Coulomb breakup of 17Ne from the viewpoint of nuclear astrophysics

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PROCEEDINGS OF SCIENCE

Coulomb breakup of ^{17}Ne from the viewpoint of nuclear astrophysics

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By the Coulomb breakup of ^{17}Ne, the time-reversed reaction ^{15}O$(2p,\gamma)^{17}$Ne has been studied. This reaction might play an important role in the *rp* process, as a break-out reaction of the hot CNO cycle. The secondary ^{17}Ne ion beam with an energy of 500 MeV/nucleon has been dissociated in a Pb target. The reaction products have been detected with the LAND-R^{3}B experimental setup at GSI. The preliminary differential and integral Coulomb dissociation cross section σ_{Coul} has been determined, which then will be converted into a photo-absorption cross section σ_{photo}, and a two-proton radiative capture cross section σ_{cap}. Additionally, information about the structure of the ^{17}Ne, a potential two-proton halo nucleus, will be received. The analysis is in progress.

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1. Introduction

Nuclear reaction processes are driving the stellar evolution and triggering the stellar explosion. Slow nuclear processes determine the lifetime of hydrogen burning main sequence stars and set the time scales for the subsequent stellar helium and carbon burning phases. Explosive nucleosynthesis can be induced by a shock front in type II supernova explosions or by accretion processes in stellar binary systems such as X-ray bursts, where the accretion of the light isotopes occurs on the hot and dense environment characteristic of the surface of a neutron star. The increase in temperature and density opens new reaction branches, possibly triggering new chains of reaction sequences. These critical trigger reactions need to be analyzed in order to understand their impact on explosive nucleosynthesis scenarios [1].

The hot CNO cycles and the *rp* process have been proposed as the dominant nucleosynthesis processes in X-ray bursts, where the CNO cycles and *rp* process are linked by the capture reaction sequence ^{15}O$(\alpha,\gamma)^{19}$Ne$(p,\gamma)^{20}$Na. However, a reaction flow between the CNO cycles and the FeNi-mass region is hampered by the waiting point nuclei. One of these waiting points is ^{15}O ($T_{1/2}$ = 122s). The nucleus ^{16}F formed by proton capture of this isotope is particle unbound. Due to this, the processing of ^{15}O to heavier nuclei has to wait for its β^+ decay. In X-ray bursts environment the α-capture reaction servers as a bypass of this waiting point, and the *rp* process turns into the αp process [2].

The present experiment tries to find an answer on the question about an alternative two-proton-capture reaction for bridging this waiting point isotope. The three-body radiative capture can proceed sequentially [2] or directly from the three-body continuum [3]. It has been suggested that the reaction rate can be enhanced by a few orders of magnitude by taking the three-body continuum into account [3]. The ^{15}O$(2p,\gamma)^{17}$Ne reaction cross section is needed to verify these predictions.

The Coulomb breakup of ^{17}Ne gives us also an opportunity to study the nuclear structure of this isotope. As a proton-dripline nucleus with a comparatively small $2p$ separation energy (S_{2p} = 950 keV), it is a promising candidate for being a two-proton halo nucleus [4].

2. Coulomb dissociation method

The Coulomb dissociation method is mainly used in the context of investigating the nuclear structure of exotic nuclei, but it is also an important tool to obtain information on relevant reactions for nuclear astrophysical scenarios using the inverse process [5]. Often, these reactions cannot be studied in a direct way because of short-lives of involved nuclei, tiny production cross sections, and several particles in the entrance channel. In the time-reversed process, the Coulomb field of a heavy nucleus is used as a source of virtual photons. From the differential cross-section for electromagnetic dissociation in a heavy target, the photo-absorpion cross section σ_{photo} can be obtained, using the virtual-photon theory. And next it can be converted into the radiative-capture cross section σ_{cap} by the principle of detailed balance [6]:

$$\sigma_{cap} = \frac{(2j_a+1)\,2}{(2j_b+1)\,(2j_c+1)}\frac{k_\gamma^2}{k^2}\sigma_{photo}. \tag{2.1}$$

3. Experimental setup

The measurement was performed using the LAND-R^{3}B detection setup at GSI (Fig. 1). In the experiment, the radioactive beam of ^{17}Ne ($E = 500$ MeV/nucleon), produced by nuclear fragmentation of ^{20}Ne in Be target was used. The fragmentation products were kinematically forward focused, and separated by the fragment separator FRS, and subsequently transported to the experimental area. The incoming ^{17}Ne beam was identified on an event-by-event basis using energy-loss and position measurements with position-sensitive pin diodes and time-of-flight measurements (Fig. 2a).

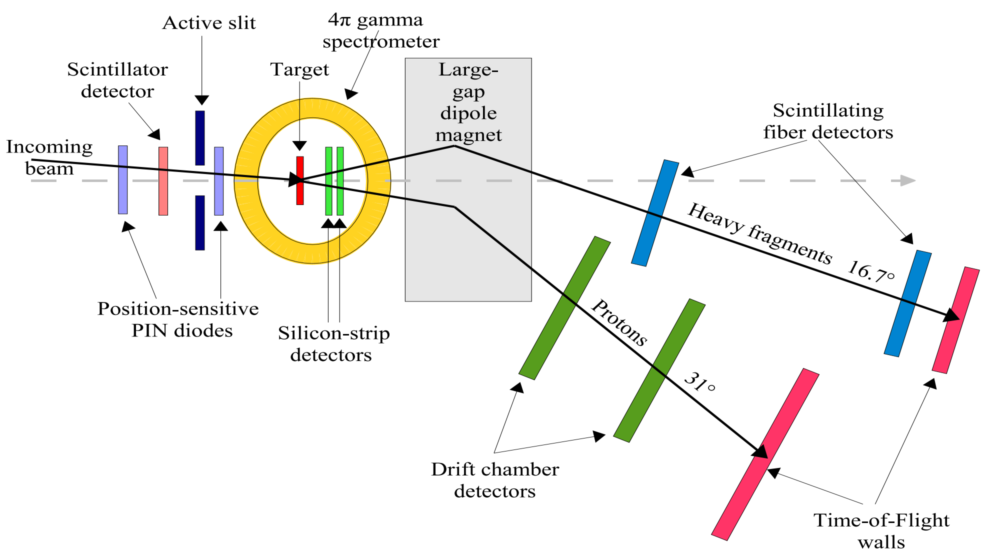

Figure 1: Schematic view of the experimental setup.

After Coulomb dissociation in a Pb target, the reaction products were identified. The magnetic rigidity was determined from four position measurements defining the trajectories of the reaction products (^{15}O and two protons) in the magnetic field of a large-gap dipole magnet (ALADIN) placed behind the target. Two Si-strip detectors located before the ALADIN magnet and two scintillating-fiber detectors in case of heavy fragments, and two drift chambers in case of protons, placed after the magnet were used to achieve this. Additional energy loss and time-of-flight measurements with two ToF walls allowed the identification of the outgoing fragments (Fig. 2b). To obtain masses and momenta of the reaction products, a tracking procedure was utilized.

The target was surround by a 4π gamma spectrometer to detect γ-rays emitted by the deexciting fragment. Thanks to this setup, the measurement was kinematically complete in the sense that all reaction products and γ-rays were detected. And the excitation energy prior to decay was reconstructed by using the invariant-mass method. The measurements were performed with different targets: a Pb target for the Coulomb dissociation reaction, a C target to estimate the nuclear contribution, and without any target to evaluate the background.

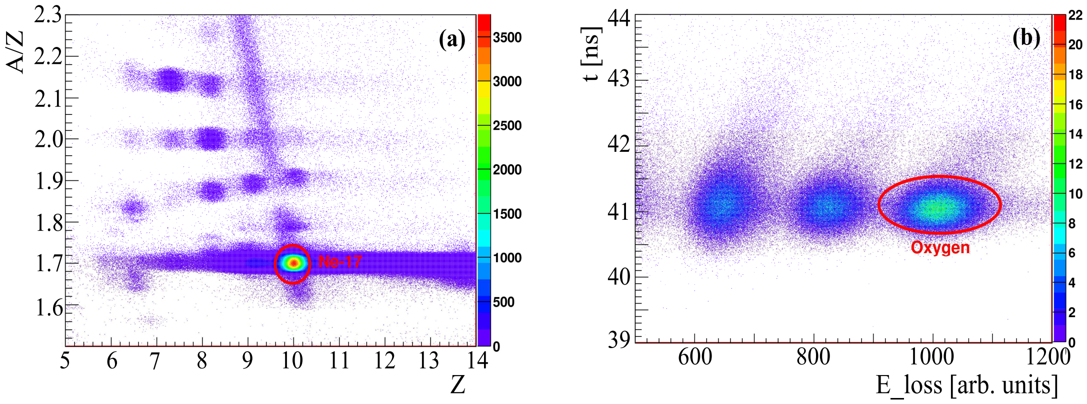

Figure 2: (a) - The identification of incoming beam nuclei; (b) - the identification of outgoing heavy fragments.

4. Required corrections

For a proper calculation of the Coulomb dissociation cross section, an efficiency correction and a geometric acceptance are required. The two-proton efficiency of proton-branch detectors was estimated, and the value obtained is $51.4 \pm 1.4\%$. To determine the geometric acceptance of the setup as a function of the excitation energy, a simulation in *R3BRoot* framework was made. The geometric acceptance curve is presented in Fig. 3, showing a flat behaviour up to 3 MeV and going down with the excititation energy due to the increasing proton loss in the ALADIN magnet gap in the y-dimension.

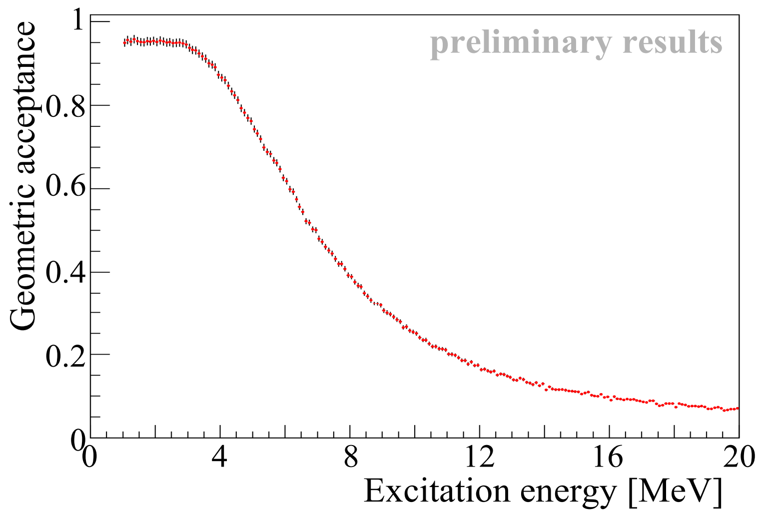

Figure 3: Geometric acceptance curve obtained by a simulation.

The outgoing ^{15}O does not go only to the ground state, but also to excitated states (Fig. 4 left panel). The γ-rays emitted by the deexciting ^{15}O were registered by the 4π gamma spectrometer, and the resulting spectrum is shown in Fig. 4 right panel, where the excitation to states above 5

MeV and 6 MeV can be observed. However only 5% of measuremed events correspond to excitated states, and their influence on the excitation energy shape is negligible.

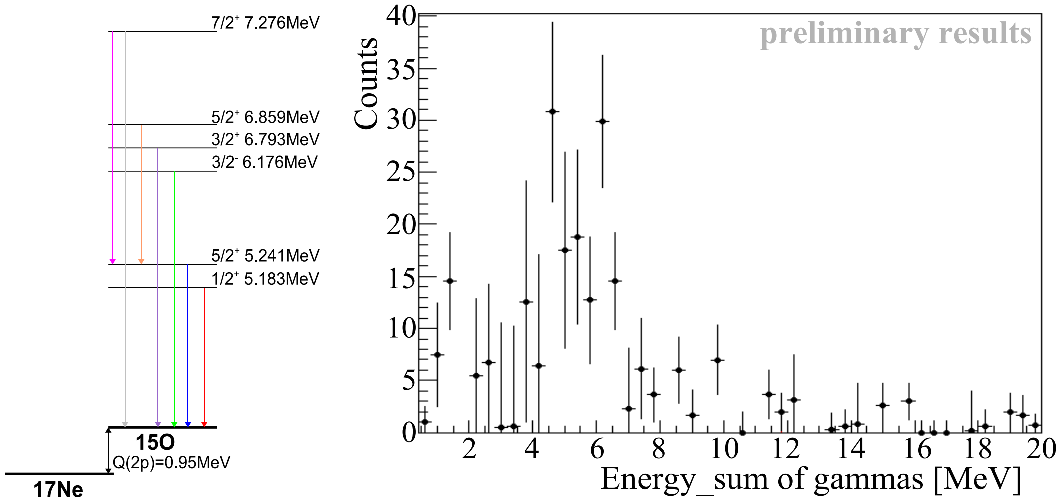

Figure 4: Left panel - the level scheme of ^{15}O; right panel - gamma energy sum spectrum.

5. Preliminary results

The Coulomb dissociation cross section is given by the formula:

$$\sigma_{Coul} = p_{Pb}\left(\frac{M_{Pb}}{d_{Pb}N_{Av}}\right) - p_C\left(\alpha\frac{M_C}{d_C N_{Av}}\right) - p_{empty}\left(\frac{M_{Pb}}{d_{Pb}N_{Av}} - \alpha\frac{M_C}{d_C N_{Av}}\right), \tag{5.1}$$

where p is the interaction probability for the target, M - the molar mass of target material [g/mol], d - the target thickness [g/cm^2], N_{Av} - Avogadro's number [mol^{-1}] and α is a scaling factor between Pb and C targets ($\alpha = 1.845$).

Using this formula, the preliminary differential (Fig. 5) and integral cross section values have been calculated.

The preliminary integral cross section has been estimated in two ways. Firstly, only ^{15}O data were utilized ($\sigma_{Coul_1} = 304 \pm 34$ mb -statistical uncertainty). Secondly, the differential cross section spectrum was integrated ($\sigma_{Coul_2} = 312 \pm 31$ mb -statistical uncertainty). The small difference ($\Delta = 2.6\%$) between these two values indicates the correctness of the efficiency and the acceptance adjustments.

Moreover the shape of the preliminary differential cross-section distribution is in agreement with experimental results from [7] and with the theoretical predictions from [8]. The analysis is in progress.

6. Summary

The secondary ^{17}Ne beam has been produced by fragmentation of ^{20}Ne. The incoming beam and outgoing reaction products have been identified and tracked. The required efficiency and acceptance corrections have been estimated. And the preliminary differential as well as integral

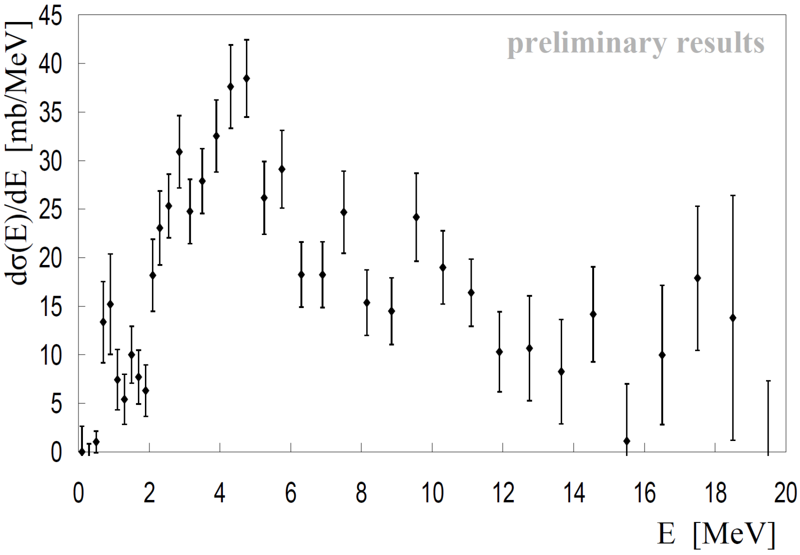

Figure 5: Differential Coulomb dissociation cross section.

Coulomb dissociation cross sections have been obtained. The next steps of the analysis will be the calculation of the photo-absorption and the radiative capture $^{15}\mathrm{O}(2p,\gamma)^{17}\mathrm{Ne}$ cross sections, which are not only relevant for the *rp* process but are also of interest with regard to the two-proton halo structure of ^{17}Ne. The corresponding analysis is ongoing.

7. Acknowledgments

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References

[1] M. Wiescher *et al.*, *Prog. Part. Nucl. Phys.* **59** 51, 2007

[2] J. Görres, M. Wiescher, F.-K. Thielemann, *Phys. Rev. C* **51**, 392, 1995

[3] L.V Grigorenko, M.V. Zhukov, *Phys. Rev. C* **72**, 015803, 2005

[4] R. Kanungo *et al.*, *Phys. Lett. B* **571**, 21, 2003

[5] T. Aumann, *Eur. Phys. J. A* **26** 441, 2005

[6] G. Baur, C.A. Bertulani and H. Rebel, *Nuc. Phys. A* **458**, 188, 1986

[7] M. J. Chromik *et al.*, *Phys. Rev. C* **66** 024313, 2002

[8] L.V Grigorenko *et al.*, *Phys. Lett. B* **641**, 254, 2006