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Short note

Further measurement of the ^{7}Be(p,γ)^{8}B cross section at low energies with the coulomb dissociation of ^{8}B

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Abstract. We have measured the dissociation of ^{8}B in the Coulomb field of ^{208}Pb at $E_{\rm in}$=51.9 MeV/nucleon and extracted the cross section of the ^{7}Be(p,γ)^{8}B reaction at $0.4 \leq E_{\rm rel} \leq 3$ MeV, which is of importance for the ^{8}B solar-neutrino production rate. The extracted astrophysical S_{17} factors are consistent with our earlier Coulomb dissociation measurement, and agree with the values deduced from the direct capture measurements by Filippone *et al.*, Vaughn *et al.* and Hammache *et al.* The S factor at zero energy was extracted to be 18.9±1.8 eV-b with the help of theoretical energy-dependence.

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The Coulomb dissociation of ^{8}B in the field of ^{208}Pb was studied for the first time at RIKEN[1,2] in order to investigate the ^{7}Be(p,γ)^{8}B reaction at low energies. The latter radiative capture process is essential for estimating the high-energy neutrino flux relevant to the solar neutrino puzzle[3]. From the Coulomb dissociation cross sections, the astrophysical S_{17}-factor of the ^{7}Be(p,γ)^{8}B reaction was extracted at center-of-mass energies ranging from 0.6 MeV to 1.7 MeV[1,2]. The results are consistent with the ^{7}Be(p,γ)^{8}B reaction cross sections measured by Filippone *et al.*[4] and Vaughn *et al.*[5].

In a recent paper [6] we report a new measurement on detailed angular distributions of the Coulomb dissociation of ^{8}B from which the E2 contribution to the E1-dominant cross section was extracted. The resultant small E2 component supports our earlier analysis assuming a pure E1 contribution. From the same experiment, new values of the E1 cross section and, in turn, the astrophysical S factors were derived again. Due to the great interest in the ^{7}Be(p,γ)^{8}B reaction, we publish the S factors from our second experiment.

The experiment was performed at the radioactive beam line RIPS[7] at RIKEN (the Institute of Physical and Chemical Research). Secondary ^{8}B beams of $2{\times}10^4$s^{-1} bombarded a 50 mg/cm^2 ^{208}Pb target. The averaged energy of ^{8}B in the target is 51.9 MeV/nucleon. The detection system consisted of a ΔE-E plastic scintillator hodoscope and a NaI(Tl) detector array DALI[8]. The former detected the reaction products, proton and ^{7}Be, in coincidence, and the latter was used for measuring the γ rays from the first excited state of ^{7}Be at 429 keV. These γ rays are associated with the ^{8}B→^{7}Be*(429 keV)+p dissociation process which cannot be discriminated by the hodoscope data alone. The energy and angle of each fragment were measured by its time-of-flight

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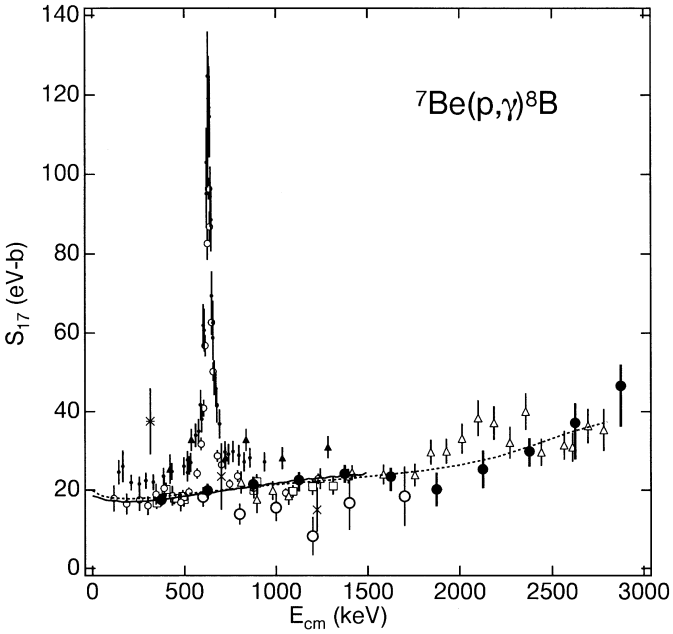

Fig. 1. Astrophysical S_{17}-factors for the ^{7}Be(p,γ)^{8}B reaction extracted from the present experiment (large solid circles) compared with those extracted in the previous Coulomb dissociation experiment[1] and those measured in the direct capture experiments by Kavanagh[10] (crosses), Parker[11] (solid triangles), Kavanagh *et al.*[12] (solid circles), Vaughn *et al.*[5] (open triangles), Wiezorek *et al.*[13] (asterisk), Filippone *et al.*[4] (open circles), and Hammache *et al.*[14] (open squares). The solid and dashed curves represent the fits to the present data with the theoretical energy dependence of Barker and Spear[16] and that of Descouvemont and Baye[17], respectively

and position information in the hodoscope, respectively. The flight path of 3.1 m long was filled with helium gas at 1 atm, which reduces background reactions compared with the case of filling with air. The p-^{7}Be relative energy $E_{\rm rel}$ which corresponds to the center-of-mass energy ($E_{\rm cm}$), and the scattering angle θ_8 defined as the angle of the p-^{7}Be center-of-mass with respect to the beam direction, are determined from the extracted energies and angles of proton and ^{7}Be. The 1σ resolutions are for example 120 keV at $E_{\rm rel}$=500 keV and 150 keV at $E_{\rm rel}$=1.5 MeV.

The p-^{7}Be coincidence yield due to the target is obtained by subtracting the data taken without the target from those with the target. The yield was extracted at $E_{\rm rel}$ >400 keV, where the subtraction is well under control with estimated accuracies of about 6%. However, at lower energies the data are not reliable because of the large contribution from the breakup in the helium gas, which is not correctly subtracted due to the additional spread of the beam in the target (multiple scattering) that is absent in the measurement without the target. In order to deduce absolute cross sections, corrections are made for the loss of fragment due to the reactions in the detector material (7% of the total yield), the dissociation reaction feeding the 429 keV state of ^{7}Be (5% on an average), and the pile-up rejection (2%). These corrections have an overall systematic uncertainty estimated to be 2% of the total yield. Further details on the experimental procedures and data-reduction method are given in our longer publication[2], and the present modification of the setup is given in[6].

From the Coulomb dissociation yield, the astrophysical S_{17} factors are extracted. The detection efficiency is evaluated by a Monte-Carlo simulation. A distorted wave calculation with the code ECIS79[9] relates the dissociation cross section to the capture cross section and hence to S_{17}. The results are shown in Fig. 1 together with our earlier results[1] and the results of the direct capture measurements[4, 5, 10–14]. The E2 contributions are corrected for with the help of the analysis in[6], though the correction is negligible below 1.7 MeV. The errors contain a common systematic uncertainty of 8.4% as well as statistical ones. The former consists of the uncertainty of the cross section discussed before (2%), that relevant to the subtraction of the yield without the target (6%), and that of efficiency evaluation (5.5%). As seen in the figure, the S_{17} factors from the present experiment are in general higher than our earlier results, but most of the error bars overlap. For the earlier results, systematic uncertainties could not be accurately evaluated, and only the statistical errors are indicated. The new data cover wider energy range of 0.4 MeV< $E_{\rm rel}$ <3 MeV and follow the tendency of the (p,γ) data. It should be noted that the M1 component is much hindered in the Coulomb dissociation. This is the reason why the present result exhibits no peak either for the M1 resonance at $E_{\rm rel}$=0.77 MeV (1^+) or for the broad ones at $E_{\rm rel}$ $\approx$2.3 MeV (3^+). The extracted S factors are in agreement with Filippone *et al.*[4] at low energies and with Vaughn *et al.*[5] at high energies. The most recent capture-data of Hammache *et al.*[14] agree with the data of Filippone *et al.* and hence with the present ones. We note that possible change of the (p,γ) cross-section data was suggested by considering a back-scattering of the recoiling ^{8}B in the target backing[15]. The Coulomb dissociation method is free from such an effect.

To extract the S factor at zero energy $S_{17}(0)$, the extrapolation procedures by Barker and Spear[16] and the one by Descouvemont and Baye[17] are applied. The resulting values are 18.5±0.3 (stat)±1.6 (syst) eV-b and 19.6±0.3 (stat)±1.6 (syst) eV-b, respectively. They are obtained by fitting the data below 1.4 MeV. If the lowest two data points in $E_{\rm rel}$ <0.75 MeV are used, $S_{17}(0)$=18.4 eV-b and $S_{17}(0)$=19.1 eV-b are deduced, respectively. Considering that the theoretical curves are more reliable at lower energies[18], statistical weight for the two low-energy data is increased by a factor of two in averaging, and we obtain the $S_{17}(0)$-factor of 18.9±1.8 eV-b, which is within the range of the most recent recommendation 19^{+4}_{-2} eV-b[19].

The same extrapolations respectively yield 19.0 eV-b and 19.5 eV-b for the Filippone's data[4] renormalized by the recent recommendation for the ^{7}Li(d,p)^{8}Li cross section of 147 mb[19]. They are consistent with the extrapolation by Johnson *et al.* for the same data, which yields

$S_{17}(0)$=20.2 eV-b[18] that corresponds to 18.9 eV-b with the new normalization.

More complete understanding of the reaction mechanism is also desirable. Though most of the theoretical studies predict rather small contribution from higher order processes including the post Coulomb acceleration, the magnitude of the correction depends on the model used to evaluate these effects. Because the higher order process become less important in general at higher incident energies, a Coulomb dissociation experiment has been performed at $E(^8\mathrm{B})$=254 MeV/nucleon at GSI. Preliminary results[20] agree with the present data and hence with the direct capture data of Filippone *et al.*, Vaughn *et al.* and Hammache *et al.*

Recent measurements of ^{7}Be fragments from the ^{8}B+^{208}Pb interaction[21] exhibit asymmetries in their inclusive parallel-momentum distributions, which are interpreted as an E1-E2 interference with an E2 amplitude larger than the one extracted in our angular distribution measurement[6]. The analysis in[21] assumes one-step excitation through pure electromagnetic interactions. Hence a more detailed analysis including nuclear breakup effects, possible multi-step excitation, and so on, might be required for complete understanding of the observed asymmetries.

In summary, we have measured the Coulomb dissociation of ^{8}B and extracted the cross section for the ^{7}Be(p,γ)^{8}B reaction at low energies. The resultant astrophysical S-factors are higher than but consistent within errors with our earlier result, and agree with the direct measurements of Filippone *et al.*[4] and Vaughn *et al.*[5] and also with the most recent result by Hammache *et al.*[14].

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