MSUCL-211
May 1976

Observation of Highly Neutron-rich ^{43}Cl and ^{59}Mn*

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ABSTRACT

We report the observation and mass measurement of ^{43}Cl and ^{59}Mn by the (^{3}He,^{8}B), 5-nucleon pickup reaction. Mass excess values of -23.14 ± 0.06 for ^{43}Cl and -55.49 ± 0.03 MeV for ^{59}Mn have been measured.

*Work supported by the U.S. National Science Foundation.

INTRODUCTION

In this paper, we report the use of the (^{3}He,^{8}B) reaction to reach the highly neutron-rich nuclei ^{43}Cl and ^{59}Mn and to measure their masses. ^{43}Cl has six neutrons more than the stable ^{37}Cl and is predicted bound against neutron decay.[1] Its high value of isospin, $T_z=9/2$, makes its mass important as a test of the numerous nuclear models and mass relations in the region far from β-stability. A recent paper of Jelly et al.[2] discusses one of these relations and also summarizes the current status of experimental data on very neutron-rich light nuclei.

Only a few light nuclei as far from β-stability have experimentally measured masses, e.g., ^{22}O with $T_z=4$[3] and $^{30,31,32}Na$ with $T_z=4$, 9/2, and 5[4]. For the $T_z=9/2$ nucleus, ^{31}Na, an experimental accuracy of about 800 keV was achieved.[4] Interestingly ^{31}Na and ^{32}Na differ from recent predictions[1,2] by 2 to 5 MeV, a discrepancy which has been interpreted in terms of a shape transition of the ground state.[5] These deviations are significant since these relations tend to yield agreement at the 200-300 keV level for nuclei closer to β-stability. The present results for ^{43}Cl represent a significantly higher precision in mass values of highly neutron-rich nuclei in addition to adding to the scarce data available. ^{59}Mn also has $T_z=9/2$ but lies much nearer the line of β-stability. Its decay properties have recently been reported concurrently with our mass measurements.[6]

Multi-nucleon pickup reactions leading to nuclei far from stability have extremely small cross sections, ranging from 1μb/sr for the (^3He,^6He), three neutron pickup reaction to a few nanobarns/sr for (p,^6He) or (^3He,^8Li), five-nucleon pickup reaction. For the (^3He,^8B) reaction, the targets have to be even thinner than those in the aforementioned five-nucleon pickup to compensate for the larger specific ionization of the ^8B ions, whereas the cross sections are comparable. The intense 74 MeV ^3He beam available from the Michigan State University cyclotron (2-3 μa on target) makes these studies feasible using a few days of beam time.

EXPERIMENTAL PROCEDURE AND RESULTS

The experimental apparatus is essentially that which has been previously described.[7] The ^8B ions were detected, identified and momentum analyzed in the focal plane of an Enge split-pole spectrograph by combining in a Sigma-7 computer the information on energy loss and position in two resistive wire proportional detectors, and time-of-flight information from a thin plastic scintillator.

^{59}Mn: The ^{64}Ni targets used for the $^{64}Ni(^3He,^8B)^{59}Mn$ experiments consisted of a self supporting foil of 0.25 mg/cm^2 thickness and of an evaporated layer of 70 μg/cm^2 on 35 μg/cm^2 carbon backing. The thickness of the 0.25 mg/cm^2 self-supporting foil was measured by means of the energy loss of 5.48 MeV alpha particles from ^{241}Am while that of the 70 μg/cm^2 carbon backed target was measured by means of the energy loss of 48 MeV ^8B ions from the $^{12}C(^3He,^8B)$ reaction. The $^{27}Al(^3He,^8B)^{22}Ne$ reaction provided

an ideal calibration for the mass measurement since the 2^+ level of ^{22}Ne at 1.27 MeV was populated with ^8B ions having essentially the same magnetic rigidity as those leading to the ground state of ^{59}Mn. Figure 1 shows spectra of ^8B ions from the ^{64}Ni and ^{27}Al targets, taken at the same spectrograph magnetic field. A peak with a width of about 200 keV is observed for the ^{59}Mn.

The structure of ^{59}Mn at low excitation is expected to be controlled by the five protons in the $(f_{7/2})^5$ coupling, i.e., a low lying $J^\pi=5/2^-$, seniority=3 state, probably the ground state, and a low lying ($E_x \gtrsim 100$ keV) level with spin $7/2^-$ and seniority 1. The (^3He,^8B) reaction is expected to populate both of these with comparable yields. Using the (^3He,^6He) reaction for empirical guidance,[8] the $7/2^-$ level would be expected to be more strongly excited than the $5/2^-$ level. The present results correspond to the centroid of the yield to these unresolved levels, and are summarized in Table 1.

^{43}Cl: Figure 2 shows the spectrum of ^8B ions observed from a target of 130 μg/cm^2 ^{48}Ca evaporated on a 30 μg/cm^2 Carbon foil, itself supported by a 5 μg/cm^2 Formvar layer. The considerable amount of oxygen in the Ca target is evident from the oxygen content of ∿40 μg/cm^2 (calculated from the ^8B yields observed). ^8B ions from the $^{12}C(^3He,^8B)^7Li$ reaction were used to measure the ^{48}Ca target thickness.

The Q-value for the $^{48}Ca(^3He,^8B)^{43}Cl$ reaction is more negative than those for ^{12}C, ^{13}C and ^{16}O. The latter have considerably larger cross sections than ^{48}Ca and are expected to obscure some region of the spectrum of interest. Data were taken from 6° to 12° in the lab, and an unobscured region corresponding to a mass excess for ^{43}Cl from -24.2 to -22.7 MeV was explored. The ^{13}C and ^{16}O contribution in that region could be accounted for and represented only a minor problem. However, in the case of ^{12}C, the existence of broad levels of ^{7}Li at 6.7 MeV excitation and higher did contribute a significant background in the region of interest and is indicated in Figure 2 by the dashed line. Figure 2 shows the sum of three spectra, measured at 8°, 9° and 10° in the laboratory then summed with proper kinematic shift for ^{48}Ca. A clear peak is seen and identified as ^{43}Cl. The possibility that this peak is not the ground state can not be definitively ruled out. Because of the broad levels of ^{7}Li a peak with cross section less than 0.005 nb/sr would have been obscured. The energy calibration for this data was obtained from the ^{7}Li and ^{11}B levels excited in the $(^{3}He,^{8}B)$ reaction on ^{12}C and ^{16}O. The experimental results are summarized in Table 1. In view of the large background from the ^{12}C in the targets, the experiment was repeated with 120 $\mu g/cm^2$ ^{48}Ca evaporated into a 200 $\mu g/cm^2$ silver foil. The results of these measurements, which were taken at angles of 7°, 8° and 9° in the lab, confirmed the earlier results and provided confirmation that the peak observed had the proper kinematic shift for ^{48}Ca.

The comparison between predictions of three mass relations,

i.e., that of Garvey and Kelson[1,2], its modification by Jelly et al.[2], and the extension of that modification to heavier masses of Davids[9], and the predictions of Liran and Zeldes[10], are shown in Figs. 1 and 2 and listed in Table 1. For ^{59}Mn, the modified relation[9] shows excellent agreement with the data. In the ^{43}Cl case, the nucleus is found to be almost one half MeV less bound than predicted by the modified mass relation[2], and in rather close agreement with the predictions of Liran and Zeldes.[10]

The present method for exploring the neutron-rich nuclei is clearly limited by the availability of highly neutron-rich targets. It does however provide highly precise results which can serve as calibration data for other work, and it offers the opportunity to study the spectroscopy of some very neutron-rich nuclei. Repeating this experiment at a higher beam energy would move the region of interest in the $^{48}Ca(^{3}He,^{8}B)^{43}Cl$ away from the severe contaminant problem caused by $^{12}C(^{3}He,^{8}B)^{7}Li$ to unbound levels. However, the next experiments planned involves the exploration further from β-stability using the $(^{3}He,^{9}C)$ reaction on the same neutron-rich targets.

Table 1. Summary of Results.
The mass excesses are given in MeV.

Final nucleus reached by the (^3He,^8B) reaction.		
Q-value in MeV	-19.61±0.03	-29.07±0.06
$d\sigma/d\Omega$ at 9° in μb/sr	0.05±0.01	0.024±0.010
experimental mass excess	-55.49±0.03	-23.14±0.06
predicted mass excess		
Garvey-Kelson (69), Ref. 1	-55.75	-23.78
Garvey-Kelson (75), Ref. 9,2	-56.01	-23.64
Garvey-Kelson (76), Ref. 11	-55.79	-23.38
Modified G-K, Ref. 9,2	-56.35	-23.61
Liran-Zeldes, Ref. 10	-56.01	-23.00

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Figure Captions

Fig. 1--Energy spectra of ^{8}B ions from the $(^{3}He,^{8}B)$ reaction on ^{27}Al and ^{64}Ni. The theoretical predictions labeled 1 and 2 are taken from reference 9, that labeled 3 is from ref. 10.

Fig. 2--Energy spectrum of ^{8}B ions from the $^{48}Ca(^{3}He,^{8}B)$ reaction. The figure shows the sum of spectra measured at 8°, 9° and 10° each with an aperture of 2° in the scattering plane. The dashed curve represents the background ^{8}B ions from the carbon backing of the ^{48}Ca target. The peaks labeled ^{11}B come from the ^{16}O content in the target. Predictions labeled 1, 2 and 3 represent Garvey-Kelson prediction of 1969 (Ref. 1), 1975 (ref. 2) and 1976 (Ref. 11), respectively. Those labeled 4 and 5 are the modification of the Garvey-Kelson relation by Jelly *et al*. (Ref. 2) and the prediction of Liran and Zeldes (Ref. 10).

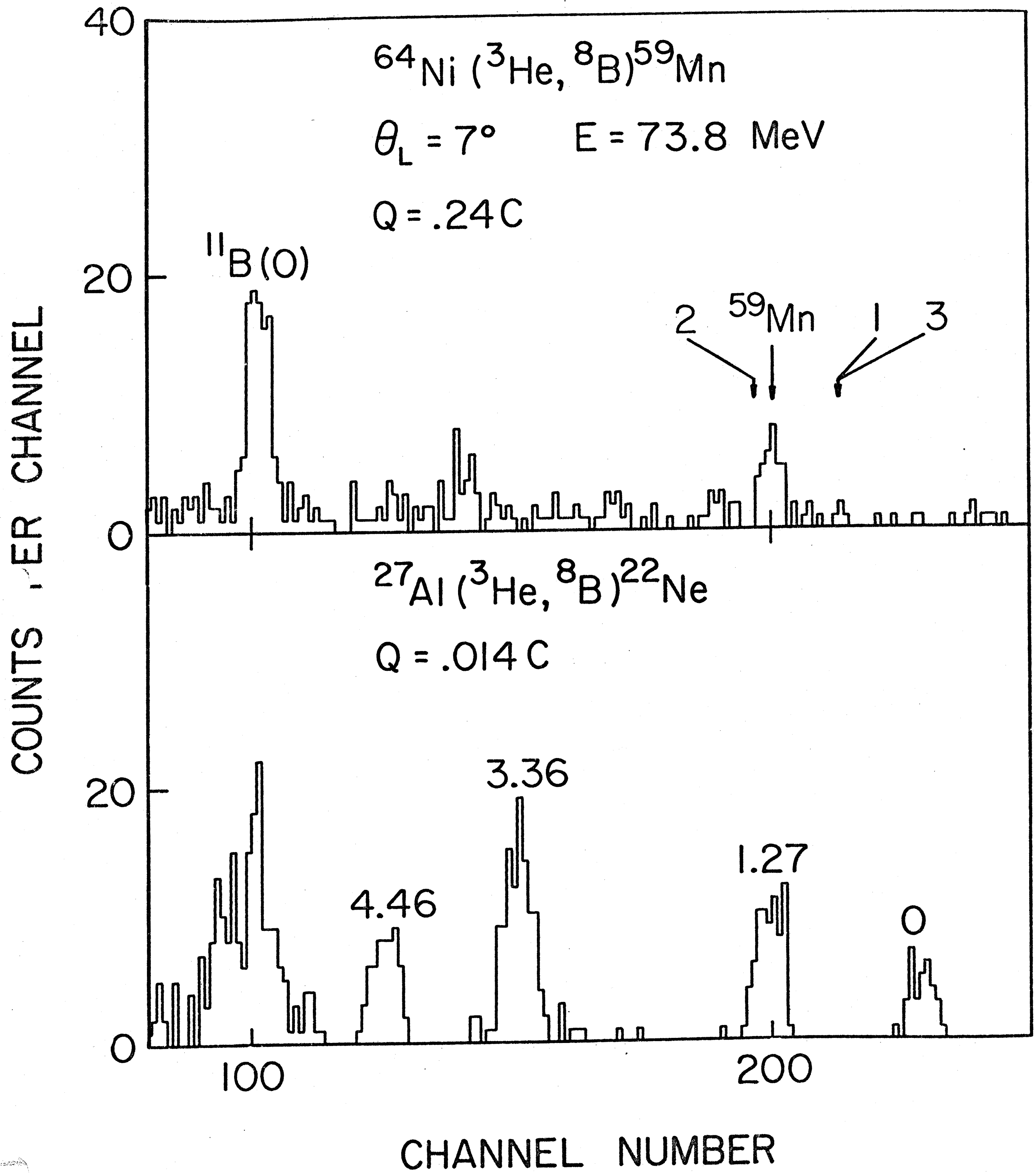
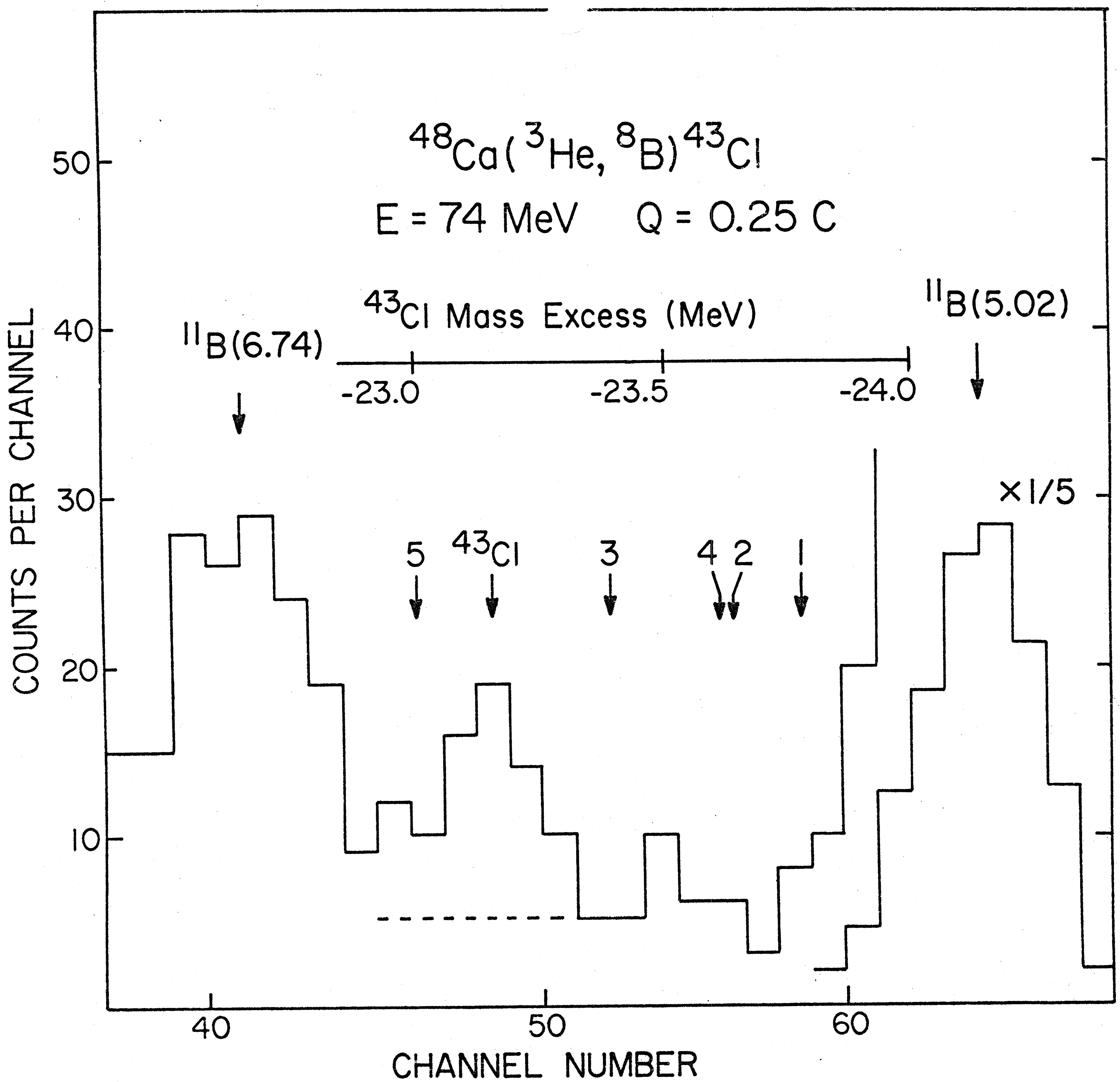

^{64}Ni (^{3}He, ^{8}B)^{59}Mn
θ_L = 7°   E = 73.8 MeV
Q = .24 C
^{11}B (0)
2
^{59}Mn
1
3
^{27}Al (^{3}He, ^{8}B)^{22}Ne
Q = .014 C
3.36
4.46
1.27
0
40
20
0
100
200
COUNTS PER CHANNEL
CHANNEL NUMBER

Figure 1



48Ca(3He, 8B)43Cl
E = 74 MeV Q = 0.25 C
43Cl Mass Excess (MeV)
-23.0
-23.5
-24.0
11B(6.74)
11B(5.02)
×1/5
5
43Cl
3
4 2
1
50
40
30
20
10
COUNTS PER CHANNEL
40
50
60
CHANNEL NUMBER

Figure 2