Investigation of the CNO-break-out reaction: $^{15}$O$(2p,\gamma)^{17}$Ne, by the Coulomb Dissociation of $^{17}$Ne

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• rp process and motivation;
• coulomb dissociation as a source of information on radiative capture processes;
• experimental setup;
• preliminary results:
  - integral Coulomb dissociation cross section;
  - differential Coulomb dissociation cross section;
  - photoabsorption cross section;
• acceptance;
• future work;
• summary.
• in cataclysmic binary systems (X-ray bursts);

• sequence of proton captures and $\beta^+$ decays;

• the proton capture is inhibited and the long half-life => the waiting points.
1. the nucleus $^{15}\text{O}$ \(\Rightarrow\) a waiting point for the break-out of the CNO cycle

CNO cycle: $^{12}\text{C}(p,\gamma)^{13}\text{N}(e,\nu)^{13}\text{C}(p,\gamma)^{14}\text{N}(p,\gamma)^{15}\text{O}(e,\nu)^{15}\text{N}(p,\gamma)^{12}\text{C}$

Heavier elements: $^{15}\text{O}(\alpha,\gamma)^{19}\text{Ne}(p,\gamma)^{20}\text{Na}$

Alternative reaction: $^{15}\text{O}(2p,\gamma)^{17}\text{Ne}(\beta)^{17}\text{F}(p,\gamma)^{18}\text{Ne}(2p,\gamma)^{20}\text{Mg}(\beta)^{20}\text{Na}$

2. the reaction rate can be enhanced by a few orders of magnitude by taking into account the three-body continuum states;
Coulomb dissociation as a source of information on radiative capture processes

Useful to measure radiative-capture reactions with:
- small cross sections;
- unstable nuclei;
- three particles in entrance channel.

\[ \text{virtual photon theory} \]

the nuclear Coulomb field \( \Rightarrow \) a source of the photodisintegration processes

\[ a + Z \rightarrow b + c + Z \]

\[ \frac{d\sigma_{CD}}{dE_\gamma} = \frac{1}{E_\gamma} n\sigma(\gamma,b) \quad \text{virtual photon theory} \]

detailed balance theorem

\[ \sigma(b,\gamma) = \frac{2(2j_a + 1)}{(2j_b + 1)(2j_c + 1)} \frac{k_\gamma^2}{k^2} \sigma(\gamma,b) \]
Coulomb dissociation as a source of information on radiative capture processes

**advantages:**

• high virtual photon flux;

• large cross section at low $E_{\text{cm}}$;

• charged particle detection;

• kinematically focused;

• experiments with radioactive ion beams possible.

**disadvantages:**

• indirect method;

• bad energy resolution;

• multipole admixtures must be clarified;

• nuclear contributions.
The uncertain part => the configuration of the two protons outside the $^{15}$O core, which occupy either $s$-wave ($[s^2]$) or $d$-wave ($[d^2]$) orbitals

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

$[s^2]$ – dominant

$[d^2]$ – dominant
production of exotic beam setup

\[ B \rho = \frac{p}{Q} \propto \frac{A}{Z} \beta \gamma \]
The energy of incoming beam = 500 MeV/u
LAND-R³B experimental setup

The energy of incoming beam = 500 MeV/u
LAND-\(R^3B\) experimental setup

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The energy of incoming beam = 500 MeV/u
Precise position from two silicon strip detectors

Precise position from fiber detectors

Precise position from drift chambers

Mass?

Output from tracker:

masses, velocities → momenta

↓ excitation energy

\[ B\rho = \frac{A}{Z}\beta\gamma \]

Charge, ToF and rough position from tof wall

Rough ToF from tof wall

Counts

Excitation energy [MeV]
background subtraction
proton arm efficiency

<table>
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<tr>
<th></th>
<th>DCh1</th>
<th>DCh2</th>
<th>TFW</th>
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<tr>
<td>Efficiency</td>
<td>63.9%</td>
<td>76.7%</td>
<td>87.6%</td>
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<tr>
<td>Total</td>
<td></td>
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</tbody>
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Coulomb dissociation cross section

\[ \sigma_{\text{Coulex}} = p_{Pb} \left( \frac{M_{Pb}}{d_{Pb} N_{Av}} \right) - p_C \left( \alpha \frac{M_C}{d_C N_{Av}} \right) - p_{\text{empty}} \left( \frac{M_{Pb}}{d_{Pb} N_{Av}} - \alpha \frac{M_C}{d_C N_{Av}} \right) \]

Integral Coulomb Dissociation Cross Section

\[ \sigma = 242 \pm 34 \text{ mb (14\% - statistic)} \]

\[ b_{\text{min}} = 10.8 \text{ fm} \]

Theoretical predictions N. Shulgina

\[ s^2 5\% - \sigma = 208 \text{ mb} \]
\[ s^2 50\% - \sigma = 394 \text{ mb} \]
\[ s^2 75\% - \sigma = 468 \text{ mb} \]

\[ b_{\text{min}} = 9.7 \text{ fm} \]
Coulomb dissociation cross section

\[ b_{\text{min}} \approx r_0[A^{1/3} + B^{1/3} - x(A^{-1/3} + B^{-1/3})] \]

\[ r_0 = 1.34 \text{ fm} \]
\[ x = 0.75 \]

C.J. Benesh, B.C. Cook, and J.P. Vary

Dissociation probabilities for 520 Mev/nucleon
\(^{11}\text{Be}\) on lead as a function of impact parameter \(b\)


\[ b_{\text{min}} = 10.8 \text{ fm} \]
\[ b_{\text{min}} = 9.7 \text{ fm} \]
Coulomb dissociation cross section

Integral Coulomb Dissociation Cross Section

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Theoretical predictions

N. Shulgina

\[ s^2 \ 5\% - \sigma = 208 \text{ mb} \]
\[ s^2 \ 50\% - \sigma = 394 \text{ mb} \]
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\[ s^2 \ \text{contribution estimation} \]
differential Coulomb dissociation cross section

preliminary results
differential Coulomb dissociation cross section

preliminary results
differential Coulomb dissociation cross section

M.J. Chromik et al.
L.V Grigorenko

s^2 - 48%

N.B Shulgina
s^2 - 50%
d^2 - 50%
E_{beam} = 240 MeV/u
differential Coulomb dissociation cross section

L.V. Grigorenko

preliminary results

M.J. Chromik et al.

L.V. Grigorenko

$s^2 - 48\%$
N.B. Shulgina

$s^2 - 50\%$

d$^2 - 50\%$

$E_{\text{beam}} = 240$ MeV/u
$^{17}\text{Ne}(\gamma, 2p)^{15}\text{O}$ cross section

**virtual photon theory**

\[ \frac{d\sigma_{CD}}{dE_\gamma} = \frac{1}{E_\gamma} n\sigma(\gamma, b) \]

\[ \Rightarrow \]

**photoabsorption cross section**

\[ \sigma(\gamma, b) = \frac{d\sigma_{CD}}{dE_\gamma} E_\gamma \frac{1}{n} \]
$^{17}\text{Ne}(\gamma, 2p)^{15}\text{O}$ cross section

preliminary results
acceptance

preliminary results
acceptance

preliminary results
What has to be done:

1. acceptance simulation;

2. acceptance correction for Coulomb excitation cross section and photoabsorption cross section;

3. recalculation of a photoabsorption cross section into a radiative capture cross section;

4. uncertainties calculation;
summary

- $^{15}\text{O}(2p,\gamma)^{17}\text{Ne}$ => maybe the alternative break-out reaction of CNO cycle;

- the Coulomb dissociation method => only one way to the three particles in entrance channel measurements;

- up to now, it is not possible to compare the experimental integral Coulomb dissociation cross section with theoretical predictions;

- good agreement between the shape of differential Coulomb dissociation cross section and theoretical predictions;

- the calculation of $^{15}\text{O}(2p,\gamma)^{17}\text{Ne}$ cross section => in progress.
Collaboration:

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Thank you!