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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 ($E_{\rm B,lab}$=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 $E_{\rm lab}$ =25.75 MeV from the ^{8}B breakup on ^{58}Ni was calculated and the spectroscopic factor for $^{8}{\rm B} \rightarrow {}^{7}{\rm Be}+p$ vertex, $S_{\rm expt} = 1.10 \pm 0.05$, was deduced. The astrophysical $S_{17}(0)$ factor was calculated equal to 20.7 ±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 $S_{\rm expt}$ 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, $iW = i(W_V f(x_V) + W_D f(x_D))$, 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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$$V_P = \alpha(E) W_V(E) f(x_V) + \beta(E) \cdot 4 W_D(E) \frac{df(x_D)}{dx_D}, \tag{1}$$

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}Be and p+^{58}Ni interactions, the systematics proposed in [6] was used.

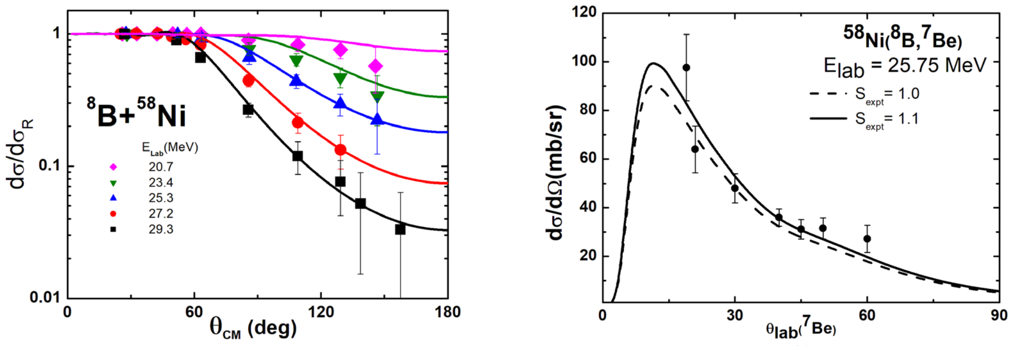

Figure 1: a) Elastic scattering angular distributions of ^{8}B from ^{58}Ni at energies around the Coulomb barrier calculated by the CDCC in comparison with the experimental data [8]. b) The differential breakup cross section of the ^{8}B+^{58}Ni reaction at E_{lab} =25.75 MeV. CDCC calculations performed 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}B+^{58}Ni system at laboratory energies E_{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}Be+^{58}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 fm were used, while for the rest of the energies, the values $r_{V,D}$ =1.28 and $a_{V,D}$ =0.45 fm showed the best fit to the data. The values W_V =90 and W_D =5 MeV were kept constant for all energies.

Table 1: DPP parameters used for the ^{7}Be+^{58}Ni system.

E_{lab} [MeV]	α	β	E_{lab} [MeV]	α	β	E_{lab} [MeV]	α	β
20.7	-1.25	15.0	25.3	-0.28	0	27.2	-0.08	0
23.4	0	0	25.75	-0.23	0	29.3	0	0

3 Breakup and transfer analysis

We assume a cluster structure of ^{8}B= $p \oplus {}^7$Be. The valence proton has an orbital angular momentum l, thus having total angular momentum relative to the core $\mathbf{J} = \mathbf{l} + \mathbf{s}$. In the case of breakup above

Table 2: Breakup and reaction cross sections for the ^{8}B+^{58}Ni system.

E_{lab} (MeV)	$\sigma_{\mathrm{bu\ th}}$ (mb)	$\sigma_{\mathrm{R\ th}}$ (mb)	$\sigma^{a}_{\mathrm{R\ exp}}$ (mb)
23.4	194.56	382.26	365±50
25.3	198.92	606.92	515±50
27.2	204.80	797.80	827±45
29.3	209.24	978.24	1007±40

^{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_{expt} = 1.0 and S_{expt} = 1.1, respectively, corresponding to the $^{8}\mathrm{B}\rightarrow{}^{7}\mathrm{Be}+p$ 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 cross 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 $^{8}\mathrm{B}\rightarrow{}^{7}\mathrm{Be}+p$ vertex, S_{expt}=1.10±0.05, allowed us to estimate the ANC, C^{2} = 0.54 ±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.

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