Evidence for a nuclear level in ^{11}B at 16.43 MeV

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Evidence for a level at 16.43 MeV in ^{11}B is found in excitation functions measured for outgoing proton channels from the reaction ^{9}Be + d. Supporting evidence for this level is found in earlier works.

In 1951, Resnick and Hanna[1] drew attention to an anomaly at 700 keV in the excitation function at 90°(lab) for the long-range protons from the reaction ^{9}Be + d. Canavan[2] concluded that a small step in his excitation function for the same measurement was within his experimental error. Although there have been more recent measurements[3,4] of the outgoing p_0, α_0, α_1, and t_0 groups from this reaction, there has been no further comment on the existence of structure at this energy. Close scrutiny of the data presented in these reports[3,4] provides supporting evidence for the presence of this feature.

In the present work, the ^{9}Be + d reaction was studied for an incident-deuteron energy range from 0.3 to 0.9 MeV in steps of 10 keV. Differential cross-section excitation functions at seven angles between 30 and 150° were measured for the reactions: ^{9}Be$(d, p_0)^{10}$Be (ground state); ^{9}Be$(d, \alpha_{0,1})^{7}$Li (ground and 0.471-MeV first excited state); ^{9}Be$(d, t_0)^{8}$Be (ground state). Deuterons were accelerated using the 1-MeV Cockroft-Walton accelerator of the University of the Witwatersrand. The machine voltage was calibrated using the well-known ^{27}Al$(p, \gamma)^{28}$Si resonances, so that the deuteron beam energy was defined to ±2 keV. Self-supporting foils of natural Be 15 to 25 keV thick for 750-keV deuterons were used as targets.

The protons from the reaction ^{9}Be$(d, p_1)^{10}$Be leading to the first excited state of ^{10}Be at 3.37 MeV are obscured over a wide angular range by the protons from the ^{16}O$(d, p_1)^{17}$O first excited state reaction, which prevented the direct measurement of the p_1 group. As a result, this excitation function was measured indirectly using a 30-cm^3 Ge(Li) detector at 90°(lab) to detect the γ rays from the decay of the 3.37-MeV first excited state of ^{10}Be.

Figure 1 shows the differential cross-section and the total cross-section excitation functions for the p_0 group. Three-point smoothing has been applied to the experimental points in all the excitation functions. The cross sections increase monotonically with energy, except for the region between 0.720 and 0.780 MeV where a small fluctuation occurs. The cross section increases less slowly than predicted by deuteron penetrability considerations reflecting the direct nature of the (d, p) reaction in this energy region.

For the p_0 group, the shape and position of the feature are well defined in the total cross section and at all angles, but it is larger at backward angles. The excitation function for the p_1 group shown in Fig. 2(a) exhibits a similar resonant effect in the same region. There is a very weak indication of the anomaly in the excitation functions for the α_0 group, but it is not apparent for the α_1 and t_0 groups. The total cross-section excitation functions for these groups are shown in Fig. 2(b). From the p_0 data, the observed fluctuation occurs at 750 ± 15 keV with a width of approxi-

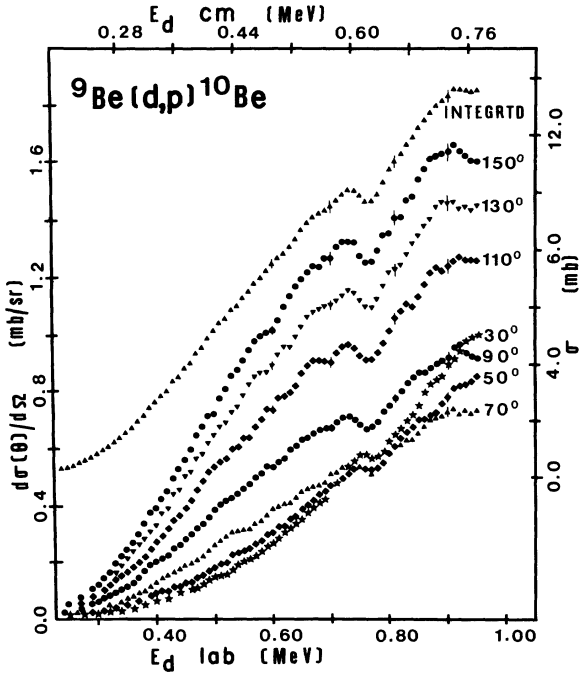

FIG. 1. Differential and integrated cross-section excitation functions for the reaction ^{9}Be$(d, p_0)^{10}$Be. Three-point smoothing has been applied to the experimental points.

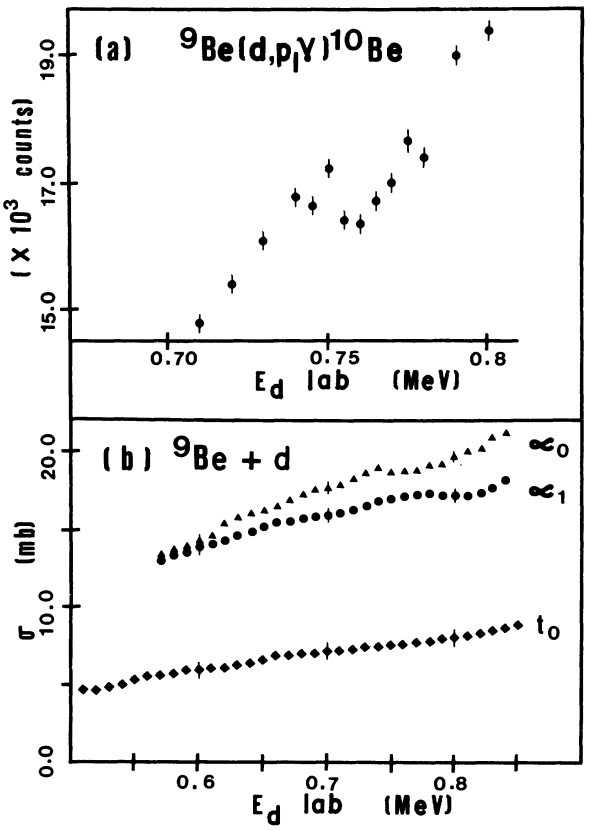

FIG. 2. (a) Excitation function for the ^{9}Be(d, p_1)^{10}Be* (first excited state) reaction. (b) Integrated excitation functions for the reactions ^{9}Be(d,α_0)^{7}Li, ^{9}Be(d,α_1)^{7}Li* (first excited state), and ^{9}Be(d,t_0)^{8}Be. Three-point smoothing has been applied to the experimental points.

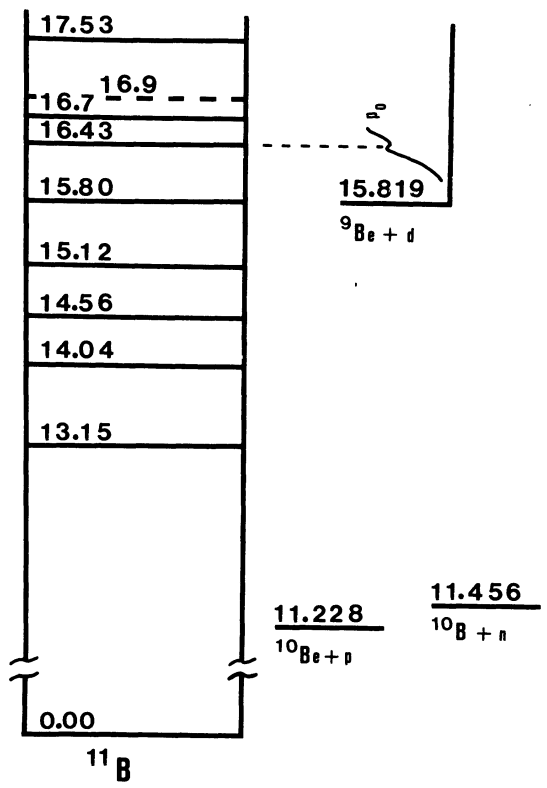

FIG. 3. Energy level scheme of ^{11}B in the region of interest, showing the position of the proposed level at 16.43 MeV.

mately 40 keV.

Figure 3 shows the ^{11}B level diagram[5] in the energy region of interest. The energy region in the ^{11}B compound-nuclear system corresponding to the region studied is devoid of levels between the known states at 15.80 and 16.70 MeV, the latter corresponding to an incident-deuteron energy of 1.08 MeV. The thresholds for neutron emission to the 4.77-, 5.11-, and 5.7-MeV excited states in ^{10}B occur for incident deuteron energies of 520, 591, and 989 keV, respectively,[6] and are well removed from the position of this anomaly. It is therefore concluded that the resonance in the cross sections at 750 keV is a compound-nuclear effect that may indicate the presence of a level in ^{11}B at an energy of 16.43 ± 0.02 MeV. Any change in the shape of the angular distribution on passing through the anomaly is too small to assist in deducing the properties of the level.

The literature has been examined for evidence of this level in the excitation functions of other reactions leading to excited states above 12 MeV in the ^{11}B compound system. A level at 16.5 MeV in ^{11}B has been identified from the measurement of the ^{11}B(γ, p)^{10}Be reaction by Sorokin *et al.*[7] who have measured the energy distributions of the photoprotons emitted by ^{11}B bombarded with bremsstrahlung γ radiation with E_{max} = 16.5 and 18.5 MeV. Their spectra revealed a large number of proton groups which they associate with the excitation of ^{11}B levels in the range 12 to 18 MeV. Four of these levels are unreported previously. Their results include indications of levels at 16.2 ± 0.1 MeV (one of the new levels) and at 16.5 ± 0.1 MeV, which was implicitly equated with the tabulated level at 16.7 MeV. Sorokin has also reexamined results from the ^{11}B(γ, n)^{10}B reaction[8] and finds confirmation of a level at 16.5 MeV. These results can be regarded as being in agreement with the present evidence of a level at 16.43 ± 0.02 MeV.

The elastic scattering of deuterons on ^{9}Be [9] and neutron yields from the ^{9}Be(d, n)^{10}B [10-12] reaction do not give any indication of an anomaly, nor is there any indication of structure in the total neutron cross sections for ^{10}B, in the incident-neutron energy range 5 to 6 MeV.[13,14] Measurements

of the reactions ^{9}Be$(d,\gamma)^{11}$B,[15,16] ^{7}Li$(\alpha,\alpha)^{7}$Li,[17] and ^{7}Li$(\alpha,n)^{10}$B[18] are too poorly defined in the region of interest. The ^{9}Be$(d,\gamma)^{11}$B reaction as studied by Battleson and McDaniels[16] was not done in sufficiently fine steps in the range 0.5- to 1-MeV incident deuteron energy to interpret unambiguously. Work on ^{10}B$(n,\alpha_0)^{7}$Li[19] and ^{10}Be$(p,\gamma)^{11}$B[20] has been reported in the energy region of interest. In both cases, the authors analyze large resonances in the excitation curves, which occur below an energy corresponding to an excitation of 16 MeV in the ^{11}B system. They do not comment on smaller fluctuations at higher energies which, if significant, would indicate the presence of states in the region 16 to 17 MeV in ^{11}B.

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