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TITLE **THE ^{11}LI NEUTRON HALO RADIUS FROM PION DOUBLE CHARGE EXCHANGE**

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The ^{11}Li Neutron Halo Radius from Pion Double Charge Exchange

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Abstract

We have analyzed the pion double charge exchange data for the direct population of the ground state of ^{11}Li by the $^{11}B(\pi^-, \pi^+)^{11}Li$ reaction and find that the measured cross section determines the rms radius of the last two neutrons in ^{11}Li to be $5.1^{+0.6}_{-0.8}$ fm.

The existence of a neutron halo in the exotic neutron-rich nucleus ^{11}Li has been inferred from the large total reaction cross-section on various light targets[1] and from the narrow momentum distribution of the outgoing ^{9}Li[2] and neutron[3] fragments in (^{11}Li,^{9}Li) dissociation experiments. However,there is a large uncertainty as to the magnitude of the halo, and results for ^{11}Li range from an total neutron rms radius[1] of 3.21 ± 0.17 fm to a neutron halo with a radius[3]of 12 fm. We calculate the DCX cross-section for the $^{11}B(\pi^-, \pi^+)$ reaction and show that the recent LAMPF data[4] can be used to determine the radius of the neutron halo in ^{11}Li.

At a pion energy of T_π=164 MeV, the DCX reaction is dominated by two sequential single charge exchanges. We have performed calculations of the DCX reaction using finite range distorted waves and a closure approximation for the intermediate states. The calculational technique has already been described elsewhere[5]. The nuclear structure input was expressed in term of shell model two-body density matrix elements derived from a p-shell calculation[6].

In calculating the DCX reaction the rms radius of the last two neutrons in ^{11}Li (R_{2n}) was varied in order to determine the value giving the best representation of the data[4] by adjusting the size of the Woods-Saxon well used to obtain the single particle wave functions. The rms radius of the two protons on which the reaction proceeds was held fixed at 2.65 fm, a value suggested by the difference in charge radius between ^{11}B and ^{9}Li.

As the volume in which the exchanged neutrons are to be found increases the cross section deceases since the reaction only has significant strength when the overlap of the wave function of the final neutrons with the initial protons is large. In the limit as the radius of the two final neutrons becomes very large, it is the initial wave function alone which controls the volume over which the reaction takes place. When this limiting situation is reached the shape of the transition density no longer changes and the cross section scales as the inverse volume squared or as $1/R^6_{2n}$. The results of the calculation are shown in Figure 1 for a range of rms radii covering those that have been suggested in the literature. We note that a radius[3] of 12 fm would imply a cross section 3 orders of magnitude smaller than that observed. We estimated the the uncertainty in the calculated cross sections from systematic stuties of nuclear structure and DCX for nuclei in this mass region and found a one standard deviation error of 40%. This gives a radius for the last two neutrons in ^{11}Li of $5.1^{+0.6}_{-0.8}$ fm. (See Fig. 1).

We now turn to a comparison of the present extracted radius with other determinations. Bertsch *et al.*[7] find a matter radius of ^{11}Li to be 2.846 fm and that of ^{9}Li to be 2.224 fm leading to an R_{2n} of 4.72 fm, a value consistent with the present result. From the neutron radii of Tanihata *et al.*[1] determined from interaction cross section measurements, assuming that the ^{9}Li core neutron radius remains fixed at 2.39 fm, we find R_{2n} to be 4.91 fm. The dissociation experiments tend to show a larger radius but they are not inconsistent with our result if we use a cluster model for the last two neutrons. Consider a di-neutron bound to the ^{9}Li core and assume that the two neutrons are produced at zero relative momentum in the dissociation process. We implemented this model by solving for the bound state wave function of a particle with a two-nucleon mass in a Woods-Saxon potential holding the binding energy fixed at 190 keV, and varying the size of the well to allow the choice of different rms radii for the di-neutron.

If we compare the recoil distribution measured by Kobayashi *et al.*[2] with the transverse momentum obtained from the di-neutron wave function decribed above the result is in basic agreement for either of the 5.4 or 6.2 fm cases shown in Figure 2a. Note that if the ^{9}Li were recoiling against two independent neutrons the width of the peak would be narrower by $1/\sqrt{2}$. We also show a comparison with the results of Anne *et al.* [3] in fig. 2b for the angular distribution of the neutrons arising from dissociation. Because of the di-neutron assumption used above, each neutron carries half of the momentum of the ^{9}Li so that there should be a factor of 2 between the widths of the distributions in Ref. 2 and 3, while if the neutrons were uncorrelated there would be a factor of $\sqrt{2}$. The agreeement is marginally satisfactory, except for the first point. Hüfner and Nemes[8] point out that for a reliable extraction of a momentum distribution the energy/nucleon should exceed 500 MeV/u, a condition met in ref 2 but not in ref. 3.

In summary, an analysis of the DCX reaction on ^{11}B leading to the ground state of ^{11}Li indicates that the measured cross section determines the radius of the neutron halo in ^{11}Li: $R_{2n} = 5.1^{+0.6}_{-0.8}$ fm.

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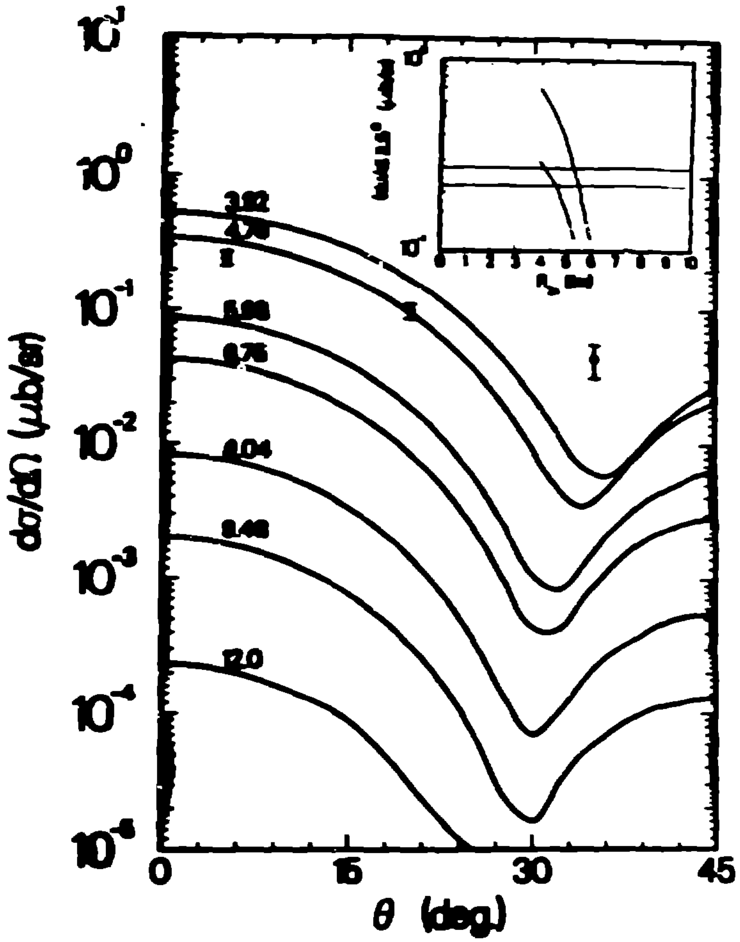

Figure 1. The angular distribution of the cross section for the DCX reaction for several values of R_{0n}. The depth of the minimum was observed to be somewhat sensitive to the details of the distortion. The insert shows the comparison of the 0° cross section (band defined by the dotted horizontal lines) with the theoretical calculations (band defined by the solid lines). It is from the values contained in this box that we obtain the quoted value of the radius and the errors.

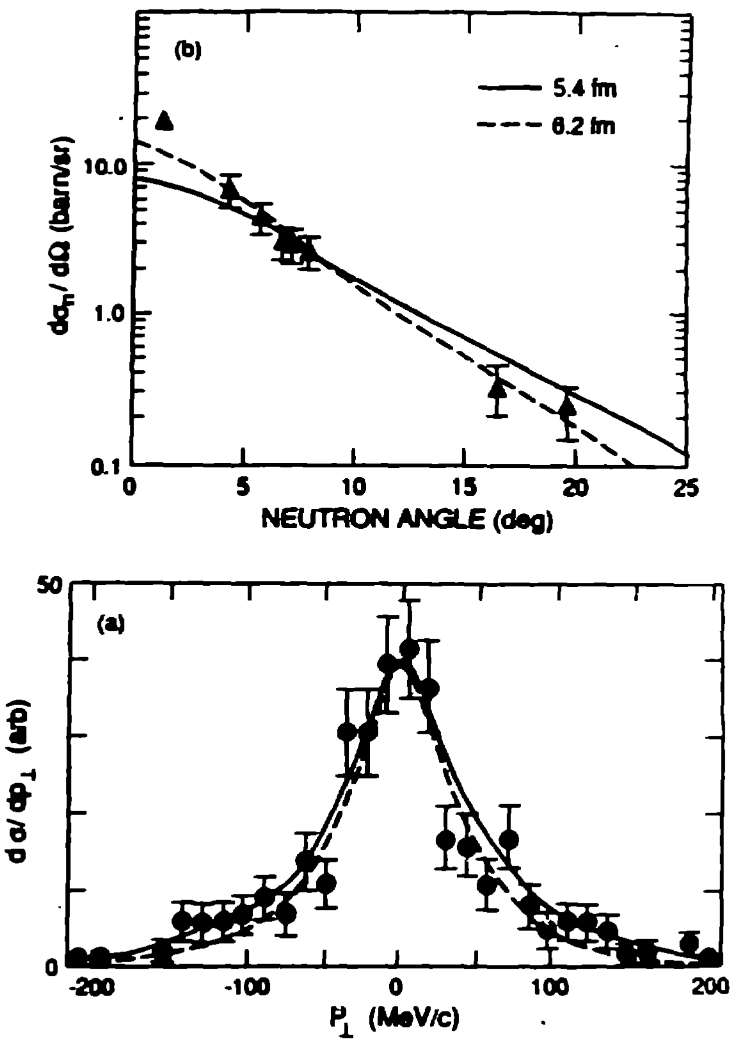

Figure 2. Comparison of the model described in the text with the data of Ref. 2(a) and Ref. 3(b).