

⁷Be and ⁸B reaction dynamics at Coulomb barrier energies

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Abstract. We investigated the reaction dynamics induced by the ⁷Be, ⁸B+²⁰⁸Pb collisions at energies around the Coulomb barrier. Charged particles originated by both the collisions were detected by means of 6 ΔE-E_{res} telescopes of a newly developed detector array. Experimental data were analysed within the framework of the Optical Model and the total reaction cross-sections were compared together and with the ^{6,7}Li+²⁰⁸Pb colli-

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sion data. According to the preliminary results, ${}^7\text{Be}$ nucleus reactivity is rather similar to the ${}^7\text{Li}$ one whereas the ${}^8\text{B}+{}^{208}\text{Pb}$ total reaction cross section appears to be much larger than those measured for reactions induced by the other weakly-bound projectiles on the same target.

1 Introduction

The study of ${}^7\text{Be}$ and ${}^8\text{B}$ dynamical behavior is relevant for the understanding of several processes in the universe [1]: ${}^7\text{Be}$ is at the top side of the reaction network which describes the primordial nucleosynthesis in the framework of the standard Big Bang, being involved in the production of the primordial lithium; jointly with ${}^8\text{B}$, is a main actor in the proton-proton chains of hydrogen burning in the main-sequence stars like our sun; in particular, ${}^7\text{Be}$ is at the vertex of two reaction chains, being the product of the ${}^3\text{He}+{}^4\text{He}$ fusion; beta decays of ${}^7\text{Be}$ and ${}^8\text{B}$ are responsible of the neutrino flux from the Sun, studied for the understanding of neutrino oscillations; finally, ${}^7\text{Be}$ is involved in additional reaction networks which describe the nucleosynthesis model of the inhomogeneous big bang and some supernovae.

${}^7\text{Be}$ and ${}^8\text{B}$ are exotic nuclei which are also intriguing for the peculiar structures they exhibit: ${}^8\text{B}$ is characterized by a proton halo (which was discovered by measuring its quadrupole moment [2]); ${}^7\text{Be}$, which is the core of ${}^8\text{B}$, shows a cluster structure consisting of a ${}^3\text{He}-{}^4\text{He}$ system. These properties, jointly with a low binding energy, open the doors for a series of static and dynamical effects which may alter the total reactivity by several order of magnitude, making of ${}^7\text{Be}$, ${}^8\text{B}+{}^{208}\text{Pb}$ study an effective workbench for testing nuclear models. Obviously, our comprehension of the behavior of these nuclei will be extended to the astrophysical case.

For the production of dripline nuclei via (p,n), (${}^3\text{He}$,n), (d,n) and (d, ${}^3\text{He}$) two-body reactions, the facility EXOTIC [3] was laid out in Laboratori Nazionali di Legnaro (LNL), Italy. The secondary RIB under production is separated from the scattered beam and other possible contaminant beams by means of a combination of 8 ion-optical devices and a series of slit-sets and collimators placed at suitable positions along the facility. EXOTIC is especially suitable for the production of RIBs by means of (p,n) reactions, since the larger projectile-to-target ratio ensures an additional forward focusing of the reaction products. So far we produced several beams like ${}^{17}\text{F}$, ${}^8\text{B}$, ${}^7\text{Be}$ (rate ~ 250 kHz), ${}^{15}\text{O}$, ${}^8\text{Li}$ and isotopes of carbon.

At the far end of the EXOTIC beam line is usually placed the EXPADES detector array [4]. It is designed to be compact, with a high granularity and a good covered solid angle. It consists of 8 silicon telescopes arranged in a cylindrical configuration. In each telescope there are a $40\ \mu\text{m}$ DSSSD acting as ΔE stage and a $300\ \mu\text{m}$ DSSSD that measures the particle residual energy. Both the DSSSD are square detectors 64 mm wide and have 32 stripes per side. A set of 8 ionization chambers can be used as alternative ΔE stage.

2 ${}^7\text{Be}+{}^{208}\text{Pb}$, ${}^{58}\text{Ni}$ collisions

In the covered angular ranges $[55^\circ, 84^\circ]$, $[96^\circ, 125^\circ]$ and $[138^\circ, 165^\circ]$ in the laboratory frame, we measured the ${}^7\text{Be}+{}^{208}\text{Pb}$ quasi-elastic scattering since the excitation of both the projectile and the target cannot be disentangled by watching only at energy spectra. At the beginning, we extracted the angular distributions at three energies: 37.4 MeV, 40.5 MeV and 42.2 MeV. A preliminary optical model best-fit, carried out employing the code FRESKO [5], allowed the extraction of three points for the total reaction cross-section where we observed a very similar behavior to the ${}^7\text{Li}$ case [6], which is its mirror nucleus.

At a later time we concentrated on the ^3He and ^4He production, since they may come from several direct processes: one neutron stripping/pickup, the stripping of one of the clusters in the projectile, the exclusive breakup which is the inverse reaction of the ^7Be synthesis in the proton-proton chains. We clearly observed that ^4He production is four to five times larger than ^3He and identified several processes over about $3.5 \cdot 10^6$ detected events: 15 neutron pickup events and 17 ^4He -p coincidences. We observed only 19 exclusive break-up events, suggesting that probably the exclusive breakup is not dominant in this collision. The exclusive breakup counts are important because this process can be exploited for the extraction of the astrophysical reaction rate from the Coulomb dissociation of the projectile [7].

The ^4He overproduction with respect to the ^3He one was already observed in the case of the ^{58}Ni target. In this case we detected only few of the processes involved in the production of ^3He and ^4He and the undetected processes were evaluated using Monte Carlo simulations. In particular the exclusive breakup was evaluated using Coupled-Channel calculations. A more accurate investigation is hoped for this collision with better experimental conditions.

3 $^8\text{B} + ^{208}\text{Pb}$ collision

For the $^8\text{B} + ^{208}\text{Pb}$ collision we moved EXPADES to the C-RIB facility at Riken, Wako-shi, Japan where the incident beam was a "Cocktail beam" containing also ^7Be and ^3He contaminants (^8B rate ~ 10 kHz purity $\sim 25\%$). However the experimental apparatus (and the C-RIB monitoring devices) provided several information that we used to separate: firstly the ^8B beam from its contaminants and secondly the reaction products each other. In particular we not only used the ΔE -Er matrix, which showed a very good charge separation, but also the time of flight- ΔE matrix. Also in this case we firstly concentrate only on the elastic events spot, extracting an angular distribution and a total reaction cross section. In Fig. 1 we show the very preliminary results for ^8B and our results for ^7Be . An interesting preliminary evidence is a factor three super-reactivity of ^8B (of about 1 b) with respect to the ^7Be case.

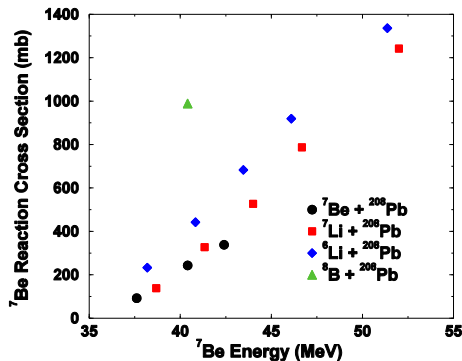


Figure 1. Very preliminary reaction cross sections for $^{6,7}\text{Li}$, ^7Be , $^8\text{B} + ^{208}\text{Pb}$. Data were normalized and plotted according to Ref. [8]. Uncertainty is about 15% for $^8\text{B} + ^{208}\text{Pb}$ and 10% for $^7\text{Be} + ^{208}\text{Pb}$, $^{6,7}\text{Li} + ^{208}\text{Pb}$ tabulated without error as reference.

4 Conclusion

In this article we showed some results about two light exotic nuclei which are involved in several astrophysical processes. We studied both nuclei performing their collision on a ^{208}Pb target and employing an high granularity detection array. We observed that in the case of ^7Be dynamics is not dominated by the breakup process, observing 19 coincidences and, since this process is useful for the determination of the astrophysical reaction rates, more efforts are required in measuring this process. Monte Carlo simulations are presently being performed in order to determinate the cross-section of each process. In the case of ^8B , preliminary results show a factor three larger reactivity with respect to the ^7Be case. Analysis is still going on and interesting results are expected.

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