STUDY OF UNBOUND NUCLEI THROUGH USING FINAL-STATE INTERACTIONS

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Introduction

In two experiments [1,2] performed at the NSCL, the interactions in the unbound system ^{9}Li+n produced in breakup reactions of ^{18}O have been explored via the final-state interactions. As a check these experiments also included the final system ^{6}He+n; and it was demonstrated that the experiments correctly reproduced the *p*-wave resonance at 0.44 MeV in ^{7}He,observed only once before in the experiment of Stokes and Young[3]. It was concluded that the n-9Li system has a very strong interaction in the l=0 channel, so that the ground state of ^{10}Li has negative parity, probably corresponding to a 2^- assignment. The present work has two objectives. The first is to investigate the influence of the initial state and to demonstrate the selectivity of the method. This was done by using ^{10,11,12}Be as projectiles. The results show that, as expected, the observed momentum distributions depend on how the product was formed. (This shows that it is necessary to go beyond a picture in which, say, ^{10}Li is formed as a separate identity, which much later decays in flight. This picture would obviously be correct for a very narrow resonance.) The second objective is to look for a low-lying *s*-state in the ^{9}He. Some calculations predict an intruder *s*-state for the light N=7 isotone. The intruder *s*-state has been observed in ^{11}Be and ^{10}Li, and if these predictions hold true the intruder state should also be found in ^{9}He.

Experimental Setup

This experiment was performed at NSCL using incident 30 MeV/u ^{12,11,10}Be on 200 mg/cm^2 ^{9}Be target. The neutrons were detected using the NSCL Neutron Walls, which is an array of large, position-sensitive neutron detectors. The fragments produced in reactions in a ^{9}Be target were deflected away from the Neutron Walls with a 1.5 Tesla sweeping magnet. Particle identification on the fragment were done using the energy-loss and the total energy of each fragment. The energy-loss is measured by silicon-strip detectors, and the total energy is measured by using an array of sixteen plastic scintillator detectors downstream from the target. The neutron energy is measured through a time-of-flight measurement. The analysis of the ^{6}He+n and ^{9}Li+n data shows good agreement with literature, while the unbound ^{8}He+n data suggests that there may be a low-lying *s*-state, with a an upper limit on the scattering length of –5 fm or smaller (i.e. numerically larger).

Data Analysis

Events in which a neutron was detected in coincidence with ^{6,8}He and ^{9}Li were selected. We gated on the coincidence events where neutrons were detected within five degrees of the detected fragment, and we analyze the velocity between the charged fragment and the neutron. Experimental data is compared with computer simulation, which takes into account of the detector resolutions and acceptances as well an energy distribution calculated based on some simple assumptions. The energy distributions are calculated by expanding the wave function of the neutron of the initial bound state with the eigenfunctions of the final states.

^{7}He Case

^{7}He has a $3/2^{-}$ bound state; a *p*-resonance of 440±30 keV with width Γ=160 keV [3]. Thus, it is a good test for our experimental technique. Figure 1 shows the velocity difference spectra scaled to incoming beam. There are two interesting features about this spectra. First, the velocity difference spectra with incident ^{11}Be the ^{12}Be have the same intensity except near the zero velocity difference region. This is because the valence neutron of the ^{11}Be has a significant *s*-state component, and these slow neutron corresponds to zero velocity difference. The second important feature is the low intensity with incident ^{10}Be. This illustrates that the ^{6}He in this case is formed mainly by alpha-particle knockout, which is not accompanied by fast neutrons. Figure 2 is a ^{6}He+n velocity difference spectra scaled to the number of detected ^{6}He fragments with no correction for neutron efficiency. The best fit here uses .a E_r=430 keV, in good agreement with the literature. The background is generated using an event-mixing technique, and accounts for approximately 40% of the total intensity in both of the ^{11,12}Be cases. Also shown are the relative intensities of the observed final-state interactions of the *p*-states. The inclusion of a *s*-wave scattering at 0 fm for ^{11}Be initial state was required to describe the region near zero-velocity difference. In the case of ^{12}Be, we have a reduced-χ^2 of 1.62, and for the ^{11}Be case, the a reduced-χ^2 is 3.23

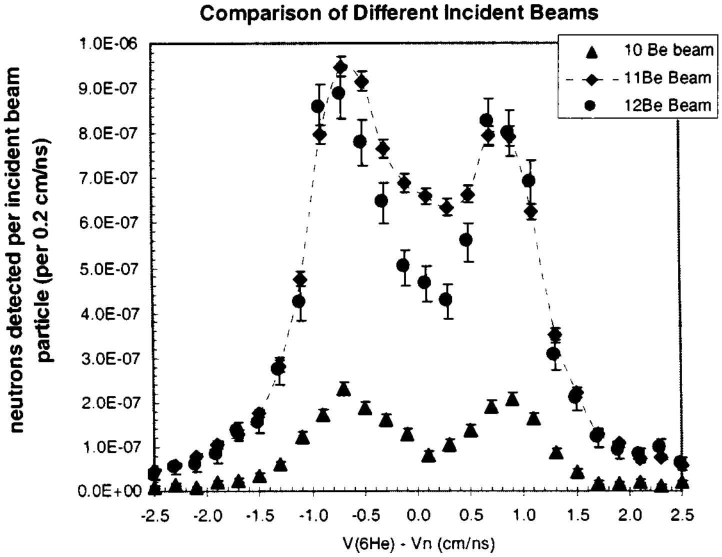

Figure 1

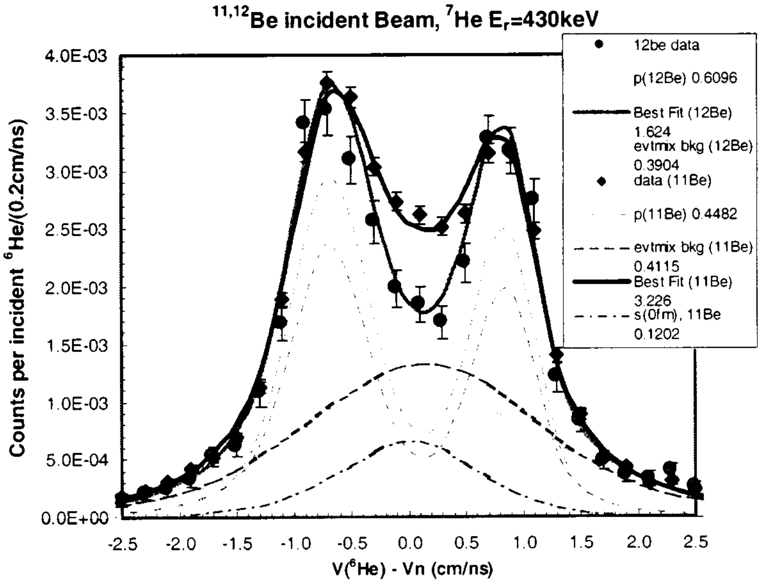

Figure 2

^{10}Li Case

An identical analysis can be performed on the ^{9}Li+n measurements. In figure 3, the velocity difference scale scaled to incident beam is shown. The velocity difference spectra is clearly narrower with the ^{11}Be beam, and can be attributed to the *s*-state of the valence neutron. The system ^{9}Li+n cannot be formed from an initial ^{10}Be nucleus. The low intensity demonstrates that we have low background and clean event selection. The data from the ^{11}Be beam is clearly narrower than those from the ^{12}Be beam, and can be explained from the fact that there is more *s*-state in the initial state. Figure 4 shows the data and the different states used in the fit. In both cases, the event-mixed backgrounds accounts for approximately 50% of the total intensity. The best fit for the ^{12}Be breakup uses a *s*-state scattering length of –20 fm or numerical larger value, and there is essentially no sensitivity beyond this value. The ^{12}Be fit shown has a reduced-χ^2=0.898; includes a *p*-resonance of 537 keV, and a d-resonance at 5 MeV. For numerically larger scattering lengths for the *s*-state, there is essentially no sensitivity beyond –20 fm. For both the ^{11,12}Be spectra, the *s*-state with scattering length of–20 fm is shown. The *p*-resonance ~540 keV has been observed by Young et al. (1994) [4]. The scattering length of less than-20 fm is consistent with Thoennessen (1999) [2]. It is known that the ^{12}Be nucleus has d-state neutrons, and our best fit of data has a small component of *d*-state scattering as well.

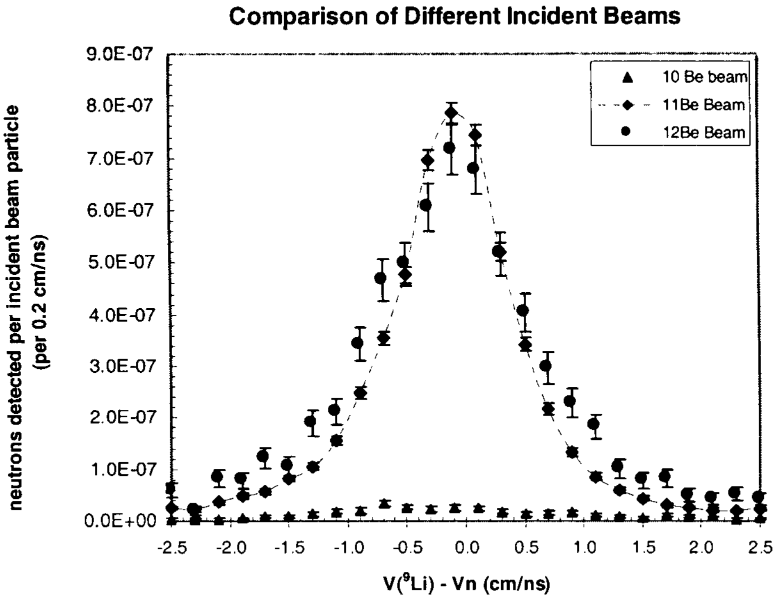

Figure 3

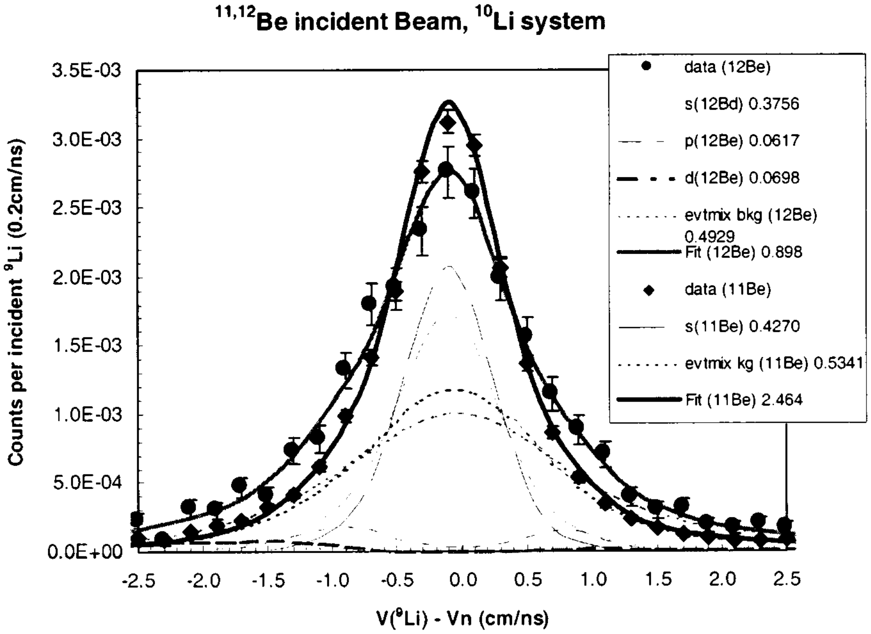

Figure 4

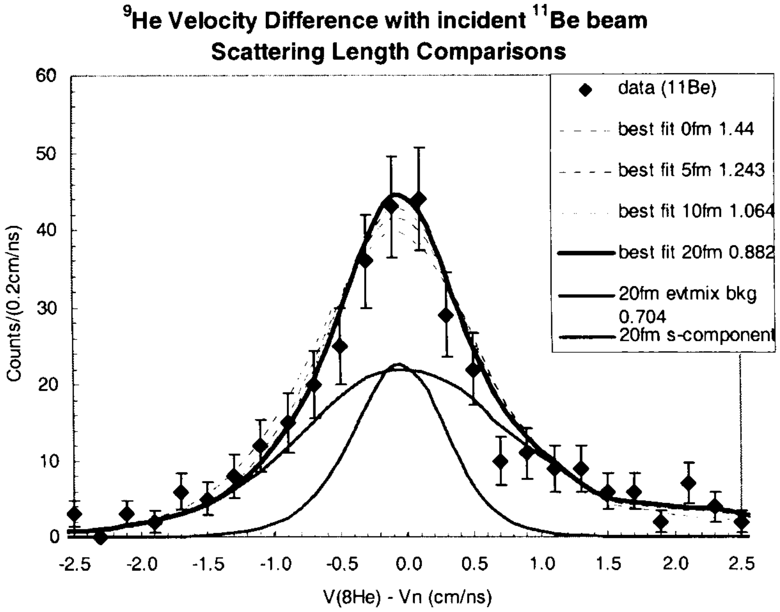

Figure 5

^{9}He Case

Figure 5 shows the best fits using different scattering lengths on the ^{9}He data and the event-mixed background.. Scattering lengths numerically larger than –5 fm give a good fit to our data. Event-mixed background accounts for 70% of the total intensity. In the legend of the spectra shown is the reduced-χ^2 of each of those fits. It is apparent that the ^{8}He+n velocity difference distribution data is narrower than the non-interacting case of 0 fm , where the reduced-χ^2=1.44. As such, we believe we are seeing evidence of some low-lying *s*-state in the ^{9}He. The data suggests that the scattering length for this *s*-state is smaller than –5fm.

Concluding Remarks

Essential in this data analysis is the manner which we calculate the final-state-interactions for different initial and final states. The current analysis uses a no-recoil approximation, which assumes that after the breakup of the initial nucleus, the more massive core sees no recoil, which simplifies the calculations of the final-state interaction. This approximation seems to be valid for the systems studied here, but it may be useful to see effect the recoil will have on the energy distributions. In addition, we have used event-mixing for our background in this analysis. We are still looking for alternatives physical theories which could explain the shape of these backgrounds

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