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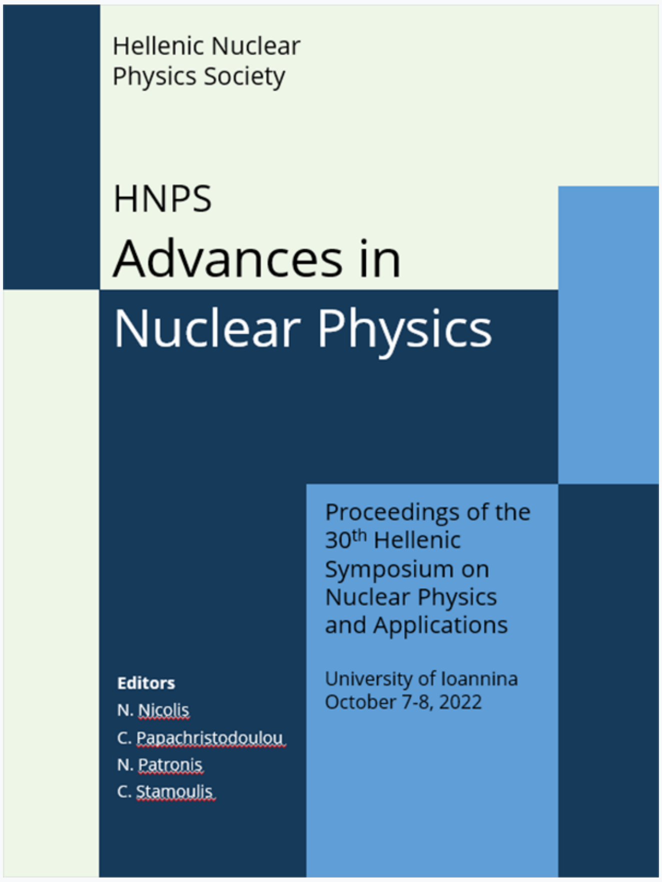

Elastic scattering measurements of 7Be+natZr at sub- and near – barrier energies

Athena Pakou

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Elastic scattering measurements of ^{7}Be+^{nat}Zr at sub- and near – barrier energies

K. Palli[1,2], A. Pakou[1*], P. O'Malley[3], L. Acosta[4], A. M. Sánchez-Benítez[5], G. Souliotis[2], E. F. Aguilera[6], E. Andrade[4], D. Godos[4], O. Sgouros[7], V. Soukeras[7,8], C. Agodi[7], T. Bailey[3], D. Bardayan[3], C. Boomershine[3], M. Broduer[3], F. Cappuzzello[7,8], S. Carmichael[3], M. Cavallaro[7], S. Dede[3], J. A. Dueñas[5], J. Henning[3], K. Lee[3], W. S. Porter[3], F. Rivero[3], W. von Seeger[3]

[1] Department of Physics and HINP, The University of Ioannina, Ioannina,Greece
[2] Department of Chemistry, National and Kapodistrian University of Athens and HINP, Greece
[3] Department of Physics and Astronomy, University of Notre Dame, Indiana 46556, USA
[4] Instituto de Fisica, Universidad Nacional Autónoma de Mexico, Mexico
[5] Departamento de Ciencias Integradas y Centro de Estudios Avanzados en Fisica,Matemáticas y Computación, Universidad de Huelva, 21071 Huelva, Spain
[6] Departamento de Aceleradores y Estudio de Materiales, Apartado Postal 18-1027,Codigo Postal 11801, Mexico, Distrito Federal, Mexico
[7] INFN Laboratori Nazionali del Sud, Catania, Italy
[8] Dipartimento di Fisica e Astronomia "Ettore Majorana", Università degli Studi di Catania, Catania, Italy

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Abstract We will present a recent experiment for elastic scattering of ^{7}Be+^{nat}Zr at five sub- and near- barrier energies, namely at 21.5, 22.5, 24, 27 and 28 MeV, for determining the optical potential. The experiment was performed at the *TriSol* radioactive beam facility of Notre Dame University, simultaneously with elastic scattering and breakup measurements of ^{8}B+^{90}Zr, the last performed at 28 MeV. This optical potential will be used as one of the coupling potentials in our CDCC calculations for ^{8}B. Furthermore, we will look for the energy dependence of the potential and its resemblance to either the one exhibited by ^{7}Li or the one by ^{6}Li, extracting useful conclusions about their structure. Preliminary data are presented and discussed.

Keywords weakly bound nuclei, breakup, elastic scattering, optical potential, threshold anomaly

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INTRODUCTION

The investigation of reaction dynamics at near barrier energies for weakly bound nuclei has been pursued systematically for the last 20 years. It proved to be a fruitful playground in relation with channel coupling effects for elastic scattering and the probing of a new type of the standard potential threshold anomaly [1-5]. It might also affect the suppression and enhancement of fusion cross sections below and above barrier [6-10]. A possible fusion hindrance [9, 11-13] below barrier may have enormous consequences on astrophysical problems. It is possible, according to a phenomenological prediction presented in [14], that the direct reactions below barrier for weakly bound nuclei and heavy targets are exhausting the total reaction cross section, giving almost no space for compound nucleus mechanisms. In fact, it was predicted that while at near-barrier energies the ratio of direct to total reactions can be similar for weakly bound nuclei on all targets, and close to ~20%, for energies below the barrier and for heavy targets this ratio increases up to ~ 100 %, leaving little or no room for fusion. On the other hand, for medium mass targets, like ^{90}Zr, this ratio tops at ~ 80% and for lighter targets, like ^{28}Si, at ~75%. Strong indication of this for heavy targets and deep sub-barrier energies was given with our recent breakup measurement for ^{8}B + ^{208}Pb at the deep sub-barrier energy of 30 MeV, reported in [15]. Measurements at deep sub-barrier energies are scarce since, at these energies, the cross sections are very small and very difficult to be measured, especially with radioactive beams. Breakup measurements with ^{8}B are appealing, not only due to the particular

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* Corresponding author: apakou@uoi.gr

structure of this nucleus, but also because breakup exhausts most of the direct reaction component with all targets, and cross sections are expected to be large and therefore easier to be measured.

In continuation of our previous study on ^{8}B + ^{208}Pb at 30 MeV, reported in [15], we have performed in August 2022, a similar study at the sub - barrier energy of 28 MeV for the system ^{8}B + ^{nat}Zr. The interpretation of these data will be performed in a Continuum Discretized Coupled Channel (CDCC) framework. In such calculations, amongst the needed coupling potentials, is the ^{7}Be + ^{90}Zr one. In this respect, our ^{8}B breakup and elastic scattering measurement included an elastic scattering measurement of ^{7}Be + ^{90}Zr at below and near barrier energies. This measurement was also performed for its own sake for supplementing the systematics on the energy dependence of the optical model potential (OMP) at near and sub-barrier energies. It is well known by now that in several cases the behavior of weakly bound projectiles differs from that of well bound ones, and also is strongly dependent on the target (see e.g [1-5] and references therein). In our recent publication [16] on the "Global approach for the reactions ^{7}Be + ^{28}Si and ^{7}Be + ^{208}Pb at near- and sub-barrier energies", reanalyzing previous elastic scattering data we have probed an OMP for ^{7}Be + ^{28}Si very different from the one for ^{7}Be + ^{208}Pb. The energy variation of these potentials is described in Fig. 1, where we can see that, while the imaginary potential drops slower or faster to zero approaching the barrier for both targets, the real part, not following the dispersion relation, is flat for the light target but obeys the dispersion relation for the heavy target, presenting the usual bump at barrier. We also note the similarity between ^{7}Be and its mirror ^{7}Li.

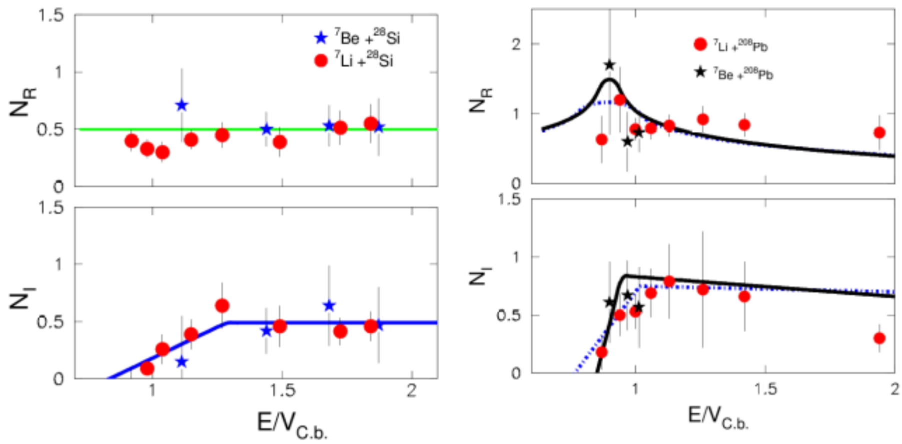

Figure 1. *Energy dependence of OMP for ^{7}Be and ^{7}Li (left) on a light target; (right) on a heavy target. Figure based in Ref. [16]*

In what follows, we will describe our experiment at the radioactive beam facility *TriSol* of the Notre Dame University and we will present some preliminary results and conclusions.

EXPERIMENTAL DETAILS

The radioactive beam facility of Notre Dame operates for the last 20 years under the name *TwinSol*, providing several radioactive beams of strong interest for the Nuclear Physics community (e.g. ^{6}He, ^{8}Li, ^{7}Be, ^{8}B). Technical details about the operation can be found in [17-18], while the obtained physics can be found in the review article by James J. Kolata et al. [10] and references therein.

The primary beam in this facility is produced by the Notre Dame UND FN tandem accelerator and impinges on a primary gas target, the appropriate vessel of which can be seen in the photo of Fig. 2. The secondary beam is handled in the original mode with two twin solenoids (*TwinSol* facility), while recently a third solenoid and bending magnet have been added and used in the present experiment for a better collimation of the secondary beam (*TriSol* facility).

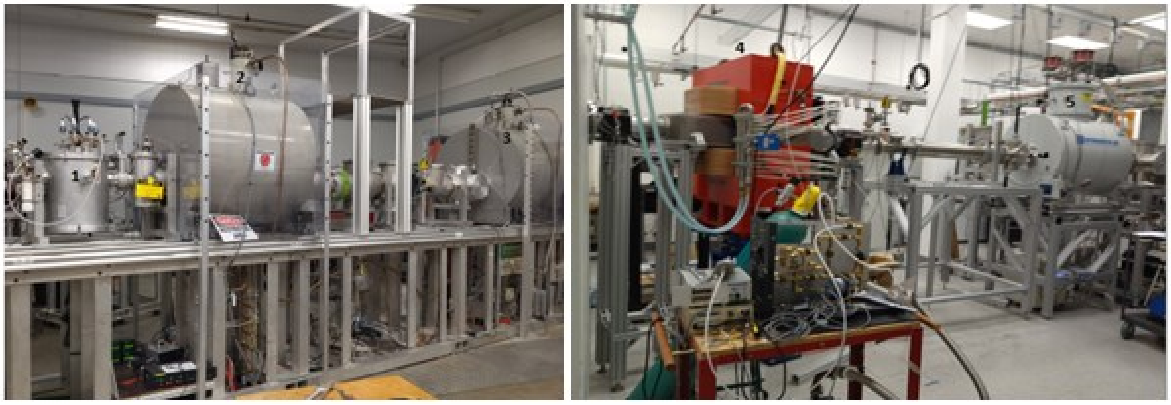

Figure 2. *Photo of the TriSol facility prolonged in two experimental halls. In the first hall we can see the (1) primary gaseous target and the two twin solenoids (2,3). In the adjacent hall the new bending magnet (4) and the third new solenoid (5) before the target chamber, can be also seen.*

The primary beams for the present experiment were ^{6}Li accelerated at 37 MeV for the boron experiment and at 23.8, 24.8, 26.1, 29 and 30 MeV for the ^{7}Be elastic scattering experiments. The ^{8}B beam was produced by using the ^{6}Li(^{3}He,n)^{8}B direct-transfer reaction and a 2.5-cm-long gaseous primary target containing 850 Torr of ^{3}He. The intensity of the primary beam was ~ 300 to 500nA, producing a ~ $1x10^{4}$ pps secondary bunched beam. The ^{7}Be beam was produced by using the direct-transfer reaction ^{6}Li(^{2}H, p)^{7}Be, replacing the ^{3}He gas cell in the primary target vessel with a ^{2}H one, at a pressure of 850 Torr. The produced secondary ^{7}Be beam was collected and transported via the *TriSol* solenoid system to a 1.92 mg/cm^{2} thick ^{nat}Zr secondary target. This beam was not bunched, since for the elastic scattering measurement the various produced beam particles were well separated amongst themselves by energy via the ΔE-E technique.

The elastic scattered nuclei at five projectile energies, 21.5, 22.5 24, 27 and 28 MeV ($E/V_{C.b.}$ =0.89, 0.93, 0.99, 1.11, and 1.15 respectively), together with the other reaction products were detected by four silicon telescopes. Three of them were provided from the SIMAS (Sistema Móvil de Alta Segmentacíon) array of LEMA (Laboratorio Nacional de Espectrometría de Masas con Aceleradores), the National Laboratory of the Physics Institute at the Autonomous National University of Mexico and the fourth telescope was provided by the "Laboratorio de Interacciones Fundamentales" (LIFE) of the research centre "Centro de Estudios Avanzados en Física, Matemáticas y Computación" (CEAFMC) of Huelva University, Spain. The first stage of these telescopes was a Double Sided Strip Silicon Detector (DSSSD) ~ 15 to 20 μm thick, backed by a second stage silicon pad ~ 150 and 500 μm thick. The DSSSD detectors with dimensions of 5.4 x 5.4 cm, provide 16 strips distributed horizontally and 16 strips vertically, allowing an analysis pixel by pixel and an interstrip rejection. Two of the telescopes were installed at forward angles at symmetrical positions, correcting for beam divergence, as well as increasing the statistics of the experiment. These were covering an angular range between ~ 20 to 60 degrees. The other two were installed backwards again at symmetrical positions, covering an angular range of ~ 110 to 150 degrees. All four detectors were installed at a distance of 6 cm far from the target ladder. A photo of the setup can be seen in Fig. 3. These telescopes allowed the excellent discrimination between the various reaction products by energy via the ΔE-E technique, as can be seen in the sample spectrum, recorded at ~ 55 degrees (strip 12), displayed in Fig. 4.

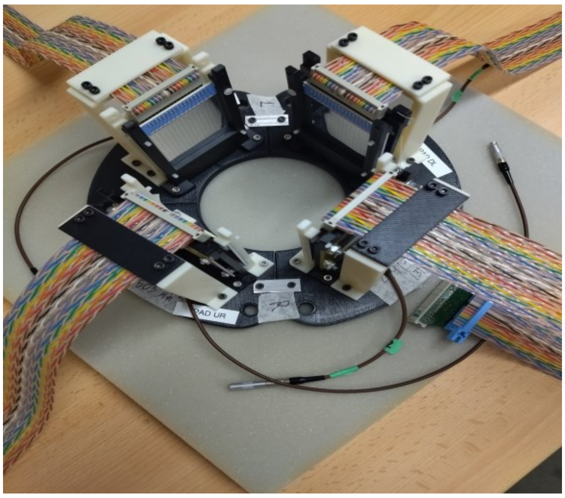

Figure 3. *A photo of the four silicon telescopes, installed at the appropriate movable platform, ready to be placed inside the target chamber*

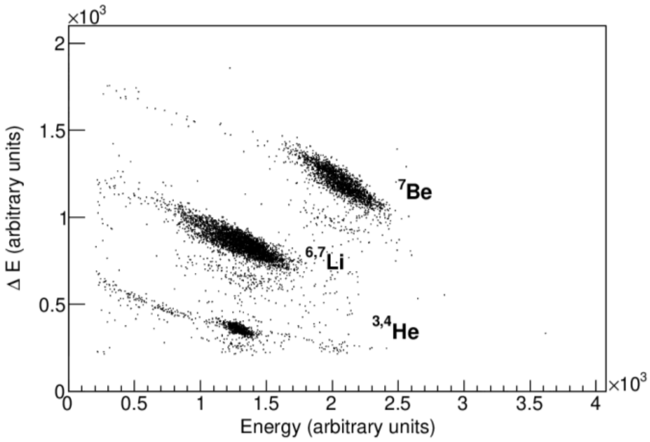

Figure 4. *A two-dimension spectrum for $^{7}Be+^{90}Zr$ at 24 MeV (strip 12 – $\theta_{lab}=55^{0}$)*

RESULTS AND DISCUSSION

The analysis of these data is in progress. A preliminary analysis at the energy of 24 MeV at the Coulomb barrier, which is a critical energy, and at 27 MeV above barrier, was performed up to now by using data of the detectors positioned at left for 24 MeV and data of both detectors for the run at 27 MeV. The normalization of the data relatively to the beam flux was extracted from the forward detectors where the elastic scattering should be of pure Rutherford type. The solid angle was taken equal to the geometric one as 4.33×10^{-2} sr. The final results were smoothed out every 2, 3 or 4 angles, depending on the data fluctuation and the obtained preliminary angular distributions are displayed in Fig. 5. An OMP fit to the data was applied taking into account a double folded potential via the code ECIS [19]. The potential was constructed via a BDM3Y1 interaction [20]. For the density of the radioactive ^{7}Be nucleus, calculated values were used under a semi-phenomenological expression reported in [21]. For the stable target, ^{nat}Zr, the nuclear matter density for ^{90}Zr was adopted from electron scattering data [22], appropriately corrected to derive it. Our best fits are compared with the data in Fig. 5. The obtained total reaction cross section of σ = 245 mb for 24 MeV and 609 mb for 27 MeV compare very well with our phenomenological prediction [14] of σ = 254 mb and 570 mb respectively, giving further support to our best fit.

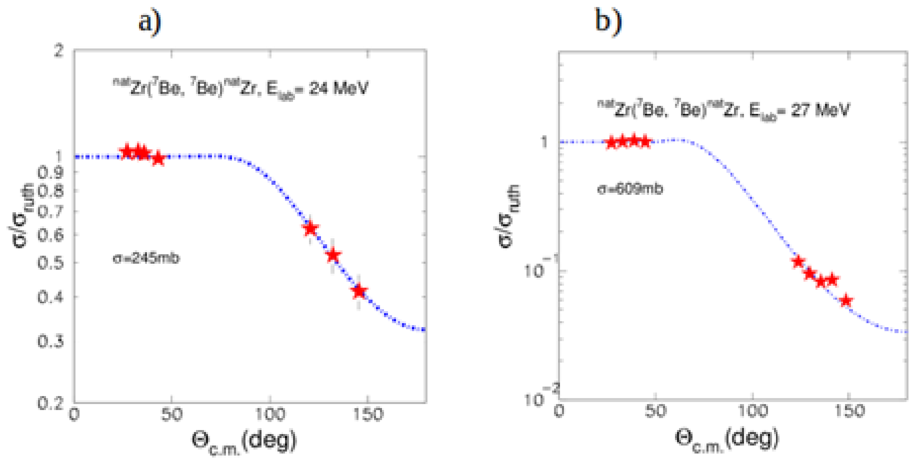

Figure 5. *Preliminary data for the angular distributions determined for $^7Be+^{nat}Zr$. a) by the left telescopes at 24 MeV and b) as a mean from the left and right telescopes at 27MeV. The data have been smoothed out every two or three and four angles depending on the fluctuation of the data. The statistical uncertainty backward was of the order of 10% and 15% for the 24 and 27 MeV energies, respectively.*

In summary

We have performed an elastic scattering experiment for the system $^7Be+^{nat}Zr$ at 5 sub- and near-barrier energies, namely 21.5, 22.5, 24, 27 and 28 MeV, and angular distributions were determined. The analysis is in progress. A preliminary analysis of the data at 24 and 27 MeV predicts via an OMP calculation, total reaction cross section of σ = 245 and 609 mb respectively, in very good agreement with a phenomenological prediction [14]. The obtained energy dependence of the potential indicates a flat real potential following the trend of the light targets [16]. We should point out here that the uncertainty in the beam energy, as well as an uncertainty in the reaction energy due to the thickness of the target, may change these results since this analysis is still in progress. Further on, taking into account that data at three more energies have to be analyzed, the present conclusions are given with caution.

Acknowledgments

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