and $\bar{E}_f$ and the consistency of $\mathcal{I}/\mathcal{I}_R$ as a function of $\bar{E}_f$ for six reactions on four widely varying nuclei support the validity of this method for interpreting isomeric-ratio data. This agreement suggests the possibility of using experimental isomeric ratios to obtain quantitative information about the region of applicability of the Gaussian form of the level-density expression, the dependence of the nuclear level density upon angular momentum, the dependence of $\mathcal{I}$ upon excitation energy, and the spin distribution in nuclei formed following particle emission.

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Investigation of the $T=\frac{3}{2}$ State at 16.97 MeV in Be^9

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A resonance in the Li^7+d reaction at a deuteron bombarding energy of 361 ± 2 keV, corresponding to a level in Be^9 at 16.97 MeV, has been investigated. Total cross sections for $Li^7(d,p_0)$ Li^8 were measured by detecting induced Li^8 activity for deuteron energies between 340 and 780 keV. In agreement with earlier work of Woods and Wilkinson, a resonance in this reaction was observed on a background rapidly decreasing with decreasing deuteron energy. This resonance and the surrounding region from 0.1 to 1.1 MeV were also studied with the $Li^7(d,\gamma)$ Be^9 reaction by measuring the yield of the gamma-ray transitions to the lower states of Be^9 with a NaI crystal. The measured width of the level was less than 600 eV in the laboratory system. The angular distribution of the on-resonance gamma rays to the ground state was isotropic to within 7%. Branching ratios for the gamma rays to several states in Be^9 were measured with a NaI crystal, a scintillation pair spectrometer, and a NaI crystal surrounded by an anticoincidence shield. The relative intensities for the gamma-ray transitions to the ground state and to the states at 1.70, 2.43, 3.04, and 4.74 MeV were found to be 100, 8.5 ± 4.3, 10.6 ± 5.3, ≤4.5, and 9.6 ± 4.8, respectively. The 15.3-MeV gamma-ray transition indicates the existence of a level in the usual sense at 1.70 MeV in Be^9. From the gamma-ray measurements below resonance at 300 keV an upper limit of 1.6×10^{-30} cm^2 was found for the direct (d,γ) cross section to low-energy states in Be^9. For the $Li^7(d,n)$ reaction, the yield of neutrons with energies above 10 MeV showed a resonance at the same energy. From neutron time-of-flight measurements relative to coincident gamma rays, neutron groups were seen corresponding to breakup of levels in Be^9 at 2.43 and 4.74 MeV. The $Li^7(d,d)$ Li^7 and $Li^7(d,\alpha)$ He^5 reactions did not show observable resonance effects. From the above results, the reduced widths for neutron and alpha-particle emission are found to be considerably smaller than the corresponding width for protons, thus supporting the hypothesis that the state in Be^9 at 16.97 MeV has an isobaric spin of $\frac{3}{2}$.

I. INTRODUCTION

A VERY narrow resonance in the $Li^7(d,p)Li^8$ reaction at a deuteron bombarding energy of about 360 keV was first observed by Woods and Wilkinson[1] while studying low-Q stripping reactions; no analysis of the level was presented at that time. Confirming results and additional information on this resonance were obtained by Imhof, Chase, and Fossan.[2] Recent interest in this state has resulted from the observations by Lauritsen, Lynch, and Griffith[3] and by Griffith[4] of a narrow (<5 keV) level in Be^9 at 14.392 ± 0.005 and by Middleton and Pullen[5] of the first excited state of Li^9 at 2.691 ± 0.005 MeV. These latter results, coupled with the early observations by Woods and Wilkinson[1] and by Imhof, Chase, and Fossan[2] have enabled Woods and Wilkinson[6] to make a probable identification of this level in Be^9 at 16.97 MeV as the second $T=\frac{3}{2}$ state which corresponds to the first excited state of Li^9. The 14.392-MeV level in Be^9 which is analogous to the ground state of Li^9 would be the first $T=\frac{3}{2}$ state.

Further analysis of the 16.97-MeV level in Be^9 has been limited by the lack of complete experimental information. If the level is $T=\frac{3}{2}$, the neutron, deuteron, and alpha channels would be strongly inhibited because

[1] D. H. Wilkinson, *Proceedings of the International Conference on Nuclear Structure, Kingston, 1960* (North-Holland Publishing Company, Amsterdam, 1960), p. 42.
[2] W. L. Imhof, L. F. Chase, and D. B. Fossan, Bull. Am. Phys. Soc. **9**, 391 (1964).
[3] T. Lauritsen, B. Lynch, and G. Griffith, Bull. Am. Phys. Soc. **8**, 597 (1963).
[4] G. Griffith, Bull. Am. Phys. Soc. **8**, 597 (1963).
[5] R. Middleton and D. J. Pullen, Nucl. Phys. **51**, 50 (1964).
[6] J. B. Woods and D. H. Wilkinson, Nucl. Phys. **61**, 661 (1965).

of the isotopic-spin rule while the proton and gamma-ray channels are allowed. Because of the low-energy available to the proton, the proton width is expected to be small, however. The purpose of this paper is to report additional investigations of this level for the various exit channels; i.e., investigations of the reactions $Li^7(d,\gamma)Be^9$, $Li^7(d,p)Li^8$, $Li^7(d,n)Be^8$, $Li^7(d,d)Li^7$, and $Li^7(d,\alpha)He^5$. In particular, a lower upper limit for the total width has been obtained, branching ratios and angular distributions for the gamma-ray decay have been measured, and relative widths for gamma-ray, proton, and neutron emission as well as upper limits for deuteron and alpha emission have been derived from the observations.

II. THE REACTION $Li^7(d,\gamma)Be^9$

Measurements for this experiment were performed with the deuteron beam of the Van de Graaff accelerator at the Lockheed Research Laboratories. However, one set of runs, as described below, was carried out on the 3-MeV Van de Graaff accelerator at Stanford University. The targets consisted of enriched Li^7 or natural lithium evaporated onto a tantalum backing. The thickness of the lithium deposit, depending upon the nature of the run, was either comparable to or considerably thicker than the resonance width.

Measurements of the energy and width of this level in Be^9 formed by Li^7+d were made by the observation of emitted gamma rays with a 4-in. diameter by 4-in. long NaI(Tl) crystal. With 2 in. of lead shielding on the sides of the crystal, measurements of the high-energy gamma rays were obtained at observation angles of 90° or greater. For these measurements, pulses were recorded in the energy interval ~12–17 MeV. Energy calibration points for the Van de Graaff analyzing magnet were obtained at settings near the $Li^7(d,\gamma)$ resonance by observing the narrow $Al^{27}(p,\gamma)Si^{28}$ resonance at 992 keV with an H^+ beam and the $Li^7(p,\gamma)Be^8$ resonance at 441 keV with an H_2^+ beam. From several runs with thick lithium targets, the energy of the $Li^7(d,\gamma)Be^9$ resonance was found to be 361 ± 2 keV. This energy corresponds to a state in Be^9 at 16.973 MeV.

An attempt was made to obtain an accurate value of the resonance width by a procedure which avoids the errors involved in changing the accelerator focus and magnet settings for small energy steps. With these accelerator parameters held constant, a variable voltage was applied to the lithium target. A further reduction in the energy spread due to time variations was achieved by programming the target to cycle through four different voltages at 2 sec intervals and appropriately routing the pulses for scaler storage. The results of several sets of runs in which the NaI crystal was placed at ~120°, are shown in Fig. 1. For displaying the resonance width the runs at different accelerator energies have been normalized in energy to lie on the same yield curve. Although several sets of runs are displayed together in

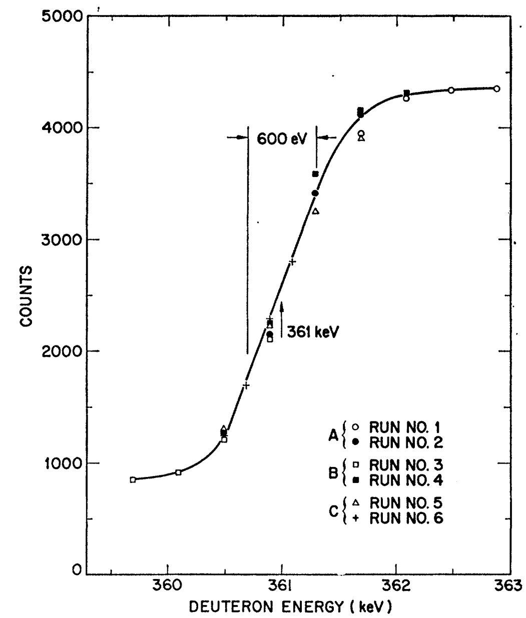

FIG. 1. The yield of gamma rays in the energy interval ~12–17 MeV, at 120°, from the reaction $Li^7(d,\gamma)Be^9$. Three sets of runs, A, B, and C, are shown for constant settings of the accelerator focus and magnet, but with a variable voltage applied to the lithium target.

Fig. 1, the resonance width was obtained independently from each set of four points. Intercomparison of the runs at different accelerator energies is necessary only to provide a counting rate level for the points above and below resonance. The best value for the measured interquartile width obtained from these runs is 600 eV, as indicated in the figure. The contribution from Doppler broadening, estimated to be less than 100 eV, is probably negligible compared to the unknown contributions from the spread in beam energy and the spread due to possible nonuniformities in the target composition. Thus an upper limit of 600 eV is placed on the resonance width.

The branching ratios for the different gamma rays are difficult to measure because of the broad line shape of NaI at these high energies and because the highest energy gamma ray is dominant. Initial measurements were performed with a 4-in. diameter by 4-in. long NaI(Tl) crystal. In order to obtain more accurate branching ratios, a pair spectrometer was used in which a 2-in. diameter by a 3-in. long NaI(Tl) crystal was placed between two 4-in. diameter by 4-in. long NaI(Tl) crystals. Finally, a set of measurements was made at Stanford University using a detector that consisted of a 5-in. diameter by 6-in. long NaI(Tl) crystal surrounded by an anticoincidence shield.[7] The best values of the branching ratios obtained from all of the data are given in Table I. The pulse-height spectra observed

[7] P. Paul, S. L. Blatt, and D. Kohler, Phys. Rev. **137**, 493 (1965). An improved version of the described system was used.

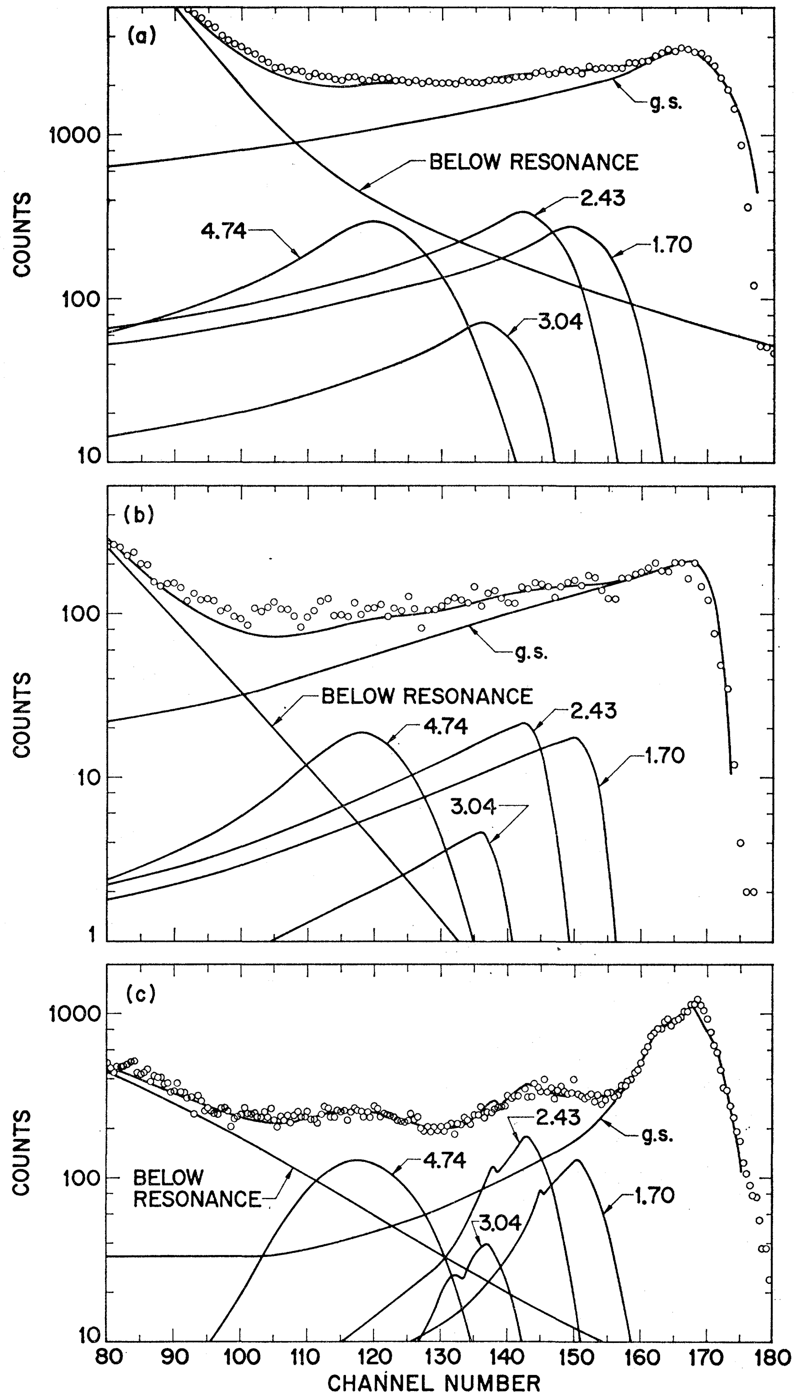

FIG. 2. The on-resonance gamma-ray spectra from the $Li^7(d,\gamma)Be^9$ reaction observed with the following experimental set-ups: (a) a 4-in. diameter by 4-in. long NaI(Tl) crystal; (b) a 2-in. diameter by 3-in. long NaI(Tl) crystal placed between two 4-in. diameter by 4-in. long NaI(Tl) crystals, and (c) a 5-in. diameter by 6-in. long NaI(Tl) crystal surrounded by an anticoincidence shield. In each case the line shapes and intensities of contributing gamma rays which correspond to the branching ratios given in Table I are shown. (g.s.≡ground state).

with each of these experimental set-ups are shown in Fig. 2. Also displayed are the line shapes and intensities of the contributing gamma rays corresponding to the branching ratios given in Table I. It has been assumed that the observed gamma rays correspond to transitions directly from the 16.97 MeV state to lower states in Be^9. This interpretation is based on the consistency of the observed spectrum with known positions of the low energy levels and on the results of an unsuccessful attempt to observe, with two 4-in. diameter by 4-in. long NaI crystals, a cascade through the state at 14.39 MeV.

Angular distributions of the emitted gamma rays were measured with a 4-in. diameter by 4-in. long NaI(Tl) crystal. In order to reduce the contribution from background neutrons at forward angles, the measurements were made with an 18-cm long paraffin cone

TABLE I. Gamma-ray branching ratios.

Final state of transition (MeV)	Energy of the gamma ray (MeV)	Relative intensities
Ground state	16.97	100
1.70	15.27	8.5±4.3
2.43	14.54	10.6±5.3
3.04	13.93	≤4.5
4.74	12.23	9.6±4.8

and a 5-cm thick boron absorber placed before the NaI crystal. Very thin lithium targets were also used to help minimize the off-resonance neutron production. For the gamma-ray energies considered, the background was small in comparison with the statistical uncertainties; furthermore, its angular distribution was not greatly different from the measured one. For the angular distribution measurements the target was oriented at various angles in order either to avoid completely or to properly account for the attenuation of the gamma rays in the tantalum backing. The thickness of brass through which the gamma rays passed in emerging from the target chamber was nearly the same (1.27 g/cm^2) at all angles of observation. The resulting angular distribution of gamma rays above 11.5 MeV is shown in Fig. 3 and is seen to be isotropic within about 3%. Angular distributions for the individual gamma rays were difficult to obtain since their relative contributions were not clearly resolved in the pulse-height spectra. Thus, the statistical accuracies of the angular distributions for each of the gamma rays, except to the ground state, were not sufficiently good to warrant drawing any conclusions regarding isotropy. For the transition to the ground state, the gamma rays were found to be isotropic within 7%.

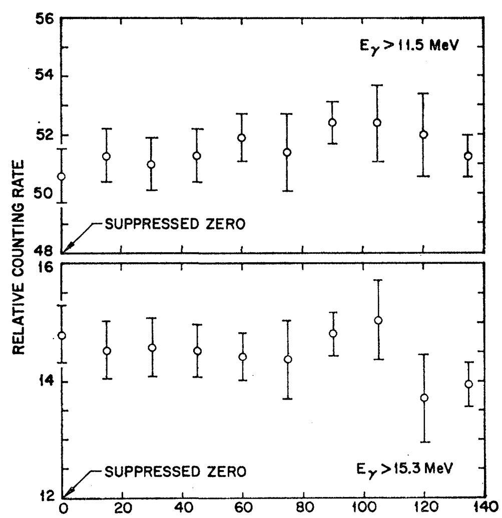

FIG. 3. Angular distribution of on-resonance gamma rays with energies above 11.5 MeV and above 15.3 MeV.

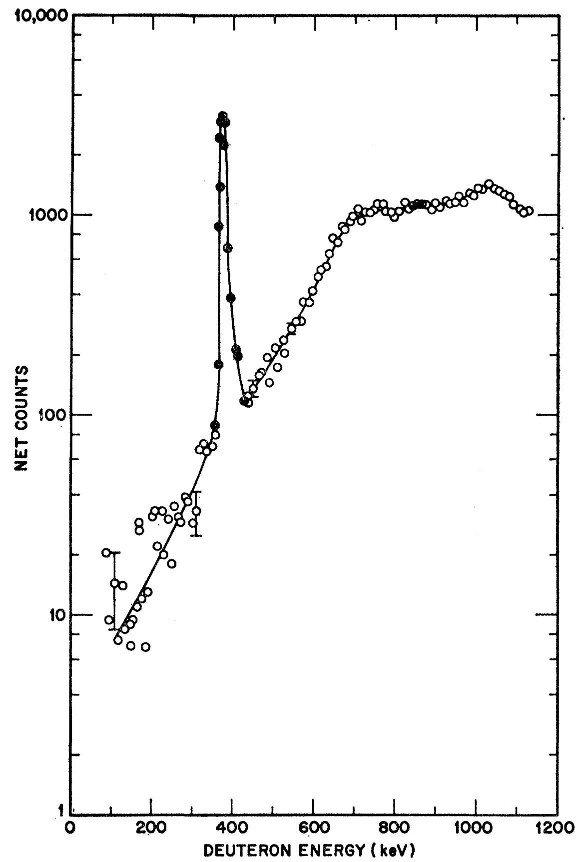

FIG. 4. The counting rate of pulses corresponding to energies between 12.8 and 17 MeV in a 4-in. diameter by 4-in. long NaI crystal at 135° as a function of bombarding energy. The solid circles indicate the region where the gamma rays were clearly separable from the background. A definite identification of the counts represented by open circles cannot be given.

Since theoretical calculations suggest that two $T=\frac{3}{2}$ states may exist[6] near 16.97 MeV, a search for additional narrow resonances was made with the $Li^7(d,\gamma)Be^9$ reaction. This search, however, was not extended above 1.1 MeV as a $T=\frac{3}{2}$ state at this corresponding excitation energy should not be very narrow. The expected larger width would be the result of the proton partial width which increases as the Coulomb barrier for the proton emission is decreased. The results of this search are shown in Fig. 4 where the observed NaI counting rate of pulses between 12.8 and 17 MeV taken at 135° is shown as a function of bombarding energy. Because backgrounds have not been subtracted, this curve off resonance should not be taken as a measure of high-energy gamma rays since a number of the counts are probably associated with the slowly varying background of neutrons.

From $Li^7(d,\gamma)Be^9$ measurements taken at 90° and below resonance at about 300 keV, an upper limit of 2×10^{-31} cm^2/sr is obtained for the direct (d,γ) cross section to low-energy states in Be^9.

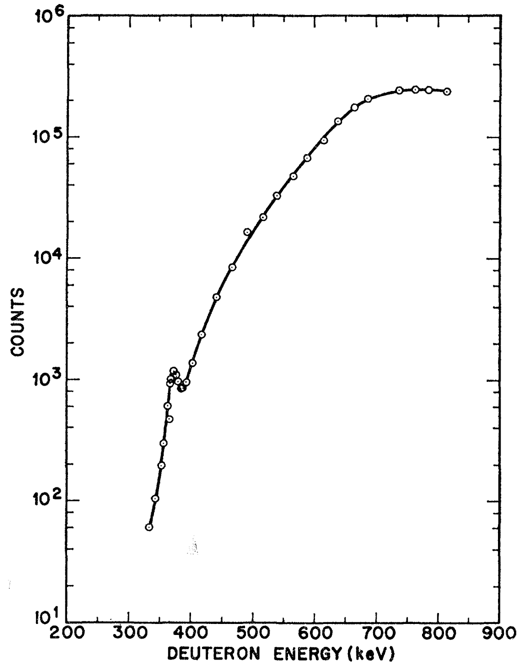

FIG. 5. Yield curve for the $Li^7(d,p_0)Li^8$ reaction as obtained from measurements of the induced Li^8 activity.

III. THE REACTION $Li^7(d,p_0)Li^8$

With the Q value for the $Li^7(d,p_0)Li^8$ reaction being -0.188 MeV, the energies of the protons emitted at a deuteron bombarding energy of 361 keV would be quite low and hence inconvenient to detect. However, the total cross section for the (d,p_0) reaction can be studied by observing the formation of $Li^8(T_{1/2}=0.84$ sec, $E_\beta{}^{\max}=13$ MeV). At this bombarding energy all transitions would be to the ground state of Li^8 since the energy of the first excited state is 0.98 MeV.

The deuteron beam incident on a thin lithium target was pulsed for 2-sec bombardment periods with a pair of electrostatic deflection plates. After a delay of 0.5 sec, high-energy electrons emitted from the target were detected in a 1-in. diameter by 1-in. long plastic scintillator. Pulses corresponding to electron energies greater than 2.5 MeV were scaled for a period of 1 sec. After another delay of 10 sec, the background counting rate was scaled for 1 sec. By repeating this operation many times at each bombarding energy, a yield curve for the $Li^7(d,p_0)Li^8$ reaction was obtained, as shown in Fig. 5.

The width and position of the observed resonance in the $Li^7(d,p_0)Li^8$ reaction are consistent with the more accurate values derived from the $Li^7(d,\gamma)Be^9$ measurements. Cross sections for the two reactions at resonance are not quoted since only an upper limit to the resonance width has been determined. However, from the yield curves, values can be obtained for the relative proton and gamma-ray partial widths corresponding to the level in Be^9 at 16.97 MeV. The ratio Γ_p/Γ_γ is found to be 0.5 within a factor of about 2.

IV. THE REACTION $Li^7(d,n)$

The $Li^7(d,n)$ reaction was studied by observing neutrons with a stilbene crystal. Discrimination against gamma rays was accomplished by pulse-shape techniques. From the pulse-height distribution in the stilbene detector the energy spectrum of high-energy neutrons, both on and off the resonance, appears to be complex, perhaps indicating decay to higher states of Be^8 and the occurrence of 2 He^4+n breakup. The yield at 90° of neutrons of energy greater than 10 MeV is plotted as a function of deuteron bombarding energy in Fig. 6. For comparison, the gamma-ray yield, measured simultaneously with a NaI crystal, is also shown. Within the experimental accuracies the two yield curves are consistent with each other in regard to the position and observed width of the resonance. From the known detection efficiencies of gamma rays in the NaI crystal and of neutrons in the stilbene crystal, the ratio of the partial width of the level for emission of neutrons to the ground state of Be^8 to that for the emission of gamma rays is found to be 1.5 within a factor of about 2. Within the experimental uncertainty, no evidence was seen for emission of neutrons from the level to higher excited states in Be^8.

In an effort to observe neutron emission from the lower levels in Be^9, the gamma rays from the 16.97-MeV level in coincidence with neutrons were measured. Figure 7 displays both the singles spectrum in the NaI crystal and the spectrum recorded in coincidence with neutron pulses in the stilbene crystal corresponding to energies above ~1 MeV. For this measurement both detectors were at 90° to the beam direction. It is seen that gamma rays to the 4.74-MeV state are in coinci-

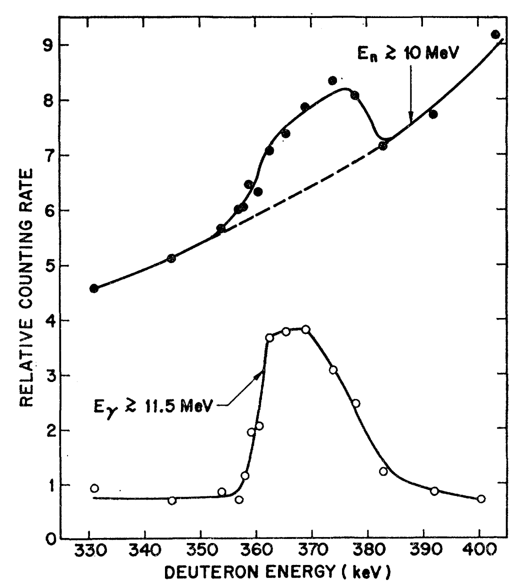

FIG. 6. The yield at 90° of neutrons with energies greater than 10 MeV as a function of deuteron bombarding energy. Also shown is the yield of gamma rays of energy above 11.5 MeV measured simultaneously.

dence with neutrons. The data, however, do not necessarily indicate that gamma-ray branchings to the lower states are not followed by neutron emission since these low-energy neutrons would have a small detection efficiency.

In order to improve the energy resolution of the neutron measurements, time-of-flight techniques were used. By pulsing the deuteron beam with electrostatic deflection plates operated at 5 Mc and using a Cronetics Inc.[8] time-to-pulse-height converter, an over-all time resolution of 2×10^{-9} sec was achieved. The neutrons were detected with a 5-in. diameter by 1-in. thick plastic scintillator. With this technique, no neutron peaks corresponding to the levels in Be^9 were observed because of the high stripping neutron background. To reduce this background, neutron time-spectrum measurements were made relative to coincident gamma rays that were detected in a 4-in. diameter by 4-in. long NaI crystal. For this purpose the deuteron beam was not pulsed. The gamma rays selected were in the energy interval (8–16) MeV. The results of one of the runs on resonance, with the plastic scintillator placed at 22.5 cm and the NaI crystal placed at 5.9 cm from the lithium target, are shown in Fig. 8. Neutron groups are seen corresponding to the levels in Be^9 at 2.43 MeV and 4.74 MeV, with inconclusive evidence for neutron emission from the state at 3.04 MeV. These data indicate neutron emission

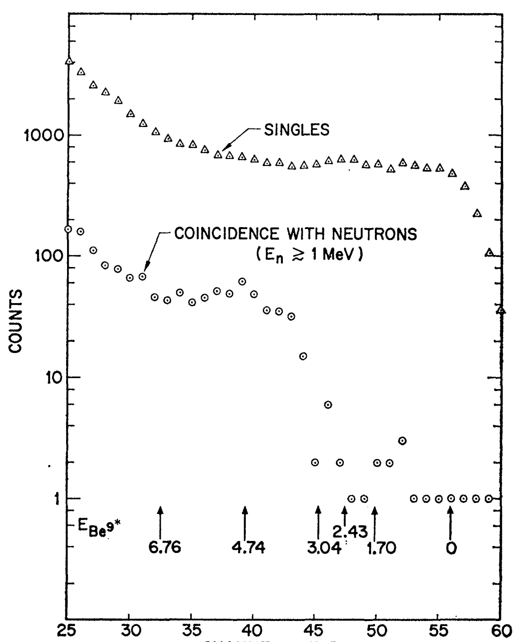

FIG. 7. The on-resonance gamma-ray singles spectrum in a 4-in. diameter by 4-in. long NaI crystal at 90° and the on-resonance spectrum observed in coincidence with neutron pulses in a stilbene crystal at 90°.

[8] Cronetics, Inc., Yonkers, New York, similar in design to that described by Sugerman *et al.*, BNL 711 (T-248), 1962 (unpublished).

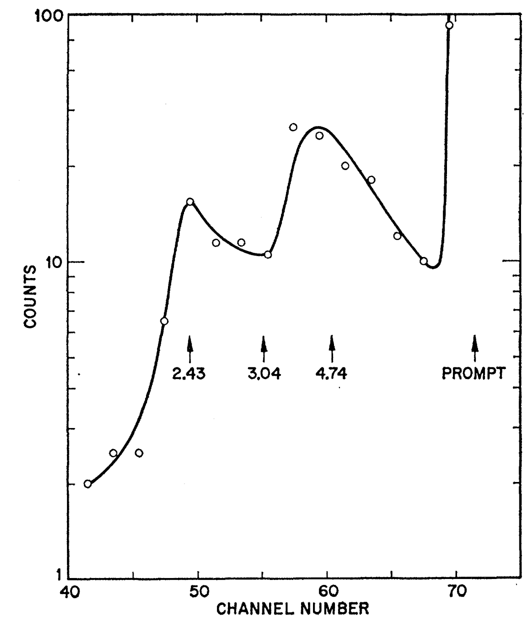

FIG. 8. The on-resonance time-of-flight spectrum of neutrons detected in a 5-in. diameter by 1-in. thick plastic scintillator relative to coincident gamma rays detected in a 4-in. diameter by 4-in. long NaI crystal. The prompt peak results from back-scattered gamma rays.

from the lower levels in Be^9 reached by on-resonance cascades but, in view of the poor statistics, do not provide a good basis for obtaining accurate branching ratios.

V. THE REACTIONS $Li^7(d,d)Li^7$ AND $Li^7(d,\alpha)He^5$

The reactions $Li^7(d,d)Li^7$ and $Li^7(d,\alpha)He^5$ were studied by observing deuterons and alpha particles in a surface-barrier solid-state detector. The kinematics of the pertinent reactions permitted identification of the particles. Alpha particles to the ground state of He^5 and elastically scattered deuterons were observed. However, no evidence was seen for the emission of these particles from the level in Be^9 at 16.97 MeV. From these results, upper limits for the relative partial widths are as follows: $\Gamma_{d_0}/\Gamma_\gamma<4\times10^2$ and $\Gamma_{\alpha_0}/\Gamma_\gamma<2\times10^1$.

VI. DISCUSSION AND CONCLUSIONS

Corresponding to a level in Be^9 at 16.97 MeV, a resonance has been observed in the Li^7+d reaction. Studies of the decay of this level have shown that gamma-ray transitions occur to the ground state of Be^9 and to states at 1.70, 2.43, 3.04, and 4.74 MeV, although the branching to the state at 3.04 MeV may be zero within the experimental uncertainties. The evidence for gamma-ray branchings to the states at 2.43 and 4.74 MeV is further substantiated by the observation of neutron-gamma coincidences indicating the subsequent emission of neutrons from these levels. The occurrence of neutron emissions from the state in Be^9 at 16.97 MeV is demonstrated by the observation of a resonance in the yield of neutrons above 10 MeV. Although such neutrons could arise conceivably from the decay of other high-excitation levels in Be^9 reached through gamma-ray cascades, the gamma-ray branching to such states is probably too weak to account for the observed neutron yield. The occurrence of a resonance in the yield of Li^8 provides direct evidence for the emission of protons from the 16.97-MeV state in Be^9. Since the first excited state of Li^8 is at 0.98 MeV, all of the emitted protons represent transitions to the ground state of Li^8.

The narrow width of the resonance, being less than 470 eV in the c.m. system, suggests that decay of the state by neutron and alpha-particle emission is strongly impeded. It has been proposed by Woods and Wilkinson[6] that this behavior can be explained by the assumption that the state has an isobaric spin $T=\frac{3}{2}$. A $T=\frac{3}{2}$ state at 16.97 MeV would correspond to the first excited state of Li^9 at 2.69 MeV. Formation of such a state by Li^7+d could take place only through isobaric impurities; breakup of the $T=\frac{3}{2}$ level into Be^8+n, $He^5+\alpha$ or Li^7+d would be highly forbidden. In particular, for a $T=\frac{3}{2}$ state of very high purity, the reduced width for neutron emission would be smaller by several orders or magnitude than otherwise expected.

A more definite establishment of this isobaric spin assignment is obtained from the direct measurements of the various modes of breakup. The results of these investigations are summarized in Table II, which contains ratios of the various partial widths and the corresponding reduced widths. It should be remembered that Γ_{n_0} and Γ_{α_0} represent the portions of the neutron and alpha widths which lead to the ground states of the respective residual nuclei, while Γ_p, Γ_γ, and Γ_d are complete partial widths. With the assumption that the above widths are representative of the complete partial widths, these values shown in Table II are consistent with the predictions for a $T=\frac{3}{2}$ state where neutron and alpha-particle emission are forbidden while decay by proton emission is allowed. Thus, both the total width and the relative partial widths strongly support the hypothesis that the state in Be^9 at 16.97 MeV has an isobaric spin of $\frac{3}{2}$.

TABLE II. Ratios of Γ_γ, Γ_p, Γ_d, Γ_{n0}, and $\Gamma_{\alpha 0}$ for the state in Be^9 at 16.97 MeV. Also presented are the ratios of the various reduced widths.[a]

$\Gamma_p/\Gamma_\gamma=0.5$	$\gamma_{n0}^2/\gamma_p^2=1.3\times10^{-3}$
$\Gamma_{n0}/\Gamma_\gamma=1.5$	$\gamma_d^2/\gamma_p^2<7$
$\Gamma_d/\Gamma_\gamma<4\times10^2$	$\gamma_{\alpha0}^2/\gamma_p^2<9\times10^{-3}$
$\Gamma_{\alpha0}/\Gamma_\gamma<2\times10^1$	
$\Gamma_{c.m.}$ (total) <470 eV	

[a] Penetrabilities obtained from W. T. Sharp, H. E. Gove, and E. B. Paul, Chalk River Report TPI-70, 1953 (unpublished).

It has been proposed by Woods and Wilkinson,[6] on the basis of independent particle model calculations performed by J. M. Soper, that the spin and parity of the 16.97-MeV state is most probably $\frac{1}{2}^-$ or possibly $\frac{5}{2}^-$. For each of these two spin assignments, the branching ratios predicted by the Weisskopf[9] radiation widths have been compared with the relative intensities of the gamma rays to the ground state, and to states at 1.70, 2.43, 3.04, and 4.74 MeV in Be^9 which have been found to be 100, 8.5±4.3, 10.6±5.3, ≤4.5, and 9.6±4.8, respectively. As an aid to this discussion, the energy-level diagram of Be^9, taken from the compilation of Ajzenberg-Selove and Lauritsen,[10] is shown in Fig. 9. Gamma-ray transitions to the $\frac{3}{2}^-$ ground state for either the $\frac{1}{2}^-$ or $\frac{5}{2}^-$ assignment would be $M1$ transitions. The Weisskopf estimate for branching to a $\frac{1}{2}^+$ level at 1.70 MeV relative to that of the ground state is too large for a $\frac{1}{2}^-$ assignment which allows an $E1$ transition, whereas for the $\frac{5}{2}^-$ assignment and an $M2$ transition, the relative branching estimate is significantly smaller than the experimental result. For the $\frac{5}{2}^-$ state at 2.43 MeV, estimates for both spin assignments to the 16.97-MeV level are within a factor of about 10 of the measured branching ratios. For transitions to the higher states in Be^9 the spin and parity assignments are not sufficiently well known to indicate a preferred spin and parity for the state at 16.97 MeV. On the basis of these comparisons, it is not reasonable to choose between either of the two spin assignments.

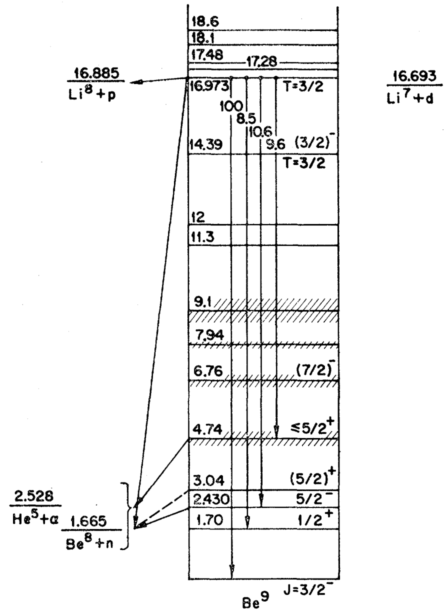

FIG. 9. Energy-level diagram of Be^9, taken from the compilation of Ajzenberg-Selove and Lauritsen (Ref. 10) along with gamma-ray branchings, observed in this experiment, from the state at 16.973 MeV.

The measured isotropic angular distribution also cannot distinguish between these two spins. Isotropic gamma-ray distributions to the ground state are con-

[9] V. F. Weisskopf, Phys. Rev., **83**, 1073 (1951).
[10] F. Ajzenberg-Selove and T. Lauritsen (to be published).

sistent with the $\frac{1}{2}^-$ assignment as well as the $\frac{5}{2}^-$ assignment where a strong favoring of s-wave deuteron capture is expected.

Recent measurements[11] of inelastic electron spectra from the $Be^9(e,e')Be^{9*}$ reaction at 180° and with 60-MeV bombarding energy, showed a broad peak corresponding to an excitation energy at about 16.9 MeV. The measured width, being greater than the resolution, was an indication of the participation of more than one level. Calculations, however, for this data based on an $M1$ transition to one level result in a radiation width $\Gamma_\gamma=20$–100 eV and for an $E1$ transition $\Gamma_\gamma\approx1000$ eV. The present experiment is consistent with the $M1$ result; any deductions regarding the other partial widths are uncertain because of the unknown contribution from another level in the electron measurements. An $M1$ transition from the $\frac{3}{2}^-$ ground state in Be^9 to the level at 16.97 MeV would be in agreement with the $\frac{1}{2}^-$ or $\frac{5}{2}^-$ assignments suggested from the calculations of Soper.

The state in Be^9 at 1.70 MeV is very close in energy to the Be^8+n system. Consequently, the experimental structure observed previously in Be^9 at 1.70 MeV with several different reactions[10] has been interpreted in two ways. Spencer *et al.*[12] have suggested that this structure is not an energy state in the usual sense but rather a result of the Be^8+n threshold at 1.668 MeV. Barker and Treacy[13] have explained the results in terms of a $\frac{1}{2}^+$ level at 1.75 MeV in Be^9. The observation in the present experiment of a gamma-ray branch leaving an excitation energy of 1.70 MeV in Be^9 adds evidence for the interpretation of this structure as a state in the usual sense.

From the measured differential cross section for the $Li^7(d,\gamma)Be^9$ reaction at about 300 keV deuteron energy, an upper limit of 1.6×10^{-30} cm^2 is obtained for a direct (d,γ) cross section to low-energy states in Be^9, assuming an electric-dipole angular distribution. There is little experimental information available on deuteron capture reactions.[14,15] A comparison can be made with the direct $Li^7(p,\gamma)Be^8$ reaction[10] at 300 keV which has a similar Q value of about 17 MeV. By adjusting the direct (p,γ) cross section for $[(N-Z)(A+1)/N(A+2)]^2$, the squared ratio of the effective charge of the deuteron to that of the proton, and for differences in penetrabilities, a predicted direct $Li^7(d,\gamma)Be^9$ cross section is obtained which is comparable to the measured upper limit.

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Note added in proof. At the suggestion of F. C. Barker (private communication), an additional search was made just above 16.97 MeV for the other expected $T=3/2$ level. In order to study this region immediately above the strong resonance, a very thin ($\sim$7 keV) target was used; the yield of gamma rays was measured in 2-keV steps from 360 to 415 keV. To within 5% of the yield from the 16.97-MeV level, no evidence was seen for an additional narrow resonance.

[11] Private communication with Professor Carl Barber.

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