States of ^{25}Al up to 7.8 MeV Excitation and the Mass of ^{25}Al†

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Accurate excitation energies were measured for 42 states in ^{25}Al. The ones below 3.7 MeV were measured with both the ^{24}Mg(^{3}He,d)^{25}Al and ^{28}Si(α,p)^{25}Al reactions to an accuracy of 2.5 keV or better. Excitation energies between 3.7 and 7.9 MeV were measured with the first reaction only. Uncertainties for the narrow states range from 2.5 to 7 keV with two exceptions. Nine states were found to have natural widths greater than 15 keV and these were measured. The agreement with previous work is excellent in the region below 3.7 MeV and is especially good with four excitation energies deduced from γ-ray energy measurements. Nine new states were found between 3.7 and 7.9 MeV and above 5 MeV our accuracy is much better than that previously reported for all but the known state at 6.3 MeV. We find ground-state Q values of -7709.3 ± 2.6 keV for the ^{28}Si(p,α)^{25}Al reaction and -3218.0 ± 4.5 keV for the ^{24}Mg(^{3}He,d)^{25}Al reaction. These results agree within 0.3 keV as to the mass of ^{25}Al but the value is 5.3 keV lower than that in the latest mass compilation.

I. INTRODUCTION

The lower-lying states of ^{25}Al are well known. Much work has been done on γ-ray transitions in this nucleus and it was here that the first demonstration of rotational bands in a medium weight nucleus was made. It has been a major subject of discussion at topical conferences as illustrated by Litherland's summary[1] of knowledge about the first 18 states. Four excitation energies below 4 MeV have been measured[2] with the exceptional accuracy of 0.5 to 3 keV. Above 5 MeV excitation, however, little was known until recently when Duray *et al.*[3] performed a triple-correlation measurement on the ^{24}Mg(p,$p'\gamma$)^{24}Mg reaction to get spectroscopic information on levels up to 7.8 MeV excitation. These authors were hampered by uncertainty of the level structure of ^{25}Al above 4 MeV. We undertook the present work to ascertain level positions and widths up to 7.8-MeV excitation using charged-particle reactions.

II. EXPERIMENTAL PROCEDURE

Our standard techniques for the accurate measurement of nuclear reaction energies using broad-range spectrographs with a tandem accelerator were applied.[4] Two reactions were used, ^{28}Si(p, α)^{25}Al and ^{24}Mg(^{3}He, d)^{25}Al; and for 26 of the 28 runs, outgoing particle energies were measured with the 50-cm broad-range spectrograph whereas for 2 of the (p,α) runs we used our new 100-cm modified broad-range spectrograph.[5] Nuclear track plates were used to record particles; Ilford KO for the α particles and Eastman NTA for the deuterons. Proton bombarding energies of 15 and 16 MeV and ^{3}He bombarding energies of 16.5, 18, 19.5, and 21 MeV were provided by the FN tandem Van de Graaff accelerator. The first reaction has the advantage of a relatively intense beam of low specific energy loss, but the large negative Q value of − 7.71 MeV seriously limits the measurable range of excitation energies. The second reaction which has a ground-state Q value of − 3.22 MeV, however, easily allows measurement of excitation energies up to 8 MeV. During the (^{3}He, d) experiment, runs were made with a self-supporting enriched ^{24}Mg target and with thinner enriched ^{24}Mg targets on Formvar backings. The self-supporting ^{24}Mg target has a stopping of about 30 keV at 18-MeV ^{3}He energy and thus the experimental resolution was relatively low for data taken with this target.

The analysis of the energy spectrum of ^{25}Al above 3.7 MeV excitation proved to be very difficult because of the presence of many broad levels overlapping narrow levels. This region was studied mostly with the (^{3}He, d) reaction, but the (^{3}He, d) cross section is such that practical yields were obtained only at forward angles, so that the ^{24}Mg targets had to be in the transmission position. We therefore had to correct for energy loss of deuterons traversing the target. Another difficulty in the analysis of the energy spectrum is the presence of very broad and strong groups from the ^{16}O(^{3}He, d)^{17}F reaction as well as contaminant groups from the ^{12}C(^{3}He, d)^{13}N reaction.

A. Excitation-Energy Measurements

The ^{28}Si(p,α)^{25}Al reaction was used to measure excitation energies up to 3.7 MeV. Targets of SiO_2 evaporated onto Formvar backings were used and three runs were made at 15 MeV; two at 20° observation angle and one at 30°. One run was made at 15.5 MeV and 20° and two runs were

made at 16 MeV and 20°. To measure the ground-state Q value, we also made runs at 14 MeV and 70° and 16 MeV and 90°. Some excitation energies were obtained from these runs. As the calculated excitation energy is quite insensitive to the input energy, the input-energy values measured with the beam analyzer are sufficient. In three cases, however, the ground-state group from the $^{12}C(p,\alpha)^{9}B$ reaction which appeared in the spectra, was used to confirm the input energy and give a more accurate value. In the three cases where the ^{25}Al ground-state group was not placed on the spectrum, separation energies were measured with respect to the 1.7898-MeV state.

18 runs were made with the $^{24}Mg(^{3}He, d)^{25}Al$ reaction. For 12 runs, the bombarding energy was approximately 16.5 MeV and observation angles ranged from 15 to 120°. We covered the excitation-energy range in several steps. Five runs recorded the ground-state group but in these runs separation energies were measured from the 451.9-keV state because the ground-state group was positioned at the extreme end of the focal surface where the calibration is somewhat uncertain. In one run the 944.7-keV state was used as a normalization state. Four runs covering the intermediate range of excitation energy were normalized to the 3.0615-MeV state. The values used for these three normalization states were the average excitation energies we obtained from the $^{28}Si(p,\alpha)^{25}Al$ runs. For the higher excitation-energy range, the states used for normalization were those at 3.6980, 4.5837, and 4.9064 MeV. The values used for these states were those we obtained from the $^{24}Mg(^{3}He, d)^{25}Al$ runs covering the lower ranges of excitation energy. The dominant uncertainty in the excitation energies comes from locating the position of the group on the focal surface. The rather thick and nonuniform ^{24}Mg targets aggravated this problem. By covering the range of excitation energies in a number of steps and measuring relatively small energy differences we minimized errors in stopping corrections. In the various runs a given group was placed at different positions along the focal surface so any uncertainties in the shape of the calibration curve were averaged over and thus minimized. Uncertainties in the input energy and reaction angle added very little to the total uncertainty.

Where groups from levels with appreciable natural width overlapped narrow groups we had to unfold the resulting spectrum. All composite groups were fitted by using nearby groups leading to isolated narrow levels to give a standard narrow group shape and using a Breit-Wigner distribution for the wide group shape. The positions, heights, width of the Breit-Wigner curve, and background were all adjusted until the sum of the functions plus background gave a satisfactory fit to the measured points. All groups were fitted by hand and in addition some wide groups were fitted by a computer program written by G. L. Marolt which performed a convolution of the narrow group shape with the Breit-Wigner function.

B. Ground-State Q-Value Measurements

The ground-state Q value measured in the initial $^{28}Si(p,\alpha)^{25}Al$ runs disagreed markedly with that calculated from the then available mass values of the 1965 compilation.[6] This did not affect our measurement of excitation energies but had a serious effect on our attempts to compare our excitation energies with those derived from the early $^{24}Mg(p,p'\gamma)$ results of Duray, Hausman, and Steiner.[7] We therefore made three additional runs with the $^{28}Si(p,\alpha)^{25}Al$ reaction, designed especially to measure the ground-state Q value. In addition five runs made with the $^{24}Mg(^{3}He, d)^{25}Al$ reaction contained sufficient information to give good measurements of that ground-state Q value.

For these Q-value runs, targets were set in the reflection position and no stopping correction was needed. The input proton energies and exact reaction angles were determined by scattering from gold, silicon, and carbon. Because of slight variations in beam direction in tandem accelerator transport systems, it is necessary to measure the reaction angle for each run when accurate Q values are desired. In one series of runs with a fixed input energy setting, elastically scattered particles from gold, silicon, and carbon were measured at a given spectrograph field; the field was then changed to allow recording of the $^{28}Si(p,\alpha)$ group and finally a second measurement of the gold and silicon elastic groups was made. We then searched for the values of input energy and reaction angle which gave the best fit to these five output energies from elastic scattering. The resulting values were used in calculating the (p,α) Q value. In a second series of runs, the new 100-cm spectrograph was used. Here the input energy and angle were obtained from the groups elastically scattered from silicon, oxygen, and carbon and from the α-particle group from the $^{12}C(p,\alpha)^{9}B$ reaction. Our procedure for the $(^{3}He, d)$ Q-value measurements was similar with the input energy and angle determined by scattering from gold, magnesium, and carbon.

III. RESULTS

A. Q Values and the Mass of ^{25}Al

Our most accurate Q-value measurement in this experiment was from two runs on the $^{28}Si(p,\alpha)$-

^{25}Al reaction made with the 100-cm spectrograph. The result was -7710.1 ± 3 keV where the error arises mainly from uncertainties in determining the input energy and the positions of the rather wide α groups. The run with the 50-cm spectrograph gave -7707.1 ± 5 keV. There is very satisfactory agreement of these two completely independent measurements taken over a year apart with two different instruments. We calibrated the two spectrographs independently against the ^{210}Po α-particle energy of 5304.5 keV. Our final result for the (p,α) Q value is -7709.3 ± 2.6 keV.

From the five ^{24}Mg(^{3}He, d)^{25}Al runs designed to measure the Q value, we obtained an average value of -3218.0 ± 4.5 keV. The standard deviation of the mean of these five runs is 0.3 keV but we feel that a larger uncertainty should be assigned because of the rather thick nonuniform targets and the consequent uncertainties in determining group positions.

Our two Q values agree remarkably well as to the mass of ^{25}Al. Using values from the 1971 Mass Table[8] for the ^{28}Si, ^{24}Mg, ^{4}He, ^{3}He, and ^{1}H mass excesses, we find from our (p,α) Q value a mass excess for ^{25}Al of -8917.5 ± 2.7 and from our (^{3}He, d) Q value a mass excess of -8917.8 ± 4.6. Although the present measurements agree within 0.3 keV they give a ^{25}Al mass 13.4 keV higher than the 1965 mass compilation[6] but 5.3 keV *lower* than the 1971 compilation.[8] The stated uncertainty in the latter tabular value is 1.4 keV. The tabular value appears to be based entirely on a Q value for the ^{24}Mg$(p,\gamma)^{25}$Al reaction listed only as a private communication. From measurement of a γ-ray energy Everling *et al.*[2] deduce a ^{25}Al excitation-energy value of 3424.3 ± 0.6. Using a value of 1201.4 ± 1.0 keV which they adopt for the ^{24}Mg$(p,\gamma)^{25}$Al proton resonance energy, from other work (see Ref. 2 for details of adjustments made in the resonance energy) they obtain a Q value for this reaction. This Q value along with the ^{24}Mg and ^{1}H masses from the 1971 adjustment[8] gives a ^{25}Al mass excess 4.1 keV higher than our value. Their stated uncertainty of 1.2 keV combinded with the mass uncertainties gives 1.6 keV uncertainty for ^{25}Al. The sum of this and our combined uncertainty (including uncertainties in masses) of 2.4 keV gives almost the 4.1 keV by which these two ^{25}Al mass values differ. One cannot say that the present results disagree with Everling *et al.*[2] but they do disagree with the 1971 mass compilation and thus it appears that the 1965 compilation value was somewhat overcorrected.

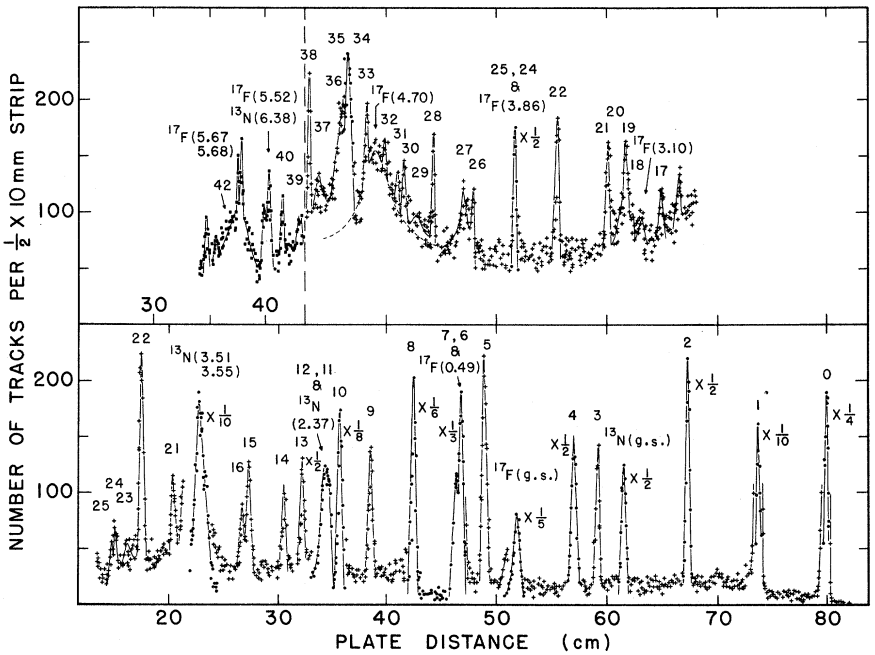

FIG. 1. Spectra of deuterons from the ^{24}Mg(^{3}He, d)^{25}Al reaction. The lower plot is from a run at 16.5 MeV and 50° with a self-supporting ^{24}Mg target. The right-hand portion of the upper plot is from a run at 18.0 MeV and 20° with a natural Mg target and the left-hand portion from a run at 21.0 MeV and 30° with the ^{24}Mg target. ^{25}Al groups are identified by a number. Numbers 1 to 10 correspond to the first 10 excited states listed in Table II. Numbers 11 to 42 are the group numbers of Table I. Groups from ^{16}O and ^{12}C are labeled with the symbol and excitation energy of the residual nucleus. Circles show a change of vertical scale.

B. Excitation Energies and Widths

In Fig. 1 we display portions of three spectra of deuterons from the ^{24}Mg(^{3}He, d)^{25}Al reaction, covering excitation energies from 0 to 8 MeV in ^{25}Al. The complex nature of the level scheme with overlapping broad and narrow levels is apparent and the strong contaminant groups from the ^{16}O(^{3}He, d)-^{17}F and ^{12}C(^{3}He, d)^{13}N reactions are seen. We call attention to the pairs and triplets of levels labeled 6, 7; 11, 12; 18, 19, 20; 24, 25; 26, 27; and 34, 35, 36. Groups 6 and 7 correspond to the 2673.6- and 2719.1-keV states, respectively. The excitation energies for the other groups together with the group labels are listed in Table I. Figures 2 through 5 are expanded plots of these groups and illustrate the procedure used to deduce group positions and widths. In the following we first give results for the excitation region below 3.7 MeV, then discuss fitting the wide groups, and finally consider the region from 3.7 to 7.9 MeV excitation.

1. Excitation Energies Below 3.7 MeV

In this region the levels have no measurable width (the width of 1.3 ± 0.4 keV listed[9] for the 3.1-MeV state is way below our resolution as is the 0.3 keV given for the 3.7-MeV state), we were able to use both the (p,α) and (^{3}He, d) reactions, and there are four precision γ-ray values for com-

TABLE I. Excitation energies of ^{25}Al between 3.7 and 7.9 MeV.

Compilation			Other measurements		This work				
Excitation (MeV) ± (keV)		Γ (keV)	Excitation (MeV)	Γ (keV)	Group label	No. of runs	σ_m (keV)	Excitation (keV)	Γ (keV)
3.84		36	3.824 [a]		11	4	1.3	3823.0 ± 2.5	36 ± 7
3.88		0.1	3.8575 [a]		12	4	0.8	3856.4 ± 2.5	
4.047	9	<10	4.038 [a]		13	7	1.6	4026.8 ± 3	
4.22		>0.12	4.198 [a]		14	8	1.6	4196.4 ± 3	
			4.507 [a]		15	7	1.3	4518.1 ± 4	
4.59		>0.47	4.573 [a]		16	7	1.9	4852.8 ± 4	
4.90		<10	4.877 [a]		17	6	1.1	4906.4 ± 4	
5.06		<10			18	6	1.0	5068.4 ± 5	
5.09		<4			19	6	2.7	5101 ± 10	
5.10		≈50	5.13 [b]		20	5	2.2	5116.5 ± 7	46.8 ± 5
					21	10	1.1	5231.7 ± 4	
5.30		200	5.28 [b]	184.9					
					22	11	0.9	5526.5 ± 7	≈18
			5.58 [b]						
					23	5	4.2	5686.1 ± 7	
			5.76 [b]	27.6	24	5	0.1	5784.9 ± 7	≈15
5.80		<4	5.79 [b]		25	5	1.4	5809.4 ± 7	
					26	11	2.2	6063.4 ± 7	
6.13		45	6.13 [b]	56	27	6	0.5	6122.7 ± 7	61 ± 7
			6.328 [c]		28	6	1.4	6322.4 ± 5	
			6.41 [b]	47.1	29	4	6.6	6409 ± 10	58 ± 7
					30	4	1.8	6517.3 ± 7	56 ± 13
			6.53 [b]		31	1		(6564)	
6.70			6.67 [b]		32	4	3.8	6644.5 ± 7	
			6.78 [b]		33	5	1.3	6770.3 ± 7	
					34	6	2.8	6881.3 ± 7	
6.92	40		6.92 [b]		35	7	3.3	6909 ± 10	
					36	6	4.6	6944 ± 10	104 ± 10
			7.02 [b]						
7.14			7.12 [b]		37	5	1.7	7112 ± 10	106 ± 20
					38	2		7183.1 ± 7	
7.25	30		7.24 [b]		39	3	2.4	7240 ± 7	
7.32		100							
			7.42 [b]		40	3	0.3	7417.4 ± 7	
(7.5)			7.58 [b]		41	1		(7564)	
7.78		340	7.77 [b]		42	1		(7819) ± 20	209 ± 20

[a] Values from Litherland. See text Ref. 1.
[b] From Duray, Hausman, and Steiner. See text Ref. 6.
[c] From Röpke, Anyas-Weiss, and Litherland. See text Ref. 10. The uncertainty is given as ±3 keV.

parison. Our excitation energies from both reactions are shown in columns 1 and 4 of Table II. Columns 2 and 5 show the number of measurements included in the average and columns 3 and 6 show the standard deviations (σ_m) of the means. The latter range from 0.5 to 1.9 keV for the (p,α) results which include more than two runs, and from 0.5 to 3.3 keV for the (^{3}He, d) results.

The value listed in the (^{3}He, d) column for the 2.72-MeV state comes from adding the measured difference of 45.8 ± 1.3 keV between this state and the 2.67-MeV state to the excitation energy for the latter. This improved the accuracy because in several of the runs giving good groups for the 2.67-MeV state, the 2.72-MeV state was weakly excited or poorly resolved (as in Fig. 1) whereas other runs allowed a good energy-difference measurement but were discarded from the averages of the excitation energies because of uncertainties in normalization group position or stopping correction. Resolved groups from a run at 16.5 MeV and 65° observation angle are shown in the lower portion of Fig. 2. The energy difference of 45.2 keV found for these two states with the (p,α) reaction agrees very well with the (^{3}He, d) value but our results are somewhat less than the 52 keV given by Litherland[1] or the 50 ± 12 keV from the summary table.[9]

In general, agreement is excellent between the (p, α) and (^{3}He, d) results with the average difference being 2.5 keV. The largest discrepancies occur for the 2.48-MeV state where σ_m is large for the (^{3}He, d) measurement, and for the 3.42-MeV state where we have only two (p, α) runs.

In the last column of Table II we list weighted averages from the two reactions. The uncertainties shown in the last column include estimates of remaining systematic errors in the calibration curve, stopping correction, and determination of particle group positions.

Our results are not only consistent but agree extremely well with the four accurate γ-ray values of Everling *et al.*[2] The average of the differences of these four values is only 0.4 keV. The values of Litherland shown in column 8 also agree very well but the older summary table[9] values differ by as much as 22 keV with the present results. There is a state listed at 3.440 MeV which undoubtedly corresponds to the 3424.8-keV state in view of the spacings of neighboring levels. We see no second state near this and surmise that the possible state listed at 3.426 MeV is in fact the same state. Thus, for the region up to 3.7 MeV we confirm the well known level structure and present excitation energies with uncertainties of 2.5 keV or less.

2. *Excitation Energies from 3.7 to 7.9 MeV*

Here we meet the first levels with natural widths sufficient to be observed in this experiment and our results now come only from the ^{24}Mg(^{3}He, d)-^{25}Al reaction. Litherland's values extend up to 4.9 MeV and above 5.1 MeV comparison may be made with the new results of Duray, Hausman, and Steiner.[7] In the range 3.7 to about 6.0 MeV excitation, energies were mainly measured relative to the 3061.5-keV state because this generally gave a strong, sharp group. Although it may appear that this state was a poor choice because there are only two (p,α) runs, we point out that the (^{3}He, d) runs normalized to this state included other states such as 2.67 and 3.70 MeV, and the

TABLE II. Excitation energies of ^{25}Al up to 3.7 MeV.

^{24}Mg(^{3}He, d)^{25}Al			^{28}Si(p, α)^{25}Al			Excitation energy comparison			Our
Excitation (keV)	No. of runs	σ_m (keV)	Excitation (keV)	No. of runs	σ_m (keV)	Table [a]	Litherland [b]	Everling *et al.* [c]	average
d			451.9	5	0.9	455 ± 2	451		451.9 ± 1.3
944.2	5	1.2	944.7	4	1.3	949 ± 3	945		944.4 ± 1.3
1613.9	5	1.4	1612.5	5	1.5	1610 ± 20	1611.5	1612.5 ± 0.5	1613.2 ± 1.6
1789.6	5	1.1	1789.8	4	0.5	1810 ± 20	1790	1789.6 ± 1.3	1789.7 ± 1.8
2485.9	4	3.3	2480.0	4	1.9	2502 ± 6	2483		2482.9 ± 2.5
2674.2	5	2.2	2673.0	4	0.8	2689 ± 6	2671		2673.6 ± 2.5
2720.0 [e]	4	0.5	2718.2	4	0.9	2739 ± 10	2723		2719.1 ± 2.5
d	7		3061.5	2	1.5	3077 ± 6	3059		3061.5 ± 2.5
3424.6	5	1.2	3430	2	7.0	3440 ± 6	3422	3424.3 ± 0.6	3424.8 ± 2.5
3697.6	8	1.1	3694.5	2	1.6	3720	3702	3696.3 ± 1.1	3696.6 ± 2.5

[a] See text Ref. 9.
[b] See text Ref. 1.
[c] See text Ref. 2.
[d] Used for normalization.
[e] Calculated by adding observed difference in excitation energy to energy of 2674.2-MeV state. The σ_m value applies to the difference.

good agreement of the resulting excitation energies assured us that the higher values were accurately tied to the lower values. Furthermore, the differences of 0.3 and 1.3 keV, respectively, between our (^{3}He, d) values and those of Everling *et al.*,[2] for the 3.42- and 3.70-MeV states support this basis for the remaining (^{3}He, d) values.

An example of a computer-generated fit to overlapping groups which arise from the 3823.0- and 3856.4-keV states is shown in the upper portion of Fig. 2. These states were previously known and our excitation values agree closely with those given by Litherland.

Figure 3 shows groups arising from the three states near 5.1 MeV, observed with targets of different thickness but with the same bombarding energy and angle. In the lower plot for the thicker target (≈ 30-keV stopping for 18-MeV ^{3}He) the broad 5116.5-keV group is seen to be greatly enhanced, whereas in the upper plot (≈ 10-keV target stopping for 18-MeV ^{3}He) the middle state appears strongest. To find the excitation energy and width of the broad state we unfolded spectra from runs in which this group was enhanced. We then subtracted a corresponding group from a spectrum in which the group was weaker and fitted the residual spectrum with two narrow group shapes. Of course we cannot be sure that these states do not have some natural width. These widths would have to be less than 20 keV. The positions are somewhat uncertain but there certainly must be at least three states here.

Evidence for two states near 5.8 MeV is shown in Fig. 4. The lower plot shows the result of a run at a bombarding energy of 21 MeV. A wide group is seen at 5.78 MeV with a slight suggestion of a group on the low-energy side. The upper plot shows data at 18-MeV bombarding energy. Here

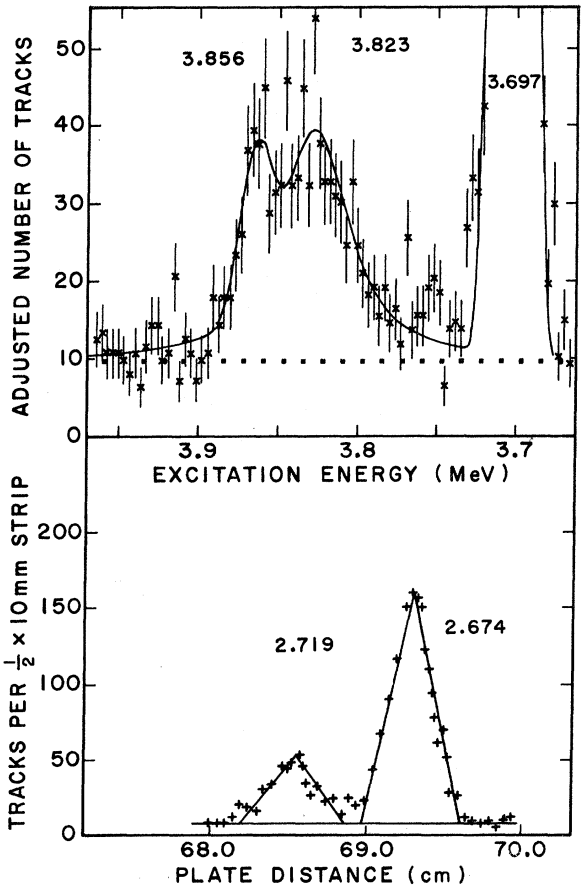

FIG. 2. The lower plot shows groups from the ^{24}Mg(^{3}He, d)^{25}Al reaction leading to two narrow states. Groups are labeled with excitation energies. Upper plot is a computer fit to two narrow states plus an overlapping state at 3.823 MeV excitation with a natural width of 34 keV. Bombarding energy was 16.5 MeV and observation angle 65°.

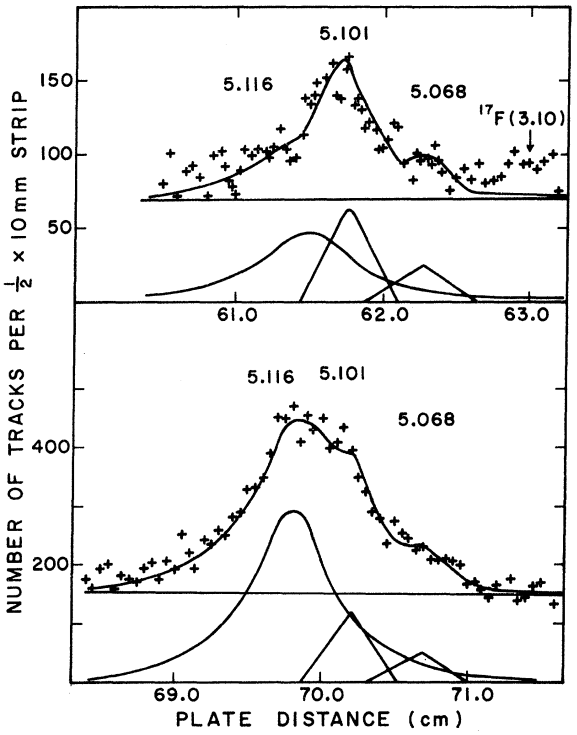

FIG. 3. Spectra of deuterons from the ^{24}Mg(^{3}He, d)^{25}Al reactions showing three overlapping groups. The bombarding energy was 18.0 MeV and the observation angle was 20°. Groups are labeled with the excitation energy in ^{25}Al. Upper run was on a thinner natural magnesium target and the lower run was on a thicker ^{24}Mg target. The three group shapes and the background which add to give the curve drawn through the points are shown in each plot. Note the enhancement of the group to the level with a natural width of 47 keV when the thicker target is used.

the asymmetric group shape with rather good statistics strongly suggests two groups. By assuming overlapping groups of the shapes shown in the figure, we could obtain good fits to both sets of data points. Five runs gave consistent values with σ_m of 0.1 and 1.4 keV, respectively, for the two excitation energies and a width of about 15 keV for the lower state. Unfortunately there is possible contamination from the ^{16}O(^{3}He,d)-^{17}F reaction and we must regard the existence of two levels here as somewhat tentative from our results alone.

The lower portion of Fig. 5 shows an example of the overlapping broad and narrow groups near 6.1 MeV and the upper portion of the figure shows a fit to the group near 6.9 MeV made by assuming the one broad and two narrow groups shown.

In Table I we list the excitation energies for 32 levels between 3.7 and 7.9 MeV excitation in ^{25}Al which were measured in this work. We again show the number of runs, σ_m, and our estimate of the over-all error. Measured widths with their uncertainties are also given. Because of target stopping we could not observe natural level widths of less than 15 keV. The group lables in column 5 correspond only to levels seen in this work. Values from other measurements and from the summary table[9] are shown for comparison. Values for the 3.82-, 3.86-, and 4.20-MeV states agree very well with Litherland's values. The other four Litherland values differ by 10 to 29 keV. Summary table values were spotty and approximate for the most part in the higher-energy range but where they exist they appear to agree. A measurement by Röpke, Anyas-Weiss, and Litherland[10] of the state at 6.32 MeV, agrees with our result. 17 levels between 5.13 and 7.77 MeV

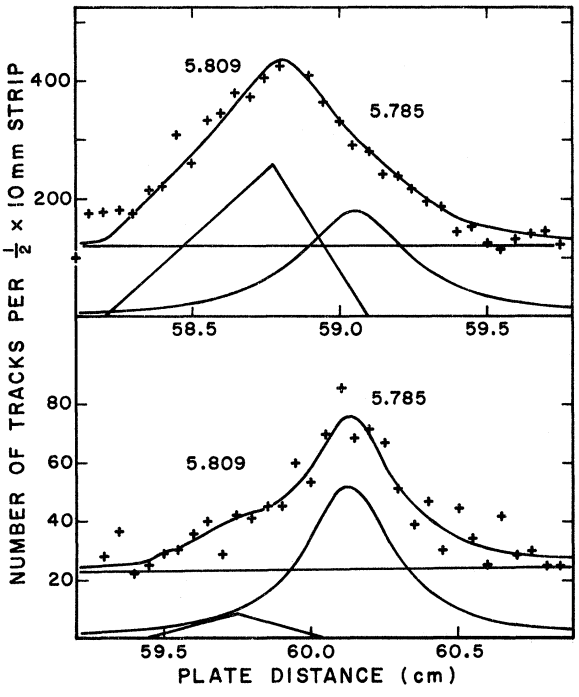

FIG. 4. Evidence for the existence of two levels in ^{25}Al near 5.8 MeV. The upper plot is from a run at 18.0 MeV and 20° on the thick ^{24}Mg target and the lower plot is from a run at 21.0 MeV and 30° on a thinner natural magnesium target. The peculiar shape used for the narrow group in the upper plot is that observed in the same spectrum for isolated groups leading to narrow states.

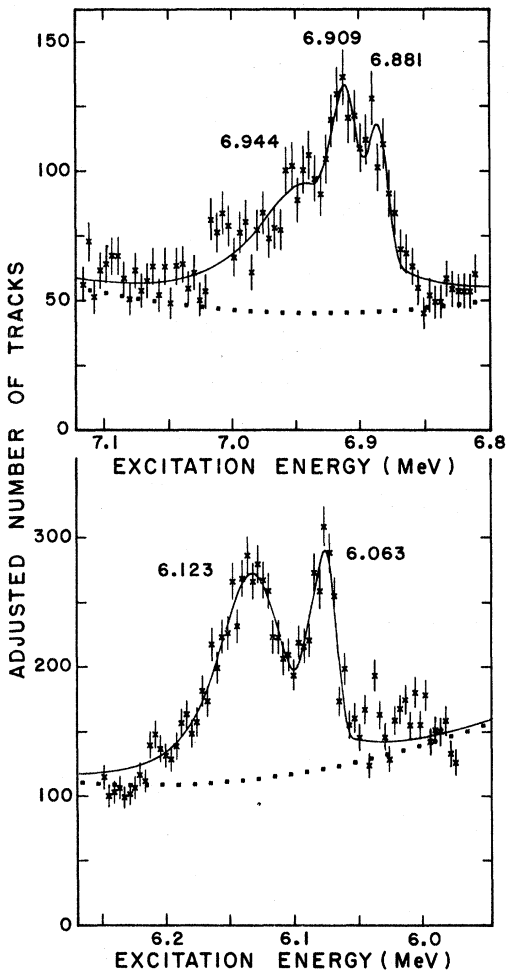

FIG. 5. The lower plot shows a group leading to a narrow level overlapped by a group leading to a level of 61-keV width. Here the bombarding energy was 16.5 MeV and the angle was 20°. The upper plot shows groups from a level of 104-keV width overlapping two groups leading to narrow levels. Bombarding energy and angle were 21.0 and 30°, respectively. Groups are labeled with the excitation energy in ^{25}Al. The curves are computer fits and the squares show the background generated in the fitting.

have recently been reported by Duray *et al.*[3] 13 of these correspond with levels we measured. Some comments may be made about the other four.

Duray *et al.* find a width of 184.9 keV for the state found at 5.28 MeV. This state undoubtedly is the one listed in the summary table[9] at an excitation energy of 5.30 MeV with a width of 200 keV. We could easily fail to see a state of this width if it is weakly excited by the (^{3}He,d) reaction. We see a state about 50 keV below the state reported at 5.58 MeV by Duray *et al.* and another state about 100 keV above, neither of which they report. Their resonance is very weak and was not seen at all in elastic scattering. One wonders if the slight fluctuation they see in the A_0, A_2, and A_4 correlation coefficients arise from the two states on either side rather than from a single state at 5.58 MeV. None of the three states in question are listed in the summary table.

Next we note that the state reported at 7.02 MeV by these authors could be swamped in our spectrum by the broad and strong 7.112- and 6.944-MeV states. Finally there is the state listed at 7.77 MeV by Duray *et al.* This could be the state we saw in one run at 7.819 ± 0.02 MeV but the discrepancy in excitation energies is then very large. We are inclined to identify our group with the state listed in the summary table at 7.78 MeV with a width of 340 keV. We found a width of 209 keV but unfortunately Duray *et al.* list no value for the width of their state. In the region covered by Duray *et al.* we see nine states that they do not report. These states are also not listed in the compilation of Endt and Van der Leun[9] but the 6322.4-keV state is reported by Röpke, Anyas-Weiss, and Litherland.[10]

SUMMARY

We have measured excitation energies of 10 states in ^{25}Al below 3.7 MeV with both the ^{24}Mg-(^{3}He,d) and ^{28}Si(p,α)^{25}Al reactions to an accuracy of 2.5 keV or better. Further, we have measured 32 excitation energies between 3.7 and 7.9 MeV using only the ^{24}Mg(^{3}He,d) reaction. Uncertainties for the narrow states range from 2.5 to 7 keV with two exceptions. Nine states were found to have natural widths greater than 15 keV and these were measured. Agreement with previous work is excellent in the region below 3.7 MeV and there is especially good agreement with four excitation energies deduced from γ-ray energy measurements. Nine new states were found between 3.7 and 7.9 MeV and above 5 MeV our accuracy is much better than that previously reported.

Ground-state Q values from the two reactions give excellent agreement for the mass of ^{25}Al but the result obtained is 5.3 keV lower than the value in the latest mass compilation.

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