Breakup of $^8$B on $^{58}$Ni at energies around the Coulomb barrier and the astrophysical $S_{17}(0)$ factor revisited

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Abstract. Calculations of breakup and direct proton transfer for the $^8$B+$^{58}$Ni system at energies around the Coulomb barrier ($E_{B,\text{lab}}=22.95$ MeV) were performed by the continuum-discretized coupled channels (CDCC) method and the coupled-reaction-channels (CRC) method, respectively. For the $^7$Be+$^{58}$Ni interaction, we used a semimicroscopic optical model potential (OMP) that combines microscopic calculations of the mean-field double folding potential and a phenomenological construction of the dynamical polarization potential (DPP). The $^7$Be angular distribution at $E_{\text{lab}}=25.75$ MeV from the $^8$B breakup on $^{58}$Ni was calculated and the spectroscopic factor for $^8$B $\rightarrow$ $^7$Be+p vertex, $S_{\text{expt}}=1.10 \pm 0.05$, was deduced. The astrophysical $S_{17}(0)$ factor was calculated equal to $20.7 \pm 1.1$ eV·b, being in good agreement with the previously reported values.

1 Introduction

The study of nuclear reactions with the proton-halo exotic $^8$B nuclei is of great interest for nuclear astrophysics in view of the problem of stellar nucleosynthesis and the production of high-energy neutrinos in the Sun. In particular, the breakup of $^8$B in the field of heavy targets can provide information about an inverse process, the proton radiative capture by $^7$Be, which occurs in the Sun at energies about 20 keV. The $^8$B+$^{58}$Ni system has been extensively studied both experimentally and theoretically by different research groups around the world. We studied the breakup of $^8$B in the field of $^{58}$Ni with the realistic $^7$Be core-target potential calculated in the semi-microscopic OMP. The analysis of the breakup, transfer and elastic-scattering cross sections allowed us to obtain the experimental spectroscopic factor $S_{\text{expt}}$ and extract the astrophysical $S_{17}(0)$ factor by using the ANC method. A comparison was made with calculations performed by using the Woods-Saxon potentials previously reported [1].

2 Elastic scattering calculations

For the $^7$Be+$^{58}$Ni interaction an optical potential of the form $U = V_F + V_P + iW + V_C$ was used, where $V_F$ is a double folded potential, $iW = i(W_Vf(x_V) + W_Df(x_D))$, $V_C$ represent the absorption and Coulomb potential, respectively and $V_P$ is the DPP, implemented by S. A. Goncharov [2]:

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\[ V_P = \alpha(E)W_V(E)f(x_V) + \beta(E) \cdot 4W_D(E) \frac{df(x_D)}{dx_D}, \tag{1} \]

where the Woods-Saxon form factor \( f(x_{V,D}) \) was used. To calculate \( V_F \), we used for the projectile an empirical density model that was constructed on the basis of the global parametrization, described in [3]; for the target, we considered an appropriately normalized empirical charge density in a three-parameter modified Fermi form with values taken from [4]. The radial part of the potential were calculated by using the CDM3Y6-Paris nucleon-nucleon effective interaction [5]. To find the OMP parameters for the \( p^+7\text{Be} \) and \( p^+^{58}\text{Ni} \) interactions, the systematics proposed in [6] was used.

Figure 1: a) Elastic scattering angular distributions of \( ^8\text{B} \) from \(^{58}\text{Ni} \) at energies around the Coulomb barrier calculated by the CDCC in comparison with the experimental data [8]. b) The differential breakup cross section of the \( ^8\text{B}^+^{58}\text{Ni} \) reaction at \( E_{\text{lab}} = 25.75 \text{ MeV} \). CDCC calculations performed with two values of the spectroscopic factors are shown in comparison with the experimental data of [9].

The elastic scattering angular distributions were calculated for the \( ^8\text{B}^+^{58}\text{Ni} \) system at laboratory energies \( E_{\text{lab}} = 20.7, 23.4, 25.3, 27.2 \) and 29.3 MeV using the FRESCO code [7]. Figure 1 (a) shows the calculations in comparison with the data reported in [8]. Our results agree well with the data, particularly at energies above the Coulomb barrier. At energies below the barrier, the calculations slightly differ from the experimental data. Table 1 shows the DPP parameters used to fit the \(^7\text{Be}^+^{58}\text{Ni} \) system data of [8]. For the energies 20.7 and 23.4 MeV, values of \( r_{V,D} = 1.2 \) and \( a_{V,D} = 0.4 \text{ fm} \) were used, while for the rest of the energies, the values \( r_{V,D} = 1.28 \) and \( a_{V,D} = 0.45 \text{ fm} \) showed the best fit to the data. The values \( W_V = 90 \) and \( W_D = 5 \text{ MeV} \) were kept constant for all energies.

<table>
<thead>
<tr>
<th>( E_{\text{lab}} )[MeV]</th>
<th>( \alpha )</th>
<th>( \beta )</th>
<th>( E_{\text{lab}} )[MeV]</th>
<th>( \alpha )</th>
<th>( \beta )</th>
<th>( E_{\text{lab}} )[MeV]</th>
<th>( \alpha )</th>
<th>( \beta )</th>
</tr>
</thead>
<tbody>
<tr>
<td>20.7</td>
<td>-1.25</td>
<td>15.0</td>
<td>25.3</td>
<td>-0.28</td>
<td>0</td>
<td>27.2</td>
<td>-0.08</td>
<td>0</td>
</tr>
<tr>
<td>23.4</td>
<td>0</td>
<td>0</td>
<td>25.75</td>
<td>-0.23</td>
<td>0</td>
<td>29.3</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

3 Breakup and transfer analysis

We assume a cluster structure of \( ^8\text{B} = p \oplus ^7\text{Be} \). The valence proton has an orbital angular momentum \( l \), thus having total angular momentum relative to the core \( J = l + s \). In the case of breakup above
Table 2: Breakup and reaction cross sections for the $^8$B+$^{58}$Ni system.

<table>
<thead>
<tr>
<th>$E_{\text{lab}}$ (MeV)</th>
<th>$\sigma_{\text{bu th}}$ (mb)</th>
<th>$\sigma_{\text{R th}}$ (mb)</th>
<th>$\sigma_{\text{R exp}}$ (mb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>23.4</td>
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<td>382.26</td>
<td>365±50</td>
</tr>
<tr>
<td>25.3</td>
<td>198.92</td>
<td>606.92</td>
<td>515±50</td>
</tr>
<tr>
<td>27.2</td>
<td>204.80</td>
<td>797.80</td>
<td>827±45</td>
</tr>
<tr>
<td>29.3</td>
<td>209.24</td>
<td>978.24</td>
<td>1007±40</td>
</tr>
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$^a$ Experimental data taken from ref. [8]

the Coulomb barrier, the excited states of proton in the continuum were represented by 167 bins with orbital angular momenta $l = 0-4$ up to energies of 6 MeV. Figure 1 (b) shows the CDCC calculations of the $^8$B breakup differential cross section for the $^8$B+$^{58}$Ni reaction with spectroscopic factors $S_{\text{expt}} = 1.0$ and $S_{\text{exp}} = 1.1$, respectively, corresponding to the $^8$B$\rightarrow^7$Be+$p$ vertex. The results are compared with the data of [9].

We calculated the direct proton transfer in the $^{58}$Ni($^8$B,$^7$Be)$^{59}$Cu reaction, which can contribute to the $^{58}$Ni($^8$B,$^7$Be) reaction section. Excited states of $^{59}$Cu up to $E_x = 3.580$ MeV were taken into consideration. The calculation showed that proton stripping provides less then 3% of the total $^7$Be emission cross sections.

Table 2 shows the breakup and reaction cross sections calculated for the $^8$B+$^{58}$Ni system at energies around the Coulomb barrier in comparison with the data taken from Ref. [8]. The reaction cross sections were obtained by fitting the elastic scattering angular distributions using CDCC calculations. An accepted value of the spectroscopic factor for the $^8$B$\rightarrow^7$Be+$p$ vertex, $S_{\text{expt}}=1.10\pm0.05$, allowed us to estimate the ANC, $C^2 = 0.54 \pm 0.03$ fm$^{-1}$, and the astrophysical $S_{17}(0)$ factor to be equal to 20.7 ± 1.1 eV-b, which are in good accordance with the previously published results [1].

4 Conclusions

We have performed CDCC calculations of the elastic scattering, breakup, direct proton transfer, and reaction cross sections for the $^8$B+$^{58}$Ni system at energies around the Coulomb barrier. All cross sections were calculated by using the $^7$Be$^{58}$Ni semi-microscopical optical model potential containing the folding and DPP parts. The direct proton transfer contribution to the reaction cross section is about 3%. The astrophysical $S_{17}(0)$ factor equal to 20.7 ± 1.1 eV-b was calculated using the ANC method, being in good agreement with previously reported values.

References
