Eur. Phys. J. A **25**, s01, 647–648 (2005)
DOI: 10.1140/epjad/i2005-06-193-x

EPJ A direct
electronic only

^{7}Be breakup on heavy and light targets

N.C. Summers[a] and F.M. Nunes

National Superconducting Cyclotron Laboratory and Department of Physics and Astronomy, Michigan State University, East Lansing, MI 48824, USA

Received: 19 November 2004 /

Abstract. We present all-order quantum mechanical calculations of ^{7}Be breakup on ^{208}Pb and ^{12}C targets. We examine the issues concerning the extraction of the astrophysical S-factor from the breakup data, via the methods of asymptotic normalization coefficients and Coulomb dissociation.

PACS. 25.70.De Coulomb excitation – 24.10.Eq Coupled-channel and distorted-wave models – 25.60.Gc Breakup and momentum distributions – 27.20.+n $6 \leq A \leq 19$

1 Introduction

The breakup of ^{7}Be into $\alpha + {}^3$He is of interest to astrophysics for the capture reaction ^{3}He(α,γ)^{7}Be. This capture reaction is of importance for the *pp* chain [1] and big-bang nucleosynthesis [2]. At astrophysical energies, the reaction rates for capture are extremely low and thus rely on extrapolations. The astrophysical quantities can be extracted from the breakup data via Coulomb dissociation on heavy targets [3], and via the asymptotic normalization coefficient (ANC) method [4].

Here we present fully quantum mechanical calculations [5] for two experiments of ^{7}Be breakup. One at the Cyclotron Lab at Texas A&M, using a ^{12}C target at 25 MeV/nucleon, and the other at the NSCL, using a ^{208}Pb target at 100 MeV/nucleon. Calculations were performed within the method of continuum discretized coupled channels (CDCC), reviewed in ref. [6], using the coupled channels code FRESCO [7]. Within CDCC, nuclear and Coulomb are treated on equal footing and the contribution from higher-order couplings can be examined.

2 Light targets

The ANC method requires a peripheral collision and a first-order reaction mechanism. Therefore the contribution to the breakup from the interior and the effect of higher-order couplings have to be examined.

In fig. 1 we show the importance of higher-order couplings on the breakup cross section for the ^{12}C target. The first-order DWBA calculation (dashed line) dramatically overestimates the CDCC cross section (solid line), which includes all couplings to all-orders. To extract astrophysical S-factors from breakup, the reaction has to be a direct first-order process. It is clear from fig. 1 that higher-order processes have to be reduced via some kinematical selection.

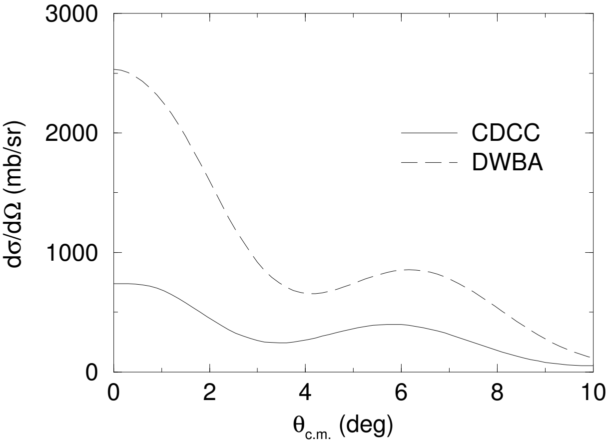

Fig. 1. Angular distribution of the cross section for ^{7}Be breakup on ^{12}C at 25 MeV/nucleon. The solid line is the full CDCC calculation and the dashed line is a first-order DWBA calculation.

Another condition of the ANC method is that the reaction is peripheral. In fig. 2 we show the J-distribution of the cross section. A simple sum of radii for $^7\mathrm{Be} + {}^{12}\mathrm{C}$ yields 5.3 fm. Relating the angular momentum to a semi-classical impact parameter, we see that 16% of the total breakup cross section comes from impact parameters less than the sum of the radii (shaded area in fig. 2). Contributions from the interior will have to be considered when extracting the ANC.

3 Heavy targets

Breakup reactions on heavy targets can extract astrophysical factors for the inverse reaction, due to the large

---

[a] Conference presenter; e-mail: `summers@nscl.msu.edu`

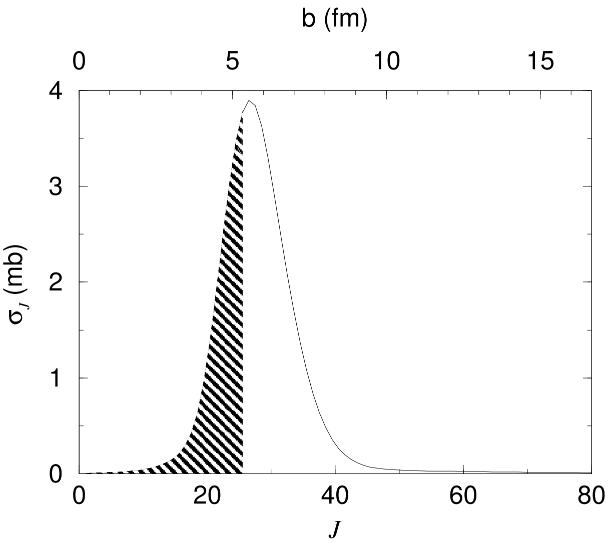

Fig. 2. J-distribution of the cross section for the ^{12}C target. The top scale relates the angular momentum to the impact parameter via the semi-classical relation $J = Kb$. The total breakup cross section is shown by the solid line and the shaded area represents impact parameters less than the sum of radii.

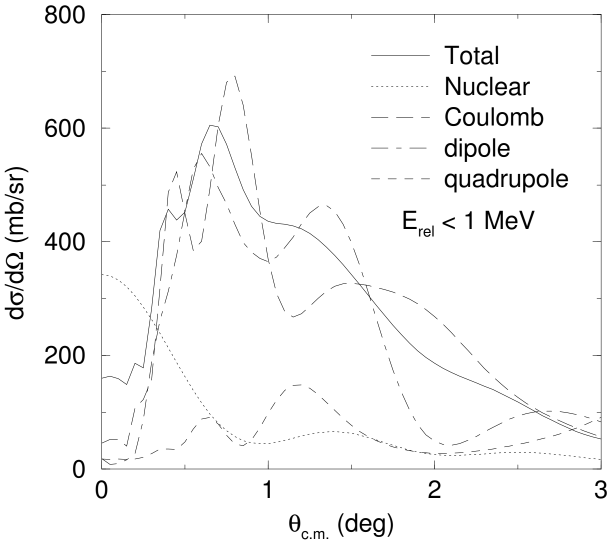

Fig. 3. Angular distribution of cross sections for ^{7}Be elastic breakup on ^{208}Pb at 100 MeV/nucleon for the lowest 2 energy bins for each j^π set. The CDCC (solid) calculation is broken down into nuclear (dotted) and Coulomb (long-dashed) contributions, and also dipole (dot-dashed) and quadrupole (short-dashed) contributions.

Coulomb field of the target [3,8]. Cross sections for these reactions are much larger and thus can provide independent measurements for the extrapolation of capture reactions to low energies. There are three main complications of breakup reactions which are not present in capture reactions: i) nuclear breakup, ii) $E2$ transitions [9], and iii) multistep effects [10].

Nuclear breakup is traditionally reduced by taking data at forward angles. Assuming semi-classical trajectories this restricts the reaction to large impact parameters outside the range of the nuclear force. But this alone is not enough to neglect the nuclear contribution [5]. By imposing an energy cut on the maximum relative energy between the final fragments the nuclear component can be reduced significantly. We simulate this energy cut in our calculations by including all relative energies in our calculation, but only summing up the cross section to the lowest two energy bins (fig. 3). This gives a maximum relative energy of approximately 1 MeV. In the CDCC method the continuum is discretized into energy bins for each j^π of relative motion between the final fragments. The full CDCC calculation for the lowest two energy bins is shown by the solid line, while the nuclear component is shown by the dotted line.

The $E2$ contribution to the breakup cross section was also examined in the CDCC method by including separately only dipole and only quadrupole contributions to breakup. In fig. 3 the dot-dashed line shows the dipole breakup while the quadrupole breakup is represented by the short-dashed line. We see that the $E2$ component has significant contributions and cannot be neglected.

The breakup data on the heavy target can also be used for the extraction of astrophysical factors by the ANC method. As with the breakup data on the light target, contributions from the interior were significant (28%), but the effect of continuum-continuum couplings was less of a problem [5].

In conclusion, we have presented calculations of ^{7}Be breakup on two different targets and energies. We discussed the issues concerning the extraction of astrophysical quantities from the data. We have shown that for the lighter target, large contributions from the interior and continuum-continuum couplings will have to be considered when extracting the ANC. For the Coulomb dissociation on the heavy target, significant nuclear and quadrupole contributions at forward angles can be reduced with energy cuts, but not eliminated.

This work was supported by the National Superconducting Cyclotron Laboratory, Michigan State University.

References

1. E.G. Adelberger *et al.*, Rev. Mod. Phys. **70**, 1265 (1998).
2. R.H. Cyburt, B.D. Fields, K.A. Olive, Phys. Rev. D **69**, 123519 (2004).
3. G. Baur, C.A. Bertulani, H. Rebel, Nucl. Phys. A **458**, 188 (1986).
4. L. Trache *et al.*, Phys. Rev. Lett. **87**, 271102 (2001).
5. N.C. Summers, F.M. Nunes, Phys. Rev. C **70**, 011602(R) (2004).
6. Y. Sakuragi, M. Yahiro, M. Kamimura, Prog. Theor. Phys. Suppl. **89**, 136 (1986).
7. I.J. Thompson, Comput. Phys. Rep. **7**, 167 (1988).
8. T. Motobayashi *et al.*, Phys. Rev. Lett. **73**, 2680 (1994).
9. B. Davids *et al.*, Phys. Rev. Lett. **81**, 2209 (1998).
10. S.B. Gazes *et al.*, Phys. Rev. Lett. **68**, 150 (1992).