}Li+^{120}Sn at E_{LAB}= 25 MeV; (Right side) activity curve obtained by monitoring in the time the kα peak of I isotopes.

unfolded by following the activity of the X-ray lines, characteristic of each element, and by fitting it using the known half-lives. In the right side of figure 1 a typical activation curve for the ^{6}Li+^{120}Sn reaction is shown, characterized by three different slopes which correspond to the half life of different isotopes produced in the reactions. One can observe the contribution of ^{123}I,^{124}I which correspond to the evaporation of 3 and 2 neutrons, respectively. The third component has been identified as ^{123}Te, which can be produced in the incomplete fusion of an α-particle with the target nucleus. The ^{123}Te is metastable and decays by internal conversion thus emitting X-rays. By fitting the activation curves for each ER one obtains its activity at the end of the irradiation time, needed for the evaluation of the fusion cross section. By knowing also the efficiency of the Si(Li) detector, the K_α fluorescence probability, the beam current as a function of time and the target thickness, it is possible to obtain the production cross section for each residue produced in the reaction. The fusion cross section is obtained by summing pver the contribution of all the ER produced inside the target.

3 Results and conclusions

In figure 1 the reduced fusion excitation functions for the two studied reactions are reported and compared. The data have been reduced by dividing the fusion cross-section by the square of the barrier radius (R_B^2) and subtracting from the center-of-mass energy the height of the Coulomb barrier V_b. At energies below the barrier, the two curves do not present any particular difference: sub-barrier fusion enhancement in the ^{7}Li induced collisions imputable to larger n-transfer Q-value cannot be deduced from these data. At energies above the barrier, the fusion cross section of the ^{7}Li+^{119}Sn system is higher than the one of the ^{6}Li+^{120}Sn. This difference is attributable to the different breakup probability of the two projectiles. In fact, by comparing, at energies above the barrier, the two fusion excitation functions with respect to the the 1D-BPM prediction, calculated by using the optical approach [19, 20], a suppression of about the 35% in the case of ^{6}Li and of about 20% in the case of ^{7}Li has been obtained.

In conclusion, by measuring the fusion cross section induced by the weakly bound ^{6}Li and ^{7}Li projectiles on different Sn isotopes, we looked for effects on fusion cross section which can be attributed to the breakup and neutron transfer channels. At energies above the barrier, we have observed the well known suppression of CF. The obtained suppression factors are in agreement with the ones pre-

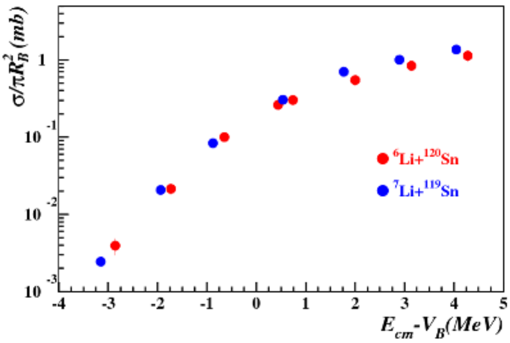

Figure 2. ^{6}Li+^{120}Sn (blue circles) and ^{7}Li+^{119}Sn (red circles) fusion excitation function reduced as $\sigma/\pi R_B^2$ vs $E_{cm} - V_B$

viously measured for heavier targets[2, 3], confirming further that there is no relation between the CF fusion suppression and the target atomic number. Concerning the possible influence of the positive neutron transfer Q-value on the fusion excitation function at energies below the barrier, no difference imputable to the different n-transfer Q-values can be deduced from our data. This behavior seems to be consistent with the one observed recently in fusion reaction of heavier systems [9, 10]. To further investigate the possible relation between the n-transfer Q-values and the fusion excitation function, we are going to extend the measurement to lower energies.

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