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DISCLAIMER

ENERGY LEVELS OF ^{12}N

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A study of the excited states of ^{12}N has been made using the $^{12}C(^{3}He,t)^{12}N$ reaction at $E(^{3}He) = 49.3$ MeV and the Berkeley magnetic spectrometer. We confirm a state of $E_x = 2.415 \pm 0.020$ MeV, $\Gamma_{c.m.} = 45 \pm 15$ keV, and we report four new states $^{12}N^*(6.10, 7.13, 9.42, 9.90)$ with $\Gamma_{c.m.} \sim 0.3, 0.5, \sim 0.2$ and 0.1 MeV. Comparison with earlier $(^{3}He,n)$ work reveals some inconsistencies, and comparison with the analog region in the mirror nucleus ^{12}B shows that the structure of ^{12}N remains poorly known.

NUCLEAR REACTIONS $^{12}C(^{3}He,t)$, $E = 49.3$ MeV; measured $\sigma(\theta)$. Γ, ^{12}N, deduced levels

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I. INTRODUCTION

Comparison of the known[1,2] states in ^{12}B with those in the mirror nucleus, ^{12}N, immediately reveals the incomplete nature of our understanding of the structure of ^{12}N: see Table 1. The reasons for this are easy to understand. While a wide variety of reactions with convenient characteristics (i.e., high + Q-values, outgoing charged particles) populate ^{12}B, the situation is quite different in ^{12}N. States in ^{12}N can, for all practical purposes, be populated only by the reactions $^{10}B(^3He,n)$ [1.569], $^{12}C(p,n)$ [-18.126], $^{12}C(^3He,t)$ [-17.362] and $^{14}N(p,t)$ [-22.141] [Q_m[3)] in brackets], and by comparable reactions involving heavy ions. The difficulties of accurate measurements of neutron energies and of obtaining the highly energetic, monoenergetic beams of particles needed to overcome the negative Q-values have only recently begun to be solved. With the exception of the $^{12}C(^3He,t)$ study of Ball and Cerny[4)] at $E(^3He)$ = 49.8 MeV who reported on states with E_x < 5.3 MeV, most of the evidence on the levels of ^{12}N derives from studies of $^{10}B(^3He,n)$, particularly those by Fuchs et al[5)] at $E(^3He)$ = 12.5-13 MeV and by Zafiratos et al[6)] at $E(^3He)$ = 4.0 and 5.8 MeV. [See Ref. 1 for a more complete listing of the experiments relating to ^{12}N.]

When a given excitation region has been studied in more than one experiment, many problems have arisen:

(1) The widths for ^{12}N*(3.11, 3.53) [energies listed here are from Ref. 1] are given as 280 ± 80, 270 ± 80 keV by Zafiratos et al[6)] and as 180 ± 40, 120 ± 40 keV by Fuchs et al[5)]:

while the difference in values is not outside the claimed errors, there is some interest in seeing whether one or the other experiment tended to be biased towards larger or smaller widths.

(2) The E_x for $^{12}N^*(5.23)$ [see Table 1:present work] is given as 5.320±0.012MeV by Fuchs et al[5], 5.27 ± 0.04 MeV by Ball and Cerny[6] and as 5.13 MeV in unpublished work quoted in Ref. 1.

(3) The states at $^{12}N^*(6.4, 6.9)$ [± 0.05 MeV] reported to be involved in the sequential decay of $^{10}B(^3He,np)$ by Bohne et al[7] are not reported in any other reaction, although comparison [see Table 1] with the mirror structure in ^{12}B certainly suggest states in that region of ^{12}N.

In fact comparison of the density of observed states in the mirror nuclei ^{12}B and ^{12}N show clearly that many states of ^{12}N have not been observed. Besides the problem that different reactions may populate different states and that few reactions populate ^{12}N (although the four reactions are not unusually selective), the greater widths of the states, the problem of multi-particle background subtraction (which may result in substantially different E_x and Γ values), the lower intensity of the "signal" from the wider peaks over the higher multi-particle background, as well as the experimental difficulties of dealing with neutrons and with highly endoergic reactions, all conspire to make the study of ^{12}N very difficult. A nucleus in which all the excited states are unbound is a frustrating system to study, at least (as in ^8Be) until one gets to a region where decay is inhibited by selection rules and states once again become sharp.

II. EXPERIMENTAL PROCEDURES AND RESULTS

The $^{12}C(^{3}He,t)^{12}N$ has been studied at $E(^{3}He) = 49.3$ MeV using the 88-inch cyclotron and the Berkeley QSD magnetic spectrometer[8]. The detail of the procedures followed have been described earlier[9] except that the E_t vs. channel calibration was made by using a carbon target and moving the groups from $^{12}N^{*}(0, 0.964)$ across the length of the detector by varying the magnetic field.

The target used was an isotopic carbon target (98.9% ^{12}C) whose thickness was $\sim$ 800 $\mu g/cm^2$. It was oriented at 30° and its thickness corresponded to an energy loss of $\sim$ 100 keV for 49 MeV ^{3}He ions. Contamination from $^{13}C(^{3}He,t)$ and from $^{16}O(^{3}He,t)$ was not observed: Q_m[3] for these two reactions are -2.239 and -15.448 MeV to the ground states of ^{13}N and ^{16}F. This experiment was concerned with determining the level structure of ^{12}N with $0 < E_x < 10$ MeV and, to some extent, the region with $E_x < 15$ MeV. Since Q_m for the $^{12}C(^{3}He,t)^{12}N$ reaction is -17.362 MeV, we would be concerned with contaminant groups in ^{13}N with $14 \lesssim E_x \lesssim 24$ MeV and with ^{16}F states with $2 \lesssim E_x \lesssim 12$ MeV. The level structure of ^{16}F is very poorly known but we have searched for all known energetically permissible states due to ^{13}C and ^{16}O contamination, and we find evidence for none.

The results we have obtained at $\theta_{lab} = 10°$ and 31° are shown in Figures 1 and 2 and are displayed in Table 1 where they are compared with previous results and with the T=1 levels in ^{12}B and ^{12}C. Certain comments are in order:

1) $^{12}N^*(1.72)$. We see no evidence for such a state. From the analog region in ^{12}B and ^{12}C five states would be expected with $E_x < 3$ MeV: only four are observed. The sharp state $^{12}N^*(2.42)$ is probably the analog of $^{12}B^*(2.72)$ and $^{12}C^*(17.76)$ $[0^+]$. The 1^- state which would then be missing has a width > 1 MeV in ^{12}C: its width and intensity above background may be such as to preclude its observation.

2) $^{12}N^*(3.14, 3.55)$. Our results are in good agreement with the results obtained earlier: the widths we report agree with the average of the results of Zafiratos et al[6] and Fuchs et al[5].

3) $4 \leq E_x \leq 6$ MeV. In that region we report two states, as do Fuchs et al[5]: however, while the ΔE_x of our two states and those of Fuchs et al is the same, there appears to be a real effect in that we report both states to be ∿ 100 keV lower than do Fuchs et al. There is no question whatsoever that the widths we observed for the two states are twice as large as reported by Fuchs et al[5]. Comparison with the analog region in ^{12}B suggests five relatively sharp states: the $^{10}B(^3He,n)$ and the $^{12}C(^3He,t)$ reaction may be preferentially populating different analog states, with the selectivity being greater in the $(^3He,n)$ reaction (and therefore leading to lower Γ) while we see unresolved states in two structures at $E_x = 4.15$ and 5.23 MeV. The equal ΔE_x in both experiments is suspicious in this connection but cannot invalidate this hypothesis.

4) ^{12}N*(6.10, 7.13). We see states at these energies for which no evidence appears in the (^{3}He,n) work[6]. Fig. 1 of the earlier (^{3}He,t) work by Ball and Cerny[4] shows some structures at these energies.

5) ^{12}N*(7.63)[5]. This state first reported in (^{3}He,n) is confirmed by us within the errors quoted. However, looking at the analog region in ^{12}B many analog states may be broad and not readily observable in ^{12}N.

6) ^{12}N*(8.45, 9.04)[5]. Unfortunately we see this excitation region at only one angle: the lower state is very weakly populated, the higher state appears to us to lie at a somewhat lower E_x(8.86 MeV) but the error (± 0.1 MeV) is large.

7) $E_x > 9.1$ MeV. We report two sharp new states at E_x = 9.42 and 9.90 MeV [$\Gamma \sim$ 0.2 and 0.1 MeV] which do not seem to appear in the (^{3}He,n) work[5] but once again Fig. 1 of Ref. 4 shows some appropriate structures. Certainly ^{12}B would suggest some five states below E_x = 10 MeV in ^{12}N. Finally no other states have been observed up to E_x = 15 MeV (10^{o}) and 13 MeV (31^{o}).

In conclusion, this attempt to unravel the puzzle of the states of ^{12}N has confirmed the existence of one doubtful state, [^{12}N*(2.4)], casts doubt on another [^{12}N*(1.7)], reports the existence of four new states, raises questions concerning selective population by the (^{3}He,n) and (^{3}He,t) reactions, and by comparison with the analog region in ^{12}B clearly shows that the level structure of ^{12}N is still very poorly known.

We are very grateful to C. Ellsworth, U. Jahnke, L. Kraus, C. Maples, Y. Terrien and K. Yagi for their help in this experiment, and to B. G. Harvey whose support was essential.

Reference List

1) F. Ajzenberg-Selove, Nuclear Physics A 248 (1975) 1.

2) F. Ajzenberg-Selove, R. Middleton and J.D. Garrett, Physical Review C 12, XXXX (1975).

3) N.B. Gove and A.H. Wapstra, Nuclear Data Tables 11 (1972) 127.

4) G.C. Ball and J. Cerny, Physical Review 177 (1969) 1466.

5) H. Fuchs, K. Grabisch, D. Hilscher, U. Jahnke, H. Kluge, T. Masterson and H. Morgenstern, Nuclear Physics A 234 (1974) 61.

6) C.D. Zafiratos, F. Ajzenberg-Selove and F.S. Dietrich, Nuclear Physics 77 (1966) 81; ibid. 89 (1966) 706.

7) W. Bohne, M. Hagen, H. Homeyer, K.H. Maier, H. Lettau, H. Morgenstern and J. Scheer, Physical Review C 2 (1970) 2072.

8) B.G. Harvey, J. Mahoney, F.G. Puhlhofer, F.S. Goulding, D.A. Landis, J.-C. Faivre, D.G. Kovar, M.S. Zisman, J.R. Meriwether, S.W. Cooper and D.L. Hendrie, Nuclear Instruments and Methods 104 (1972) 21.

9) F. Ajzenberg-Selove, C.F. Maguire, D.L. Hendrie, D.K. Scott and J. Mahoney, Physical Review (submitted for publication) (1975).

Table 1. Known T=1 states in the A=12 triad

^{12}B [a]			^{12}C [b]			^{12}N Previous results[d]			^{12}N Present results	
E_x (MeV)	J^π	$\Gamma_{c.m.}$ (keV)	E_x (MeV)	J^π	$\Gamma_{c.m.}$ (keV)	E_x (MeV±keV)	J^π	$\Gamma_{c.m.}$ [e] (keV)	E_x (MeV±keV)	$\Gamma_{c.m.}$ (keV)
g.s.	1^+	bound	15.110	1^+	0.042	g.s.	1^+	bound	g.s.	bound
0.9531	2^+	"	16.107	2^+	6.5	0.964±8	2^+	< 35	≡ 0.964 [ℓ]	< 20
1.6737	2^-	"	16.58	2^-	300	1.192±9	$(2)^-$	140±35	1.190 ± 20	80 ± 30
2.621	1^-	"	17.23	1^-	1150	(1.72 ±0.08)			(h)	
2.723	0^+	"	17.76	0^+	80	2.43 ±40			2.415 ± 20	45 ± 15
3.388	3^-	3.1	18.36	(3^-)	210	3.114±15	π=+	210±50	3.136 ± 30	240 ± 40
3.759	2^+	37	18.80	2^+	80	3.533±15	$(2)^+$	170±50	3.550 ± 50	150 ± 100
4.302	1^-	9	(19.25	(1^-)	1100)					
						4.25 ±30 [f]		290±70	4.150 ± 80 [i]	650 ± 100
4.37	2^-	broad								
4.521	4^-	110	19.57	(4^-)	400					
4.99	1^+	50								
						5.320±12		180±20	5.230 ± 80 [i]	400 ± 80
5.607	3^+	110	20.5	(3^+)	~250					
5.725	3^-	60	20.6	(3^-)	200					
5.8	$(1)^-$	broad							6.100 ± 80	300 ± 100
6.6	$(1)^+$	140				(6.4) [g]				

Table 1 (continued)

	^{12}B		^{12}C	^{12}N		^{12}N	
6.8	$(1)^+$	broad		(6.9)[g]		7.130 ± 100[f]	500 ± 100[f]
7.55	>3	≤14					
				7.629±20	200±40	7.480 ± 100	180 ± 80
7.84	>0	60					
7.94	>0	27					
8.1		900±200					
8.12							
8.24	>1	65					
8.38		40					
				8.446±17	90±30		
8.58	>1	75					
8.71						(8.860 ± 100)[j]	∼ 100
9.03	>1	120		9.035±12	16±20		
9.18				(9.2)[g]		9.420 ± 100	∼ 200
9.43		85					
9.59		60					
9.76							
(9.83)							
10.00	>0	100				9.900 ± 100	100 ± 50
	(c)		(c)			(k)	

Table 1 (continued)

a) From References 1 and 2.

b) The analog assignments of the first seven T=1 states can be made with considerable confidence. Analog assignments shown here for higher states are based on reasonable ΔE_x and on uncertain J^π assignments. Many T=1 states with $J^\pi = 1^-$, for instance, have been reported in ^{12}C but their analogs in ^{12}B have not been established: see Ref. 1.

c) T=1 states with $E_x > 10$ MeV in ^{12}B and > 25 MeV in ^{12}C have been observed: see Ref. 2 and 1, respectively.

d) The states with $E_x < 3.6$ MeV have been reported in several experiments: see Ref. 1 (Tables 12.25, 12.26 and 12.27). The higher states come primarily from the $^{10}B(^3He,n)^{12}N$ study of Ref. 5. Correspondence with analog states in ^{12}B and ^{12}C is established only for the first three states and probably for $^{12}N^*(3.53)$. The other states are shown listed in line with that state in ^{12}B which has most closely the same E_x.

e) The widths listed here are derived from Ref. 5 and 6. It should be noted that we have used a revised set of widths from Ref. 5 (see Table 12.26, Ref. 1) for which we thank T. G. Masterson (private communication).

f) May be due to unresolved states.

g) See Ref. 7.

Table 1 (concluded)

h) We see no evidence for this state.

i) The ΔE_x of the 5.23 and 4.15 MeV state is the same as for the two states 5.32, 4.25 observed by Fuchs et al[5] but the absolute values appear to be really 100 keV lower [our errors are conservative]. Our E_x, when comparable, for the higher states always tend to be lower: for instance 7.48 - 7.63. In the case of the 4.15-4.25 and 5.23-5.32 states the widths we observe are substantially larger: the (^{3}He,t) reaction may be exciting additional (unresolved) states.

j) Has been observed only at one angle (31°).

k) No other states are observed up to E_x = 15 MeV (10°) and 13 MeV (31°).

l) Used for calibration.

Figure Captions

Figure 1. Spectrum of the tritons from the $^{12}C(^{3}He,t)^{12}N$ reaction at $\theta_{lab} = 10°$, $E(^{3}He) = 49.3$ MeV. This composite figure shows the results from four runs: Run 3830 [32.152 MHz, 0.235 mC], run 3860 [30.010 MHz, 0.407 mC], run 3920 [29.302 MHz, 1.14 mC] and run 3890 [26.000 MHz, 1.30 mC] [frequency of spectrograph, incident charge]. A complete plot of run 3890, and a plot of run 3900 [23.499 MHz, 1.0 mC] show no other groups in ^{12}N with $E_x < 15$ MeV: see the discussion in the text. The ordinate shows the average number of counts in a four-channel bin: statistical errors are shown for four points. The abscissa shows E_x in ^{12}N (in MeV).

Figure 2. Spectrum of the tritons at $\theta_{lab} = 31°$. This composite figure shows the results from run 3930 [30.753 MHz, 1.09 mC], 3940 [28.296 MHz, 1.37 mC] and 3950 [26.301 MHz, 3.63 mC]. Plots of runs 3960 and 3970 which cover $10 < E_x < 13$ MeV in ^{12}N show no other groups. See also caption of Fig. 1.

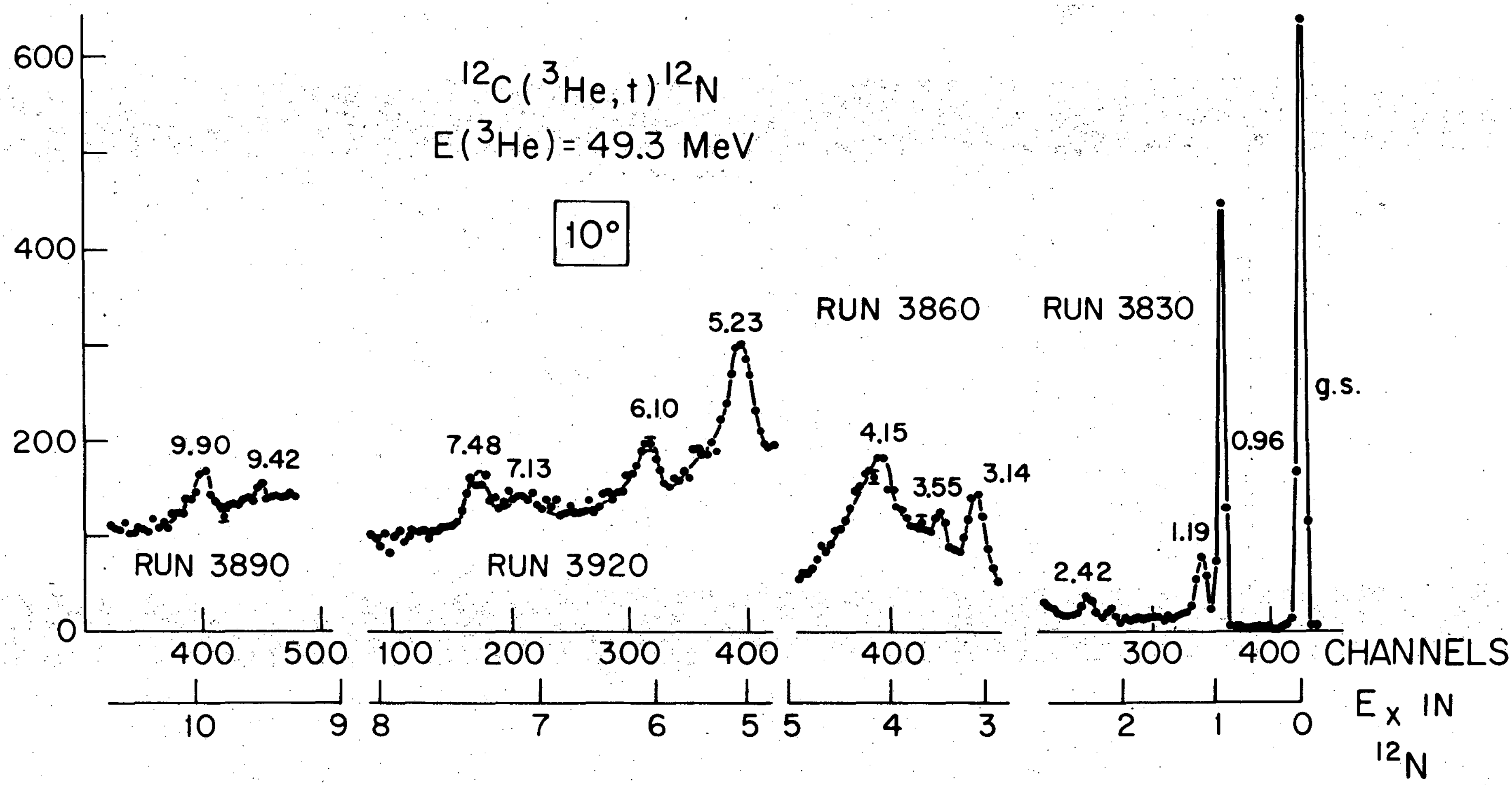
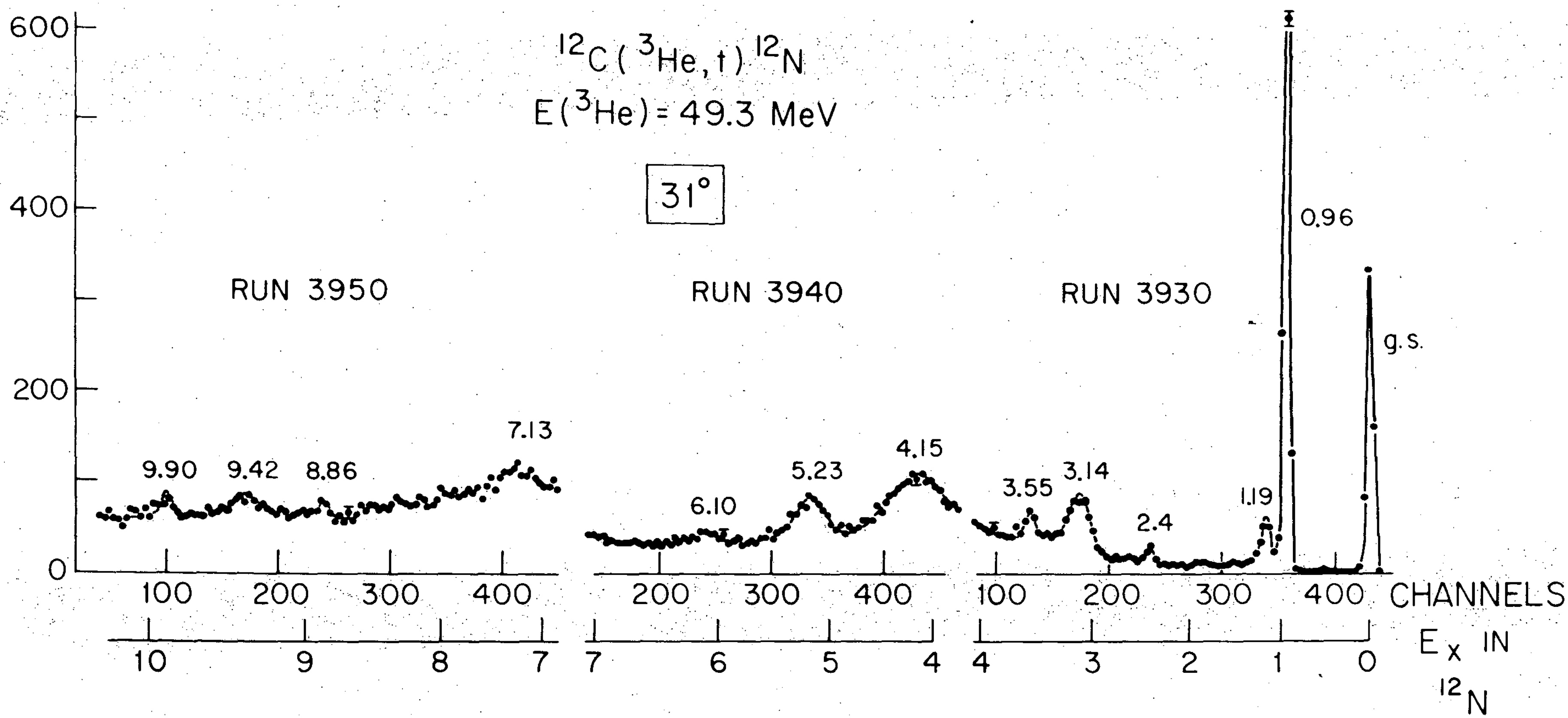

$^{12}C(^3He,t)^{12}N$
$E(^3He)=49.3$ MeV
10°
600
400
200
0
9.90
9.42
RUN 3890
7.48
7.13
6.10
5.23
RUN 3920
RUN 3860
4.15
3.55
3.14
RUN 3830
2.42
1.19
0.96
g.s.
400 500 100 200 300 400 400 300 400 CHANNELS
10 9 8 7 6 5 5 4 3 2 1 0
E_x IN ^{12}N

Fig. 1



600
400
200
0
$^{12}C(^3He,t)^{12}N$
$E(^3He) = 49.3$ MeV
31°
RUN 3950
RUN 3940
RUN 3930
0.96
g.s.
7.13
9.90
9.42
8.86
6.10
5.23
4.15
3.55
3.14
2.4
1.19
100 200 300 400
200 300 400
100 200 300 400
CHANNELS
10 9 8 7
7 6 5 4
4 3 2 1 0
E_x IN ^{12}N

Fig. 2

U U ∪ ∪ 4 4 U 4 0 7 3

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