Title

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A J DEPENDENCE IN THE (^{3}He,α) REACTION CONFIRMING NEW SPECTROSCOPIC ASSIGNMENTS IN ^{14}N AND ^{13}C†

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Abstract

A J dependence has been observed in the (^{3}He,α) reaction which confirmed the $(p_{3/2},p_{1/2})^{-1}_{1+,T=1}$ state in ^{14}N at 13.72±0.04 MeV and the lowest T = 3/2 state in ^{13}C at 15.108±0.014 MeV.

In an investigation of the p shell hole states of ^{14}N and ^{13}C through the ^{15}N(^{3}He,α)^{14}N and ^{14}C(^{3}He,α)^{13}C reactions, we have found that the shapes of the angular distributions are sensitive to the J of the picked up neutron, an effect observed in other reactions[1]. States with the configurations $(p_{1/2})^{-2}$ and $(p_{3/2},p_{1/2})^{-1}$ were observed in ^{14}N and it was possible to identify all six of these states, including the $(p_{3/2},p_{1/2})^{-1}_{1+,T=1}$ state which had not been assigned previously. Of particular interest in the ^{13}C spectrum was the measurement of the lowest T = 3/2 state. An accurate measurement of the excitation of this state was necessary as one component of a rigorous test of the isobaric multiplet mass equation[2].

†Work performed under the auspices of the U. S. Atomic Energy Commission.

The $^{15}N(^{3}He,\alpha)^{14}N$ and $^{14}C(^{3}He,\alpha)^{13}C$ reactions were carried out at energies of 39.8 and 44.8 MeV, respectively, using the ^{3}He beam from the Berkeley 88" cyclotron. Particles were detected using a (dE/dx)-E counter telescope which fed a particle identifier[3]. The ^{15}N gas target was 98% pure. A ^{14}C target from Brookhaven, which contained a large amount of ^{12}C and also some ^{16}O, was made by depositing ^{14}C on a 2 mg gold backing. Typical energy spectra are shown in fig. 1 where the energy resolution (FWHM) in both reactions was around 200 keV.

If we assume that ^{15}N and ^{14}C contain a closed neutron shell and then consider a pure pickup mechanism, we would only expect to populate certain p shell hole states in ^{14}N and ^{13}C. Table 1 indicates the states which should be made by pick up of either a $p_{1/2}$ or a $p_{3/2}$ neutron. It is observed experimentally that these are the only states which are made with a large cross section.

Intermediate coupling shell model calculations[4-7] have shown that the six lowest p^{-2} states in ^{14}N are those listed in table 1. Of the seven large peaks observed in the $^{15}N(^{3}He,\alpha)^{14}N$ reaction, six correspond to the first five p^{-2} configurations (see table 1), which have already been well established[8-10]. The seventh peak at 13.72±0.04 MeV has been assigned the configuration $(p_{3/2},p_{1/2})^{-1}_{1+,T=1}$. Calculations[4-7] have predicted values for the energy of this state which range from 10 to 15 MeV.

Angular distributions for the $^{15}N(^{3}He,\alpha)^{14}N$ reaction are shown in fig. 2. The two distributions which correspond to the pick up of a $p_{1/2}$ neutron are similar in shape but differ from those corresponding to the pick up of a $p_{3/2}$ neutron[11]. The main difference occurs in the angular region from $\theta_{c.m.}$ = 15-45 deg. As compared to the $p_{3/2}$ pick up shape, the cross section for $p_{1/2}$ pick up drops off much more quickly after the first maximum and the second maximum is almost non-existent. Another difference occurs in the region $\theta_{c.m.} = 55$-75 deg., where the $p_{1/2}$ pick up states are at a maximum while the $p_{3/2}$ pick up states all[11] reach a minimum. Artemov et al.[12] have recently studied the ($^3He,\alpha$) reaction on ^{14}N and ^{16}O at energies from 17.4 to 36.6 MeV. Their data at 36.6 MeV seems to show some of the trends which are reported here.

In ^{14}N the 9.17 and 10.43 MeV levels are populated almost equally, in good agreement with the calculations by Rose et al.[10] who found that the contributions from the p^{-2} and (s,d) configurations to the 9.17 and 10.43 MeV levels must be approximately equal. On the basis of a simple j-j coupling model, one would expect that the cross sections of the $(p_{3/2},p_{1/2})^{-1}_{2+,T=0}$ and the $(p_{3/2},p_{1/2})^{-1}_{1+,T=0}$ states should be equal to the cross sections of the corresponding T = 1 states. This is roughly observed experimentally; therefore, both the magnitude and the shape of the angular distribution of the 13.72 MeV level help to confirm its assignment.

In ^{13}C three levels were populated as expected (see table 1). A sharp state at 15.108±0.014 MeV was attributed to the T = 3/2 ground state analog. An accurate determination of the energy of this level, in good agreement with previously reported results[2,13,14], was possible because of the large amount of ^{12}C impurity in the ^{14}C target.

The angular distributions for the $^{14}C(^3He,\alpha)^{13}C$ reaction are shown in fig. 3. A similar J dependence is observed in this reaction in the region $\theta_{c.m.} = 15$-45 deg., where the 1/2- ground state has a very deep minimum which is not observed in the 3/2- states. The distribution of the 15.108 MeV T = 3/2 state is similar to that of the 3.68 MeV level in agreement with its assignment.

For additional comparison the $^{12}C(^{3}He,\alpha)^{11}C$ ground state transition is shown in fig. 3. Its angular distribution shows the expected J dependence corresponding to $p_{3/2}$ pick up[15].

We have seen that the J dependence observed in the 1p shell is consistent for all nuclei studied so far and has been useful as a spectroscopic tool. DWBA calculations which include spin-orbit terms have met with some success in predicting J-dependent effects[16,17]; however, no attempt has yet been made to fit these data.

We would like to thank D. L. Hendrie for several valuable discussions.

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Table 1

Levels of ^{14}N and ^{13}C Strongly Populated in the ($^{3}He,\alpha$) Reaction

Reaction	Neutron picked up	Level	$J\pi$	T	Dominant Shell Model Configuration[a]
$^{15}N(^{3}He,\alpha)^{14}N$	$p_{1/2}$	G.S.	1+	0	(1,0); $(p_{1/2})^{-2}$
	$p_{1/2}$	2.31	0+	1	(0,1); $(p_{1/2})^{-2}$
	$p_{3/2}$	3.95	1+	0	(1,0); $(p_{3/2},p_{1/2})^{-1}$
	$p_{3/2}$	7.03	2+	0	(2,0); $(p_{3/2},p_{1/2})^{-1}$
	$p_{3/2}$	9.17	2+	1	(2,1); (s,d) + $(p_{3/2},p_{1/2})^{-1}$
	$p_{3/2}$	10.43	2+	1	(2,1); (s,d) + $(p_{3/2},p_{1/2})^{-1}$
	$p_{3/2}$	13.72	1+	1	(1,1); $(p_{3/2},p_{1/2})^{-1}$ [b]
$^{14}C(^{3}He,\alpha)^{13}C$	$p_{1/2}$	G.S.	1/2-	1/2	
	$p_{3/2}$	3.68	3/2-	1/2	
	$p_{3/2}$	15.108	3/2-	3/2[b]	

[a] Assignments made in references 8-10.

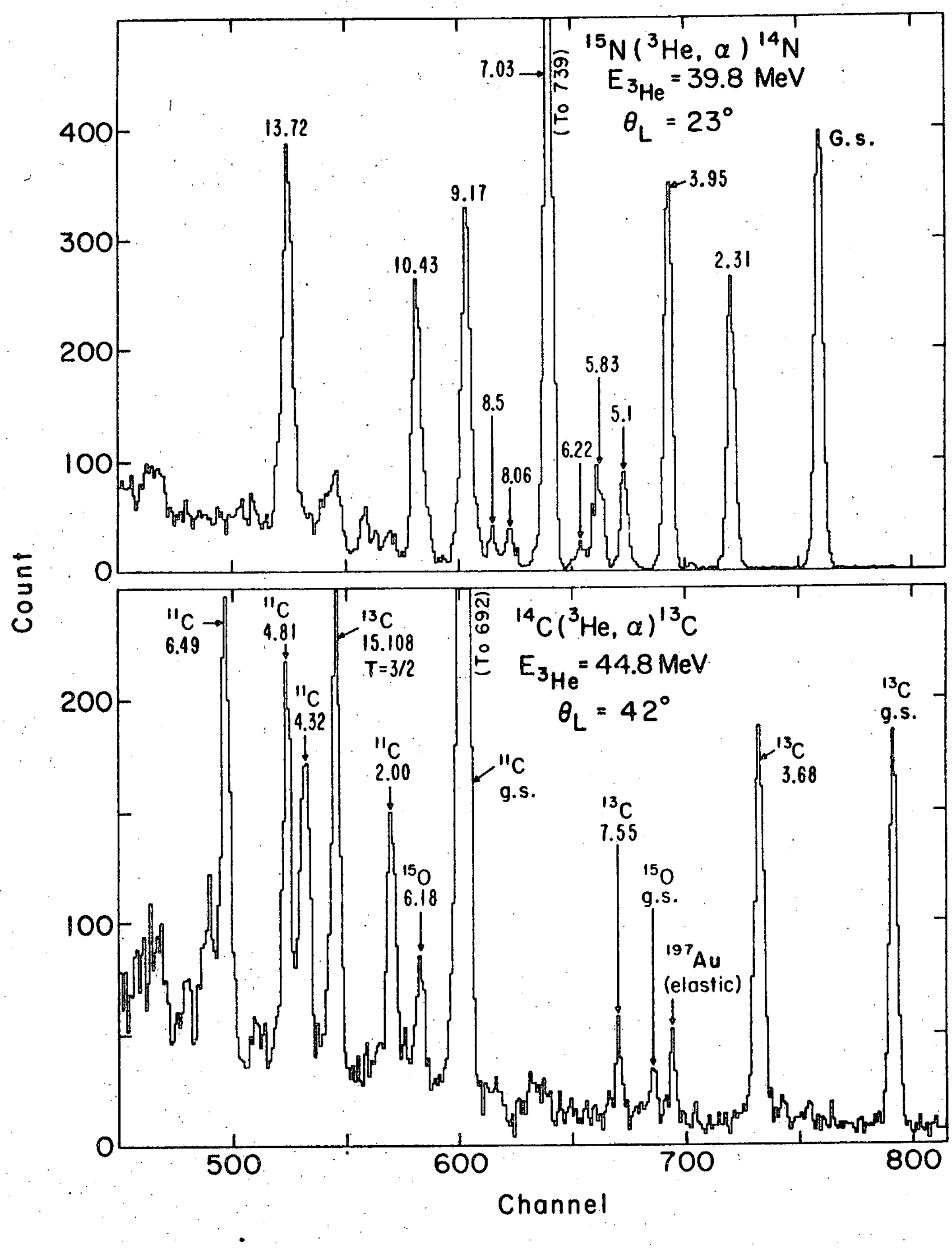
[b] New assignments made in this letter.

Figure Captions

Fig. 1. Energy spectra of the $^{15}N(^{3}He,\alpha)^{14}N$ and $^{14}C(^{3}He,\alpha)^{13}C$ reactions. The ^{197}Au elastic peak represents a ^{3}He contamination in the α spectra of 0.1%.

Fig. 2. Angular distributions from the $^{15}N(^{3}He,\alpha)^{14}N$ reaction. $p_{1/2}$ pick up states are indicated with broken lines. $p_{3/2}$ pick up states are shown as solid lines.

Fig. 3. Angular distributions from the $^{14}C(^{3}He,\alpha)^{13}C$ and $^{12}C(^{3}He,\alpha)^{11}C$ reactions. $p_{1/2}$ pick up states are indicated with broken lines. $p_{3/2}$ pick up states are shown as solid lines.



^{15}N(^{3}He, α)^{14}N
E$_{^3He}$ = 39.8 MeV
θ$_L$ = 23°
13.72
10.43
9.17
8.5
8.06
7.03
(To 739)
6.22
5.83
5.1
3.95
2.31
G.s.
^{14}C(^{3}He, α)^{13}C
E$_{^3He}$ = 44.8 MeV
θ$_L$ = 42°
^{11}C 6.49
^{11}C 4.81
^{11}C 4.32
^{13}C 15.108 T=3/2
^{11}C 2.00
^{15}O 6.18
(To 692)
^{11}C g.s.
^{13}C 7.55
^{15}O g.s.
^{197}Au (elastic)
^{13}C 3.68
^{13}C g.s.
Count
Channel
0
100
200
300
400
500
600
700
800
MUB-9892

Fig. 1

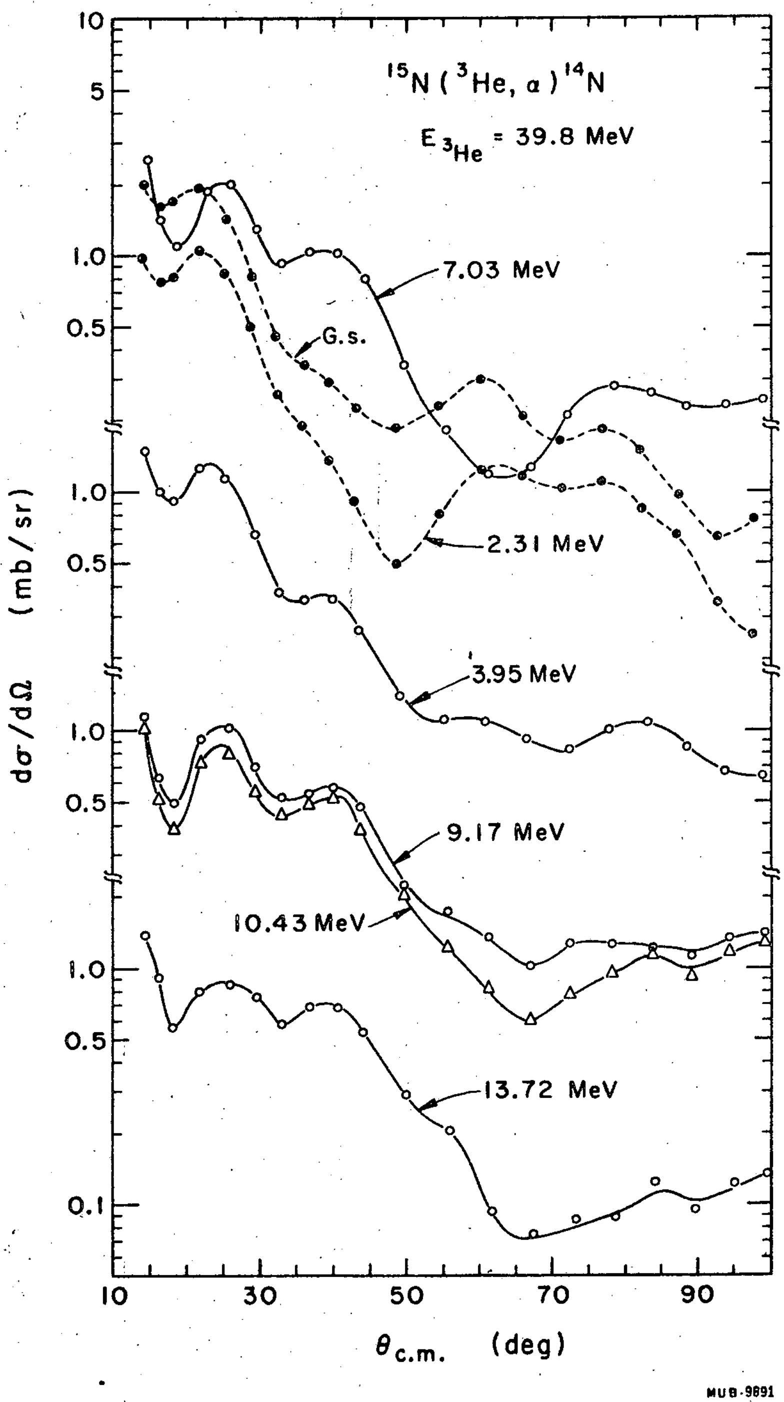

15N (3He, α) 14N
E 3He = 39.8 MeV
7.03 MeV
G.s.
2.31 MeV
3.95 MeV
9.17 MeV
10.43 MeV
13.72 MeV
dσ/dΩ (mb/sr)
θc.m. (deg)
10
5
1.0
0.5
0.1
10
30
50
70
90
MUB-9891

Fig. 2

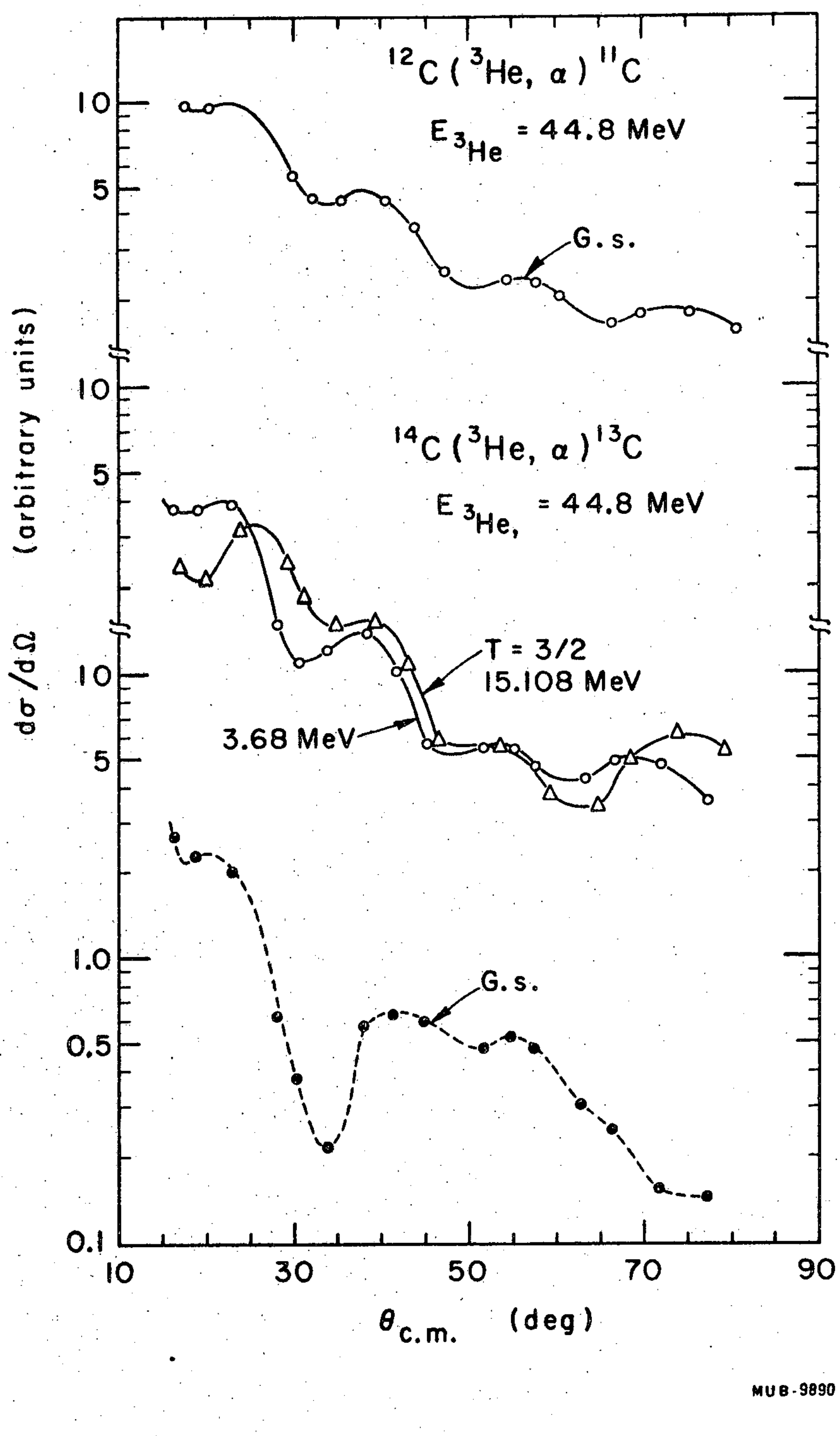

$^{12}C(^3He, \alpha)^{11}C$
$E_{^3He}$ = 44.8 MeV
G.s.
$^{14}C(^3He, \alpha)^{13}C$
$E_{^3He}$ = 44.8 MeV
T = 3/2
15.108 MeV
3.68 MeV
G.s.
dσ/dΩ (arbitrary units)
θc.m. (deg)
10
5
1.0
0.5
0.1
10
30
50
70
90
MUB-9890

Fig. 3