MEASUREMENT OF E2 TRANSITIONS IN THE COULOMB DISSOCIATION OF ^{8}B

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A recent study [1] of the Coulomb dissociation of ^{8}B has been performed in order to garner information on the rate of the inverse radiative capture reaction ^{7}Be(p,γ)^{8}B, which is critical for solar neutrino flux predictions. Although at solar energies the radiative capture reaction proceeds almost exclusively by E1 transitions, E2 photons can contribute significantly in Coulomb dissociation. The size of this E2 contribution must be known in order to infer the radiative capture rate from Coulomb dissociation data.

Measurements of the distribution of longitudinal momenta of ^{7}Be fragments resulting from the breakup of ^{8}B on heavy targets can be used to gauge the E2 strength in this reaction. First order perturbation theory calculations of the Coulomb dissociation of ^{8}B predict that the distribution of the longitudinal momenta of the emitted ^{7}Be fragments will be asymmetric due to interference between E1 and E2 transition amplitudes [2]. The magnitude of this asymmetry depends on the beam energy, because the ratio of the number of virtual E1 photons to E2 photons increases with beam energy. Hence, an effective way to gauge the strength of E2 transitions in the Coulomb dissociation of ^{8}B is to measure the asymmetry of the longitudinal momentum distributions of the emitted fragments at different beam energies. A recent study of the longitudinal momentum distribution of ^{7}Be fragments from the Coulomb dissociation of 41 MeV/u ^{8}B on a gold target [3] found an asymmetry of roughly the predicted size, but poor statistics prevented a definitive conclusion.

We used the new S800 spectrometer at the NSCL to carry out a much improved experiment. The large solid angle ($7° \times 10°$), high resolution, and large momentum acceptance (6%) of the S800 made possible a high precision, high statistics measurement. The beam energies were chosen to be 44 and 81 MeV/u. The lower energy is close to the energies of the earlier experiments of Refs. [1, 3].

^{8}B nuclei were dissociated in a 28 mg cm^{-2} Pb target. The spectrometer was set at 0° to detect ^{7}Be fragments, and was operated in a dispersion matched mode, so that the momentum spread of the incident beam did not limit the momentum resolution of the spectrometer. The focal plane of the S800 was instrumented with two position sensitive cathode readout drift chambers (CRDCs) [4], a 16 segment ionization chamber, and 3 thick plastic stopping scintillators. Energy loss signals were provided by the ionization chamber, and the first scintillator was the source of total energy signals. Reaction products were unambiguously identified by comparing the energies and energy losses of the detected particles with those of a calibration beam of ^{7}Be having the same rigidity as the ^{8}B beam. The ion optics code COSY INFINITY [5] was used to calculate momenta and scattering angles for each event from the magnetic field settings and the two dimensional position signals provided by each CRDC.

First order perturbation theory calculations of the Coulomb dissociation of ^{8}B on Pb at the energies of this experiment based on the model of Ref. [2] have been performed. The model predicts that $S_{17}(0)$ = 18 eV b, and that S_{E2}/S_{E1} = 9.5×10^{-4} at a fragment relative energy of 0.63 MeV. This E2 strength is smaller than that of the model of Kim *et al.* [6] by about a factor of 2. The total momentum distribution was calculated for several ^{7}Be scattering angle cuts. Projecting these events on the beam direction yielded the calculated longitudinal momentum distribution.

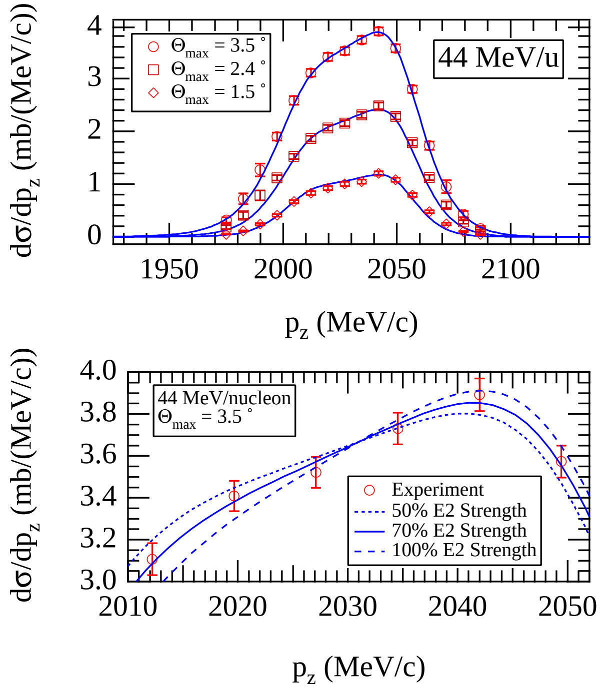

Figure 1: (a) Laboratory frame longitudinal momentum distributions of ^{7}Be fragments formed in the Coulomb dissociation of 44 MeV/u ^{8}B on Pb with maximum scattering angles of 1.5, 2.4, and 3.5°. The curves are the results of first order perturbation theory calculations convoluted with the experimental resolution of 5 MeV/c. The error bars indicate the relative uncertainties of the data points, which are dominated by statistical errors. (b) Central region of the 3.5° angle cut at the same beam energy. The curves are calculations performed with different E2 strengths, normalized to the center of the distribution.

The measured longitudinal momentum distributions of ^{7}Be fragments produced in the Coulomb dissociation of ^{8}B on Pb at 44 MeV/u are shown in Fig. 1 (a) for three different angle cuts. Uncertainties in the target thickness and beam intensity resulted in systematic uncertainties in the measured cross sections of $\pm$ 9%. The predicted longitudinal momentum distributions, convoluted with the experimental resolution of 5 MeV/c, are superposed on the measured distributions. The description of the data with the original model was quite good, but not precise. Both the value of $S_{17}(0)$ and the E2 strength are implicit in the structure model used, but are not robust predictions of such models. Since the predicted cross sections depend on $S_{17}(0)$ and the E2 strength, the normalization and E2 strength are effectively free parameters. We therefore adjusted the E2 strength and the overall normalization of the model to minimize χ^2 for the central 6 points of the 3.5° distribution. This yielded a normalization factor of 1.22 and an E2 strength 0.7 times as large as the original value. Fig. 1 (b) shows the central region of the 44 MeV/u momentum distribution for the 3.5° angle cut. Also shown are three calculations with different E2 strengths, expressed as fractions of the original E2 strength of the model, normalized to the center of the distribution. The dependence of the calculated asymmetry on the E2 strength is apparent.

Good agreement between the observed and predicted shapes of the distributions implies that the shapes of the E1 and E2 responses predicted by the model of Ref. 2 are realistic, requiring only slight adjustments in absolute magnitude. Independent DWBA calculations [7, 8] find that the cross section for nuclear breakup is less than 0.5% of the cross section for Coulomb breakup in the angular range of our

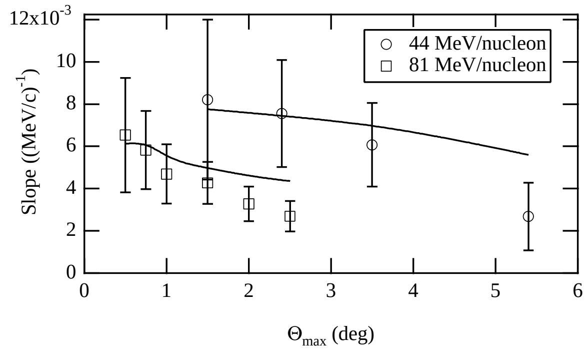

Figure 2: Comparison of slopes extracted from the central regions of the logarithms of the measured and theoretical longitudinal momentum distributions plotted versus maximum scattering angle. The agreement between the experimental results and the calculations is good at the smallest angle cuts. Deviations between the experiment and the theory (solid lines) are evident at large scattering angles, suggesting that nuclear breakup becomes important at these angles.

44 MeV/u measurement. Hence nuclear breakup is not expected to have a significant influence on either the shape or size of the 44 MeV/u longitudinal momentum distributions. The evident asymmetry of the distributions, characteristic of interference between ℓ=1 and ℓ=2 amplitudes, is therefore interpreted as the result of interference between E1 and E2 transition amplitudes.

The value of $S_{17}(0)$ corresponding to the best fit normalization factor is 22 eV b, well within the limits of the recommendation of the 1997 INT Workshop on Solar Fusion Cross Sections [9]. The value of the ratio S_{E2}/S_{E1} at a fragment relative energy of 0.63 MeV corresponding to this E2 strength is 6.7 $\times 10^{-4}$, which is consistent with the upper limit of 7 $\times 10^{-4}$ given in Ref. 10. However, the E2 strength was extracted from the present experiment under the assumption of first order perturbation theory. If higher order dynamical effects are significant, then the E2 strength extracted here is a lower limit; for a given E2 strength, the predicted asymmetry is smaller when higher order effects are included than when they are neglected [2]. The results of this experiment apparently contradict those of two earlier experiments that found the E2 strength to be smaller than all published theoretical predictions [11, 12].

In order to compare the asymmetries measured in the experiment with those predicted by the model, the slopes of the central regions of the longitudinal momentum distributions were extracted. However, the slopes of the theoretical distributions are proportional to the normalization factor by which the calculation has been multiplied. It is possible to eliminate this dependence on the normalization factor by taking the logarithm of the distributions before extracting a slope. Therefore, straight lines were fitted to the logarithms of the measured and theoretical distributions between 2020 and 2035 MeV/c for the lower energy, and between 2771 and 2791 MeV/c for the higher energy. The results of this comparison are shown in Fig. 2. The calculations at both energies were performed with the same optimal E2 strength described above. The systematically smaller slopes at the higher beam energy reflect the lesser relative importance of E2 transitions there. At both energies, the experimental slopes decrease more rapidly with angle than the Coulomb dissociation calculation predicts. This is interpreted as the result of nuclear induced breakup at angles approaching the grazing angle, which is 4.4° at the higher beam energy. Nuclear breakup results in a symmetric longitudinal momentum distribution [3], and could lead to smaller slopes.

Fig. 3 depicts a measured longitudinal momentum distribution of ^{7}Be fragments produced in the

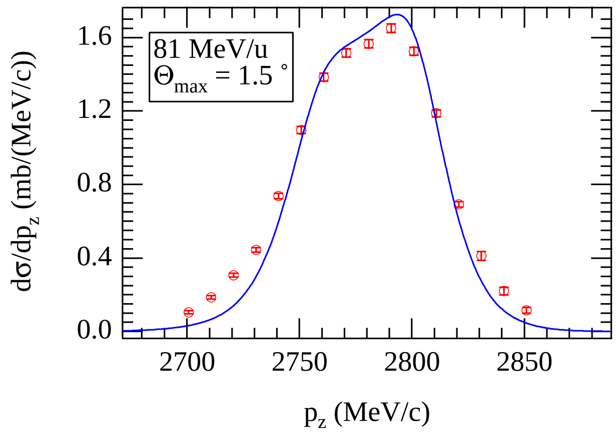

Figure 3: Measured longitudinal momentum distribution of ^{7}Be fragments with scattering angles less than 1.5° formed in the dissociation of 81 MeV/u ^{8}B, along with the prediction of the model. The slightly greater width of the experimental distribution indicates the presence of a broad component possibly due to nuclear breakup not accounted for in the calculation.

dissociation of ^{8}B on Pb at 81 MeV/u. Also shown is the prediction of the model with the same optimal E2 strength, again convoluted with the experimental resolution. The agreement between experiment and calculation at this energy is not as good as at 44 MeV/u. The main difference between the prediction of the model and the experimental measurement is the slightly greater width of the measured distribution. It is possible that nuclear breakup not accounted for by the model is responsible for broadening the measured distributions. The nuclear breakup cross sections are approximately equal at the two beam energies of this experiment [13], while the Coulomb excitation cross section at a given impact parameter is roughly proportional to the inverse square of the beam velocity. Hence nuclear breakup is relatively more important at 81 MeV/u. For this reason we utilized only the 44 MeV/u data in extracting the E2 strength. Nevertheless, including the 81 MeV/u data in the analysis would change the result little.

In summary, longitudinal momentum distributions of ^{7}Be fragments formed in the Coulomb dissociation of 44 and 81 MeV/u ^{8}B on Pb have been measured with high precision and statistics. At 44 MeV/u, the shapes of the measured distributions and the magnitudes of the measured cross sections agree with first order perturbation theory calculations based on a simple, single-particle model of the structure of ^{8}B. The model predicts that interference between E1 and E2 transition amplitudes will produce observable asymmetries in the longitudinal momentum distributions of the fragments formed in the Coulomb dissociation of ^{8}B at the beam energies investigated in this experiment. These asymmetries were in fact observed. The 81 MeV/u distributions were not as well fit, perhaps because of a small nuclear component, so the 44 MeV/u distributions alone were used to extract the E2 strength. Nevertheless, the theoretical predictions for the slopes of the central regions of the momentum distributions based on this E2 strength agree well with the 81 MeV/u data at small angles, where nuclear effects are expected to be small. The measured distributions are consistent with a value of $6.7^{+2.8}_{-1.9} \times 10^{-4}$ for the ratio S_{E2}/S_{E1} at the a fragment relative energy of 0.63 MeV.

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