Measurement of the 4.8-MeV ^{9}B State Width by the Reaction ^{10}B(^{3}He,α)^{9}B(α)^{5}Li at E(^{3}He) = 2.3 and 5.0 MeV

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The analog of the 4.7-MeV state of the ^{9}Be nucleus has been observed in its mirror ^{9}B by the reaction ^{10}B(^{3}He,α)^{9}B(α)^{5}Li$_{(\mathrm{g.s.})}$ at $E(^3\mathrm{He}) = 2.3$ and 5.0 MeV. The excitation energy and width of the state have been deduced. The value of 1.5 ±0.3 MeV found for the width is in line with the value deduced by the reaction ^{7}Li(^{3}He,n)^{9}B, but it is larger by a factor of about 4 than the one measured by the proton following the β^+ decay of the ^{9}C nucleus.

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While the 4.7-MeV state in the ^{9}Be nucleus has been extensively studied and its relevant parameters quite accurately determined, the same does not hold true for the corresponding state in its ^{9}B mirror. Indeed, the first clear experimental evidence for this state appears in the spectrum of neutrons coming from the reaction ^{7}Li(^{3}He,n)^{9}B studied at $E(^3\mathrm{He}) = 3.1$ MeV by Gul, Armitage, and Hooton.[1] From such a spectrum, these authors found the values of 4.8 ±0.1 MeV and 1.0 ±0.2 MeV, respectively, for the excitation energy and width of the state.

More recently the above ^{9}B state has been observed in the spectrum of the delayed protons following the β^+ decay of ^{9}C measured by Esterl *et al.*[2] Although the contribution of the above state in this spectrum appears as a very small fluctuation superimposed on a strong background, these authors assign an excitation energy of 4.8 ±0.2 MeV and a width of 0.4 ±0.2 MeV to it. This latter value is in strong disagreement with the one deduced by Gul, Armitage, and Hooton.

However, the 4.8-MeV ^{9}B peak, although well defined in the spectrum measured by Gul, Armitage, and Hooton, rises on the right-hand side of a very broad and pronounced bump and near the left side of the peak contributed by the 2.83- and 2.3-MeV states of the same nucleus. Because of this, one can expect the width value deduced by Gul, Armitage, and Hooton to be influenced by the errors arising when a small contribution has to be extracted from an intense background. Therefore we decided to perform a new experiment in which the above effect was absent or at least reduced. Taking advantage of the particle decay of the ^{9}B state, we observed it by carrying out a kinematically complete experiment. We formed the ^{9}B state as the intermediate system for the reaction ^{10}B(^{3}He,α)^{9}B(α)^{5}Li and observed in coincidence the α particles first emitted by such a reaction with the ones coming from the α-^{5}Li decay of the ^{9}B state.

We chose to observe this decay channel of the ^{9}B state by bearing in mind the weakness of the contribution of this state to the spectrum measured by Esterl *et al.* In fact, such a weakness shows that the p-^{8}Be channel, the other possible decay channel of the ^{9}B state in question, the only one which could be observed by Esterl *et al.*, appears scarcely populated by the decay of the above state. Although the p-^{8}Be channel presumably does not contribute much to the spectra, in our experiment we avoided the observation of this channel because it could deform our α-α bidimensional spectra. To this end we observed the reaction products by two silicon surface-barrier detectors having just enough depletion-layer widths to stop completely the α particles but not the protons.

Unfortunately, the reaction products which do not interest us and the presence of four bodies in the final state of the reaction do not allow us to place the detectors at arbitrary angles with respect to the ^{3}He-beam direction without degrading the spectra of our concern.

With regard to this point we found the best conditions were met at the 2.3- and 5.0-MeV ^{3}He beam energies when the detectors were placed at the angle pairs $\theta_1 = 60°$, $\phi_1 = 0°$ and $\theta_2 = 75°$, $\phi_2 = 180°$ and at the last energy also at $\theta_1 = 120°$, $\phi_1 = 0°$ and $\theta_2 = 45°$, $\phi_2 = 180°$.

On the other hand, because of the finite width of the ^{5}Li$_{(\mathrm{g.s.})}$ nucleus, another problem arises. In fact, the consequent finite width of the α-^{5}Li$_{(\mathrm{g.s.})}$ channel spreads the recorded α-α coincidence events coming from the three-body reaction ^{10}B(^{3}He,α)^{9}B(α)-^{5}Li$_{(\mathrm{g.s.})}$ on a continuous set of kinematical curves rath-

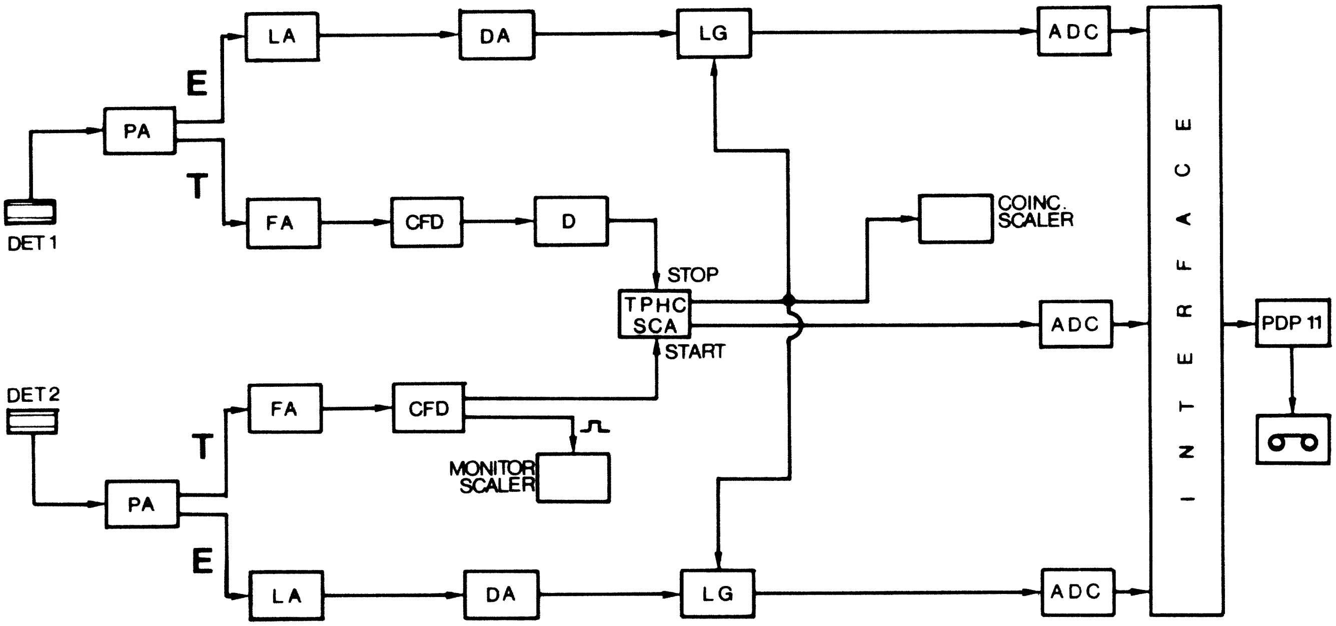

FIG. 1. Sketch showing the experimental apparatus.

er than only on one.

Thus the choice of a unique data projection locus on the coincidence plane becomes questionable. We have overcome this problem by assuming as the data projection locus the central kinematical curve (the one corresponding to the angles defined by the beam direction and the detector axes) and by projecting onto it the data located on a strip around such a curve only 0.6 MeV wide. We performed the data projection by the method we used in all our previous works.[3,4] Although the method works well in deconvolving the data from the finite energy resolution of the detectors when the kinematical curve for the reaction is unique, because of the narrow width of the projected data strip, we believe that it works in the same way in the present case.

Figure 1 is a sketch of the experimental apparatus. The 2.3- and 5.0-MeV ^{3}He beams were produced by the 7.5-MV Van de Graaf accelerator of the National Laboratories in Legnaro (Padova). The ^{10}B target was obtained by evaporation of metallic boron onto a carbon backing of 30 μg/cm^2 and was about 30 μg/cm^2 thick. The two 100-μm-thick surface-barrier detectors subtended a solid angle of 3.5 msr and were placed, as has been said, at $\theta_1 = 60°$, $\phi_1 = 0°$ and $\theta_2 = 75°$, $\phi_2 = 180°$ in both $E(^3\text{He}) = 2.3$- and 5.0-MeV runs and at $\theta_1 = 120°$, $\phi_1 = 0°$ and $\theta_2 = 45°$, $\phi_2 = 180°$ in the 5.0-MeV one.

The chosen detector thicknesses, while being enough to stop all the α particles, did not do the same for the protons. This, by allowing us to discriminate the α-particle pulses from the proton ones, prevented the detection of the α-p coincidences and left out this last contribution from the spectral region of our interest.

As Fig. 1 shows, the linear pulses were analyzed by being sent to the analog-to-digital–converter inputs of the data-acquisition system through two linear gates. These were gated by the pulses developed at the output of a time-to-pulse-height–converter/single-channel–analyzer system when the timing signals reaching its inputs occurred within a 20-ns time. With such a high resolving time the chance coincidences were reduced to a very low level and no correction to the data was necessary for them.

Figures 2(a), 2(b), and 3 show the distributions of the α-α coincidence events obtained by projection of the data onto the rectified relative central kinematical curve versus the curvilinear abscissa s. Figure 4 shows the same distribution as Fig. 2(a), but we have subtracted the background due to reaction products which do not interest us.

In Fig. 4 two peaks appear, although they are not well resolved. The first peak corresponds to the detection of the α particles emitted in the first step of the reaction by detector 1 and of the ones coming from the ^{9}B decay by detector 2 (type-1 event). The second peak corresponds to the opposite occurrence (type-2 event).

In the same figure, the curves labeled with $E_{2\text{-}3}$ and $E_{1\text{-}3}$ represent the relative energy versus the curvilinear abscissa s associated with the α particles and ^{5}Li nucleus system following the ^{9}B intermediate-state decay. The first curve applies when the type-1 event occurs, and the second one when we have the type-2 event.

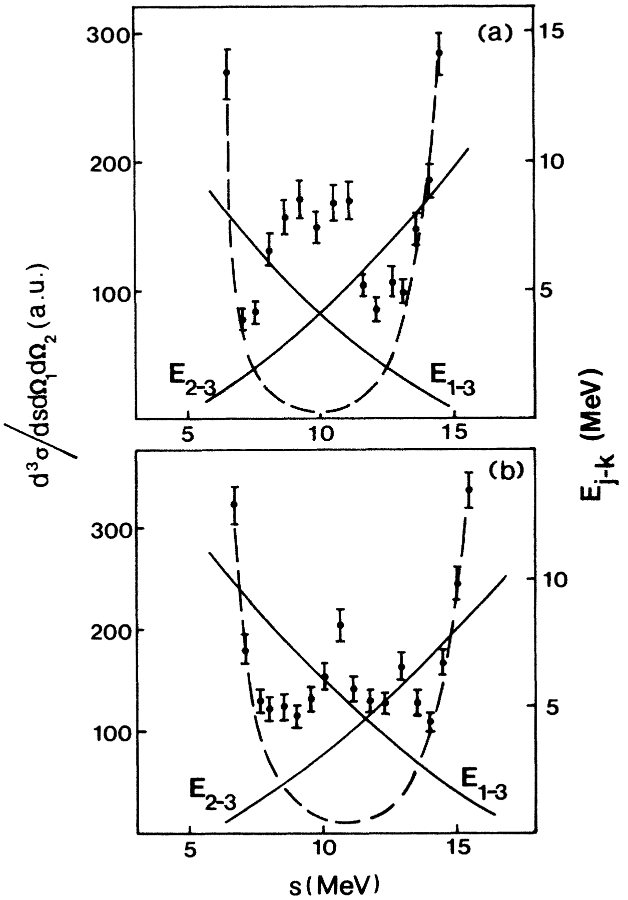

FIG. 2. Distribution of the data along the rectified central kinematical curve vs curvilinear abscissa s for the reaction $^{10}B(^3He,\alpha)^9B(\alpha)^5Li_{(g.s.)}$: (a) $\theta_1=60°$, $\phi_1=0°$ and $\theta_2=75°$, $\phi_2=180°$, $E(^3He)=2.3$ MeV; (b) same as (a), but with $E(^3He)=5.0$ MeV. The dashed lines limit the portions of the spectra contributed by the studied ^9B state. For the meaning of the continuous lines labeled with $E_{1\text{-}3}$ and $E_{2\text{-}3}$ see text.

As one can see in this figure, each of the above-mentioned peaks represents its maximum at an α-$^5Li_{(g.s.)}$ relative energy of about 3.2 MeV, and therefore, if the reaction proceeds through a strictly sequential mechanism, these peaks indicate the existence of a state in the ^9B nucleus at an excitation energy of 4.9 MeV when such an energy is referred to the ground state of the same nucleus.

In order to separate the events contributing to the two peaks, we used the MINUIT code as we did in similar situations in our previous works.[3-5] If one neglects the interference effect due to the identity of the particles and one assumes that the event distribution on each peak can be represented by the Lorentzian form in the relative-coordinates system, the MINUIT code allows us to determine the position and width of each peak. The results obtained by the code are represented by the various curves shown in Fig. 4.

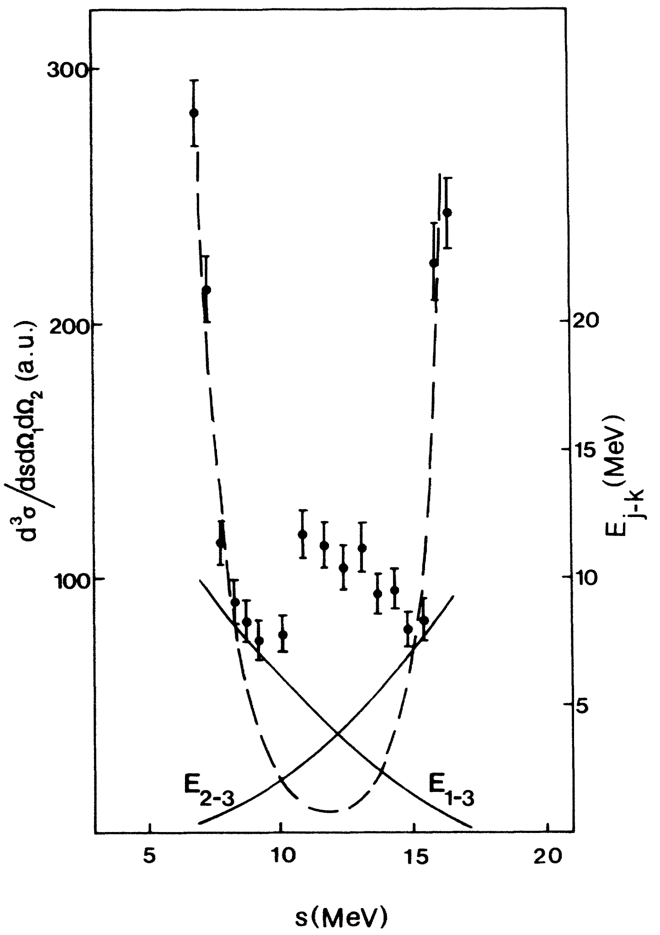

FIG. 3. Same as Fig. 2(b), but with $\theta_1=120°$, $\phi_1=0°$ and $\theta_2=45°$, $\phi_2=180°$.

From an averaging of the values of the energies corresponding to the peaks and their widths as deduced by the MINUIT-code analysis for the three distributions shown in Figs. 2(a), 2(b), and 3, our best estimates for the excitation energy and width of the studied ^9B state are

$$E_x=4.9\pm0.2 \text{ MeV}$$

and

$$\Gamma=1.5\pm0.3 \text{ MeV},$$

respectively. The estimated measurement errors take into account both the statistical errors and the finite energy-resolution power of the electronic system used.

While the excitation-energy value we found agrees with the ones reported by other authors,[1,2,6] the same cannot be said for the width. Indeed, our value is in good agreement with the one found by Gul, Armitage, and Hooton, but it differs by a factor of about 4 with respect to the one reported by Esterl *et al.*

Although the peaks contributed by the 4.9-MeV ^9B

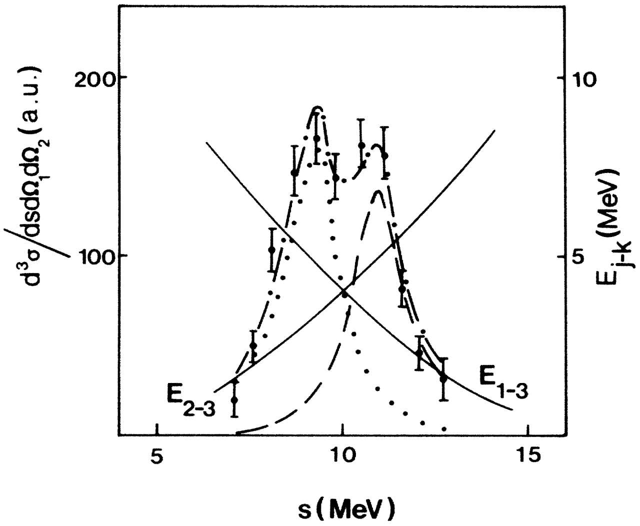

FIG. 4. Distribution of the data shown in Fig. 2(a). Dotted and dashed lines represent the contributions, as obtained by the MINUIT-code analysis, for the data associated with the type-1 and type-2 events, respectively (see text). The dash-dotted line represents the sum of the two contributions.

state are not well resolved in our spectra, they are quite well enough pronounced to indicate that the α-^{5}Li channel, which had not yet been observed, is an efficient decay channel for the above ^{9}B state.

On the other hand, because the deduced widths are in good agreement among themselves within the experimental errors, a sequential mechanism appears to be appropriate for the reaction at the ^{3}He bombarding energies at which the reaction has been studied.

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