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Coupled channels calculations of ^{11}Be breakup

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Abstract. Recent measurements of the cross sections for the diffractive breakup of ^{11}Be on a light (^{12}C) target have been reported. These data cover a fraction of the final-state three-body phase space and cuts on these data exhibit resonant structures in the neutron-^{10}Be continuum. These breakup data provide a motivation to test the coupled discretised continuum channels method in the context of the spectroscopy of continuum states in ^{11}Be and similar neutron-rich systems near the dripline.

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1. Introduction

The light neutron-rich nucleus ^{11}Be continues to be a challenge to quantitative models of nuclear reactions. ^{11}Be is usually modelled, for reaction purposes, as a weakly bound neutron and ^{10}Be(0^+,gs) core [1, 2]. Their separation energy is 0.504 MeV . However, there is much evidence, e.g. [3], of a 20-30% excited 2^+ core component in the ^{11}Be ground state and of resonant states in the low energy ^{10}Be+n continuum. Because of its weak binding, a non-perturbative treatment of the the breakup channel is necessary in reactions of ^{11}Be with a target nucleus. There are, however, rather limited data on the diffractive (elastic) breakup of ^{11}Be with which to test reaction models. Neutron angular distribution measurements were reported by Anne *et al* [4]. New ^{11}Be breakup data have also recently been presented by Fukuda *et al* [5], on a ^{12}C target at 67 MeV per nucleon - data taken at RIKEN. In this contribution we outline the initial results of breakup reaction calculations for this system within the coupled discretised continuum channels (CDCC) framework.

2. Coupled channels model and results

In the coupled channels formalism, excitations of the projectile into the continuum (breakup) are treated by discretising the continuum into bins. These bins form a truncated model space for the relative motions of the projectile fragments and are truncated at a maximum relative energy and angular momentum. Each bin state is represented by a square integrable wave function, a weighted sum of the scattering states contained within the bin. Details can be found in, for example, Ref. [6]. Our CDCC calculations were performed using the coupled channels code FRESCO [7].

To assist with planned, detailed theoretical comparisons of the CDCC and the time-dependent calculations of [1], we assumed the same ^{10}Be-neutron Hamiltonian as Capel *et al* [1]. This has (parity-dependent) Woods-Saxon potential depth parameters chosen to reproduce the $2s_{1/2}$ and $1p_{1/2}$ ^{11}Be bound states and the $d_{5/2}$ resonance near 1.8 MeV. Similarly, our present ^{10}Be-^{12}C and neutron -^{12}C interactions were taken from references [8] and [9]. The former reproduces elastic scattering data for ^{10}Be on ^{12}C at 59.4 MeV per nucleon.

The present calculations assume a model space that includes ^{10}Be-neutron relative motion channels with $j^\pi = 1/2^+$ through $5/2^+$, each with relative energies up to 20 MeV. The associated bin wave functions were calculated to ^{10}Be-n separation distances r_{bin} of 60 fm. To accurately include Coulomb breakup contributions, projectile-target partial waves up to 10000 were used together with a matching radius of R_{asy} of 1000 fm for the solution of the resulting coupled equations. We have used up to 15 bins to describe the $d_{5/2}$ resonance region from 0.5 to 2 MeV.

The contributions to the CDCC breakup cross section from each ^{11}Be* j^π channel are shown in Figure 1 as a function of relative energy. The largest contributions to the cross section arise from $p_{3/2}$ and $d_{5/2}$ breakup states. The $p_{3/2}$ contribution peaks near 0.5 MeV producing a shoulder on the total distribution. The $d_{5/2}$ contribution produces the resonance peak. Adding higher partial waves had a negligible effect on the results shown.

A comparison of the CDCC calculation with the data is shown in Figure 2 for (a) the full measured angular range (full symbols) and (b) for the most forward angles (open symbols). The theoretical cross sections have been folded with the instrumental

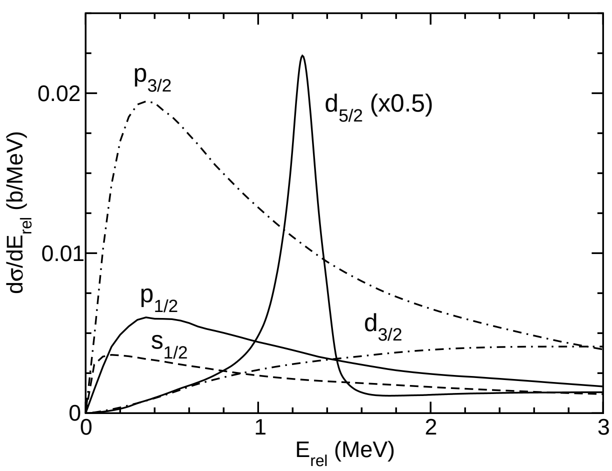

Figure 1. Contributions of each partial wave to the CDCC breakup cross section.

resolution [5]. This broadens the $d_{5/2}$ resonance peak, also shifting it to lower energy. The full CDCC cross sections are enhanced below 1.5 MeV compared with the data. Above this energy the agreement is good, with the exception of a broad resonance in the vicinity of 3MeV, This resonance is usually assigned $j^{\pi} = 3/2^{+}$ [5] and is expected to have $[^{10}\mathrm{Be}(2^{+}) \otimes s_{1/2}]$ parentage. Such excited core components are absent from the present calculations. Recent work by Batham *et al* [10], within the eikonal approximation, suggests such core degrees of freedom will enhance the elastic breakup channel.

Our CDCC calculation overpredicts the (dominantly Coulomb) small angle breakup data. A rescaling of the CDCC result, by 0.78, is consistent with the data and with the spectroscopic factor of 0.72 needed by an ($E1$) semi-classical calculation [5]. A scaling of the full cross section by this same factor would however underpredict the measured cross section. This suggests that the nuclear optical model potential sets currently used underpredict the nuclear breakup contributions to the reaction in comparison with those for Coulomb breakup. Significant optical model sensitivity was indeed noted here and in [1].

Figure 3 shows the theoretical angular distributions. These have been convoluted with an instrumental resolution of FWHM 0.48° but are otherwise absolute predictions. The (left) angular distribution is for a relative energy cut of $0 \leq E_{rel} \leq 0.2$ MeV, below the $d_{5/2}$ resonance. As expected, Figure 2, this distribution is dominated by the $\ell = 1$ transitions. The (right) angular distribution is for the energy cut $1.2 \leq E_{rel} \leq 1.4$ MeV, where the $d_{5/2}$ resonance dominates. Consistent with our enhanced Coulomb breakup component, the cross section is not reproduced in detail, also suggestive of an incorrect admixture of $\ell = 1$ and 2 transitions within the present model.

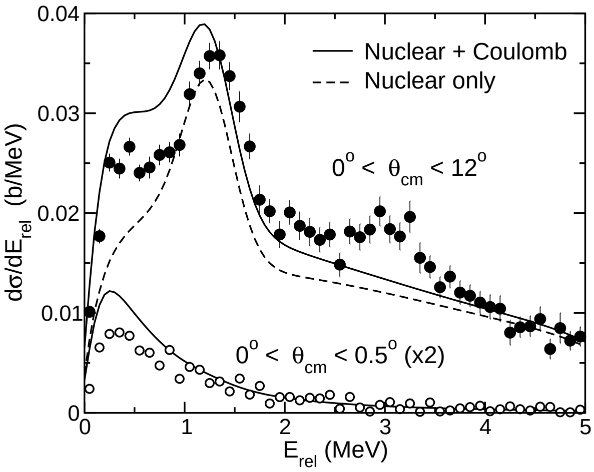

Figure 2. CDCC and experimental cross sections as a function of relative energy.

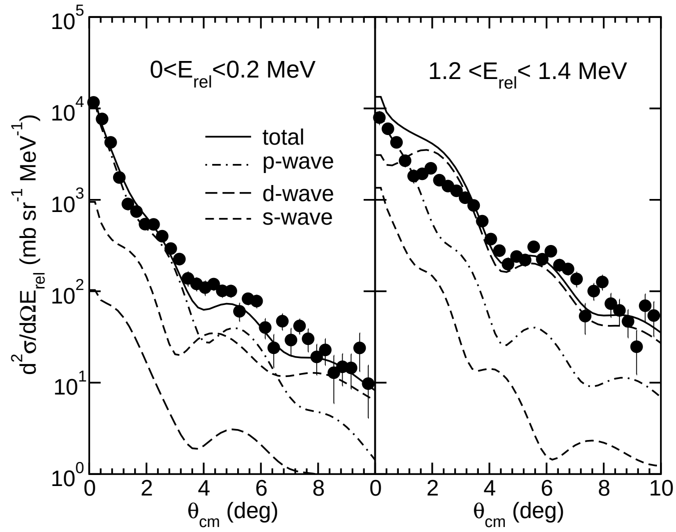

Figure 3. Angular distribution for (left) $0 \le E_{rel} \le 0.2$ MeV corresponding to the structureless continuum and (right) $1.2 \le E_{rel} \le 1.4$ MeV corresponding to the region containing the $d_{5/2}$ resonance.

3. Discussion

Breakup of ^{11}Be was considered within the CDCC method. An alternative, approximate, time-dependent framework has been discussed in [1]. A detailed comparison of these theoretical approaches will be presented elsewhere. Our first comparisons with the data of Fukuda *et al* [5] show very promising results, but w ith an underestimate of nuclear compared with Coulomb breakup. Our calculations reveal sensitivity to the optical potentials used for the core and nucleon, as was observed in [1]. These need to be more carefully investigated to better understand the reaction mechanism and the applicability of the CDCC for continuum spectroscopy from such data.

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References

[1] P. Capel, G. Goldstein, and D. Baye, Phys. Rev. C **70**, 064605 (2004)
[2] J.A. Tostevin *at al.*, Phys. Rev. C **66**, 024607 (2002)
[3] T. Aumann *et al.*, Phys. Rev. Lett. **84**, 35 (2000)
[4] R. Anne *et al.*, Nucl. Phys. A, **575**, 125 (1994)
[5] N. Fukuda *et al.*, Phys. Rev. C **70**, 054606 (2004)
[6] J.A. Tostevin, F.M. Nunes, and I.J. Thompson, Phys. Rev. C **63**, 024617 (2001)

[7] I.J. Thompson, Comput. Phys. Rep. **7**, 167 (1988)
[8] J. S. Al-Khalili, J. A. Tostevin, and J. M. Brooke, Phys. Rev. C **55**, R1018 (1997)
[9] F. D. Becchetti, Jr. and G. W. Greenlees Phys. Rev. **182**, 1190 (1969)
[10] J.A. Tostevin, P. Batham, G. Podolyák and I.J. Thompson, Nucl. Phys. A **746**, 166 (2004); P. Batham *et al.*, Phys. Rev. C, submitted.