SCATTERING OF ^{8}He ON ^{208}Pb AT ENERGIES AROUND THE COULOMB BARRIER*

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We have measured the angular distributions of elastic scattering and ^{6,4}He fragments produced in the collisions of an exotic beam of ^{8}He on a ^{208}Pb target at laboratory energies of 18 and 22 MeV, just around the Coulomb barrier (19 MeV). The measurements were performed at the SPIRAL/GANIL facility in Caen, France. In this paper, we present preliminary data on elastic cross sections and discuss the results using optical model and coupled reaction channel calculations.

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1. Introduction

Nuclei far from stability have small binding energies and large asymmetry between proton and neutron numbers. These structural features produce extended wave functions for the few valence nucleons producing the so-called halo, often arranged in Borromean configurations, where any of its two-body subsystems are unbound [1]. These features largely affect the interaction with heavy targets at low collision energies, and a number of detailed experimental studies have been carried out so far for the case of light neutron halo systems like ^{11}Li, ^{6}He or ^{11}Be [2,3]. Due to the extended mass distribution and the loosely bound structure, the behaviour of neutron halo nuclei is very different from stable, tightly bound nuclei. In the scattering with heavy targets at low energies, the combination of the nuclear interaction and the strong electric field will make the core and the halo neutrons move in opposite directions, thus producing strong coupling to dipole modes of the system at relatively low excitation energy [4,5]. These effects are amplified at energies near the Coulomb barrier, where the time scale of the collision process is comparable to the typical excitation time of the collective degrees of freedom and the coupling to the corresponding continuum state. This strong coupling scenario dominates the shape of the angular distribution of the reaction fragments, allowing a detailed study of reaction processes and extraction of useful structural quantities like spectroscopic factors or Coulomb dipole transition strengths [6].

Post-accelerated ^{6}He beams are among the most popular, presently available at many low energy Radioactive Beam Facilities (RBFs). Recent experiments to investigate near-barrier halo effects in the system $^{6}\mathrm{He} + {}^{208}\mathrm{Pb}$ have been performed in the Cyclotron Research Center/UCL in Louvain-la-Neuve (Belgium) [5, 6, 7, 8]. The results show that the Coulomb rainbow, a typical feature of near-barrier heavy ion collisions involving tightly bound stable beams, has completely disappeared as compared with ^{4}He scattering on similar systems at the same centre of mass collision energy. The existence of long-range absorption mechanisms, acting at large distances, can be directly deduced from the shape of the elastic angular distributions. The angular and energy distributions of the ^{4}He fragments produced in the interaction with heavy targets revealed the main contribution of the neutron transfer channel through continuum states. This mechanism seems to play also a dominant role in sub-barrier fusion reactions with heavy targets, and an important experimental effort has been very recently carried out at FLRN-JINR (Dubna, Russia) and UCL to disentangle the relevant reaction processes [9, 10].

The scattering of ^{8}He with heavy targets has attracted the interest of the scientific community due to its peculiar nuclear structure. It is a well-known skin nucleus, having a larger but tighter neutron layer as compared to the weakly bound $2n$-halo in ^{6}He. On the other hand, the binding energies for $1n$ and $2n$ systems are similar, whereas in the case of ^{6}He the breakup of the $2n$ system from the alpha core is energetically favoured. These differences in geometry and binding energies should be reflected in the elastic scattering and reaction cross sections. The scattering of ^{8}He on gold and copper targets was previously investigated at GANIL (Caen, France) [11,12], where a first measurement of fusion cross sections and $1n/2n$ transfer channels at Coulomb barrier energies was performed.

We have performed optical model (OM) and coupled reaction channel (CRC) calculations with the code FRESCO [13] for the system ^{8}He + ^{208}Pb at different energies around the barrier to investigate the effect of the $1n$ stripping process on the elastic channel, and the results are shown in Fig. 1. The calculations were similar to those for this system described in Ref. [3], and employed double-folded real potentials and interior Woods–Saxon imaginary potentials to simulate the ingoing-wave boundary condition. Thus, all surface absorption in these calculations is generated by the couplings to the $1n$ stripping. The solid curves denote the results of the full CRC calculations, while the dashed curves indicate the results of OM calculations with all couplings switched off. At energies well below the barrier (16 MeV and 18 MeV) this process leads to a strong absorption pattern similar to ^{6}He scattering on ^{208}Pb at the same collision energies, which accounts for a more than 50% reduction in the elastic cross sections at backward angles. At colli-

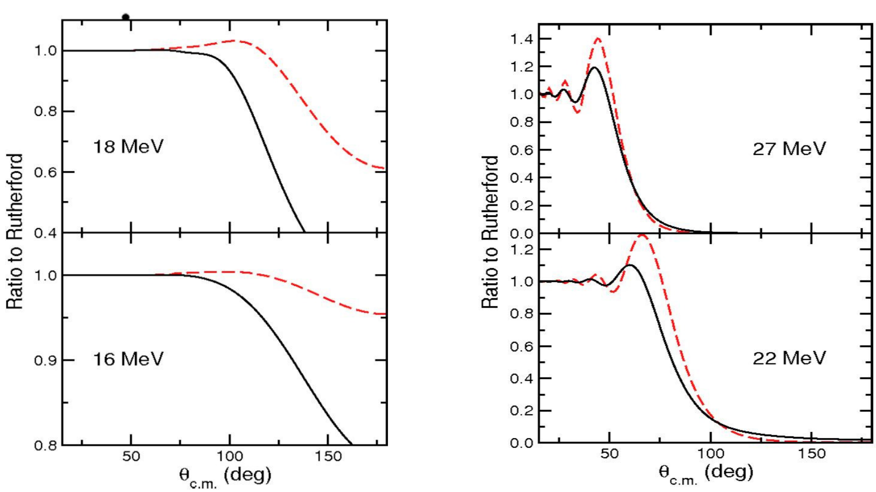


Fig. 1. CRC calculations (solid/black line) including the $1n$ stripping channel for the system ^{8}He + ^{208}Pb at collision energies Elab = 16, 18, 22 and 27 MeV. The neutron stripping produces a strong reduction on the elastic cross sections as compared to the results of simple OM calculations (dashed/red curves).

sion energies just around and above the barrier (22 MeV and 27 MeV) there is a partial suppression of the Coulomb rainbow. Although a sizeable part of the Coulomb-nuclear interference effect is removed due to the weak binding of the neutrons, the effect of the tight neutron skin still resembles that of a traditional stable heavy ion nucleus. This dynamical scenario is very different to the case of the scattering system $^6\mathrm{He} + {}^{208}\mathrm{Pb}$, which is dominated by the $2n$ transfer process and the rainbow effect is completely suppressed. In this work we report on recent measurements performed at SPIRAL/GANIL facility in Caen (France) for the system $^8\mathrm{He} + {}^{208}\mathrm{Pb}$ at energies just around the Coulomb barrier. In particular, we focus on the elastic channel and the effect of the $1n$ stripping channel on it.

2. Experimental setup

The experiment was performed at the SPIRAL/GANIL facility in Caen (France). The ^{8}He beam is produced by means of the fragmentation of a ^{13}C primary beam at 75 MeV/nucleon in a dedicated target for the production of helium isotopes. After being purified and re-accelerated in the CIME cyclotron, this method allows for the delivery of an intense ^{8}He beam with a diameter around 5 mm and an intensity between 10^4 and 10^5 pps on target. The ^{8}He can be ionized to +1 and +2 charge state. For nuclear reactions at low energies around the Coulomb barrier the +1 charge state is normally selected because a larger intensity can be achieved. Once the beam was produced and accelerated, it was driven through various collimators and beam diagnostics into the reaction chamber. The target was a self-supported foil of ^{208}Pb with a thickness of 1 mg/cm^2 and it was placed inside the GLORIA (GLObal ReactIon Array) silicon array developed at the University of Huelva.

The GLORIA detector array consists of twelve DSSSD detectors arranged in six particle detector telescopes. All the telescopes are tangent to a sphere of 60 mm radius centered in target position, resulting in a overall solid angle of the system of 26.1% of 4π. Each telescope is made of a 40 μm ΔE-detector of 50 mm $\times$ 50 mm, segmented in 16 strips on each side, and by a 1 mm E-detector of the same size and segmentation; the strip pitch was of 4 mm for all detectors of the array. The relative position of these telescopes with respect to the reaction target was optimised considering the following parameters: *(i)* a maximum angular range coverage, *(ii)* a good angular resolution (less than 5°), *(iii)* an angular range overlap between telescopes and *(iv)* a symmetric position of detectors. The array was designed in such a way that it covers a continuous angular range between 15° and 165°, with no gaps and with a high granularity. The angular coverage and solid angles corresponding to the final position of the telescopes are presented in Table I. The ^{208}Pb target was introduced tilted 30° with respect to the vertical position avoiding the shadowing of detectors and ensuring the detection of particles around 90°.

TABLE I

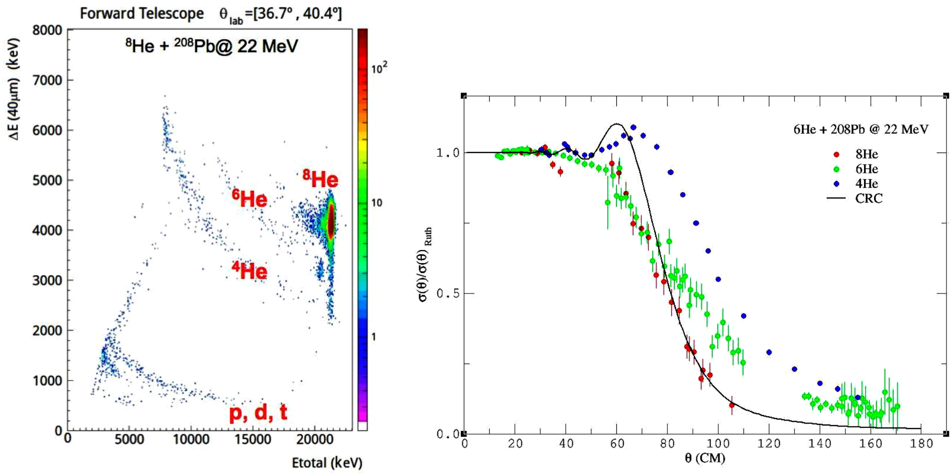
Angular coverage and solid angle for each telescope.

Telescope	θ_{center} [deg]	Angular range [deg]	Solid angle [msr]/% 4π
1 Forward	38	15.0–62.5	547.2/4.35
2 Backward	142	117.0–165.0	547.2/4.35
3 Forward	38	15.0–62.5	547.2/4.35
4 Backward	142	117.0–165.0	547.2/4.35
5 Top	75	82.0–128.0	547.2/4.35
6 Bottom	105	52.0–97.5	547.2/4.35

In order to fully exploit the available beam time, a fusion stack consisting of several ^{206}Pb, aluminium and mylar foils was placed behind the reaction chamber, at the end of the S3 frame. For the energy calibration of detectors, we used four calibration points: a triple alpha source was used before and after the measurements of ^{8}He scattering and the elastic peak, taking into account energy loss in the target and detector dead layer. A test signal was sent to the preamplifiers with a low rate pulse generator for evaluating the efficiency of the electronic chain related to each DSSSD detector.

3. Preliminary results

A typical particle $\Delta E(E)$ spectrum obtained at forward angles with beam energy Elab = 22 MeV is shown in Fig. 2 (a). The elastic as well as the ^{6,4}He production channels are clearly separated, and even a small fraction of contaminants of ^{6}He ions, estimated below 0.0001%, was observed during the experiment. The energy resolution achieved in our experiment was around 40 keV. In Fig. 2 (b) we show with red dots the preliminary results obtained for the elastic channel of ^{8}He+^{208}Pb system at 22 MeV. The data are normalised to the corresponding Rutherford cross sections and compared with ^{6}He + ^{208}Pb [5] and ^{6}He + ^{208}Pb [14] scattering systems at similar collision energies. The ^{4}He data is plotted with blue dots and was measured at Elab = 23.5 MeV; it exhibits a strong rainbow pattern around the grazing angle (around 75° Lab) characteristic of light stable nuclei. The angular distribution of ^{6}He is plotted with green dots, and shows the usual strong absorption pattern down to 50° Lab, where the Coulomb-nuclear rainbow has disappeared. A simple inspection of the data reveals that the total re-



(a) (b)

Fig. 2. (a) Typical $\Delta E(E)$ spectrum obtained at forward angles. (b) Extracted angular distribution of the elastic scattering at Elab = 224 MeV. See the text for discussion.

action cross section for ^{8}He projectiles is higher than for ^{6}He at the same bombarding energy. The angular distribution of the elastic scattering of ^{8}He follows the trend of the ^{6}He data up to about the grazing angle, where the absorption becomes even stronger. This effect is consistent with the observation of a strong yield of ^{4}He and ^{6}He fragments at the $\Delta E(E)$ spectrum shown in Fig. 2 (a). As the impact parameter reduces with increasing angle, the combined effect of nuclear and Coulomb couplings produce a larger removal of elastic flux than in the case of ^{6}He scattering system. We also plot in Fig. 2 (b) the curve for the full CRC calculation at 22 MeV taken from Fig. 1. The description of the $^{8}\mathrm{He}+{}^{208}\mathrm{Pb}$ data at backward angles is good, as expected since it is in this angular region where $1n$ stripping couplings have most influence on the elastic scattering. For angles in the region where the Coulomb rainbow peak would be we see that the calculations overpredict the data, indicating significant effects due to channels not included in our coupling scheme. These are most likely breakup and/or $2n$ stripping ($3n$ and $4n$ stripping, while in principle possible for ^{8}He, must be considered unlikely given the possible reaction mechanisms) by analogy with results for $^{6}\mathrm{He}+{}^{208}\mathrm{Pb}$ where it is just in this region that breakup has most influence on the elastic scattering. The effect of coupling to the $1n$ stripping appears to be more important for ^{8}He compared to ^{6}He, which may be explained by the larger spectroscopic factor for the $^{8}\mathrm{He}/{}^{7}\mathrm{He}$ overlap compared to the $^{6}\mathrm{He}/{}^{5}\mathrm{He}$ one.

4. Summary and conclusions

We have measured the elastic scattering and reaction channels for the system $^8\mathrm{He} + {}^{208}\mathrm{Pb}$ at 18 MeV and 22 MeV using the novel charged particle detctor array GLORIA. The experiment was performed at the SPIRAL radioactive beam facility at GANIL (Caen, France). The elastic and ^{6,4}He reaction channels have been properly separated by the use of particle telescopes composed of DSSSD detectors of 40 μm and 1000 μm thickness. The preliminary angular distribution of elastic channel at 22 MeV exhibits an absorption pattern similar to the one found for the ^{6}He system, becoming even larger as the scattering angle increases beyond the grazing angle. The data analysis is still in progress.

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