MEASUREMENT OF PARENTAGE IN STRIPPING REACTIONS OF HALO NUCLEI

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Abstract

Recent experiments performed using the S800 spectrograph at the National Superconducting Cyclotron Laboratory have shed a new light on techniques to measure the valence wave function of halo nuclei. The momentum of the heavy fragment resulting from the stripping of the halo particle is measured by the spectrograph, and its final excited state is measured by means of a NaI g-detector array located around the target. The large angular and momentum acceptances of the S800 provide a measurement of the full momentum vector. The analysis of the shape of the momentum distributions corresponding to different core fragment final states distinguishes between core excitations coming from reactions where a particle from the core - rather than the halo - is removed in the reaction, and components of the halo wave function where the halo particle is coupled to an excited state of the core.

Introduction

Stripping reactions of valence particles in halo nuclei may be a way to probe the spacial extent of their wave functions. Typically, the momentum distribution of the remaining core is measured at forward angles, and interpreted as the Fourier transform of the spacial wave function, with the appropriate core absorption effects taken into account. However, a careful comparison with calculations shows that discrepancies occur in the tails of the distributions, which suggests that the core is not merely a spectator of the reaction, but might also play an active role in the reaction (1). The detection of g-rays in coincidence with the core fragments provides an identification of the reaction process and of the different components of the valence wave function. The momentum distributions corresponding to nucleons removed from different orbits and different core fragment final states will exhibit different shapes, and from the absolute calibrations of both the cross sections and the g-rays array efficiency, as well as an appropriate reaction model, spectroscopic factors can be deduced. For example in the case of ^{11}Be, the ground state wave function of the valence neutron is known to be predominantly *s*-wave but may have some *d*-wave coupled to the 2^+ state of ^{10}Be. The ground state wave function also has 4 neutrons in the $0p_{3/2}$ shell and removal of these neutrons produces a hole state in ^{10}Be, either a 1^- or 2^- at around 6 MeV. In this contribution, we show that the measured core recoil momenta in coincidence with different final states of the core is consistent with this picture.

Two test cases: ^{11}Be and ^{15}C

Both ^{11}Be and ^{15}C are interesting to study because they are known to have a dominant *s*-wave component in their ground state wave functions (2,3), but rather different binding energies (0.5 MeV and 1.2 MeV respectively). Fig. 1 shows the momentum distributions of the ^{10}Be core fragments after the breakup of ^{11}Be on a CH_2 target. The losange distribution is gated on the Doppler corrected 3.37 MeV $2^+ \rightarrow 0^+$ transition in ^{10}Be. The dotted line is an l=0 Hankel wave function calculation [4] and clearly doesn't account for the total distribution, especially in the tails. In the inset the difference between the total distribution and the one gated on the γ-ray (multiplied by 16 to account for the efficiency) is in much better aggreement with the calculation. One possible interpretation of this result is that a neutron from the ^{10}Be core rather than the halo is removed in the reaction. In that case the neutron is removed from the $0p_{3/2}$ shell, which means that the shape of the momentum distribution should that of a p-wave. On the other hand, the excited ^{10}Be core could result from a parentage to its 2^+ in the wave function of ^{11}Be. In this case however, because the ground state of ^{11}Be is $1/2^+$, the parentage would be $^{10}\mathrm{Be}^{2+} \otimes 0d_{5/2}$ and one would expect to observe a d-wave for the gated momentum distribution. Fig. 2 shows the data compared to the two calculations, which indicates that these events come from reactions where a neutron is removed from the ^{10}Be core rather than the halo.

A similar situation occurs in ^{15}C, where the observed γ-ray at 6.09 MeV corresponds to the $1^- \rightarrow 0^+$ transition in ^{14}C. In the case of a neutron removal from the ^{14}C core, this neutron would have been in the $0p_{1/2}$ shell, whereas a contribution from a parentage to the 1^- state in ^{14}C in the wave function of ^{15}C would lead to $^{14}\mathrm{C}^{1-} \otimes 1s_{1/2}$ and/or $^{14}\mathrm{C}^{1-} \otimes 0d_{5/2}$ configurations. Fig. 3 shows the data with the l=0 Hankel wave function calculation, as well as the p-wave corresponding to the removal of a neutron from the ^{14}C core. The results obtained on these two nuclei (^{11}Be and ^{15}C) indicate that knockout reactions where a neutron is removed from the core are not uncommon, and have to be taken into account for a precise analysis of the momentum distributions.

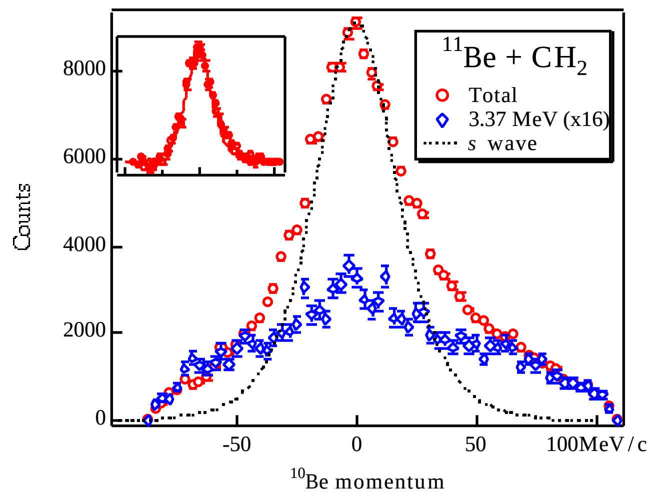

FIGURE 1. Momentum distributions of ^{10}Be after the breakup of ^{11}Be on a CH_2 target. See text for details.

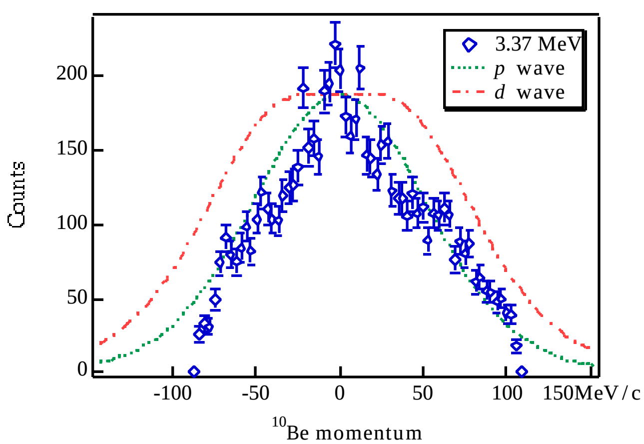

FIGURE 2. Momentum distribution of ^{10}Be gated on the 3.37 MeV γ-ray. The calculations correspond to two possible interpretations (see text).

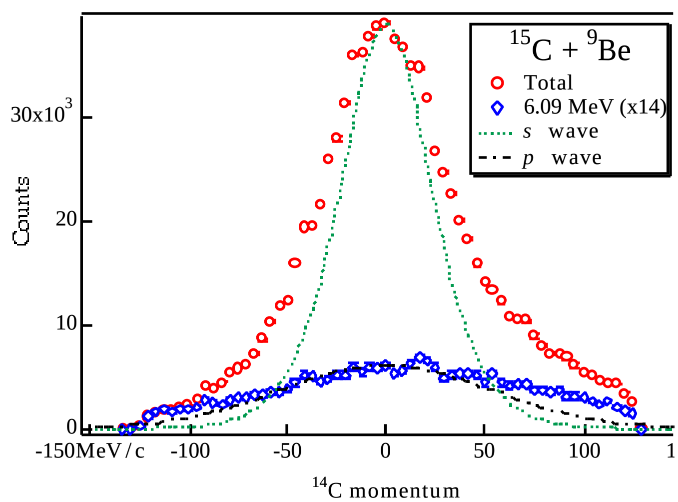

FIGURE 3. Momentum distributions of ^{14}C fragments after the breakup of ^{15}C on a Be target. Total (circle) and gated on the 6.09 MeV γ-ray (losanges). The dotted line corresponds to a pure s-wave calculation, and the dashed-dotted line to a p-wave if a neutron is removed from the core rather than the halo.

A more complex case: ^{17}C

Shell model calculations suggest that the ground state of ^{17}C is more complex than that of ^{11}Be or ^{15}C, as the $0d_{5/2}$ and $1s_{1/2}$ orbits are close to each other, and that both s and d single-particle components could be present in the wave function. Parentages of 1.58 and 0.16 for the $0d_{5/2}$ and $1s_{1/2}$ orbits are obtained with the WBP interaction (5), assuming a coupling to the 2^+ state of ^{16}C and a $3/2^+$ ground state for ^{17}C. The momentum distribution calculated for this configuration is shown in fig. 4 together with the data (circles), as well as an l=2 Hankel wave function calculation. The shell model calculation agrees remarkably well with the data and futhermore, the momentum distribution gated on the $2^+ \rightarrow 0^+$ transition in ^{16}C (losanges) has basically the same shape as the total distribution (see figure). This observation is radically different from the behavior observed in ^{11}Be and ^{15}C. It points towards the shell model description of this nucleus, where the valence (halo) neutron is coupled to an excited ^{16}C core. Moreover, the intensity of the 1.77 MeV peak accounts for about 80% (preliminary number) of the total cross section, whereas the branching observed for ^{11}Be and ^{15}C is only about 5-10%.

The few results presented here were obtained on the large acceptance and high resolution spectrograph S800. The qualities of this instrument, used in combination with a γ-ray detection array, allow a very detailed study of the wave functions of halo nuclei, as well as the discrimination of the various processes taking place in knockout reactions.

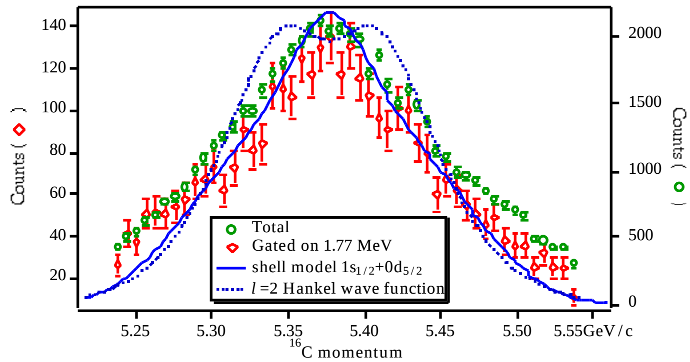

FIGURE 4. Momentum distributions of ^{16}C after the breakup of ^{17}C on a Be target. See text for details.

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References

1. D. Bazin *et al.,* Phys. Rev. C **57**, 2156 (1998).
2. J.H. Kelley *et al.,* Phys. Rev. Lett. **74**, 30 (1995).
3. J.D. Goss *et al.,* Phys. Rev. C **8**, 514 (1973).
4. P.G. Hansen, Phys. Rev. Lett. **77**, 1016 (1996).
5. E.K. Warburton and B.A. Brown, Phys. Rev. C **46**, 923 (1992).