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DEPENDENCE OF INTEGRATED CROSS SECTIONS ON THE ROTATIONAL STATES OF SODIUM-23 IN THE REACTION MAGNESIUM-25 (d,α) SODIUM-23 AT 20.9 MeV

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16. Abstract

The integrated cross sections for production of K = 3/2 states in the ^{25}Mg(d, α)^{23}Na reaction obey a linear relation of the form $\sigma = a(2I + 1) - b$. A comparison of these results with similar data from the ^{27}Al(d, α)^{25}Mg reaction suggests that the negative intercept is a consequence of band mixing in the states of ^{23}Na.

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SUMMARY

The angular distributions of differential cross sections corresponding to production of rotational states with rotational quantum number (K) of 3/2 from the (d, α) reaction on magnesium 25 (^{25}Mg) were measured from 15^{o} to 165^{o} (laboratory system). The mean deuteron energy was 20.9 MeV (laboratory system). The angular distributions are similar and peaked in the forward direction. This is indicative of a direct reaction mechanism. The integrated cross sections obey a simple linear relation (of the form $\sigma = a(2I + 1) - b$). A comparison of these results with similar data from the $^{27}Al(d, \alpha)^{25}Mg$ reaction suggests that the negative intercept is a consequence of rotational band mixing in the states of ^{23}Na.

INTRODUCTION

In a study of the $^{27}Al(d, \alpha)^{25}Mg$ reaction at 20.9 MeV, we observed that the angular distributions of differential cross sections for production of states in a given rotational band (K = 5/2 and K = 1/2) were strikingly similar both in magnitude and shape (ref. 1). The integrated cross sections for the first three states of the K = 5/2 and K = 1/2 rotational bands were 459, 475, and 417 microbarns and 38, 38, and 95 microbarns, respectively. The noticeably higher value of 95 μb for the K = 1/2, I = 5/2 state was thought to reflect a mixing of the I = 5/2 states of the K = 5/2 and K = 1/2 rotational bands. This interpretation is consistent with that suggested from inelastic alpha particle scattering experiments on ^{25}Mg (ref. 2). Using the 20.9-MeV results and other data for five deuteron energies between 4.74 and 14.7 MeV, the authors of references 3 and 4

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assumed that the integrated cross section could be decomposed as $\sigma\left(\alpha_\nu^K\right) = \sigma_D\left(\alpha_\nu^K\right) + \sigma_C\left(\alpha_\nu^K\right)$ and showed that for a given energy $\sigma_D\left(\alpha^K\right)$ is nearly constant for each rotational band and that $\sigma_C = a(2I + 1)$. The terms σ_C and σ_D are the contributions due to compound and direct processes, ν corresponds to the ν^{th} state of ^{25}Mg, and K is the rotational band quantum number. In their analysis, our results for a deuteron energy of 20.9 MeV imply that $\sigma_C < 0$. They also observed that for energies above 8 MeV, the values for $\sigma_D\left(\alpha_4^{1/2}\right)$ were consistently higher than those for $\sigma_D\left(\alpha_1^{1/2}\right)$ and $\sigma_D\left(\alpha_2^{1/2}\right)$.

Similar measurements on the $^{25}Mg(d, \alpha)^{23}Na$ reaction provide further tests of the systematics observed in the $^{27}Al(d, \alpha)^{25}Mg$ reaction, since ^{23}Na is also commonly depicted as a collective-type nucleus. The ground, 0.440-, 2.078-, and 2.705-MeV states (fig. 1) are presumed to be the $I = 3/2^+$, $5/2^+$, $7/2^+$, and $9/2^+$ members of a $K = 3/2$ rotational band. Theoretical calculations (ref. 5) indicate that these states contain admixtures of other states of the same I in rotational bands with $\Delta K = \pm 1$. If the integrated cross sections are sensitive to this band mixing, as they apparently are in the $^{27}Al(d, \alpha)^{25}Mg$ reaction, then measurements on the $^{25}Mg(d, \alpha)^{23}Na$ reaction should reflect this.

SYMBOLS

I	total angular momentum quantum number
K	value of the projection of the angular momentum I parallel to the nuclear symmetry axis
$\sigma\left(\alpha_\nu^K\right)$	integrated cross section for production of the ν^{th} state having rotational quantum number K
$\sigma_D\left(\alpha_\nu^K\right)$, $\sigma_C\left(\alpha_\nu^K\right)$	contributions to the integrated cross section due to direct and compound processes

EXPERIMENTAL PROCEDURE

The ^{25}Mg target was a self-supporting, vacuum-evaporated film having an areal density of 1.203±0.050 milligrams per square centimeter. It was bombarded with the 20.9±0.1-MeV deuteron beam from the Lewis Research Center cyclotron. The alpha-particle detection and discrimination scheme was the same as in previous (d, α) experiments (refs. 6, 7, and 8). A typical alpha-particle spectrum for a laboratory reaction angle of 20° is shown in figure 2. The alpha-particle groups of interest were fitted with skewed gaussian functions to obtain the experimental yields for calculation of the differential cross sections.

RESULTS AND DISCUSSION

Angular distributions of differential cross sections corresponding to production of the first four $K = 3/2$ states of ^{23}Na in the reaction ^{25}Mg(d, α)^{23}Na at 20.9 MeV are displayed in figure 3. The numerical data are presented in table I. The overall energy resolution was 200 keV. Consequently, the 2.641- and 2.705-MeV states of ^{23}Na were not resolved. The errors shown in figure 3 and table I reflect the statistical uncertainty of the yields and the error associated with fitting the skewed gaussian functions to the data. The absolute uncertainty is assessed at 15 percent.

We note that these angular distributions have the same basic shape over the entire angular range. The cross sections integrated over angular ranges of 15° to 165° (σ) and 95° to 165° (σ_C) are shown as functions of $2I + 1$ in figure 4. We observe, as did the authors of references 3 and 4 for the ^{27}Al(d, α)^{25}Mg reaction, that σ and σ_C can be adequately characterized by functions of the form $\sigma = a(2I + 1) + b$ and $\sigma_C = a'(2I + 1)$. We have called σ_C the integral of $d\sigma/d\Omega$ from 95° to 165°. In references 3 and 4, σ_C is called the integral of $d\sigma/d\Omega_{isotropic}$ over the full angular range studied, where $d\sigma/d\Omega_{isotropic}$ is the minimum value of $d\sigma/d\Omega$. The form of our curve for σ_C against $2I + 1$ would be unaltered if we used this same interpretation. The authors of references 3 and 4 logically interpreted b as the contribution to the total integrated cross section due to direct processes. In the present study, such an interpretation is not possible because b is clearly negative. A consistent way of interpreting this result would be to say that the admixture in the $K = 3/2$ states from states in the $K = 5/2$ rotational band increases as I increases. This would tend to increase σ as I increases. The theoretical calculations of Kelson and Levinson (ref. 5), which characterize the $3/2^+$, $5/2^+$, and $7/2^+$ states of ^{23}Na with $K = 3/2$ amplitudes of 0.992, 0.862, and 0.777, and $K = 5/2$ amplitudes of 0, 0.453, and 0.556, respectively, would tend to corroborate this reasoning. Additional evidence for these admixtures may be seen in figure 5, where angular distributions for $K = 5/2$ to $K = 5/2$ and $K = 5/2$ to $K = 3/2$ transitions in the reactions ^{27}Al(d, α)^{25}Mg and ^{25}Mg(d, α)^{23}Na are displayed. The striking overall similarity both in magnitude and shape indicate that the major admixture in the $K = 3/2$, $I = 9/2$ state of ^{23}Na comes from the $K = 5/2$ rotational band.

CONCLUDING REMARKS

We conclude, that the results of this investigation agree with those from a study of the $^{27}Al(d, \alpha)^{25}Mg$ reaction if we account for band mixing in the states of ^{23}Na.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, April 27, 1971,
129-02.

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TABLE I. - EXPERIMENTAL

(a) Ground state			(b) 0.440-MeV excited state		
Center-of-mass reaction angle, θ_{cm}, deg	Differential cross section, $d\sigma/d\Omega$, $\mu b/sr$	Estimated error, $\Delta\sigma$, $\mu b/sr$	Center-of-mass reaction angle, θ_{cm}, deg	Differential cross section, $d\sigma/d\Omega$, $\mu b/sr$	Estimated error, $\Delta\sigma$, $\mu b/sr$
16.50	33.40	1.86	16.51	102.71	2.77
21.98	28.43	1.78	22.00	79.12	2.91
27.45	19.84	1.19	27.47	60.66	2.03
32.90	18.68	1.05	32.93	46.98	1.67
38.33	12.03	1.26	38.36	38.04	1.97
43.73	13.71	1.04	43.76	44.67	1.85
49.11	10.29	.74	49.14	39.93	1.38
54.45	9.18	.67	54.49	36.23	1.35
59.76	8.23	.59	59.80	26.89	.96
65.03	6.75	.66	65.07	22.61	1.15
70.27	6.08	.44	70.31	16.34	.68
75.46	7.61	.47	75.51	14.53	.64
80.62	7.44	.51	80.66	12.53	.64
85.73	7.83	.33	85.77	12.46	.41
90.79	7.19	.46	90.84	11.92	.60
95.81	6.28	.42	95.86	8.79	.49
100.79	7.62	1.98	100.84	12.33	1.97
105.73	8.75	.57	105.77	12.13	.59
110.62	9.19	.88	110.66	13.55	.96
115.46	9.16	.93	115.51	12.83	1.00
120.27	7.57	1.04	120.31	11.66	1.16
125.03	6.63	.79	125.07	10.51	.80
129.76	7.12	1.02	129.80	11.24	1.07
134.45	8.10	.88	134.49	11.60	.96
139.11	8.55	1.08	139.14	13.40	1.20
143.73	9.20	.59	143.76	14.93	.68
148.33	10.54	1.01	148.36	15.93	1.16
152.90	9.88	1.11	152.93	19.10	1.23
157.45	14.03	2.30	157.47	23.02	2.69
161.98	13.00	1.53	162.00	25.25	1.85
166.50	16.63	2.06	166.51	25.43	2.37

DATA FOR $^{25}Mg(d, \alpha)^{23}Na$

(c) 2.078-MeV excited state

16.56	155.54	3.24
22.06	138.09	5.35
27.55	101.47	3.92
33.02	80.53	4.00
38.47	62.52	2.38
43.89	60.25	3.10
49.28	60.07	2.94
54.64	51.13	1.87
59.96	42.40	1.42
65.24	33.18	1.39
70.49	29.25	1.36
75.69	22.21	1.27
80.85	20.23	.80
85.96	18.85	1.15
91.03	16.24	.95
96.06	14.28	1.01
101.03	17.94	1.25
105.96	16.67	.71
110.85	17.70	1.38
115.69	18.43	1.60
120.49	17.83	1.54
125.24	16.36	.78
129.96	18.48	1.81
134.64	18.23	1.22
139.28	18.13	1.53
143.89	20.45	1.16
148.47	21.62	2.48
153.02	22.94	1.33
157.55	27.85	2.96
162.06	28.21	2.16
166.56	28.20	2.30

(d) 2.705-MeV excited state

16.58	235.38	3.93
22.09	203.93	6.62
27.59	161.81	4.97
33.06	118.00	4.97
38.51	84.81	2.80
43.94	83.24	3.64
49.33	82.05	3.44
54.69	81.04	2.37
60.02	72.48	1.85
65.31	61.81	1.90
70.56	48.52	1.79
75.76	40.54	1.75
80.92	35.28	1.07
86.04	30.11	1.48
91.11	23.30	1.17
96.13	22.35	1.30
101.11	25.15	1.44
106.04	26.46	.87
110.92	27.00	1.67
115.76	24.36	1.83
120.56	23.59	1.76
125.31	23.01	.92
130.02	28.96	2.20
134.69	32.48	1.58
139.33	31.48	1.98
143.94	29.99	1.41
148.51	31.46	3.05
153.06	33.24	1.54
157.59	39.76	3.49
162.09	36.33	2.44
166.58	34.26	2.54

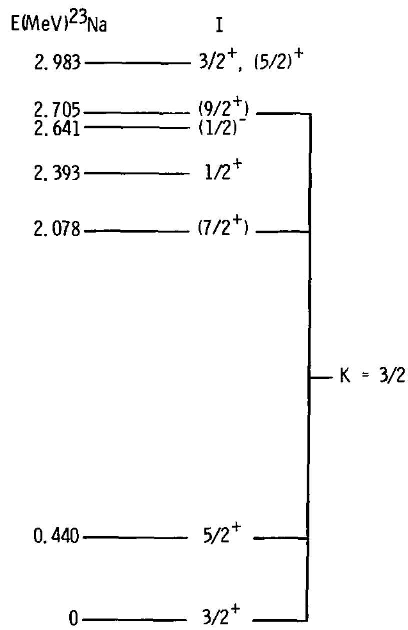

Figure 1. - The low-lying states of ^{23}Na. (The spin assignments were taken from ref. 9, the energies from ref. 10.)

Peak	Rotational quantum number, K	Total angular momentum quantum number, I	Excitation energy, W, MeV
0	3/2	$3/2^+$	0
1	3/2	$5/2^+$	0.440
2	3/2	$(7/2^+)$	2.078
3		$(1/2)^-$	2.641
	3/2	$(9/2^+)$	2.705

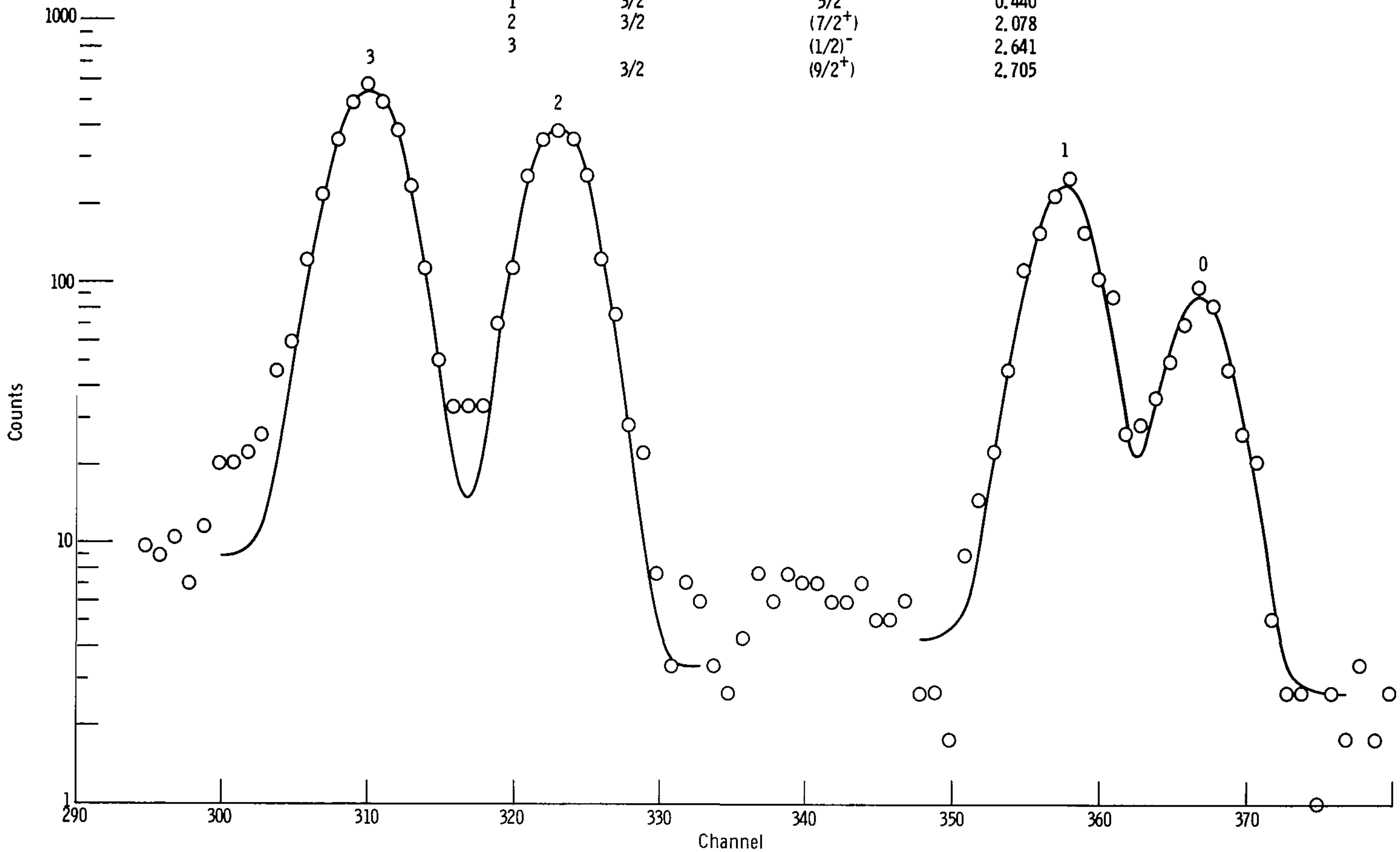

Figure 2. - Alpha-particle spectrum obtained at 20^0 for $^{25}Mg(d,\alpha)^{23}Na$ reaction at 20.9 MeV. The solid curve is a least-squares fit of skewed Gaussian functions.

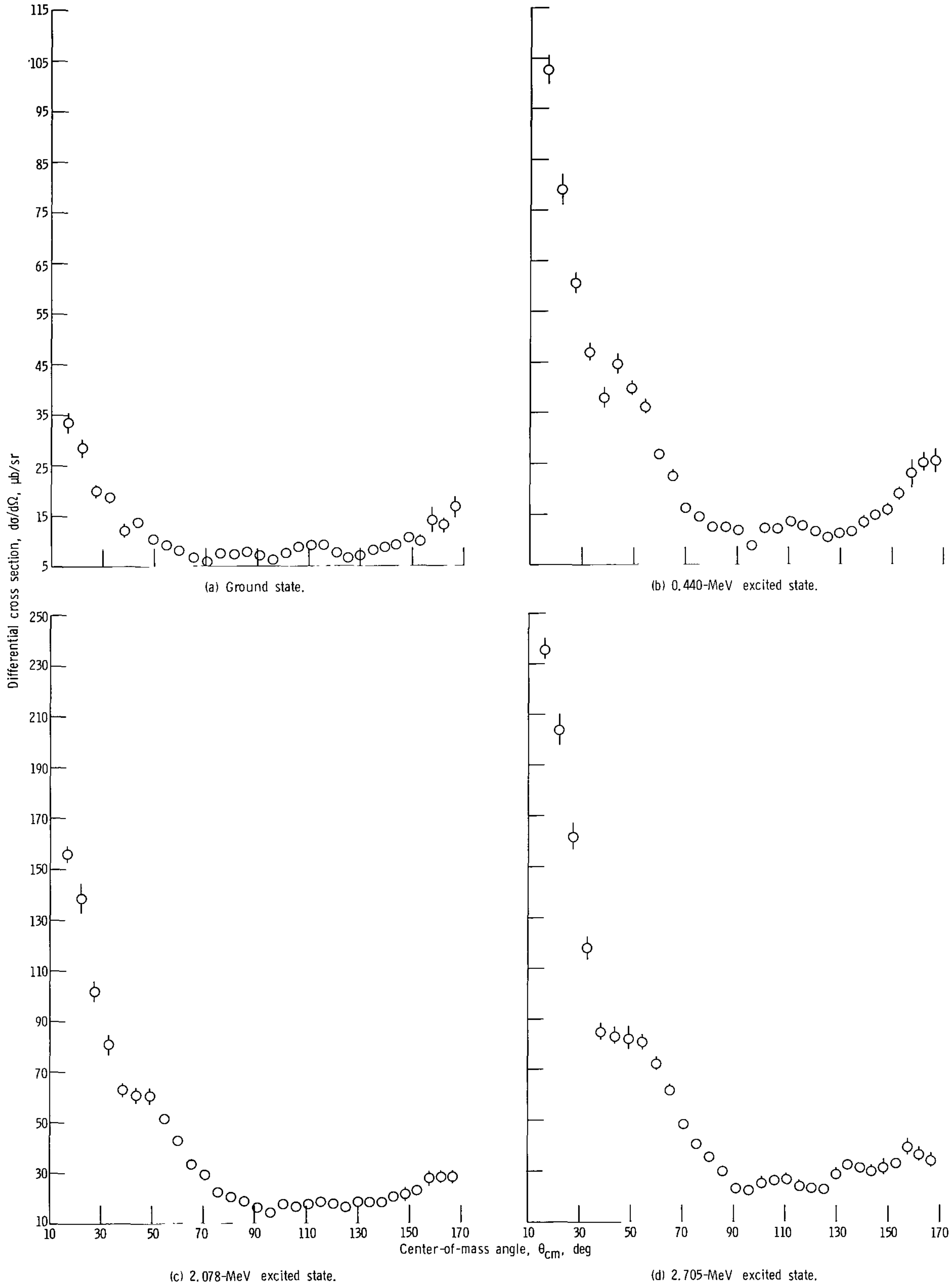

Figure 3. - Angular distributions of differential cross sections for production of $K = 3/2$ states of ^{23}Na in the reaction $^{25}Mg(d,\alpha)^{23}Na$ at 20.9 MeV.

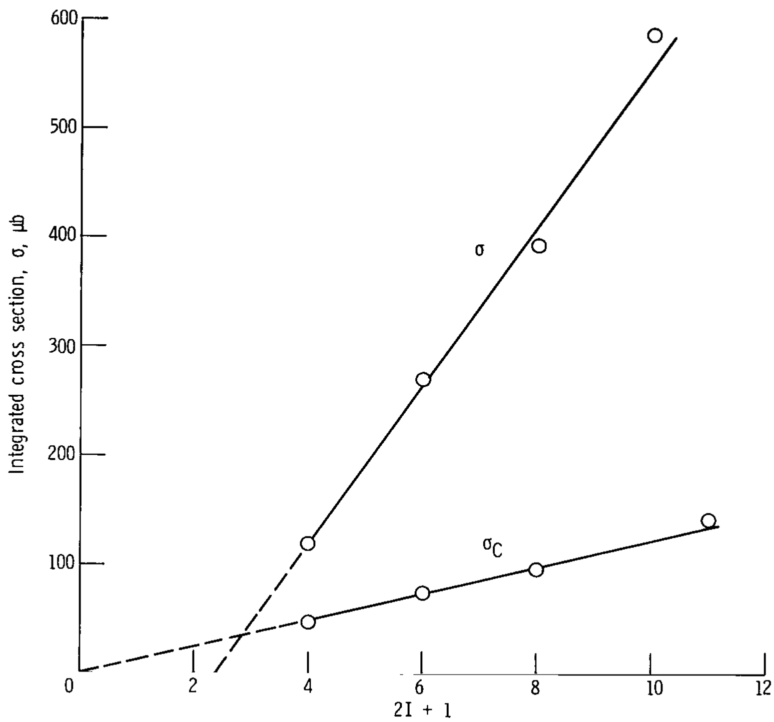

Figure 4. - Integrated cross sections as functions of 2I + 1, where I is the spin quantum number of the final state. (The largest value of σ_C is plotted against 2I + 1 = 11 because the 2.641- and 2.705-MeV states were unresolved.)

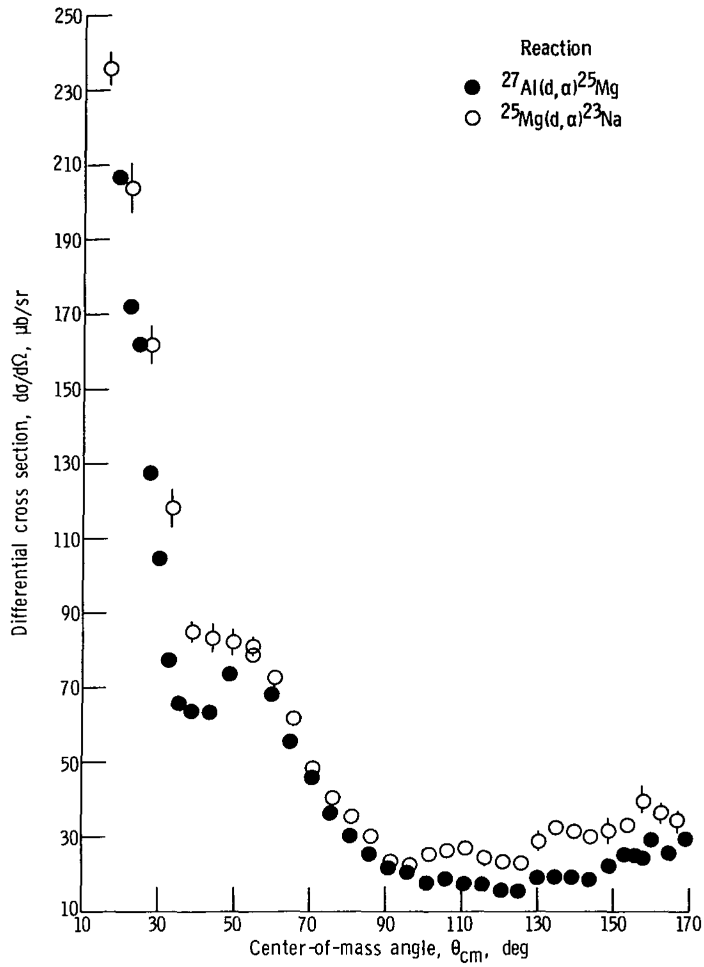

Figure 5. - Angular distributions of differential cross sections for K = 5/2 to K = 5/2 and K = 5/2 to K = 3/2 transitions for the reactions $^{27}Al(d,\alpha)^{25}Mg$ and $^{25}Mg(d,\alpha)^{23}Na$.

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