Coulomb breakup of halo nuclei within an adiabatic model

P Banerjee, J A Tostevin and I J Thompson

Department of Physics, School of Physical Sciences, University of Surrey,
Guildford, Surrey GU2 5XH, United Kingdom

Abstract. We investigate the Coulomb dissociation of halo nuclei, assuming that the excitation of the projectile is to states in the low energy continuum. The method used retains all finite-range effects associated with the interactions between the breakup fragments and can use realistic wave functions for the halo nuclei. We apply the method to Coulomb breakup of ^{6}He and ^{19}C on heavy targets, at incident energies below 100 MeV/nucleon, for calculations of alpha particle energy distributions and parallel momemtum distributions of ^{18}C respectively. The absolute magnitudes of the energy distributions and the widths of the parallel momentum distributions are sensitive to the assumed structures of the halo nuclei.

The study of breakup of halo nuclei is important for probing their structures. There have been several approximate theoretical analyses, both semi-classical [1] and quantum mechanical [2], on the Coulomb breakup of halo nuclei - particularly for ^{11}Li and ^{11}Be. For two-neutron halo nuclei, these calculations were not based upon realistic three-body wave functions of these nuclei. Instead, the two halo neutrons were treated as a 'dineutron' cluster orbiting the core. A zero-range approximation was assumed in the dineutron-core interaction. For the one-neutron halo nuclei, the use of the zero-range DWBA approximation [2] does not permit calculations for non-s-wave projectiles. At high beam energies, the zero-range DWBA assumption is also of doubtful applicability, even for s-wave projectiles.

Following the theories in [3], we present finite range quantum mechanical calculations of elastic Coulomb breakup of the halo nuclei ^{6}He and ^{19}C, which allow the use of realistic wave functions. We assume that the excitation of the projectile can be treated adiabatically, i.e. that the breakup configurations excited by the Coulomb interaction between the charged core and the target are low energy relative motion states between the breakup fragments. We also assume that there is no interaction between the valence neutron(s) and the target. Within the adiabatic model, the Coulomb breakup amplitude factors into two parts [4, 5] - one part associated with the dynamics of the reaction, and the other factor with the structure of the halo nucleus through its ground state wave function.

1. Calculations on the two-neutron halo nucleus ^{6}He

We calculate the α-particle energy spectrum at $\theta_\alpha = 5°$ following the elastic breakup of ^{6}He on a Au target at beam energy of 65 MeV/nucleon, assuming two model ^{6}He three-body wave functions. These wave functions, both with the correct breakup threshold, are calculated using the hyperspherical harmonic expansion method. The first wave function (A), from [6], has a two-neutron separation energy of 0.975 MeV and a ^{6}He rms matter radius of 2.50 fm. The second wave function (B), calculated assuming a modified three-body interaction term, has separation energy 0.985 MeV and a smaller rms matter radius of 2.35 fm. The experimental data, at 63.2 MeV/nucleon beam energy, are from [7]. The calculated cross sections (Fig.1) are seen to account for of order 50–70% of the measured strength at the peak position. This agrees with the estimates of the Coulomb breakup contribution made in [7]. Therefore, in case of breakup of ^{6}He, the nuclear contributions are substantial even on high Z targets, at least in the kinematical region covered by the data of [7]. Significantly, Coulomb breakup calculations of ^{6}He using a dineutron model are seen to overestimate the measured cross sections by a factor of 5 or so. The 'dineutron' is assumed to be in a $1s$ state in a Woods-Saxon potential (with radius and diffuseness parameters 1.15 fm and 0.5 fm respectively) whose depth has been adjusted to reproduce the binding energy of 0.975 MeV. The resulting ^{6}He wave function has rms radius of 2.47 fm.

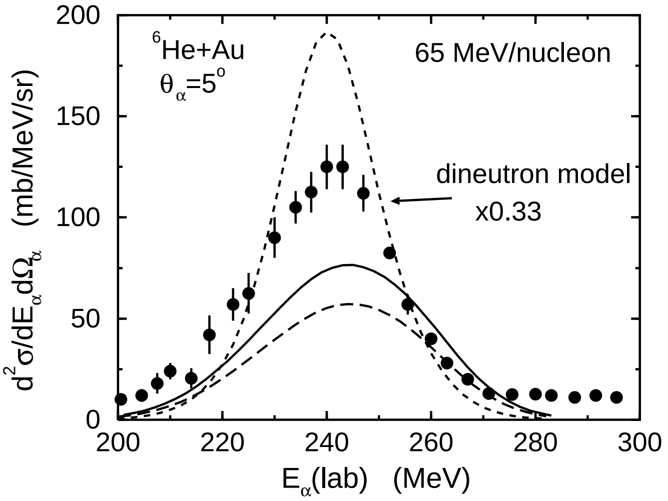

Figure 1. Calculated α-particle energy spectrum from Coulomb breakup of ^{6}He on Au at 65 MeV/nucleon. The solid and dashed lines use ^{6}He models A and B respectively. All calculated energy spectra are shifted by 20 MeV [5]. The dotted line shows the result for the dineutron model.

2. Calculations on the one-neutron halo nucleus ^{19}C

There is uncertainty regarding the ground state structure of ^{19}C. We consider three configurations for the valence neutron in ^{19}C and calculate the parallel momentum distribution of ^{18}C following breakup of ^{19}C on a Ta target at 88 MeV/nucleon beam energy. This has been recently measured at MSU [8]. We consider (a) a $1s_{\frac{1}{2}}$ state bound to a 0^+ ^{18}C core by 0.24 MeV, (b) a $1s_{\frac{1}{2}}$ state bound to a 2^+ ^{18}C core by 1.86 MeV and (c) a $0d_{\frac{5}{2}}$ state bound to a 0^+ ^{18}C core by 0.240 MeV. The binding potentials in all cases are of Woods-Saxon type with the same radius and diffuseness parameters as used above. Their depths have been calculated to reproduce the respective binding energies. The widths (FWHM) of the parallel momentum distributions are 27, 71 and

83 MeV/c respectively. The published width, deduced from the MSU data, is 41±3 MeV/c although these data have limited statistics. These data, therefore, do not distinguish clearly between the possible options for the ^{19}C ground state structure at this time. It was option (b) above which best reproduced the recent measurement [9] of the neutron angular distribution following ^{19}C breakup on Ta at 30 MeV/nucleon [4].

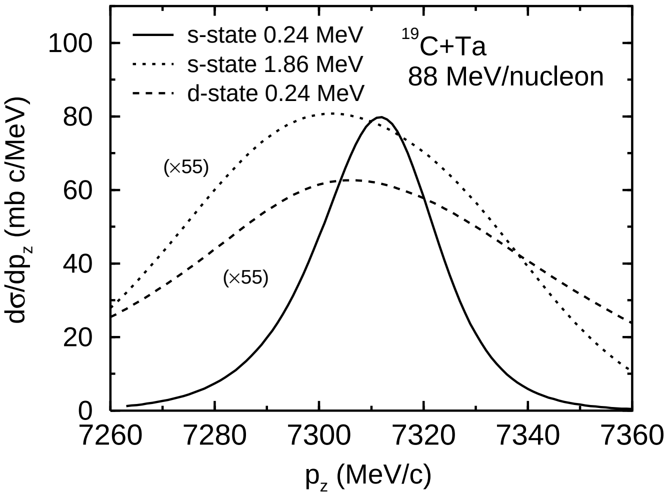

Figure 2. Calculated parallel momentum distribution of the ^{18}C fragment from Coulomb breakup of ^{19}C on Ta at 88 MeV/nucleon.

Acknowledgments

The financial support of the United Kingdom Engineering and Physical Sciences Research Council (EPSRC) in the form of Grant No. GR/J95867 is gratefully acknowledged.

References

[1] Canto L F *et al* 1993 *Phys. Lett.* **B318** 415
[2] Banerjee P and Shyam R 1993 *Nucl. Phys.* **A561** 112
[3] Tostevin J A *et al* 1998 *Phys. Lett.* **B424** 219; 1998 *Phys. Rev.* **C57** 3225
[4] Banerjee P, Thompson I J and Tostevin J A 1998 *Phys. Rev.* **C** (in press)
[5] Banerjee P, Tostevin J A and Thompson I J 1998 *Phys. Rev.* **C** (in press)
[6] Danilin B V, Thompson I J, Vaagen J S and Zhukov M V 1998 *Nucl. Phys.* **A632** 383
[7] Balamuth D P *et al* 1994 *Phys. Rev. Lett.* **72** 2355
[8] Bazin D *et al* 1998 *Phys. Rev.* **C57** 2156
[9] Liegard E *et al* 1998 LPC-Caen report LPCC 98-03