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Fusion of ⁸He with ²⁰⁶Pb around Coulomb barrier energies

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Abstract. The experimental study of the fusion of light neutron-rich nucleus ⁸He with ²⁰⁶Pb is reported in this work. A fusion stack of ²⁰⁶Pb targets has been used for this study. The most prominent evaporation residue (²¹⁰Po), which has half-life of 138 days and decays by alpha emission, is populated in the reaction. Radiochemical analysis technique is used to extract the yield of this evaporation residue.

1 Introduction

From the first experiments where evidences for a halo structure in ¹¹Li were reported [1], similar effects were also found in other exotic nuclei far away from the valley of stability. The availability of these exotic nuclei has triggered new interest in the field of nuclear structure and reaction dynamics [2,3]. There have been also many improvements in the theoretical side which provide a deeper understanding of experimental findings by using different approaches. The coupled channels approach is nowadays extensively being used to understand simultaneously different reaction channels by means of codes like FRESCO [4]. The strength and coupling between the different reaction channels can be properly described by the use of coupled channels calculations [5], including coupling to the continuum. Even for four body correlations [6], the theoretical framework was reasonably well established along last few decades from the study of nuclear reactions with stable heavy ions. At coulomb barrier energies, the data can also be described using semi-classical models [7], complementary to the sophisticated coupled channels calculations, providing an elegant insight on the relevant mechanisms participating in the dynamics of the collision process.

Sub-barrier fusion of neutron rich nuclei depends strongly on the reaction channels still present at energies below the barrier. In neutron-rich nuclei the fusion cross section could be increased due to a reduction in the effective Coulomb barrier [8]. However the characteristic low binding energy should favour the break-up channel and reduce the fusion probability [9]. Several experiments were performed to study the effect of neutron halo on the fusion process, and extraordinary experimental efforts have been carried out in the past for measuring sub-barrier fusion of ⁶He [9–11]. The case of ⁸He is different, as we are dealing with a skin nucleus, a system with a thick layer of neutron matter surrounding the inner nuclear core. Whether the halo or the skin will produce strong effects on fusion cross sections is still a matter of investigation. Very recently, a first measurement to understand the fusion mechanism was performed at GANIL using ¹⁹⁷Au targets [12].

The motivation of the present work is the understanding of the interplay between the various reaction channels

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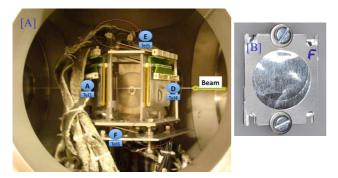


Fig. 1. [A] Picture of experimental setup used for the detection of the charged particles produced in the ${}^{8}\text{He}+{}^{208}\text{Pb}$ collisions (see text for details) [B] Picture of the fusion stack which was placed downstream of the scattering chamber in a separate chamber.

in the fusion process. A new experiment was performed using the SPIRAL RIB facility at GANIL (Caen, France) in October 2010, where two targets along the beam line were used. In this experiment, the ⁸He beam was first scattered on a ²⁰⁸Pb target, where direct reaction processes were investigated by using the Huelva University charged particle array (GLORIA). A few meters downstream the beam line, a fusion stack of four ²⁰⁶Pb targets (separated by mylar in front and aluminium in back) was placed to measure subbarrier fusion cross sections. Here the evaporation residues (ER) produced after the fusion of ⁸He with ²⁰⁶Pb were implanted on ²⁰⁶Pb and successive Al assembly, where the vield of ²¹⁰Po (an active alpha emmiter having a half life of 138 days) was accumulated during several hours of irradiation. The details of experimental setup, radiochemical procedure and the results are given in the following sections.

2 Experimental Details

In the experimental setup, a new simple but highly efficient charged particle detector array developed at the University of Huelva (Spain) named GLORIA (GLObal ReactIon Array) was used to measure the elastic scattering and direct reaction channels. In addition, a stack of ²⁰⁶Pb foils was used to extract the fusion residues using the activation technique. The schematics of the experimental setup, the scattering chamber and the GLORIA array, is shown in Fig. 1[A]. The fusion stack was placed downstream of the scattering chamber for irradiation, as it is shown in Fig. 1[B]. The GLORIA silicon ball is a compact and high granularity detection system, covering a wide angular range from $\theta_{lab} = 10^{\circ}$ to 170°. The system is made of 12 DSSSD (16 x 16 strips each) particle telescopes. For each telescope: ΔE -40 μ m, E-500 μ m. The detector system is fully equipped by its own analog chain, logic and DAQ system on a VME platform. The typical two dimensional spectrum of ΔE vs. Etot for ⁸He+²⁰⁸Pb reaction measured at $E_{lab} = 22$ MeV and $\theta_{lab} = 26.7^{\circ}$ is shown in Fig. 2. In the case of the fusion stack used for irradiation, it consists of stack of four ^{206}Pb targets separated by mylar (~ 2.5 $\mu\text{m})$ in the front (to stop the backscattered ERs) and aluminium (~ 14.7 μ m)

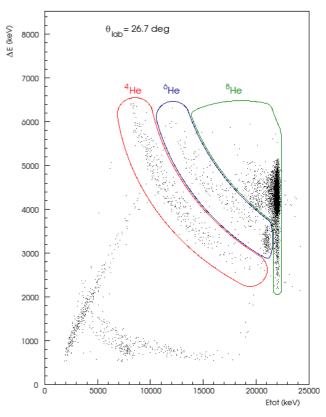


Fig. 2. A typical two dimensional spectrum of ΔE vs. Etot for ⁸He+²⁰⁸Pb reaction measured at $E_{lab} = 22$ MeV and $\theta_{lab} = 26.7^{\circ}$. Different isotopes of 'He' can be easily identified in this telescope.

in the back (to degrade the beam energy). The whole stack is irradiated for 22 MeV. The incident beam energy on the successive target foils was determined based on the energy loss for the mylar, Pb and Al foils using SRIM [13]. After irradiation, the activated ²⁰⁶Pb foils went through a radiochemical treatment in which the ²¹⁰Po was isolated and deposited on a silver coin. The coins were introduced in the alpha station system at University of Huelva, where the yield of ²¹⁰Po was obtained.

2.1 Preparation of samples and radioactivity measurement

The fusion stack irradiated during the experiment has been subjected to chemical processing at the Radiochemical laboratory at the University of Huelva. The picture of the measurement cell is shown in Fig. 3. Each target was dissolved and a known amount of ²⁰⁹Po was added as a tracer in order to fix an efficiency of the chemical process. The element of interest was extracted and put into dedicated alpha activity measurement cells. As the half-life of alpha decay from ²¹⁰Po is 138 days, the activity is measured for 30 days to accumulate sufficient statistics. We also took a background run to confirm that no other peaks were present in the region around 5300 keV (emitted alphas from ²¹⁰Po). A typical spectrum for one of the samples after one month of



Fig. 3. Picture of measurement system at the Radiochemistry laboratory at the University of Huelva. In the inset, the detector and the sample holder can be seen.

statistics is shown in Fig. 4[A]. The distinct peak of alpha particles from 210 Po at 5300 keV can be seen along with the room background (228 Th peak) and the radiotracer 209 Po peaks. The peak of interest (210 Po) has been fitted (shown in Fig. 4[B]) and the area under that peak was extracted.

3 Results and Discussion

In order to determine the cross-section of interest (production of ²¹⁰Po), the total flux of the projectiles during the irradiation is necessary. It will be obtained by normalizing the elastic scattered particles detected in the forward angle ($\theta < 30^{\circ}$), where Rutherford scattering is expected. The analysis of the elastic scattering channel is in progress to get the final (production of ²¹⁰Po) cross-sections.

4 Summary

The production of ²¹⁰Po populated in the fusion of ⁸He with ²⁰⁶Pb has been measured for energies around the Coulomb barrier. The method of activation in a stack of foils has been utilized for this study. The elastically scattering projectiles from ²⁰⁸Pb target at forward angles will be utilised for absolute normalization to determine the production crosssections. The full elastic scattering distribution data acquired in the same experiment will also be reported shortly.

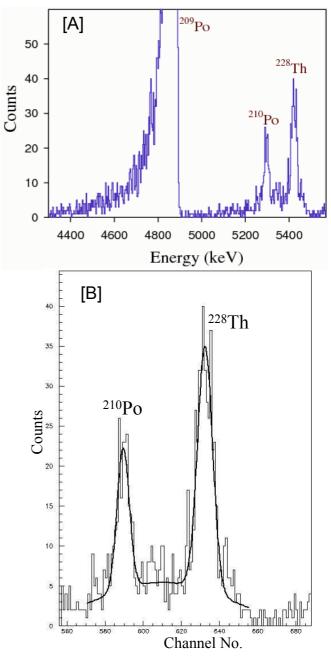


Fig. 4. [A] Typical energy spectrum from the sample after radiochemical and self deposition process on the silver disk. The peak corresponding to the alpha decay of ²¹⁰Po at 5300 keV is clearly seen to be separated from other radioactive contaminants. The bigger peak corresponding to the alpha decay energy of the radiotracer ²⁰⁹Po at 4880 keV can also be seen. [B] Fitting procedure used to extract the yield of ²¹⁰Po.

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