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MOMENTUM OF ^{9}Li FROM ^{11}Li+C REACTION*

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The momentum distribution of ^{9}Li fragments produced in the reaction of ^{11}Li+C (790 MeV/A) is calculated. The distribution is shown to contain two Gaussian components, in agreement with experiment. The ratio of the numbers of ^{9}Li fragments in the two components shows that the ^{11}Li neutron density at large radii is not consistent with the dineutron model of this nucleus.

In an earlier publication [1], a Monte Carlo method was used to simulate the formation of ^{9}Li in the reaction ^{11}Li+C (790 MeV/A) for comparison with experimental measurements [2-4] of the ^{9}Li inclusive cross section and the total reaction cross section. The radial neutron density distribution was parametrized as the sum of two Fermi components, and at radii greater than 2.5 fm, an exponential component:

$$\rho_n(r) = \frac{6\rho_0}{(8-d)\left\{1+\exp\left[(r-c)/a\right]\right\}} + \frac{(2-d)\rho_0}{(8-d)\left\{1+\exp\left[(r-c)/a\right]\right\}}$$

$$+ N\exp(-2r/L)/r^{2} \qquad (1)$$

The first term represents the density distribution of the six

$s_{1/2}$ + $p_{3/2}$ neutrons. There are two loosely bound outer $p_{1/2}$ neutrons. The second term gives the Fermi distribution of (2-d) of them, while the third term gives the exponential distribution of d $p_{1/2}$ neutrons. There are two independent variables in eq.(1), d and the exponential decay length L. N was obtained from d and L by requiring that the exponential term contain just d neutrons. The diffusivity a of the two Fermi terms was obtained from d by requiring that the volume integral of eq.(1) contain eight neutrons.

^{9}Li can be formed in five different ways as a result of nucleon-nucleon collisions: a) by the removal of two loosely bound $p_{1/2}$ outer neutrons, b) by the removal of one $p_{1/2}$ and one $p_{3/2}$ neutron, c) by the removal of two tightly bound inner $p_{3/2}$ neutrons, d) by the removal of one $p_{1/2}$ neutron and decay of the unbound ^{10}Li thus formed, or e) by removal of one $p_{3/2}$ neutron and decay of ^{10}Li. It was assumed that ^{9}Li formed by process c) would be too excited to survive further decay.

Experiments show that the perpendicular momentum distribution of ^{9}Li fragments contains two Gaussian components with widths of 23±5 and 95±12 MeV/c. The ratio of the number of events in the broad distribution to that in the narrow one is 1.73±0.33 [3]. In ref.1, it was assumed that ^{9}Li in the broad distribution came from processes b)+e), in which a tightly bound inner $p_{3/2}$ neutron was removed. Those in the narrow distribution came from a)+d) where only loosely bound outer $p_{1/2}$ neutrons were removed. The ratio R of (no. broad)/(no. narrow) was therefore just R=(b+e)/(a+d). No attempt was made to calculate R or the actual distribution widths from the dynamics of the reaction.

In the present work, the momentum of ^{9}Li was assumed to come from recoil from the Fermi momentum of a neutron (or neutrons) that were struck by a projectile nucleon and (if only one neutron was lost) from subsequent decay of the neutron-unbound ^{10}Li thus produced. The Fermi momentum of a neutron at radius r was calculated from the Thomas-Fermi model. The maximum value P_f(max) at r was therefore proportional to the cube root of the total (p+n) density at r with a value of 260 MeV/c in the full-density center region. The actual momentum value was obtained from a spherical distribution with radius P_f(max). It was assumed to be isotropic.

The ground state of ^{10}Li is produced by process a), the removal of a loosely bound $p_{1/2}$ outer neutron. It is unbound to neutron decay by 0.806 MeV. Thus the ^{9}Li recoils with a total momentum of 36.9 MeV/c. If ^{10}Li came from process b), removal of a tightly bound $p_{3/2}$ neutron, it was assumed to be excited to 7.25 MeV which is about the usual nucleon separation energy. The ^{9}Li therefore recoiled with a total momentum of 117 MeV/c. Again, the momentum was assumed to be isotropic. There was an additional small component of momentum perpendicular to the projectile direction from Coulomb scattering of the ^{11}Li.

The upper part of Fig.1 shows a comparison of the calculated ^{9}Li perpendicular momentum distribution with experiment. The calculation was made with a decay length L of 4.4 fm and with the number of neutrons d in the exponential tail equal to 0.8. These values gave the best agreement with the ^{9}Li inclusive cross section, the total reaction cross section and the ratio R of (no. broad/no. narrow) [1]. A double Gaussian fit to the calculated distribution gave widths of 73 and 26 MeV/c. The broad component is somewhat narrower than the experimental value (95±12 MeV/c). The width of the narrow component is in good agreement with the experimental value (23±5 MeV/c), and so is the ratio R - 1.74 compared with an experimental value of 1.73± 0.33.

The lower part of Fig.1 shows the result of a calculation made with L=8.2 fm and d=2. These values correspond to the presence of a dineutron in the exponential tail of the density distribution [5]. Clearly the agreement with experiment is poor. The widths of the calculated Gaussian components were 75 and 24 MeV/c, but R was only 0.33, about one fifth of the experimental value. Moreover, as shown in ref.1, the ^{9}Li inclusive cross section and the total reaction cross section were too large when the dineutron parameters were used.

Fig. 2 (upper) shows the effect of varying the power of the density that was used in calculating the local neutron Fermi momentum, using L=4.4 fm and d=0.8. The value of R is rather sensitive to the power. The experimental value (1.73) is found for powers of 0.33 and again for 0.8. For the latter value, though, the width of the broad component is only 59 MeV/c.

Fig. 2 (lower) was obtaind with the dineutron parameters (L=8.2 fm, d=2). A value of R in agreement with experiment could be obtained by arbitrarily making the local Fermi momentum depend on the local density to the 0.11 power. However, the width of the narrow momentum component then became 38 MeV/c, almost twice the experimental value. The dineutron parameters could not be "forced" to fit all experimental results simultaneously. In any case, there is no justification in the Thomas-Fermi model for such a low power.

The source of the broad and narrow momentum components was investigated by confining the calculation to events in which a single neutron was removed either from the inner $p_{3/2}$ or the outer $p_{1/2}$ shells. In the former case, the broad component gave a width of 73 MeV/c, but there was no narrow component. In the second case, the widths of the components were 69 and 27 MeV/c respectively, but the value of R was 0.14, i.e. there was almost no broad component.

The average radius in ^{11}Li from which a single inner neutron was scattered was 4.36 fm: for an outer neutron it was 6.21 fm. When two inner neutrons were removed, their average radius was 3.10 fm. For two outer neutrons, the average was 5.65 fm. Thus, as expected, removal of two neutrons requires interactions at smaller radii where the ^{11}Li density is large enough that there is an appreciable probability of finding two neutrons in the paths of the projectile nucleons. In fact, 93% of the ^{9}Li came from single neutron removal and subsequent decay of ^{10}Li.

The same methods have been used [6] to calculate fragment inclusive momenta and the momenta of a given fragment in different coincidence channels from the fragmentation of ^{12}C and ^{16}O at 2 GeV/A. Again it was found that good agreement with experiment was obtained by assuming the local Fermi momentum to be proportional to the cube root of the local density.

The value of the decay length L can be derived from the binding energy of the outer neutron. For a dineutron, the small binding energy (0.15 MeV) gives L=8.2 fm [5]. A value of L=4.4 fm is obtained from the binding energy of a single neutron in ^{11}Li (0.96 MeV). Since L=8.2 fm could not be forced to give results in agreement with experiment, it seems that the dineutron model does not well describe the neutron density in ^{11}Li at large radii.

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FIGURE CAPTIONS.

Fig. 1 Comparison of the calculated and experimental perpendicular momentum distribution of ^{9}Li. The solid line is the calculation. Points with error bars are experimental values.

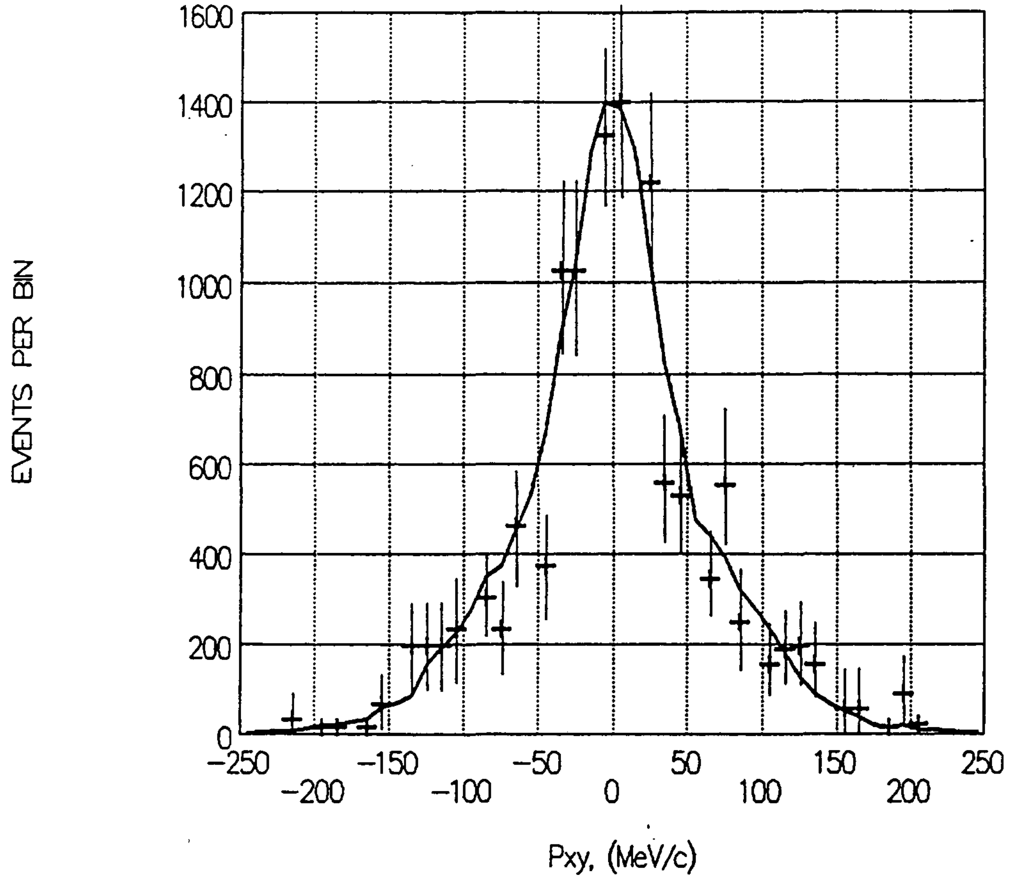
Upper graph: Calculated with "best fit" values of L=4.4 fm, d=0.8 (see text).

Lower graph: Calculated with dineutron parameters of L=8.2 fm, d=2.

Fig. 2 Dependence of the ratio R of the areas of the broad and narrow momentum components on the power of the local density used to calculate the local Fermi momentum.

Upper graph: Calculated with L=4.4 fm, d=0.8

Lower graph: Calculated with dineutron parameters of L=8.2 fm, d=2.



1600
1400
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EVENTS PER BIN
−250
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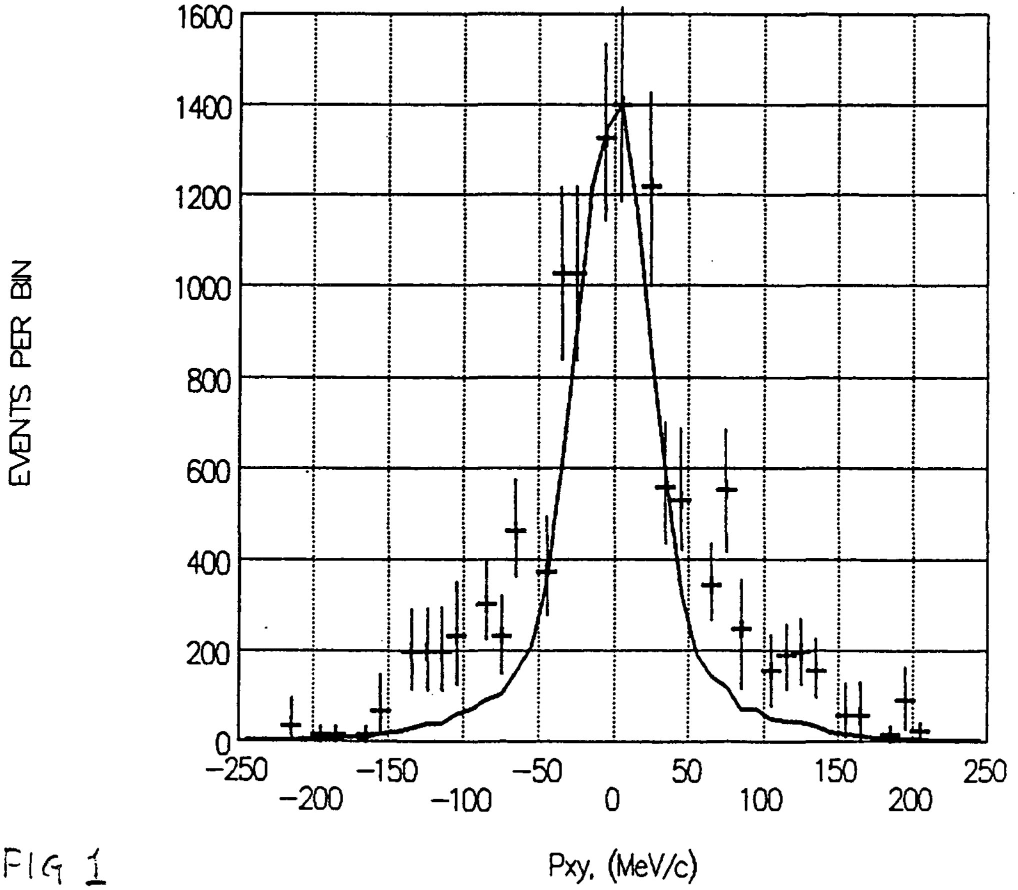
Pxy, (MeV/c)



1600
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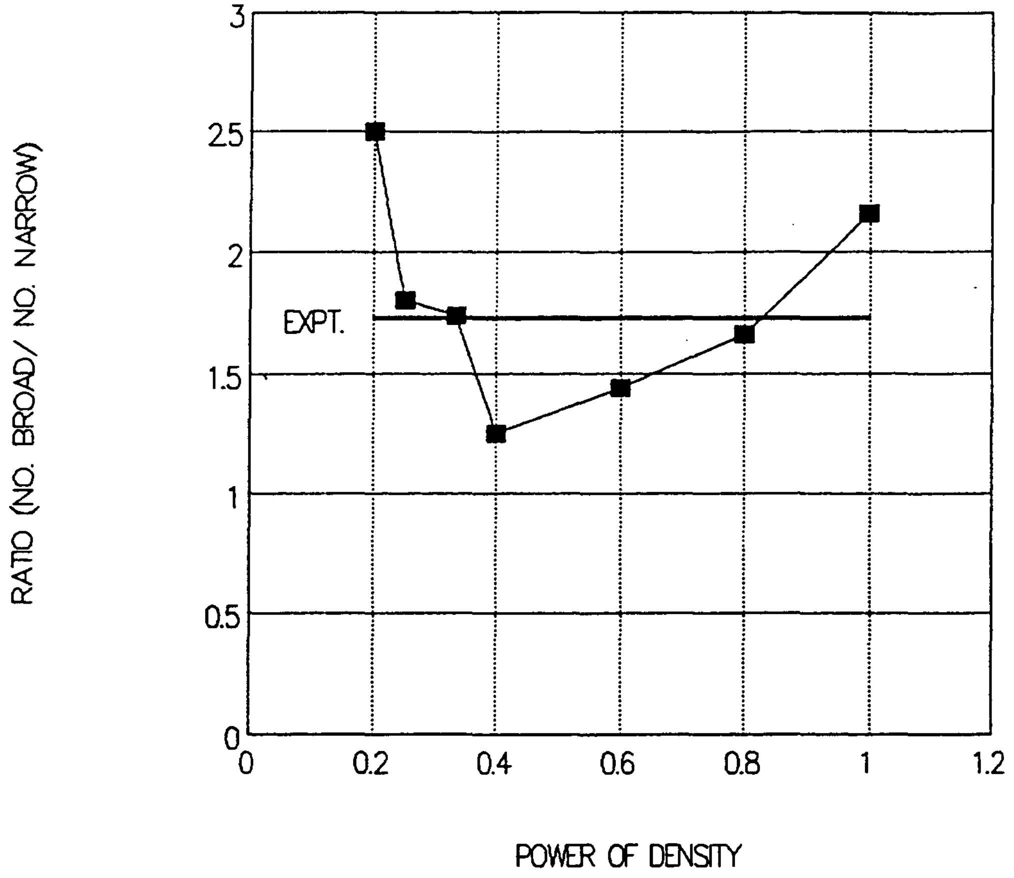
FIG 1


3
2.5
2
1.5
1
0.5
0
0
0.2
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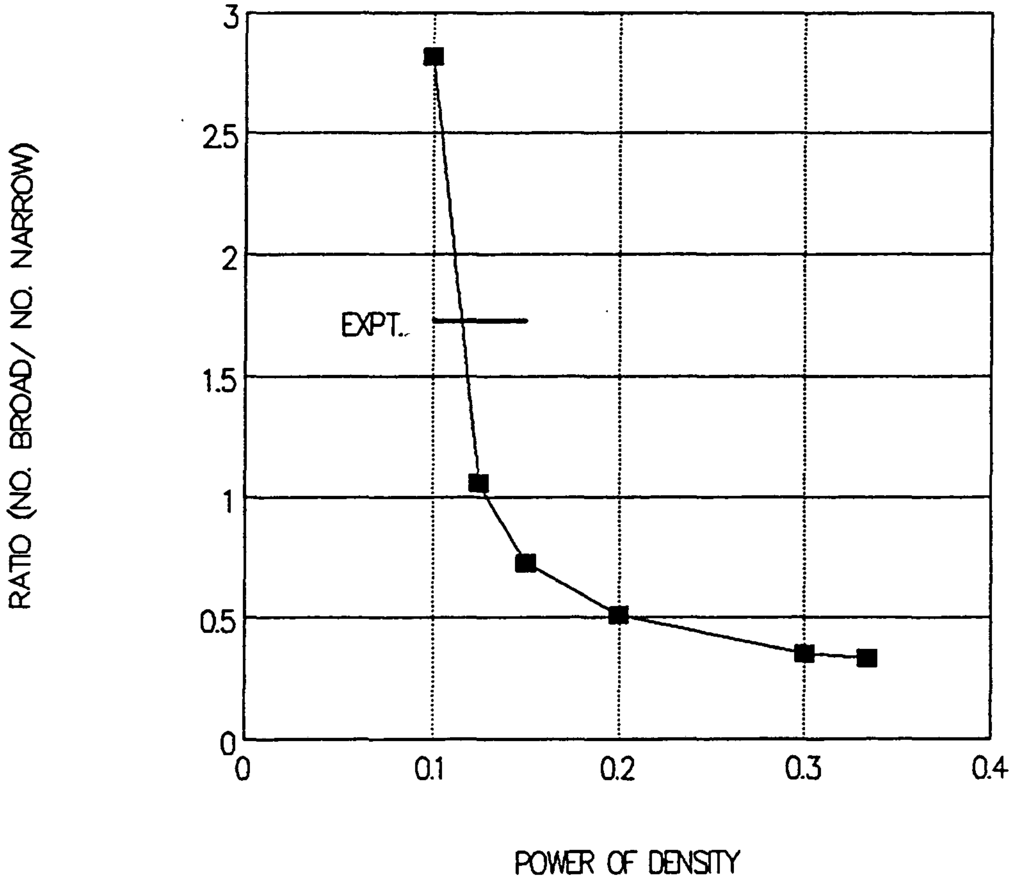
0.6
0.8
1
1.2
EXPT.
RATIO (NO. BROAD/ NO. NARROW)
POWER OF DENSITY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2
1.5
1
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0.3
0.4
EXPT.
RATIO (NO. BROAD/ NO. NARROW)
POWER OF DENSITY

FIG 2

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