Gamma decay of the 13.42-MeV state of ^{15}N†

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The γ decay of the 13.42-MeV state of ^{15}N, studied via the reaction ^{14}C$(p,\gamma)^{15}$N using Ge(Li) detectors, is found to be 100% to ^{15}N(g.s.) with $\Gamma_p\Gamma_{\gamma_0}/\Gamma = 1.70 \pm 0.5$ eV, $\Gamma_{\gamma_0} = 3.0 \pm 0.9$ eV, and a $M2/E1$ mixing ratio of 0.00 ± 0.04.

[NUCLEAR REACTIONS ^{14}C(p,γ), E_p=2.5–3.7 MeV, measured $\sigma(E,\theta)$, deduced branching ratios, J, Γ_γ, $M2/E1$ mixing ratio of the 13.42-MeV state of ^{15}N; enriched target.]

A state in ^{15}N at 13.39 MeV was suggested[1] as a $T=\frac{3}{2}$ state with $J^\pi = \frac{5}{2}^+$. Later work[2,3] determined the state to be at 13.42 MeV with $J^\pi = \frac{3}{2}^+$ and suggested two alternative interpretations: (i) as the third $T=\frac{3}{2}$ state with a configuration of ^{14}C(g.s.)$\otimes 1d_{3/2}$ and with at least a 10% $T=\frac{1}{2}$ admixture; (ii) a $T=\frac{1}{2}$ α cluster state of ^{11}B(g.s.) + α. The $T=\frac{3}{2}$ interpretation appears doubtful since the existence of the originally suggested analog state in ^{15}C at 2.48 MeV is no longer likely according to more recent experimental and theoretical evidence.[4] The second interpretation was further examined in a recent work.[5] The γ decay of the state has previously been studied with NaI detectors.[3,6] These studies were mainly concerned with the ground state transition. We report here a Ge(Li) detector measurement to determine the strength for possible transitions to other final states and the $M2/E1$ mixing ratio of the ground state transition.

The experiment was carried out at the University of Kansas and at Brookhaven National Laboratory with an experimental method similar to that employed in Ref. 7, using the same ^{14}C target. Excitation functions of the reaction ^{14}C$(p,\gamma)^{15}$N were measured simultaneously at two or three angles with Ge(Li) detectors having adequate energy resolution to separate γ rays of small energy difference such as those from transitions to final states at 5.270 and 5.299 MeV. Angular distribution data on the observed resonance were taken with a single Ge(Li) detector.

Figure 1 shows a typical γ ray spectrum, taken at E_p = 3.695 MeV. Prominent γ rays from the reaction ^{14}C$(p,\gamma)^{15}$N are identified as those from the transitions $E_x\to$g.s., $E_x\to 5.270\to$g.s., and $E_x\to 5.299\to$g.s. Background includes γ rays at 6.13 MeV from ^{19}F$(p,\alpha\gamma)^{16}$O and at 7.63–7.65 MeV from ^{56}Fe$(n,\gamma)^{57}$Fe, and part of the continuous yield due to the presence of neutrons. Figure 2 shows the yield curves of γ_0 at 125°, 0°, 30°, 55°, and 90° and of γ_1 and γ_2 at 90°. The absolute cross section, with uncertainty less than 25%, is based on normalization to that in Refs. 6 and 7. The results of Refs. 6 and 7 are in good agreement. The γ_0 yield curves show a resonance structure having both the energy and width consistent with those of the 13.42-MeV state of ^{15}N observed[2,3] in the reactions ^{14}C(p,p), (p,n), (p,γ), and ^{11}B(α,α).

To extract the resonance parameters, the γ_0 angular distributions, based on yield curves at five angles (Fig. 2) are least-squares fitted with Legendre polynomials $W(\theta) = A_0(1 + a_1P_1 + a_2P_2)$. The a_1 coefficient is negligible in the energy region studied. At the resonance $a_2 = -0.5$. An asymmetry is seen in the $4\pi A_0$ curve, indicating interference with structure of the same parity. The resonance cross section is taken to be the difference between the peak cross section in the $4\pi A_0$ curve and a background cross section (~15% of the peak cross section) obtained from smooth interpolation. The deduced resonance strength is $\Gamma_p\Gamma_{\gamma_0}/\Gamma = 1.70 \pm 0.5$ eV and $\Gamma_{\gamma_0} = 3.0 \pm 0.9$ eV, using the values[3] $J=\frac{3}{2}$, $\Gamma_p/\Gamma = 0.572$, $\Gamma_{\text{c.m.}} = 61$ keV.

Figure 3 shows the measured angular distribution of γ_0 on the resonance and its χ^2 vs arctan$x$ analysis for assumed J values of $\frac{5}{2}$ and $\frac{3}{2}$. The result independently confirms the previously established $\frac{3}{2}$ assignment[2,3] and yields a $M2/E1$ mixing ratio of 0.00 ± 0.04, positive parity having been assigned to the resonance.[2,3] The solution for the dip near 60° of the $J=\frac{3}{2}$ curve may be discarded

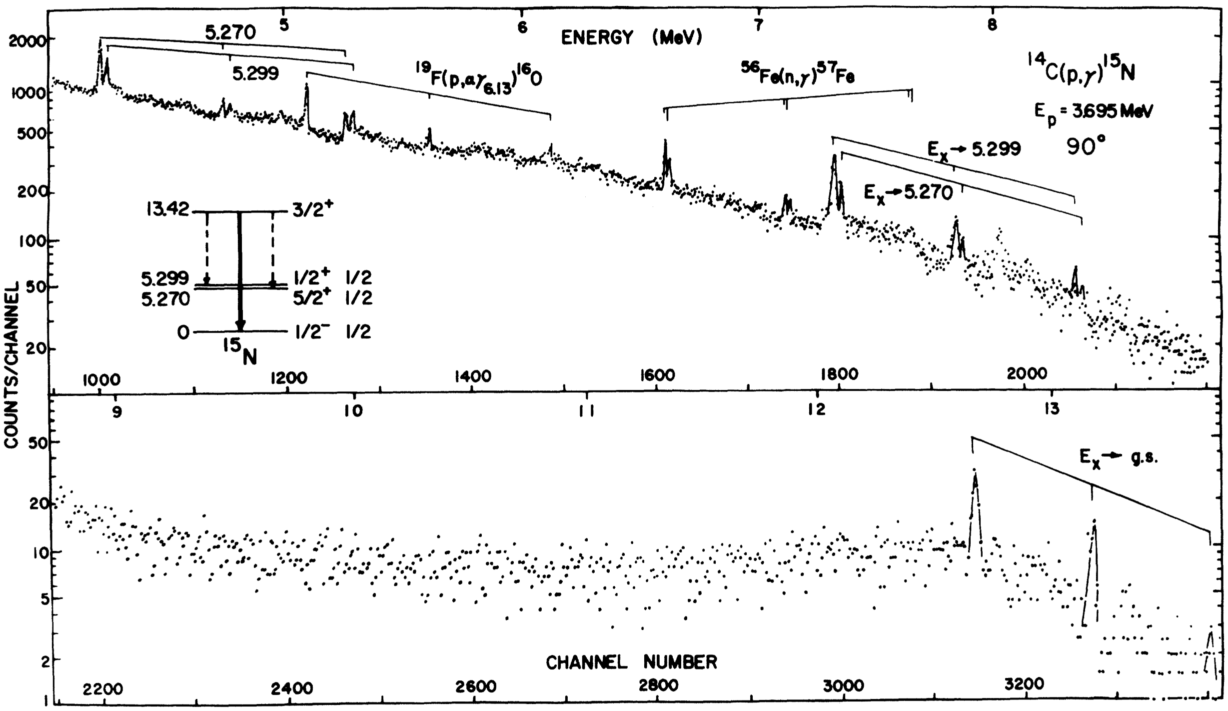

FIG. 1. γ spectrum measured by a single 40-cm^3 Ge(Li) detector at 90° and E_p=3.695 MeV. Prominent γ rays from $^{14}C(p,\gamma)^{15}N$ are identified as those from the transitions $E_x \rightarrow$g.s., $E_x \rightarrow 5.270 \rightarrow$g.s., and $E_x \rightarrow 5.299 \rightarrow$g.s. The 6.13- and 7.63–7.65-MeV γ rays are from $^{19}F(p,\alpha\gamma)^{16}O$ and $^{56}Fe(n,\gamma)^{57}Fe$, respectively. Data points above channel 2000 are averages of every two channels. The insert shows the decays of the 13.42-MeV state of ^{15}N.

since it would imply a $M2$ strength of 60±20 W.u. (Weisskopf units).

The γ_1 and γ_2 channels and their secondary γ rays at 5.270 and 5.299 MeV all show appreciable yield (Figs. 1 and 2), but no pronounced resonant structure. The γ rays from decays to low-lying states above the second excited state do not show measurable strength. The experimental results are summarized in Table I.

A recent 2h-1p calculation,[6] using realistic two-body matrix elements, successfully predicts the depleted $B(E1)$ values from the first two $T=\frac{3}{2}$ states and reproduces the location of the collective $T=\frac{3}{2}$ and $\frac{1}{2}$ $E1$ states in $A=15$ nuclei. The first $1d_{3/2}$, $T=\frac{3}{2}$ state in ^{15}N is predicted at 16.2 MeV. A simple weak-coupling estimate based on the level scheme of ^{17}O would put this state at 17.5 MeV in ^{15}N. Both values are too high compared to the suggested $T=\frac{3}{2}$ state at 13.42 MeV. On the other hand, the calculation predicts a $\frac{3}{2}^+$, $T=\frac{1}{2}$ state at 12.9 MeV with $B(E1)$ value in good agreement with experiment (Table I). The state has very little overlap with the $^{14}C+p$ channel which is consistent with the observed narrow width (61 keV) for the 13.42-MeV state. This comparison supports the $T=\frac{1}{2}$ interpretation for the state.

Compared to the first two $T=\frac{3}{2}$ states[7] of ^{15}N both of which are predominantly of $J=l+\frac{1}{2}$, it is not a reliable means to probe the suggested[2,3] $T=\frac{3}{2}$ ($T_>$) nature of the 13.42 MeV state by studying its $M1$ transition to its antianalog state ($T_<$). This is because of the fact that $M1$ transition rates between $T_>$ and $T_<$ states of $J=l-\frac{1}{2}$ are smaller[8] by a factor of about 30 than between states of $J=l+\frac{1}{2}$ due to the factor $(g_p-g_n)^2$ and the difference in $6j$ coefficients. The $M1$ strength could be diminished further by any fragmentation of the antianalog state as indicated in recent experiments.[8] Thus, in spite of the weakness, established in the present work, for any possible $M1$ transitions to the $J=\frac{3}{2}$, $T=\frac{1}{2}$ state, this (p,γ) study sheds no light on the isospin of the 13.42-MeV state.

In conclusion we note two points: (i) The deduced value $\Gamma_{\gamma_0}(E1)=(3.0\pm0.9)\times10^{-3}$ W.u. for the 13.42-MeV state of ^{15}N is of the same order as the mean strength of the measured[9] $E1$ transitions in nuclei of $5\leq A\leq 40$. (ii) The present study of $^{14}C(p,\gamma)^{15}N$ shows no observable γ-decay strength from the resonance structures observed[3] in $^{14}C(p,p)$, (p,n), and (p,α) at $E_p=2.91$ ($\frac{3}{2}^-$), 2.93 ($\frac{3}{2}^+$), 3.38 ($\frac{3}{2}^-$), and 3.65 ($\frac{1}{2}^+$) MeV. The results are consistent with estimates based on the experimental values[3] of Γ_p/Γ and the mean Γ_γ strength of measured transitions in light nuclei.[9]

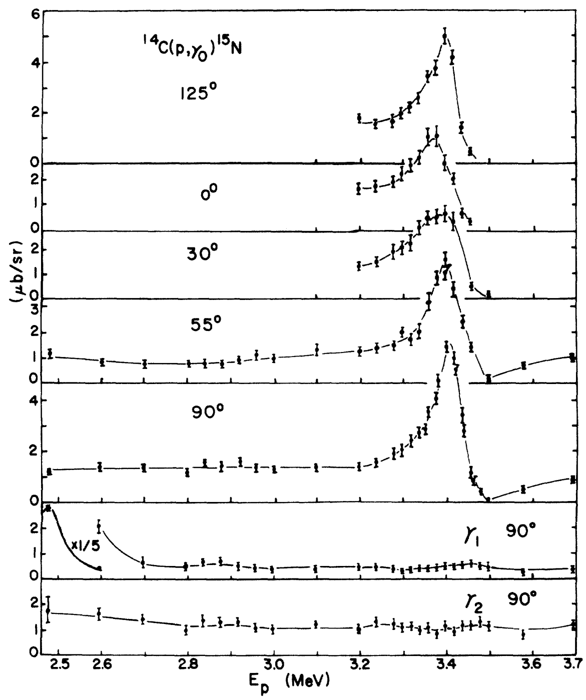

FIG. 2. The yield curves of the capture reaction $^{14}C(p,\gamma)^{15}N$ at 125°, 0°, 30°, 55°, and 90° for γ_0 and at 90° for γ_1(5.270) and γ_2(5.299). The solid lines are drawn through the data points.

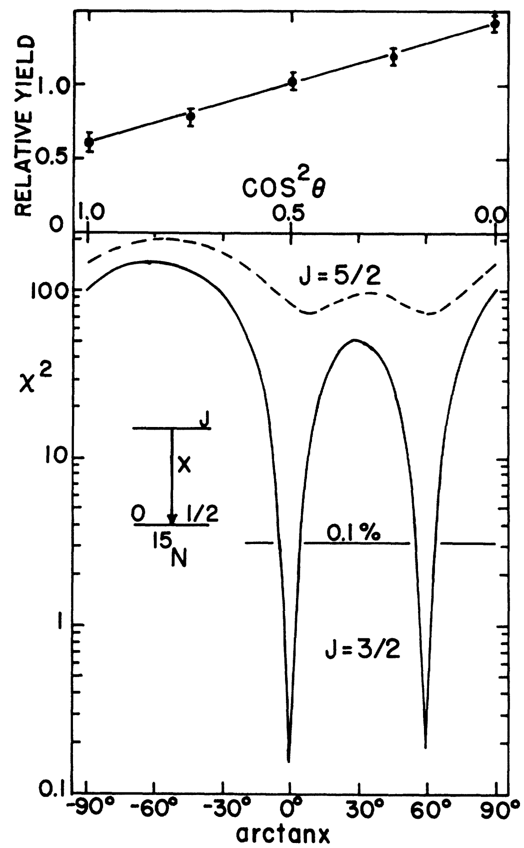

FIG. 3. Top: angular distribution of $^{14}C(p,\gamma_0)$ at E_p =3.405 MeV with the solid line being the theoretical fit for the $J=\frac{3}{2}$ case. Bottom: the χ^2 vs arctan$x$ calculations with assumed J values of $\frac{3}{2}$ and $\frac{5}{2}$.

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TABLE I. γ transitions of the $\frac{3}{2}^+$, 13.42-MeV state of ^{15}N.

Final state E_x (MeV)	J^π	Branching (%)	Mixing ratio	Γ_γ (eV)	$B(E1)$ (e^2fm^2) Experiment	Theory [a]
0	$\frac{1}{2}^-$	100	0.00 ± 0.04	3.0 ± 0.9	0.0012 ± 0.0004	0.0009
5.270	$\frac{5}{2}^+$	<8		<0.25		
5.299	$\frac{1}{2}^+$	<8		<0.25		
6.324	$\frac{3}{2}^-$	<5		<0.15	<0.0005	0.0006
7.16	$\frac{5}{2}^+$	<5		<0.15		
7.30	$\frac{3}{2}^+$	<5		<0.15		

[a] Reference 6.

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