cannot be explained by any reasonable mixing of *LS* states and that therefore these results must be due to mesonic current contributions of 0.27 nm.

For the $A = 13$ mirror pair, calculations performed using the intermediate-coupling shell model and the usual magnetic moment operator show that if there is a sufficient deviation from *jj* coupling toward *LS* coupling, the magnetic moments can lie outside the Schmidt limits.[8-10] Analysis of the available experimental data, not including the magnetic moments or *M*1 transition rates, indicates that the coupling is intermediate between *LS* and *jj*, but is not of sufficient precision to determine the exact coupling.[10] Therefore, the prediction of the model for the magnetic moments cannot be precisely determined at present.

It should be pointed out that the Hamiltonian used in these calculations includes exchange and velocity-dependent (spin-orbit) interactions which change the form of the current operator. Since the proper form of this operator is not known, these terms have not been taken into account. Therefore, the calculation of the magnetic moments and magnetic transition rates is not self-consistent.[11]

The sum of the moments of N^{13} and C^{13} as calculated in intermediate coupling is independent of the coupling and is equal to the sum of the Schmidt moments to within 0.04 nm,[12] in agreement with the experimental results. From this agreement one can conclude that the mesonic current contributions in N^{13} and C^{13}, if they exist, obey the mirror principle (i.e., they are equal and opposite in a pair of mirror nuclei).[3,13]

A more detailed discussion of this work will be published subsequently.

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[11]In principle, it seems reasonable that these currents should be equivalent to the mesonic exchange currents since the nuclear force is believed to derive from the interchange of mesons.

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[13]We have not discussed the relativity contribution to the magnetic moment as it is expected to be small compared to the deviation from the Schmidt moment. See reference 2.

IDENTIFICATION OF DOUBLET STATES AT 5.16 Mev in B^{10}

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The isotopic spin analog of the first excited states in Be^{10} and C^{10} should be located at an excitation energy of about 5.1 Mev[1] in the self-conjugate nucleus B^{10}. In this region three levels have been reported previously[2] at 4.77, 5.11, and 5.16 Mev, of which the first two levels may readily be eliminated as candidates for the $J^{\pi} = 2^+$, $T = 1$ isotopic spin analog. The energy displacement of the 4.77-Mev state, from the expected position at 5.1 Mev, would be exceptionally large and the broad width ($\Gamma_{c.m.} = 1.2$ kev) of the 5.11-Mev state makes an assignment of $T = 1$ very unlikely for that state. Recently Meads et al.[3] have shown, from a comparison of proton and deuteron (about 10-Mev incident energy) inelastic scattering by B^{10}, that the isotopic spin of both the 4.77- and 5.11-Mev states is $T = 0$.

The state at 5.16 Mev has presented a puzzle. Investigation of the 5.16-Mev level when fed by 2.40-Mev gamma-ray transitions from the 7.56-Mev level in B^{10} yields results which are not supported when the 5.16-Mev level is produced by other means. From a study of the angular distributions of the gamma rays emitted from the 5.16-Mev level, produced in the $Li^6+\alpha$ reaction, Meyer-Schützmeister and Hanna[4] found that the possible J^π assignments were 1^+ or 2^+, the decay scheme favoring the latter assignment. The apparent absence of transitions to the $J^\pi=0^+$, $T=1$ state at 1.74 Mev would appear to rule out a $J^\pi=1^+$, $T=0$ assignment to the 5.16-Mev level on the basis of Morpurgo's rule.[5] Since a $J^\pi=1^+$, $T=1$ assignment cannot be reconciled with the $T=1$ system of levels in the mirror nuclei Be^{10} and C^{10}, the proper assignment for the 5.16-Mev level would be expected to be $J^\pi=2^+$, $T=1$. Recently the $T=1$ assignment has been supported by Meads et al.[3] as a result of their comparison of proton and deuteron inelastic scattering. On the other hand, the strong 2.40-Mev gamma ray emitted by the $J^\pi=0^+$ state at 7.56 Mev in B^{10} indicates that the assignment of the 5.16-Mev level[6] populated by this transition must be $J=1$.

The intrinsic c.m. width of the 5.16-Mev level of B^{10} formed in the $Li^6+\alpha$ reaction has been reported by Hanna[7] to be less than 500 ev. In a preliminary investigation of $Be^9(d,n)B^{10}$ reactions, Chase and Warburton[8] report both neutron and gamma-ray thresholds for the 5.16-Mev level with $\Gamma_\gamma>0.1\Gamma$. For $Be^9(p,\gamma)B^{10}$ reactions, Meyerhof, Tanner, and Hudson[9] have shown, from the spectra in coincidence with capture gamma rays to the 5.16-Mev level, that $\Gamma_\gamma\approx0.1\Gamma$ for this state. Similar results were obtained by Meyerhof and Chase[10] for the gamma rays emitted from the interaction of 2.8-Mev deuterons with a thick beryllium target. On the other hand, Sprenkel and Daughtry[11] did not observe gamma rays in coincidence with 2.40-Mev transitions from the 7.56-Mev level and placed a limit of $\Gamma_\gamma<0.01\Gamma$ for the 5.16-Mev state. In order to explain the disagreement of their results with those presented above, Sprenkel and Daughtry[11] postulated the existence of doublet states at 5.16 Mev in B^{10}.

Since the doublet state that is fed by 2.40-Mev gamma rays is expected to have a $J=1$, $T=0$ assignment, the decay of this state should proceed mainly through the transition to the $J^\pi=0^+$, $T=1$ state at 1.74 Mev in B^{10}. The expected predominance of this transition (3.42 Mev) arises from the selection rules for the strong reduction in strength of $E1$ and $M1$ transitions between levels of the same isotopic spin in self-conjugate nuclei.[5,12] Accordingly a search was made for a 3.42-Mev gamma-ray transition that should result from the decay of a $J=1$ doublet member produced by bombarding Li^6 with alpha particles of about 1.17 Mev. Since the known member of the 5.16-Mev doublet decays by 3.01-Mev (64%), 4.44-Mev (29%), and 5.16-Mev (7%) transitions,[4] the detection of a peak corresponding to the full energy of a 3.42-Mev gamma ray is rendered difficult, because the peak lies in the same spectral region as the second escape peak of the 4.44-Mev transition. In order to increase the sensitivity for the detection of 3.42-Mev gamma rays, spectra were taken in coincidence with either of the other members of the 3.42-1.02-0.72 Mev cascade. Two NaI(Tl) crystals (8 in. diameter × 8 in. long and 5 in. diameter × 5 in. long) were placed at 90° with respect to the alpha beam and at a distance of about 3/4 in. from the Li^6 target. To minimize escape-peak formation, the larger NaI(Tl) crystal was used for the detection of the coincidence spectrum. The fixed channel, for the smaller crystal, extended from 0.6 to 1.2 Mev for selection of the 0.72- and 1.02-Mev cascade gamma rays. Coincidence spectra were obtained at alpha-energy inter-

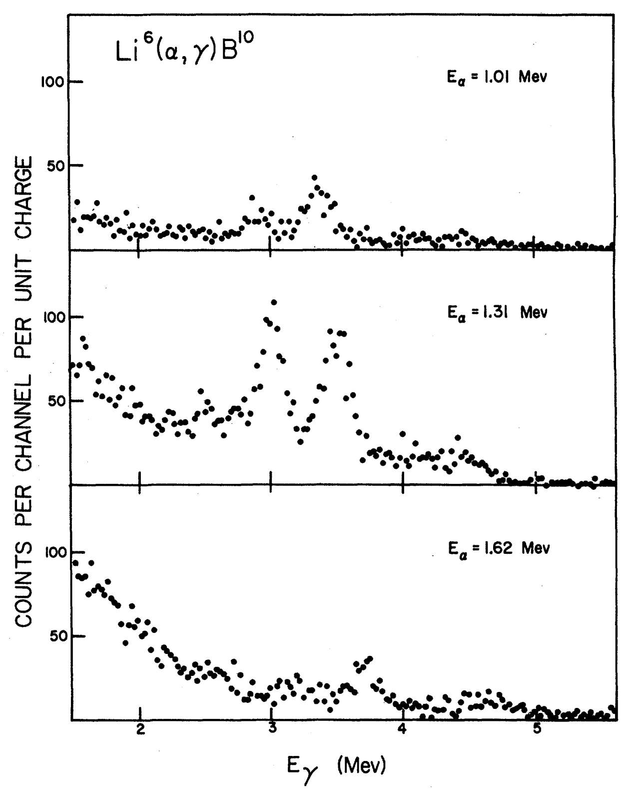

FIG. 1. Gamma-ray coincidence spectra in the region of the 1.20-Mev resonance in $Li^6(\alpha,\gamma_{3.42})B^{10}$. The middle spectrum also shows gamma rays from the previously known 1.175-Mev resonance.

vals of 75 kev using an enriched Li^6 target with an average thickness of 50 kev. A peak corresponding to a 3.42-Mev transition was seen to appear at about $E_\alpha = 1.0$ Mev, increase sharply in intensity to reach a maximum at about $E_\alpha = 1.2$ Mev, and then gradually decrease in intensity (Fig. 1 and Fig. 2). The position of the peak shifted in a regular manner (Fig. 1), showing a change in gamma-ray energy from 3.36 Mev at $E_\alpha = 1.0$ Mev to 3.70 Mev at $E_\alpha = 1.6$ Mev. Peaks corresponding to 3.01- and 4.44-Mev transitions from the previously known member of the doublet were found to be very intense in the coincidence spectrum taken at $E_\alpha = 1.19$ Mev. Because of the nonuniform thickness of the target, the 3.01-Mev peak is still apparent in the spectrum taken at $E_\alpha = 1.31$ Mev (Fig. 1). For positive identification of the 3.42-1.02-0.72 Mev cascade chain, a spectrum was taken in coincidence with the "3.42-Mev" gamma ray detected in the large crystal. The resultant spectrum showed the presence of only two gamma rays at 0.72 and 1.02 Mev, which provided identification of the expected cascade chain.

The "3.42-Mev" gamma-ray yield curve (Fig. 2) was fitted with the single-level expression:

$$\sigma_{\alpha\gamma} = \pi ƛ^2 g \frac{\Gamma_\alpha \Gamma_\lambda}{(E_\lambda + \Delta_\lambda - E_\alpha)^2 + (\Gamma_\lambda/2)^2}, \qquad (1)$$

where the energy dependence of the resonance

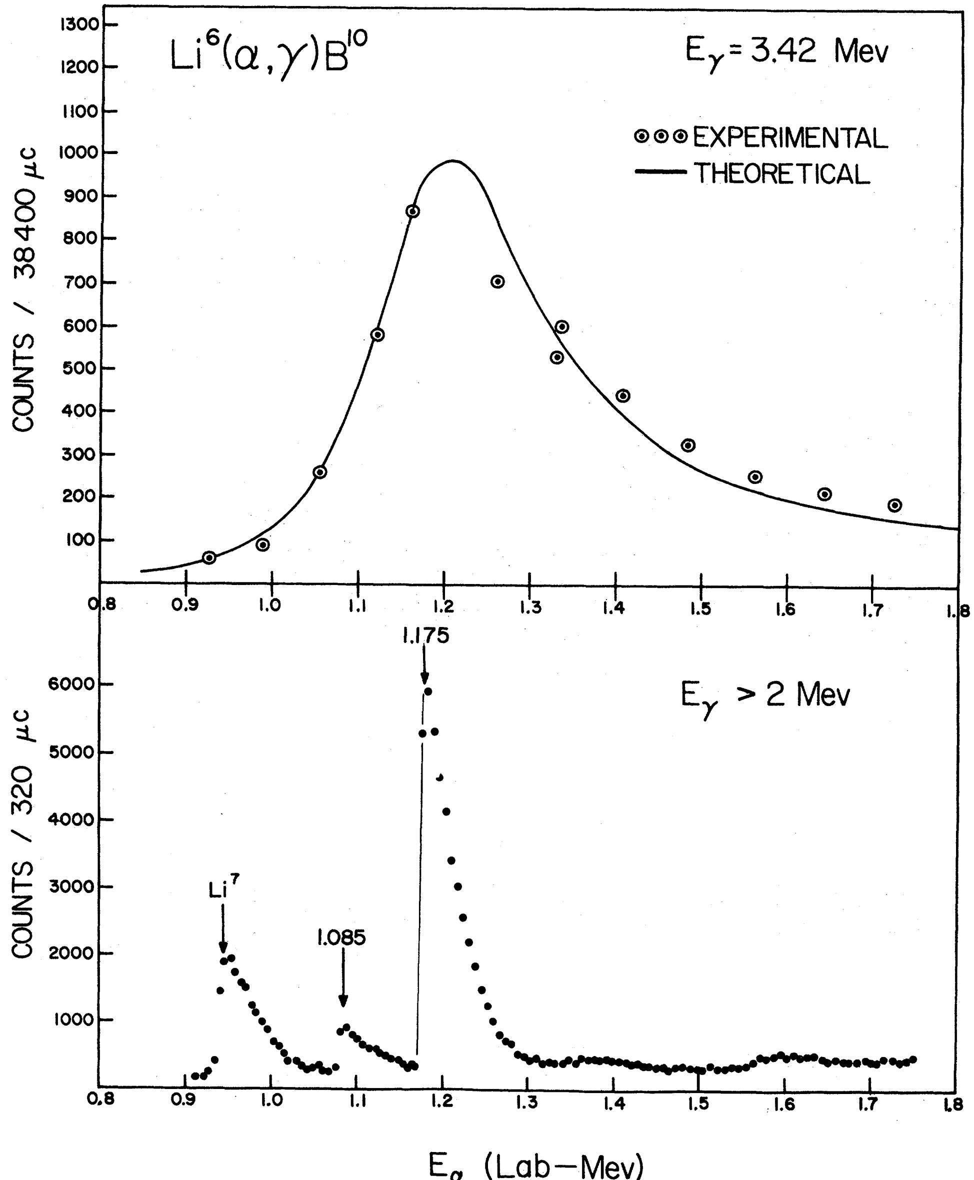

FIG. 2. Yield curves for $Li^6(\alpha,\gamma)B^{10}$. The upper graph shows the coincidence yield of the "3.42-Mev" gamma ray as a function of alpha-particle bombarding energy. The theoretical curve was calculated for the resonance assignments in the text. The lower graph shows the yield of gamma rays of energy greater than 2 Mev. The previously known resonances in $Li^6(\alpha,\gamma)B^{10}$ are indicated by their resonance energies, as is the $Li^7(\alpha,\gamma)B^{11}$ resonance, resulting from the presence of Li^7 in the target. The broad peaks at 1.4 and 1.6 Mev probably result from $C^{13}(\alpha,n)O^{16}$ reactions in carbon deposits on the analyzing slits of the accelerator system.

parameters is given by Sachs.[13] Using an interaction radius of 4.94×10^{-13} cm and assuming s-wave formation, the theoretical curve satisfactorily fit the experimental data when $E_\gamma(\text{lab}) = E_\lambda + \Delta_\lambda{}^0 = 1.210 \pm 0.035$ Mev ($B^{10*} = 5.18$ Mev) and $\Gamma_\lambda{}^0(\text{lab}) = 0.340 \pm 0.050$ Mev. The ~200-kev (c.m.) breadth of the state agrees with the report that the 2.40-Mev gamma ray feeding the state appears to have an observable energy spread.[11,14] The width corresponds to about 86% of the single-particle limit for s-wave (α) formation and 190% for p-wave formation. $Be^9(d,n)B^{10}$ angular distribution data[15] imply a negative-parity state in the 5.1-Mev region for which the newly found state offers the only possibility. However, the large width measured here favors s-wave formation although there is enough uncertainty in the resonance parameters to allow p-wave formation of approximately single-particle width.

Comparison of the thick-target yields for the 3.01- and 3.42-Mev gamma rays, using the previously determined[4] 3.01-Mev gamma-ray yield, provided the value $\Gamma_{\gamma\,3.42} = 0.06 \pm 0.03$ ev. This radiation width corresponds to $|M|^2 \sim 0.06$ which is well within the predicted[16] range of an allowed $M1$ transition. An upper limit of ~1/3 the intensity of the 3.42-Mev transition was placed on any other gamma ray emanating from this broad 5.18-Mev state. The branching ratio $\Gamma_\gamma/\Gamma \sim 3\times10^{-7}$ is consistent with the upper limit of 10^{-2} established by Sprenkel and Daughtry.[11]

The identification of another state in the 5.1-Mev region of B^{10} finally allows a solution of the puzzle regarding the isotopic spin analog of the first excited states in Be^{10} and C^{10}. The 7.56-Mev level decays by 2.40-Mev gamma rays to feed the $J=1$, $T=0$ broad level centered at 5.18 Mev, leaving the previously known narrow 5.16-Mev level for the long sought $J^\pi = 2^+$, $T=1$ state. These assignments allow reconciliation of all conflicting results from the previous experiments described above.

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