Energies and widths of states in ^{9}B

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The reaction ^{9}Be(^{6}Li,^{6}He) has been used to populate states of ^{9}B. Data have been fitted to extract excitation energies and widths of low-lying levels.

The question of energies and widths of low-lying levels of ^{9}B is a timely one. In several cases, a state is known[1] in ^{9}Be, but its mirror is unknown in ^{9}B. Recent work[2] reported the energy and width in ^{9}B of the analog of the 4.7-MeV state of ^{9}Be. But most current work concerns a search for the first excited state of ^{9}B—the analog of the $\frac{1}{2}^{+}$ level[1] at 1.68 MeV in ^{9}Be.

Sherr and Bertsch[3] (SB) did a systematic calculation of Coulomb energies of unbound single-particle states in light mirror nuclei and predicted the $\frac{1}{2}^{+}$ state in ^{9}B to lie at 0.9 MeV, with a large (1.4 MeV) width. Early experimental work is summarized in that paper. On the other hand, Barker[4] in his calculations finds an "inverted" Thomas-Ehrman shift for this level—predicting it to be higher in ^{9}B than in ^{9}Be—in conflict with the calculations of SB.

Kadija *et al.*,[5] with ^{9}Be(^{3}He,t), report finding the state at $E_x = 1.16 \pm 0.05$ MeV, with $\Gamma = 1.30 \pm 0.05$ MeV. The authors of Ref. 2 report[6] $E_x = 1.8 \pm 0.2$ MeV and $\Gamma = 0.8 \pm 0.3$ MeV for the first-excited state of ^{9}B, as populated in the ^{10}B(^{3}He,α)^{9}B reaction, at very low energies.

We have sought to populate the level in question with the ^{9}Be(^{6}Li,^{6}He) reaction. Data were collected with two ΔE-E telescopes. A two-dimensional spectrum of ΔE vs E is displayed in Fig. 1. A software gate on these data allowed for easy separation of ^{6}He from α particles, even though the α's were over a thousand times more prolific.

An energy spectrum of the outgoing ^{6}He, for a beam energy of 32 MeV and a scattering angle of 20°, is displayed in Fig. 2. The ground state and a state at 2.36 MeV dominate the spectra, but a peak between the two is apparent. This peak is probably the looked-for first-excited state. The extracted energy and width of this state depend somewhat on the assumed peak shape, but those differences are smaller than the uncertainties quoted in the following. The fit in Fig. 2 (χ^2 per degree of freedom $=0.2$) includes an exponential background and an experimental Gaussian line-shape resolution width of 300 keV, as determined from the ground state. Natural line shapes of the states were assumed to be of Lorentzian form. Final fitted parameters are listed in Table I, along with measured cross sections at this angle. Our energies and widths are compared with other recent values in Table II. For both the first-excited state and the level at 4.6 MeV, there is (as is well known) a strong interplay between the width and background level if both are allowed to vary in the fitting procedure. Because of this correlation, each width was fixed and the fit performed allowing energies and background level to vary. Then the widths were changed and the fit repeated. Throughout this procedure, the g.s. and levels at 2.36 and 2.79 MeV, and their widths, were held fixed at the values in Table I. From these fits, we quote a width of 0.86 ± 0.26 MeV for the first-excited state, and $\Gamma = 0.68 \pm 0.43$ MeV for the width of the 4.6-MeV level. The state at 3.5 MeV is not listed in the compilation, but we cannot fit the spectrum without including it.

We also attempted a fit that included a broad state near 3 MeV, as reported[7] in (p,n). Those results are displayed in Fig. 3, and the resulting fitted parameters for this broad state are $E_x = 2.946 \pm 0.075$ MeV, $\Gamma = 1.157 \pm 0.148$ MeV, with no need for either the 2.78- or 3.5-MeV states in the fit. The quality of the fit is somewhat poorer than that of Fig. 2, but the effect on the parameters of the 1.3-MeV state is slight—except for an 18% reduction in its cross section. In what follows, we use the results from Fig. 2.

For the first-excited state, the spread among measurements of excitation energy is greater than would be expected from the quoted uncertainties. Arena *et al.* obtain a value closer to the theoretical values of Barker, while the result of Kadija *et al.* is near the energy predicted by SB. Our measured energy lies in between, but closer to the lower value. Our result differs from the lower value by about 1.5 times the combined uncertainty and about 1.7 times from the upper value. If we weight

TABLE I. Results of the reaction ^{9}Be(^{6}Li,^{6}He)^{9}B at $E(^6\text{Li})=32$ MeV and θ (lab) = 20°.

E_x (MeV)	Γ (MeV)	$\frac{d\sigma}{d\Omega}$ (μb/sr)
0[a]	0.54×10^{-3} [a]	40±2
1.32±0.08	0.86±0.26	12.2±2.0
2.361[a]	0.081[a]	19±2
2.788[a]	0.550[a]	19±3
3.48±0.08	0.67±0.22	13±2
4.60±0.16	0.68±0.43	7±3

[a]Held fixed at these values, from Ref. 1.

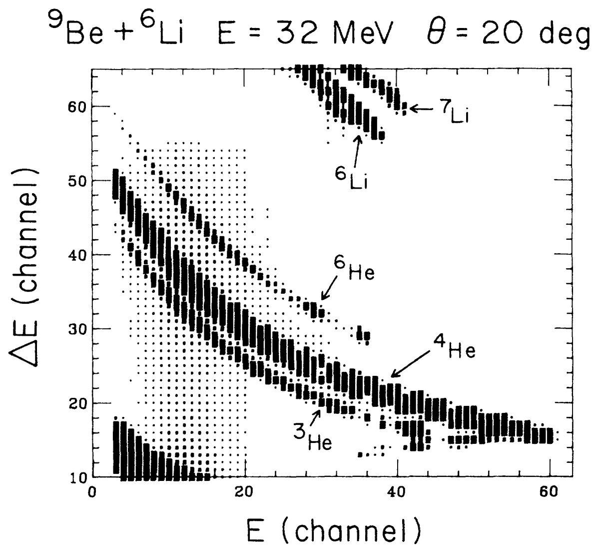

FIG. 1. Two-dimensional ΔE-E spectrum of reaction products from ^{9}Be + ^{6}Li.

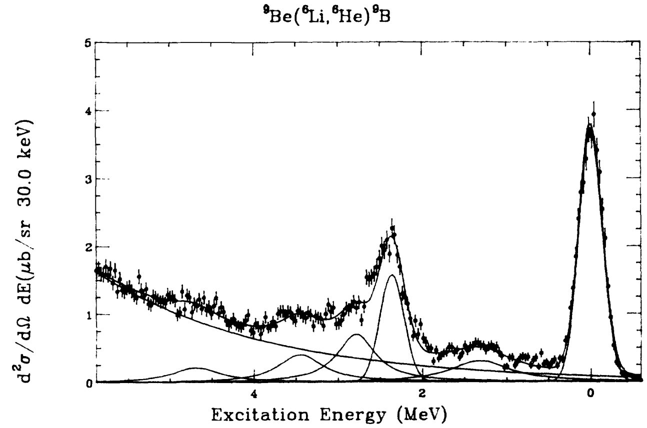

FIG. 2. Energy spectrum of ^{6}He from the reaction ^{9}Be(^{6}Li,^{6}He). Bombarding energy is 32 MeV, and laboratory angle is 20°. Fit is described in the text.

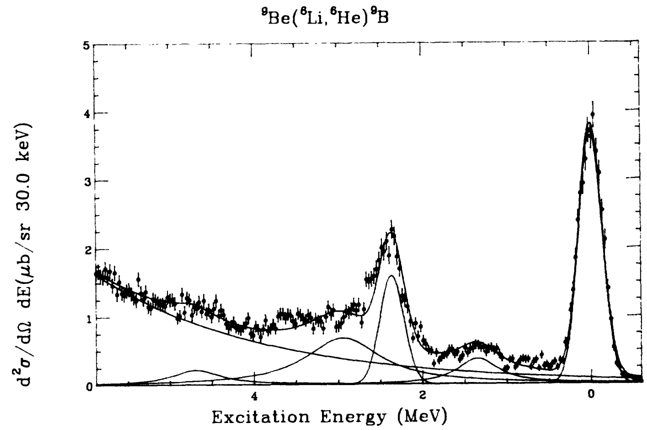

FIG. 3. Same as Fig. 2, but with a broad state at 3.0 MeV.

TABLE II. Energies and widths in ^{9}B.

	First excited state		"4.7-MeV" state	
	E_x (MeV)	Γ (MeV)	E_x (MeV)	Γ (MeV)
Present work	1.32±0.08	0.86±0.26	4.60±0.16	0.68±0.43
Kadija *et al.*[a]	1.16±0.05	1.30±0.05	4.80±0.03	1.5±0.3
Arena *et al.*	1.8±0.2[b]	0.8±0.3[b]	4.9±0.2[c]	1.5±0.3[c]

[a]Reference 5.
[b]Reference 6.
[c]Reference 2.

the measurements according to their quoted uncertainties and average them (a procedure that is perhaps not justified), the result is 1.25 MeV with a weighted χ^2 of about 4. On the other hand, our width agrees with the result of Arena *et al.*, and differs from the result of Kadija *et al.*, by 1.5 times the combined uncertainty.

Our results, in light of the earlier two measurements, suggest that the Thomas-Ehrman shift has the "usual" sign as in SB, rather than "inverted" as in Barker. But, perhaps more measurements are needed because of the large spread in existing values of excitation energy of the first excited state of ^{9}B.

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