$^{10}B(^{7}Li, p)^{16}N$ and J^{π} of $^{16}N(3.520)$†

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Results of the $^{10}B(^{7}Li, p)^{16}N$ reaction suggest $J=2$ if the 3.520-MeV "level" is a single state and $J=0$ and 1 if it is an unresolved doublet.

[NUCLEAR REACTIONS $^{10}B(^{7}Li, p)$, $E=16$ MeV; measured $\sigma(E_p, \theta)$; deduced $J(3.520)$.]

The present experimental evidence on the spin and parity of the 3.52-MeV state of ^{16}N is ambiguous. In $^{15}N(n, n)^{15}N$ total cross section measurements[1] (with a resolution of 1.5 keV), the state is seen as a resonance with $\Gamma \sim 3$ keV. If it is a single state, the magnitude of the total cross section requires $J \geq 1$. An analysis[2,3] of the $^{15}N(d, p)^{16}N$ cross section populating this state yields the result that $l=2$, with $J^{\pi}=1^{-}$, $(2, 3)^{-}$ (if it is a single state populated by a single l value) or $l=1+3$, with $J^{\pi}=2^{+}$ (if it is a single state populated by an admixture of two l values). A study of the $^{14}C(^{3}He, p)^{16}N$ reaction[4] favors $J^{\pi}=2^{+}$, but the fit of an $L=2$ distorted-wave (DW) curve to the data is poor, especially at forward angles. A DW analysis[5] of the $^{14}N(t, p)^{16}N$ reaction shows that this state is populated with $L=1$ or 2, or both. This information is summarized in Table I.

Finally, in the $^{17}O(d, ^{3}He)$ reaction[6] to this state, the angular distribution is reported to have $l=2$, requiring $J^{\pi}=(0\text{–}5)^{+}$. Our inspection of the data, however, shows that both $l=1$ and 2 are present. Thus, in the absence of contamination from an impurity, we believe these data suggest that the 3.52-MeV "level" actually consists of two states of opposite parity. We have attempted to test this idea and to place further restrictions on the J value by means of the $^{10}B(^{7}Li, p)^{16}N$ reaction. Earlier studies[7-9] of $(^{7}Li, p)$ reactions have shown that the reaction mechanism is virtually pure compound nuclear, with total cross sections proportional to $2J+1$, where J is the final-state spin. This reaction should then allow us to eliminate some of the possible J^{π} values.

In an earlier study[8] of the $^{10}B(^{7}Li, p)^{16}N$ and $^{11}B(^{7}Li, d)^{16}N$ reactions, a $(2J+1)$ analysis of the data suggested $J(3.36)+J(3.52)=6$. With the knowledge[10] that $J^{\pi}(3.36)=1^{+}$, that analysis would have required $J(3.52)=5$. That work also suggested $J(3.96)=4$ and $J(4.32)+J(4.38)=5$, all in contradiction with present assignments. However, those authors point out the unreliability of extrapolating from $E_x=0$ to $E_x=3.5$ MeV. Now, no such extrapolation is necessary since the other states in this region have unique J^{π} assignments.

The present $^{10}B(^{7}Li, p)^{16}N$ reaction was initiated with a 16-MeV beam of Li ions from the University of Pennsylvania EN tandem. The target was a gold-backed foil of about 50 $\mu g/cm^2$ thickness of B enriched to 96.5% in ^{10}B. Outgoing protons were momentum analyzed in a multiangle spectrograph and detected in K5 nuclear emulsion plates. Mylar foils prevented all particles except protons from reaching the emulsion. Angular distributions were extracted for five states[10] in the region $E_x=3.0\text{–}4.5$ MeV and were then integrated to get

TABLE I. Results of various experiments for the J^{π} of $^{16}N(3.520)$.

Reaction	Ref.	Result	J^{π} Restriction	Remarks
$^{15}N(n, n)$	1	$\Gamma=3$ keV	≥ 1	If a single state
$^{15}N(d, p)$	2, 3	$l=2$	1^{-}, $(2, 3)^{-}$	If a single state formed by a single l value
		$l=1+3$	2^{+}	If a single state formed by mixture of two l values
$^{14}C(^{3}He, p)$	4	$L=2$	2^{+}	Poor fit at forward angles
$^{14}N(t, p)$	5	$L=1$ or 2 or both	$(0\text{–}2)^{-}$ and/or $(1\text{–}3)^{+}$	Evidence for two L values is not compelling

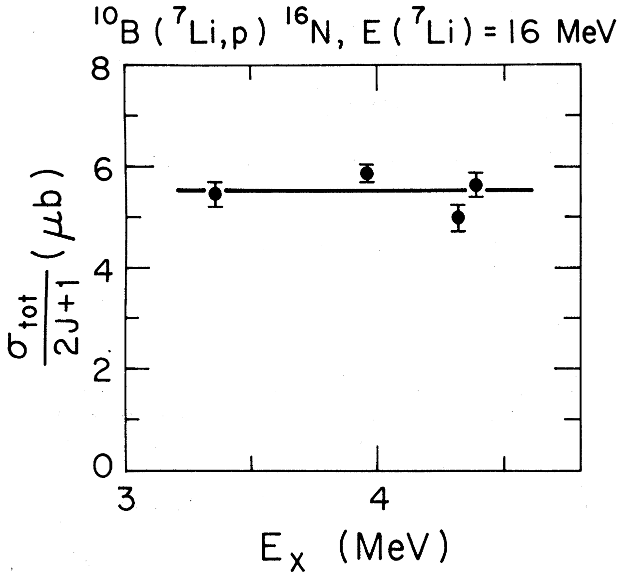

FIG. 1. Plot of $\sigma_{tot}/2J+1$ vs E_x for the $^{10}B(^7Li, p)^{16}N$ reaction leading to four states of known (Refs. 5 and 10) J in the region $E_x = 3.0$–4.5 MeV.

total cross sections. These are plotted in Fig. 1 as a function of excitation energy, after dividing by $2J+1$. We see that the quantity $\sigma_{tot}/2J+1$ is very nearly a constant for the four levels of known[5,10] J. The results are listed in Table II. The average value of $\sigma_{tot}/(2J+1)$ for the four levels is 5.49 ± 0.23. If we divide the value of σ_{tot} for the 3.520-MeV level by this average we get

TABLE II. Results of the reaction $^{10}B(^7Li, p)^{16}N$ at $E(^7Li) = 16.0$ MeV.

E_x	J^π	σ_{tot} (μb)	$\frac{\sigma_{tot}}{2J+1}$ (μb)
3.36	$1^{\ddagger}$	16.4 ± 0.7	5.46 ± 0.22
3.52	?	25.5 ± 0.9	...
3.96	3^+	41.0 ± 1.2	5.86 ± 0.16
4.32	1^+	15.0 ± 0.8	5.00 ± 0.26
4.39	1^-	16.9 ± 0.8	5.64 ± 0.26
Average			5.49 ± 0.23

$$\frac{\sigma_{tot}(3.520)}{(\sigma_{tot}/(2J+1))_{ave}} = \frac{25.5 \pm 0.9}{5.49 \pm 0.23} = 4.6 \pm 0.3 .$$

A strict interpretation of these results requires $2J+1 = 5$ or 4. Other values are more than four standard deviations away. A value of 5 implies a single state with $J = 2$. The $^{15}N(d, p)^{16}N$ results[2,3] then favor positive parity. A value of $2J+1 = 4$ implies a doublet with spins 1 and 0. The $^{15}N(d,p)$-^{16}N results[2,3] would rule out a positive-parity doublet with spins 0 and 1, so that at least one state has negative parity.

We thus suggest $J^\pi = 2^+$ if the 3.520-MeV level is a single state and $J^\pi = (1^\pm$ and $0^\pm)$ (with at least one state having negative parity) if it is a doublet. Perhaps further experiments can uniquely settle the question.

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