Energy Levels in Be^9

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(Received March 3, 1955)

Magnetic analysis of the reaction $B^{11}(p,\alpha)Be^9$ at three angles verifies the existence of rather broad excited states of Be^9 at 1.75 and 3.02 Mev, the peaks of which almost vanish at 90° where the original investigation showed only the well-known 2.43-Mev state.

In addition to the 2.43-Mev state of Be^9 observed with high resolution in the reaction[1] $B^{11}(d,\alpha)Be^9$, and in inelastic scattering,[2] rather definite indications of levels at 1.8, 3.1, and 4.9 Mev have been more recently reported[3] on the basis of scintillation crystal spectrometry in the reaction $Li^7(He^3,p)Be^9$ and[4] in $B^{10}(t,\alpha)Be^9$. Both observations were made at 90°. The possible existence of the additional levels is of interest because the intermediate-coupling interpretation[5] requires several levels in this energy region, and is consistent with having the first three excited states rather close together.

We have observed the reaction $B^{11}(d,\alpha)Be^9$ with $E_d=1.51$ Mev, as in reference 1, at three angles, analyzing the alpha energies with our two-dimensional-focusing magnetic spectrometer.[6] The procedure was similar to that used in the preceding paper. The resolution was poorer in this work than can ordinarily be obtained with this instrument because of difficulties in stabilizing the field. The data are shown in Figs. 1, 2, and 3. The ground state and 2.43-Mev state peaks appear prominently at all angles, and at 50° and 101° (lab) peaks corresponding to states at 1.75 and 3.02 Mev also appear rather clearly. At 90° they are barely discernable above background. These peaks appear to be perhaps significantly wider than the instrumental width indicated by the sharper peaks, suggesting appreciable natural width of the states. These curves indicate excited states of Be^9 at 1.75±0.02, 2.43±0.02, and 3.02±0.03 Mev, in good agreement with the work

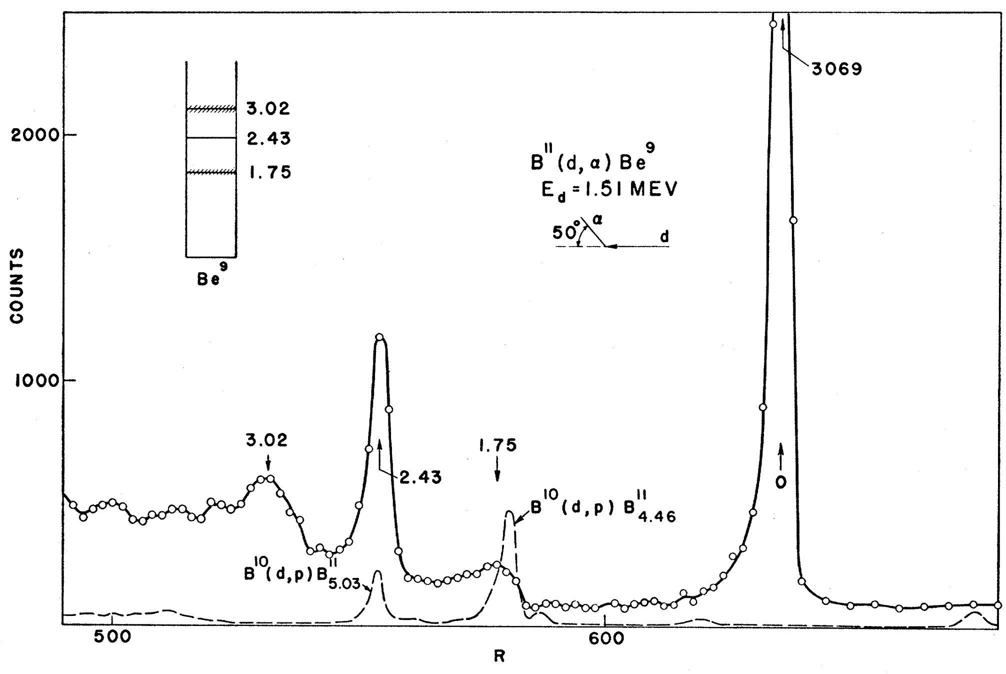

FIG. 1. Momentum analysis of $B^{11}(d,\alpha)Be^9$ at 50°. The broken line indicates protons.

* Work done under the auspices of the U. S. Atomic Energy Commission.
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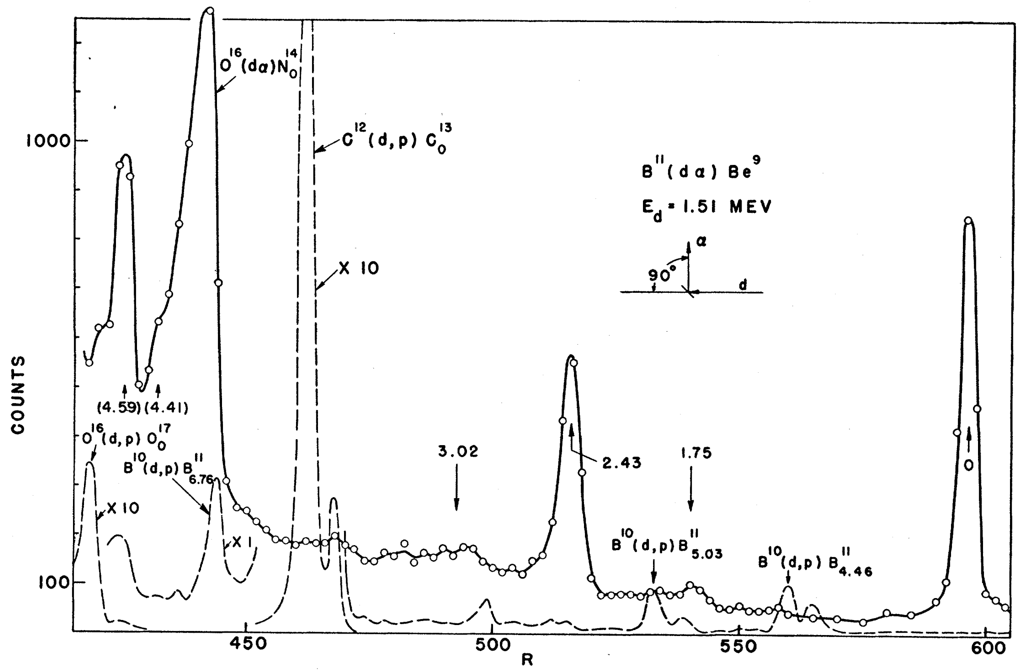

FIG. 2. Momentum analysis of $B^{11}(d,\alpha)Be^9$ at 90°.

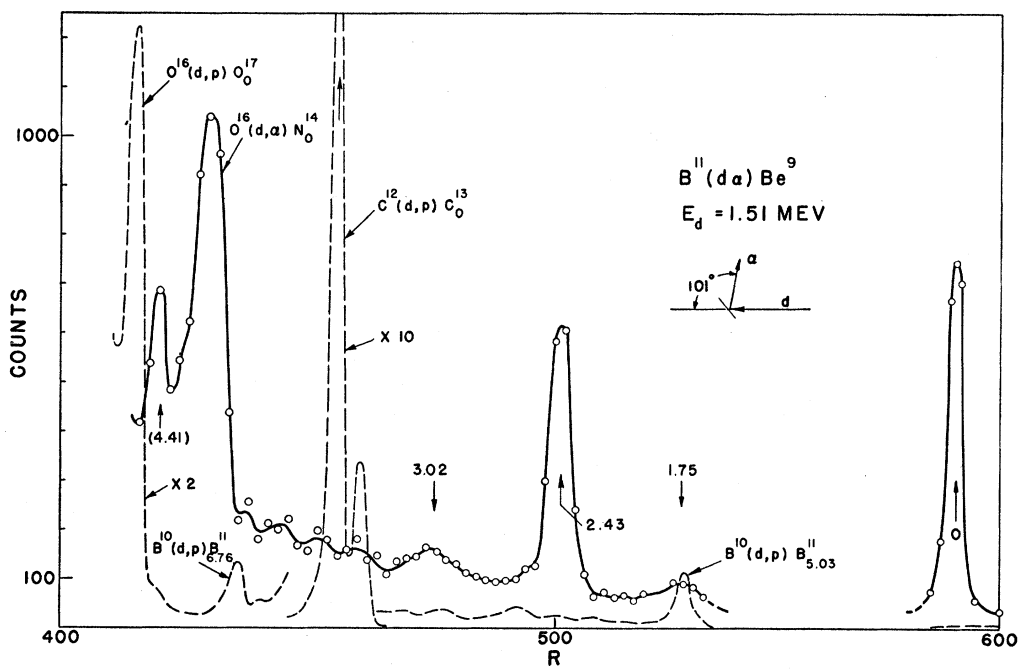

FIG. 3. Momentum analysis of $B^{11}(d,\alpha)Be^9$ at 101°.

of Moak, Good, and Kunz.[3] The apparent large natural width of the 1.75- and 3.02-Mev groups, and their low intensity, especially at 90°, explain their not having been seen by Van Patter *et al.*[1] with high resolution which enhances sharp peaks.[7]

Figures 2 and 3 show a very strong peak from $O^{16}(d,\alpha)N^{14}$. The region between this and the 3.02-Mev

[7] It has been pointed out [G. C. Phillips *et al.*, Bull. Am. Phys. Soc. **30**, No. 3, 55 (1955), not given in abstract] that the observed peak at 1.75-Mev excitation could be due to the onset of three-body breakup. While our results do not completely contradict this interpretation, we find it difficult to attribute entirely to calibration error the difference between our apparent onset of 1.56 Mev in Fig. 1 and the 1.665-Mev threshold for three-body breakup. A recent analysis by D. Kurath, more refined than in reference 5, suggests that only the first two excited states of Be^9 lie close together, which favors the three-body interpretation.

state peak exhibits a fluctuating background without enough consistency with angle to permit specific assignments.

Additional groups of particles discriminated as alphas are observed for $E_\alpha = 3.21 \pm 0.03$ Mev at 90° and $E_\alpha = 3.10 \pm 0.03$ Mev at 101° (Figs. 2 and 3). We have been unable to assign these to plausible contaminations of the natural boron target on a thick tantalum backing. If assigned to $B^{11}(d,\alpha)Be^9$, they correspond to states at 4.59 and 4.41 Mev in Be^9. These might correspond to the broad 4.9-Mev level reported in reference 3, although it seems unlikely that such groups would have been missed in the high-resolution work of reference 1. We suggest instead that they are probably spectroscopic[6] "ghosts" of the adjacent $O^{16}(d,p)O^{17}$ peaks. Such a ghost appears, for example, on the high-energy side of the $C^{12}(d,p)C^{13}$ peak at both 90° and 101°. The pulses of these peaks are discriminated in the surplus above the alpha channels and thus recorded as protons, though with more careful discrimination the ghost pulses have ordinarily been found between the larger pulses of the direct proton peak and the smaller alpha pulses, the ghost protons presumably having lost energy on scattering from the inner (small-radius) wall of the deflection chamber. Apparently in the energy region of the peaks in question the ghost pulses happen to fall just in the alpha channels, for they do not appear elsewhere. We have thus not indicated levels corresponding to these peaks in the energy level diagram shown in the small insert of Fig. 1, even as broken lines, but further investigation of the region above 4 Mev is surely needed. The deuteron scattering edge at an equivalent of about 4.6 Mev in Be^9 prevented our observation of states at higher energies.

PHYSICAL REVIEW VOLUME 99, NUMBER 1 JULY 1, 1955

Photofission of U^{238}

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Chemical separation of the products resulting from photofission at various maximum bremsstrahlung energies E_0 of U^{238} serve to define the 3-dimensional yield surface $S(Y,A,E_0)$. An analysis of this surface by the photon difference method established the 3-dimensional photofission cross section surface $S(\sigma,A,h\nu)$. The peak-to-valley cross section ratio (asymmetric to symmetric fission) is examined in some detail and the results are combined with high-energy photofission data from the literature to extend our calculations and analysis to 300 Mev.

INTRODUCTION

PHOTOFISSION, the fission process induced by nuclear absorption of electromagnetic energy, has been the subject of a number of investigations. For a discussion of the earlier work in this field the review article by Spencer and Ford[1] may be consulted. The early work indicated that the cross section for photofission, $\sigma_{\gamma f}$, increased from zero at the threshold to a maximum value at about 14 Mev and decreased thereafter with increasing energy. This cross-section shape is similar to that found for other photonuclear reactions and is termed the "giant" resonance cross section.[2–4] Recent work by Duffield and Huizenga[5] has shown that this giant photofission cross section in U^{238} has a peak value of about 0.18 barn and a width of 7 Mev at half-maximum.

An examination of the photofission yield as a function of mass number, at a given photon energy shows it to have the usual double humped mass distribution. Schmitt and Sugarman[6] have studied the shape of such mass-yield curves from natural uranium when irradiated with bremsstrahlung of maximum energy $E_0 = 7$, 10, 16, 21, 48, 100, and 300 Mev. Since these curves contain contributions from all photons in the spectrum whose energy is above the photofission threshold (5.1 Mev in uranium)[7] the direct interpretation of their curves is somewhat difficult.

Richter and Coryell[8] have given photofission mass-yield curves for natural uranlum at energies $E_0 = 10$ and 16 Mev. Hiller and Martin[9] published a similar curve for thorium obtained with bremsstrahlung of 69-Mev peak energy.

In line with other photonuclear investigations being carried out in our laboratory we have studied the photofission process in natural uranium as a function of

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