PROCEEDINGS OF SCIENCE

Study of the ^{15}O$(2p,\gamma)^{17}$Ne reaction by the Coulomb Dissociation method

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The ^{15}O$(2p,\gamma)^{17}$Ne reaction, which might play an important role in the *rp* process, has been studied by the Coulomb Dissociation method using a secondary ^{17}Ne ion beam of 500 MeV/nucleon incident on a Pb target. From this experiment the Coulomb Dissociation cross section σ_{Coulex} will be deduced and then converted into a photoabsorption cross section σ_{photo} and a radiative capture cross section σ_{cap}. Also information on the structure of the ^{17}Ne nucleus, a possible two-proton halo, will be obtained. The analysis is still in progress.

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1. Introduction and motivation

The *rp* process takes place most notably in cataclysmic binary system, such as X-ray bursts [1]. In the X-ray binary system a neutron star accretes hydrogen and helium-rich matter from an envelope of a close companion star. When hydrogen is present, nuclear burning proceeds via the rapid proton capture process, which is a sequence of proton captures and β^+ decays. The proton capture reaction rates are orders of magnitude faster than the competing β^+ decays. When the proton capture is inhibited, the reaction flow has to wait for a relatively slow β^+ decay to continue. The longer lived β^+ emitters are called waiting points.

At these high temperature and density conditions, the CNO cycle and the *rp* process are linked by the α capture reaction on ^{15}O, which allows to process the initial CNO material towards heavier nuclei. However, the main obstacle for a continuous reaction flow between the CNO cycle and the FeNi-mass region are the waiting point nuclei. One of these waiting points is ^{15}O. The $^{15}O(2p,\gamma)^{17}Ne$ reaction could serve as a bypass of this point.

The three-body radiative capture can proceed sequentially [1] or directly from the three-body continuum [2]. 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 [2]. In order to verify these calculations, the $^{15}O(2p,\gamma)^{17}Ne$ cross section has to be deduced by studying the time-reversed process, the Coulomb dissociation of ^{17}Ne.

The proton dripline nucleus ^{17}Ne has a comparatively small $2p$ separation energy ($S_{2p} =$ 970 keV) and represents a promising candidate for a two-proton halo [3]. The main uncertainty of the ^{17}Ne ground state is connected to the yet unknown mixture of the d^2 and s^2 configurations of the two protons outside the ^{15}O core. In a schematic notation the ^{17}Ne ground-state wave function can be abbreviated to [4]:

$$\Psi_{g.s} \sim \alpha[s^2] + \beta[d^2] \tag{1.1}$$

In the case of large s^2 weights of proton configurations the nucleus ^{17}Ne has a halo structure, while in the case of large d^2 weights the halo is strongly suppressed.

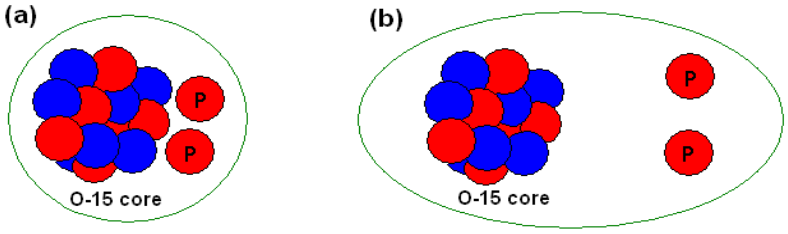

Figure 1: The structure of a ^{17}Ne nucleus. (a) - the d^2 component is dominant (the Coulomb Exitation cross section σ_{Coulex} will be small); (b) - the s^2 component is dominant (σ_{Coulex} will be large).

2. Coulomb Dissociation as a source of information on radiative capture processes

The cross sections for radiative capture not always can be determined from direct experiments. Especially, problems appear in cases of very small cross sections, unstable nuclei and three particles in entrance channel. For these situations the Coulomb Dissociation method is useful.

In this technique a nuclear Coulomb field is used as a source of the photodisintegration process, and instead of studying directly a radiative capture process [5]

$$b + c \rightarrow a + \gamma \tag{2.1}$$

the time reversed process can be considered (Fig. 2).

$$a + \gamma \rightarrow b + c \tag{2.2}$$

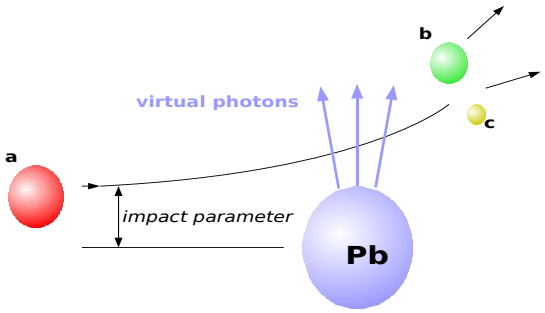

Figure 2: Coulomb dissociation in the field of a Pb target.

Using the detailed balance theorem, the photoabsorption cross section σ_{photo} can be converted into the radiative capture cross section σ_{cap}.

$$\sigma_{cap} = \frac{(2j_a+1)\,2}{(2j_b+1)\,(2j_c+1)} \frac{k_\gamma^2}{k^2} \sigma_{photo}, \tag{2.3}$$

where the wave number in the (b+c) channel is given as

$$k^2 = \frac{2\mu_{bc} E_{c.m.}}{\hbar^2} \tag{2.4}$$

with μ_{bc} the reduced mass, and the photon wave number is

$$k_\gamma = \frac{E_\gamma}{\hbar c} = \frac{E_{c.m.} + Q}{\hbar c}. \tag{2.5}$$

By means of the virtual-photon theory the photoabsorption cross section σ_{photo} is related to the differential Coulomb excitation cross section $\frac{d\sigma_{Coulex}}{dE_\gamma}$ by the equation

$$\frac{d\sigma_{Coulex}}{dE_\gamma} = \frac{1}{E_\gamma} n_{E1} \sigma_{photo}, \tag{2.6}$$

where n_{E1} is the number of virtual photons.

3. Experiment

The secondary ^{17}Ne ion beam, with energy $E = 500$ MeV/nucleon, has been produced by fragmentation of a ^{20}Ne primary beam (in a Be target), delivered by the synchrotron SIS at GSI, Darmstadt. The ^{17}Ne fragments have been separated in the fragment separator FRS and transported to the experimental area. The incoming ^{17}Ne beam has been identified by means of energy-loss and position measurements with position-sensitive pin diodes and a time-of-flight measurements. It has been focused on the secondary target (Pb - 200 mg/cm^2 or C - 370 mg/cm^2). The reaction products have been identified using two Si-strip detectors before they have been deflected by a large-gap dipole magnet. After the magnet the heavy fragments have been detected with two scintillating fibre arrays and a two-layer Time-of-Flight (ToF) wall. For proton identification two drift chambers and a big two-layer ToF wall have been used [6]. By means of energy-loss and time-of-flight measurements particles have been identified (Fig. 3).

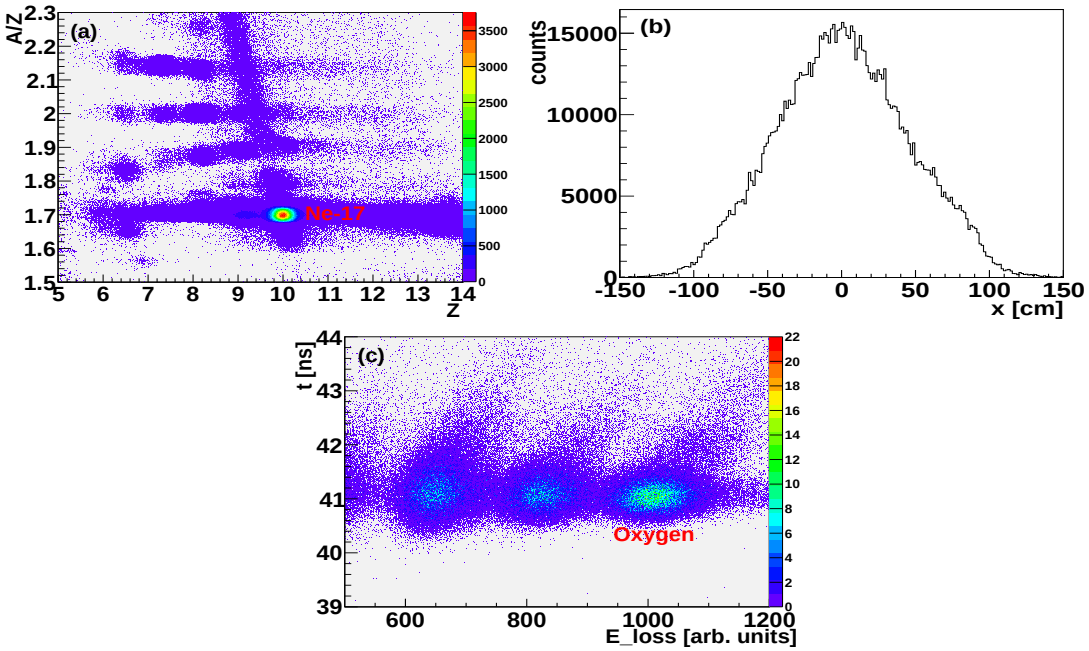

Figure 3: (a) - The identification of incoming beam nuclei; (b) - detected protons in a big two-layer ToF wall; (c) - the identification of outgoing fragments.

The outgoing oxygen fragments and protons have been tracked and their mass and momenta have been determined. The mass spectra are shown on Fig. 4.

The measurements have been performed not only for a Pb target, but also for C and without any target to subtract the non-specific reactions, taking place outside of the target and reactions in the target due to nuclear interactions.

The measured Coulomb excitation cross section is given by the formula

$$\sigma_{Coulex} = p_{Pb}\left(\frac{M_{Pb}}{d_{Pb}N_{Av}}\right) - p_C\left(\alpha\frac{M_C}{d_C N_{Av}}\right) - p_{empty}\left(\frac{M_{Pb}}{d_{Pb}N_{Av}} - \alpha\frac{M_C}{d_C N_{Av}}\right), \qquad (3.1)$$

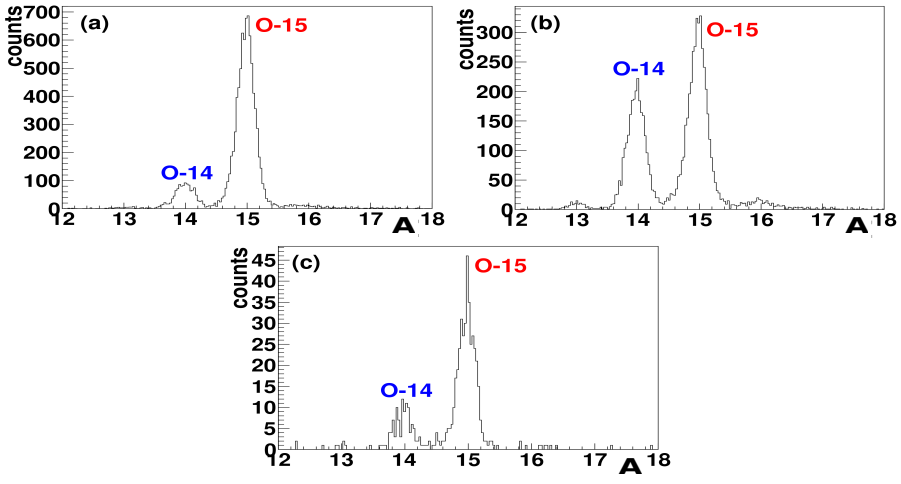

Figure 4: The oxygen mass spectra after tracking. (a) - for runs with Pb target; (b) - for runs with C target; (c) - for runs without target.

where p is the interaction probability for a 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.

4. Summary

By using an energetic secondary beam of ^{17}Ne, produced in a fragmentation reaction, the $^{15}O(2p,\gamma)^{17}Ne$ reaction has been investigated. From this experiment cross sections for Coulomb excitation, photoabsorption and radiative capture will be obtained, which are not only relevant in the *rp* process but also are of interest with regard to the proton-halo structure of ^{17}Ne. Up to now the incoming beam and outgoing reaction products have been identified. The analysis is still in progress.

5. Acknowledgments

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