Title
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Berkeley, California

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John R. Meriwether, Italo Gabrielli, David L. Hendrie,
Jeannette Mahoney, and Bernard G. Harvey

December 1965

I. INTRODUCTION

The scattering of medium energy alpha particles has been used as an effective tool for the study of nuclear spectroscopy in numerous cases. Since the alpha particles are strongly absorbed, the observed scattering to low-lying excited states results primarily from the surface of the nucleus. This makes the method particularly advantageous for the study of surface vibrational states. The most useful experimental information is the variation of the differential cross section as a function of the center-of-mass scattering angle. In general, these angular distributions obey the Blair phase rule[1] and give characteristic patterns indicative of the angular momentum transferred to the nucleus. For an even-even nucleus this is equivalent to a spin and parity assignment of the state excited. The two phonon, 4+ states are an exception and do not give characteristic angular distributions at any particular incident energy. The relative phase of these distributions has been seen to vary with respect to that of the elastic as a function of the incident alpha energy.[2] Hence, one may not be able to make definite spin assignments without studying the scattering at several energies.

One of the most useful of the theoretical models for alpha scattering is that of Austern and Blair.[3]

The model uses the standard form for the elastic scattering amplitude

$$f_{e\ell}(\theta) = f_c(\theta) + \frac{i}{2k} \sum_{\ell=0}^{\infty} e^{i\sigma_\ell} (2\ell+1)(1-\eta_\ell) P_\ell (\cos \theta)$$

where $f_c(\theta)$ is the Coulomb amplitude, σ_ℓ the Coulomb phase shift for the ℓth partial wave, η_ℓ the complex amplitude of the ℓth outgoing partial wave,

P_ℓ (cos θ) the Legendre Polynomial of order ℓ, and k the relative wave number. The form of η_ℓ is parametrized to be

$$\eta_\ell = \epsilon + B\Delta \frac{d\epsilon}{d\ell} + i(A\Delta \frac{d\epsilon}{d\ell} + D\Delta^2 \frac{d^2\epsilon}{d\ell^2})$$

where

$$\epsilon = (1 + e^{(L-\ell)/\Delta})^{-1}$$

The parameters L, Δ, A, B, and D were determined by a least squares fit to the experimental elastic cross sections with the aid of a search program due to Springer,[4] who along with Darriulat, suggested the form for η_ℓ. In the Austern-Blair model the scattering amplitude for the excitation of a single phonon is given by

$$f_{IM_I};00 = \left\{ \frac{i}{2} (2I+1)^{1/2} \sum_{\ell\ell'} i^{\ell-\ell'} (2\ell'+1)^{1/2} e^{i(\sigma_\ell+\sigma_{\ell'})} \right.$$

$$\left. \times \langle \ell' I,00 | \ell,0 \rangle \langle \ell' I,-M_I M_I | \ell,0 \rangle \frac{\partial\eta_{\bar{\ell}}}{\partial\bar{\ell}} Y_{\ell'}^{-M_I} (\theta,0) \right\} C_1(I)$$

where $\bar{\ell}$ equals $(\ell+\ell')/2$. All of the terms enclosed in braces can either be calculated or determined from the fit to the elastic angular distribution. This quantity when squared $(\frac{d\sigma}{d\Omega} = |f|^2)$ may be compared to the experimental to obtain the matrix element, $C_1^2(I)$.

$$(\frac{d\sigma}{d\Omega})_{exp}/(\frac{d\sigma}{d\Omega})_{calc} = C_1^2(I) = \delta^2(I)/(2I+1)$$

In general we chose to determine the ratio at the second observed maximum in the angular distributions. From the values of $\delta^2(I)$ $(\equiv \beta_e(I)R_e; R_e$ is the electromagnetic radius) the reduced transition probability can be determined.

$$B(EI)\downarrow = \left[\frac{3}{4\pi} Z R_e{}^I\right]^2 \frac{\beta_e(I)}{2I+1} = \frac{(3/4\pi)^2 Z^2 R_e{}^{2I-2} \delta^2(I)}{2I+1}$$

Specifically,

$$B(E2)\downarrow = 1.643 \times 10^{-2} Z^2 A^{2/3} \delta^2(2) \qquad (\text{fermis})^4/e^2$$

$$B(E3)\downarrow = 1.690 \times 10^{-2} Z^2 A^{4/3} \delta^2(3) \qquad (\text{fermis})^6/e^2$$

This paper presents a study of the levels of Cr^{52} using an Austern-Blair analysis of our inelastic scattering data.

The success of the Thankappan and True model[5] for the levels of Cu^{63} prompted us to study the levels of Cr^{53}. In terms of this model, Cr^{53} would be considered as an odd neutron in any one of three shell model states—$p_{3/2}$, $p_{1/2}$, or $f_{5/2}$—coupled to the quadrupole vibration of the core, Cr^{52}. Although this model cannot take into account a proton hole in Cr^{52}, the levels of V^{51} were investigated experimentally in order to consider the possibility of such a coupling.

II. EXPERIMENTAL

The Berkeley 88-inch cyclotron was used to produce incident alpha particles of 23.5, 33, 50, and 75 MeV which were scattered from isotopically pure Cr^{52}, Cr^{53}, and V^{51} targets. The targets were thin, evaporated metal foils—between 200 and 400 $\mu g/cm^2$.

The beam handling system and the scattering chamber have been described elsewhere.[6] The scattered alphas were detected in a unit consisting of four lithium-drifted silicon counters fixed at two (2.0) degree intervals. Thus the unit measured four energy spectra simultaneously at each position to which it was rotated. Pulses from the detectors were amplified by field effect transistor preamplifiers[7] placed in the vacuum system. The pulses were further amplified[8] and then routed into quadrants of an ND-160, 4096 channel analyzer (one quadrant for each counter). After the accumulation of the energy spectra, the contents of the analyzer memory were transferred directly into the core of a PDP-5 computer.[9] All of the preliminary, and some of the final processing of the data was completed using the computer. For example, the spectra were permanently stored on magnetic tape, plotted, and those peaks that were completely resolved were integrated. The center of mass cross sections and scattering angles were then immediately calculated. Peaks in the spectra which were not experimentally resolved were separated using the IBM-7094 program, VFIT.[10]

III. RESULTS

Cr^{52}

Figure 1 shows the energy spectra taken at a laboratory angle of 50° obtained from the scattering of 50 MeV alpha particles from Cr^{52}. This angle was chosen because none of the alpha groups of interest are obscured by the groups due to the impurities, carbon and oxygen. Angular distributions for the principal alpha groups are shown in Figs. 2-5. The solid curves are the Austern-Blair model[3] calculated angular distributions. The 2.97-MeV state, reported to be 2+ by van Patter,[11] is very weak at most angles, and no angular distribution could be obtained. The same is true for the 2.65-MeV, 0+ state. The angular distributions for the 3.45-, 4.10-, 4.73-, and 5.07-MeV states are very similar to those for the 4+ states at 2.37 and 2.776 MeV. An assignment of 4+ is thus indicated. The states at 6.16, 6.54, and 7.10 MeV appear to be negative parity and probably are 3- states. This is in agreement with the electron scattering data of Bellicard, et al.[12] Several states between 4.9 and 7 MeV were too weakly excited to determine the angular distributions. The 5.46-MeV group was strong but gave a featureless angular distribution. This group probably represents more than one state.

Similar measurements were made using 23.5, 33, and 75 MeV alpha particles. Figure 6 shows the angular distribution and the theoretical curves for the 1.434-MeV quadrupole state at each energy.

The phase of the 2.37- and 2.776-MeV, 4+ states changes as a function of the incident energy as shown in Fig. 7. We previously observed this behavior for Ni^{58} and Ni^{62}.[2] The rate of change of the phase with energy for the two states is different, but at present we have no explanation to offer for this fact.

The reduced transition probabilities for a number of states were determined in the manner given in the Introduction. These are listed in Table I. It should be noted that the values are generally independent of energy, as they should be. The values we obtain are consistently lower, by a factor of two or more, than the electron scattering data of Bellicard,[12] the Coulomb excitation work of McGowan,[13] or the Saclay group's[14] smooth cut-off analysis of their alpha scattering data. We have reanalyzed the Saclay data using the Austern-Blair model and find a large reduction in the value of $B(E2)\downarrow$ obtained. These data along with Peterson's,[15] which is in agreement with ours, are given in Table II. It would probably be erroneous to attribute the above discrepancies to failures of the Austern-Blair model as there are many examples, in particular Ni^{62}, where the agreement of this method of analysis with electromagnetic methods is excellent.

Cr^{53}-V^{51}

The energy spectra for Cr^{53} and V^{51} are shown in Fig. 8. These were obtained from the scattering of 50 MeV alpha particles.

The angular distributions for the first three excited states of Cr^{53}, shown in Fig. 9, are very similar to the first 2+ state in Cr^{52}. This is indicative of the quadrupole nature of these states. In Cr^{53}, as in the case of Cu^{63},[16] there are three quadrupole states whose differential cross sections sum to that of the core state. Contrary to the copper case, the Cr^{53} levels do not have $B(E2)\downarrow$ values which are individually equal to that of the core state. These values are presented in Table III. They are calculated by use of the equation given at the bottom of the Table. The weak-coupling model predicts that the values of δ^2 and of B(E2)↓ should be the same for all members of the weak-coupled multiplet; Table III shows that this expectation is not realized for Cr^{53} or V^{51}. The deuteron scattering experiments of Bock et al.[17] gave relative B(E2)↓ values in good agreement with ours—i.e., the 1/2- level of Cr^{53} is excited 2-3 times as strongly as expected from the simple weak-coupling model and the 5/2- level is excited only one half as strongly as expected.

Bock et al.[17] also calculated relative transition probabilities to several levels of Cr^{53} based on a modification of the simple weak-coupling core-excitation model. From the unified model calculations of Ramavataram[18] and the shell model calculations of Vervier[19] they obtained the amplitudes for the quadrupole component for each level of the multiplet. Since according to these calculations the 1/2- and 5/2- levels are appreciably mixed with single-particle components, they should be less strongly excited than predicted by the unmodified weak-coupling model. Agreement with the experimental results for the 5/2- level was improved, but naturally the agreement was poorer for the 1/2- level. Preliminary calculations by Philpot and True[20] indicate that the B(E2)↓ values may be explained by the model of Thankappan and True.[5]

The Cr^{53} group observed at an excitation of 1.96 MeV has an angular distribution that is indicative of a quadrupole excitation. Bock et al.[17] suggest that this level is the 5/2- level appearing in the calculation of Ramavataram[18] at 1.89 MeV and in the shell-model calculation of Maxwell and Parkinson[21] at 2.01 MeV. According to the calculations of Bock et al.[17] the level should be strongly collective and indeed it was strongly excited in their deuteron scattering experiment (about 1/4 as strongly as the 1.29 MeV 7/2- level) as well as in the present work, where the ratio of differential cross sections (1.96 MeV/1.29 MeV) was about 1/5.

The lifetime of $(4 \pm 2) \times 10^{-15}$ seconds[22] for the 2.32 MeV 3/2- state of Cr^{53} corresponds to an enhancement of 200 Weisskopf units for an E2 transition to the ground state, and corresponds to about 0.6 Weisskopf units for an M1 transition. Our very small cross section to this level confirms the M1 nature of the transition assumed by Ramavataram[18] and others, since any observable E2 mixing would imply some enhancement for this decay mode.

In V^{51} the first five states appear to have strong quadrupole angular distributions although we are not in disagreement with the $\ell=4$ contributions, predicted by the shell model.[23] In addition, the sum of their differential cross sections equals that of the first 2+ in Cr^{52}. As seen in Table III their $B(E2)\downarrow$ values are not equal to the Cr^{52} state.

It is interesting to note that the sum rule predicted by the weak coupling model[24] holds even though the coupling is not weak and none of the other predictions are realized.

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FOOTNOTES AND REFERENCES

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†NATO Fellow, on leave from Istituto di Fisica Dell'Universita, Trieste, Italy.

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FIGURE CAPTIONS

Fig. 1. Level scheme for Cr^{52} and an energy spectra (E'_α = 50 MeV, $\theta_{lab} = 50^\circ$) for $Cr^{52}(\alpha,\alpha')$.

Fig. 2. Angular distributions (E_α = 50 MeV) for the 1.434-, 3.16-, and 3.78 MeV, 2+ states of Cr^{52}. The curves are the Austern-Blair calculation.

Fig. 3. Angular distributions (E_α = 50 MeV) for the 4.59-, 6.16-, 6.54-, and 7.10 MeV, 3- states of Cr^{52}. The curves are the Austern-Blair calculation.

Fig. 4. Angular distribution (E_α = 50 MeV) for the 2.37- and 2.776-MeV, 4+ states of Cr^{52}. The curves are drawn through the points.

Fig. 5. Angular distribution (E_α = 50 MeV) for the 3.42- and 4.10-MeV states of Cr^{52}. The curves are drawn through the points.

Fig. 6. Angular distributions for the 1.434-MeV, 2+ state for incident alphas of 75, 33, and 23.5 MeV. The curves are the Austern-Blair calculation.

Fig. 7. The change of the phase of the 2.37- and 2.776-MeV, 2+ levels with incident energy. The 4.59 MeV data is for reference only. The 42 and 44 MeV data are taken from References 15 and 14 respectively.

Fig. 8. Energy level schemes and energy spectra (E_α = 50 MeV, $\theta_{lab} = 50^\circ$) for Cr^{53} and V^{51}.

Fig. 9. Angular distribution for the 0.564-, 1.008-, and 1.29-MeV states of Cr^{53}. The curves are the Austern-Blair model calculation. The 1.434, 2+ level of Cr^{52} is shown for reference.

Fig. 10. Angular distribution for the low lying V^{51} levels. The curves are the Austern-Blair model calculation; the 1.434, 2+ level of Cr^{52} is shown for reference.

Table I. B(EI)↓ values obtained for Cr^{52}.

Level (MeV)	Jπ	E_{IN} (MeV)	$\delta^2(I)$	$\frac{B(EI)\downarrow}{e^2}$ (fm^{2I})
1.434	2+	23.5	0.44	57.9
		33	0.41	53.9
		44.4[a]	0.36	47.3
		50	0.41	53.9
		75	0.31	40.4
3.16	2+	23.5	−0.055	7.23
		33	0.036	4.73
		44.4[a]	0.026	3.42
		50	0.042	5.52
3.78	2+	23.5	0.080	10.5
		33	0.090	11.8
		44.4[a]	0.13	17.1
		50	0.12	15.8
		75	0.11	14.4
4.59	3-	23.5	0.138	269
		33	0.153	298
		50	0.142	277
6.16	3-	50	0.034	64.7
6.54	3-	50	0.058	108.8
7.07	3-	50	0.057	108.5

[a]Data from Ref. 14—analysis, this work.

Table II. Comparison of various B(E2)↓ values for the 1.434 MeV, 2+ state in Cr^{52}.

B(E2)↓	Determination	Analysis	Reference
57.9	23.5 MeV (α,α')	A-B	a
53.9	33.0 MeV (α,α')	A-B	a
53.9	50.0 MeV (α,α')	A-B	a
46.0	75.0 MeV (α,α')	A-B	a
60.1	42.0 MeV (α,α')	A-B	15
102	44 MeV (α,α')	BSW	14
47.3	44 MeV (α,α')	A-B	14[a]
103	150-180 MeV (e,e')	-	12
124	Coulomb excitation	-	13

[a]This work.

Table III. Cr^{53} and V^{51} B(E2)↓ values.

	Level (MeV)	Jπ	δ^{2} [a]	$\frac{B(E2)\downarrow}{e^2}$ fm^4
Cr^{53}	0.564	1/2-	1.35	178
	1.008	5/2-	0.27	35
	1.29	7/2-	0.53	69
V^{51}	0.320	5/2-	0.56	67
	0.930	3/2-	0.32	38
	1.609	11/2-	0.28	33
	1.813	9/2-	0.13	16
	2.409	"7/2"	0.14	17

[a] $\delta^2 = [(d\sigma/d\Omega)_{exp}/(d\sigma/d\Omega)_{cal} \times (2I+1)] \times [\sum_i (2J_i+1)/(2J+1)]$

I = (spin of core state) = 2; J_i = (spin of i^{th} level of Cr^{53}) = 1/2, 3/2, 5/2, 7/2; J = spin of Cr^{53} level.

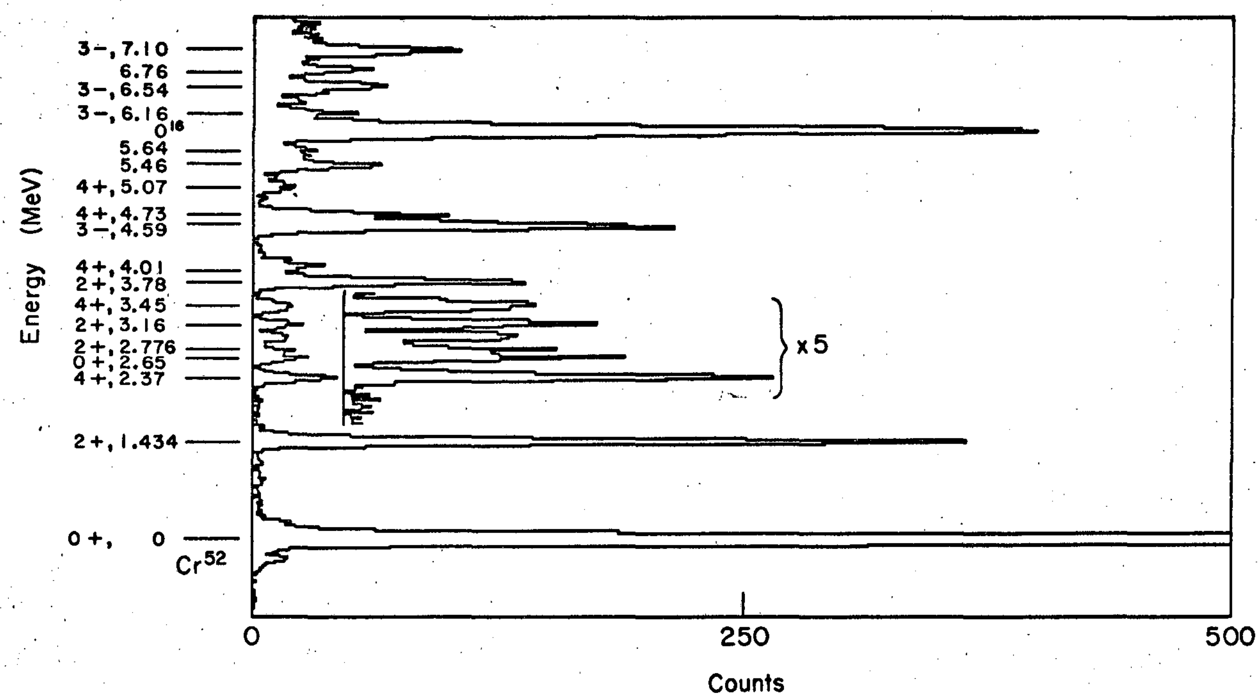

3−, 7.10
6.76
3−, 6.54
3−, 6.16
O16
5.64
5.46
4+, 5.07
4+, 4.73
3−, 4.59
4+, 4.01
2+, 3.78
4+, 3.45
2+, 3.16
2+, 2.776
0+, 2.65
4+, 2.37
2+, 1.434
0+, 0
Cr52
Energy (MeV)
x 5
0
250
500
Counts
MUB-8638

Fig. 1

Fig #1

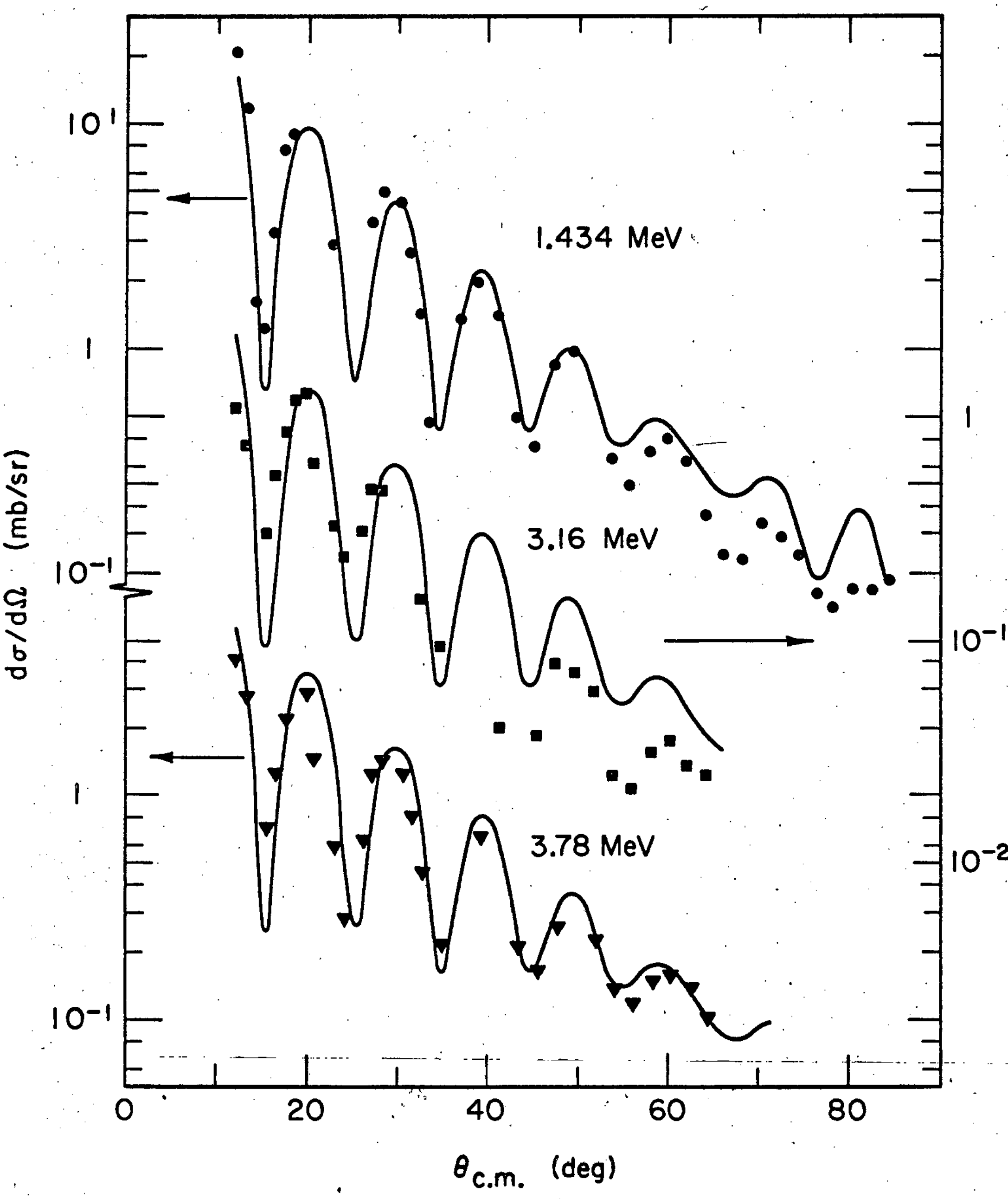
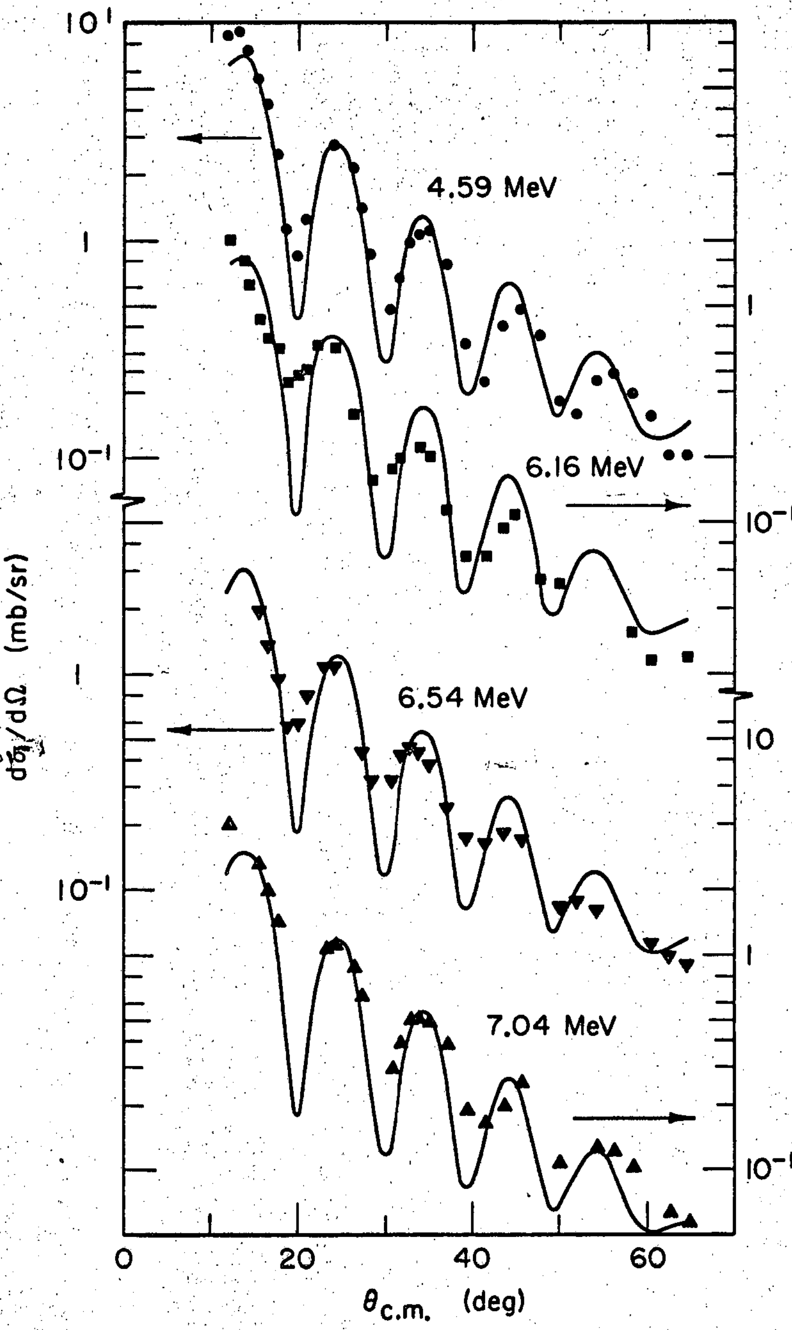

10^1
1
10^{-1}
1
10^{-1}
1
10^{-1}
10^{-2}
1.434 MeV
3.16 MeV
3.78 MeV
$d\sigma/d\Omega$ (mb/sr)
0
20
40
60
80
$\theta_{c.m.}$ (deg)
MUB-8639

Fig. 2

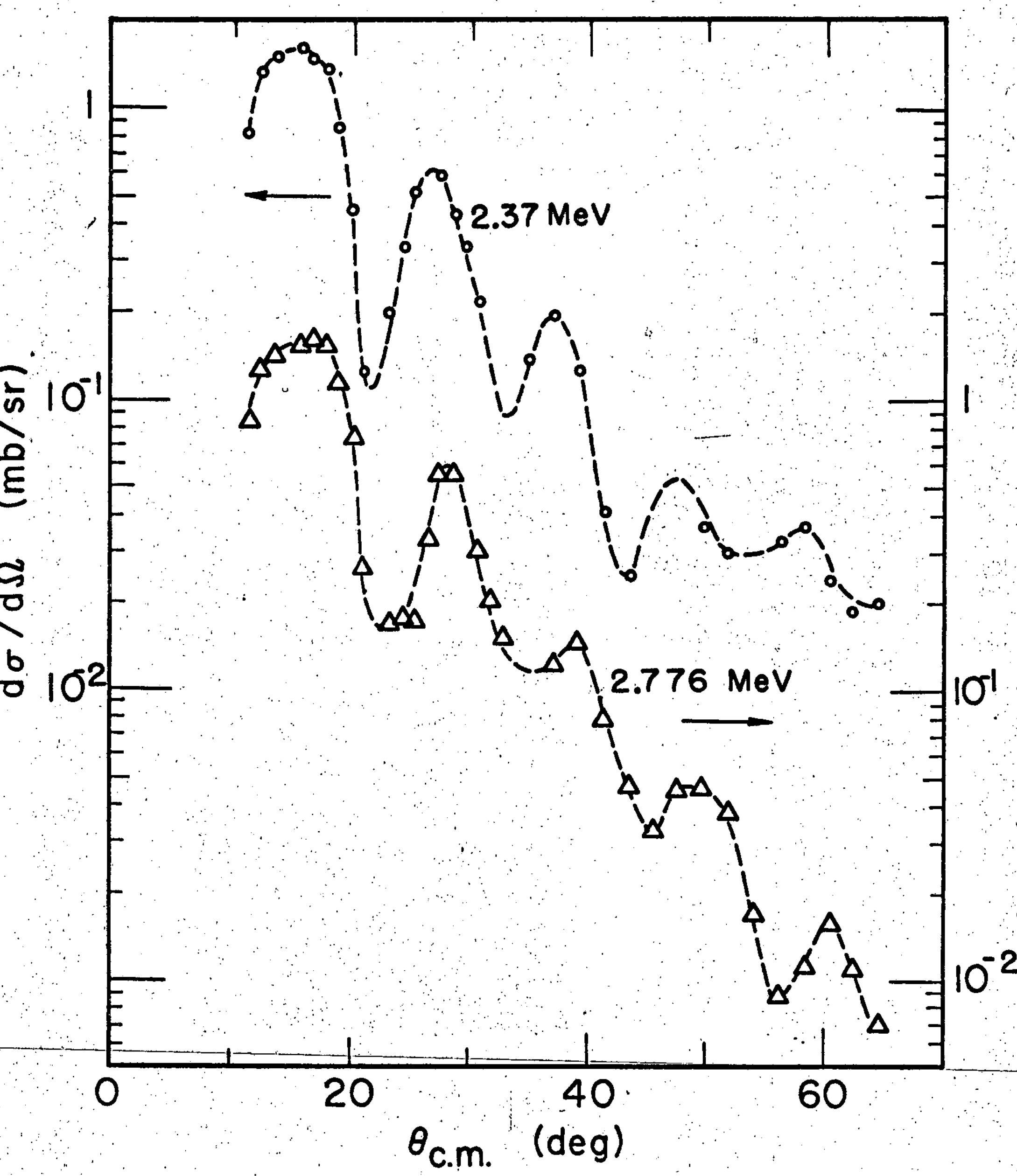
Fig 2



MUB-8640

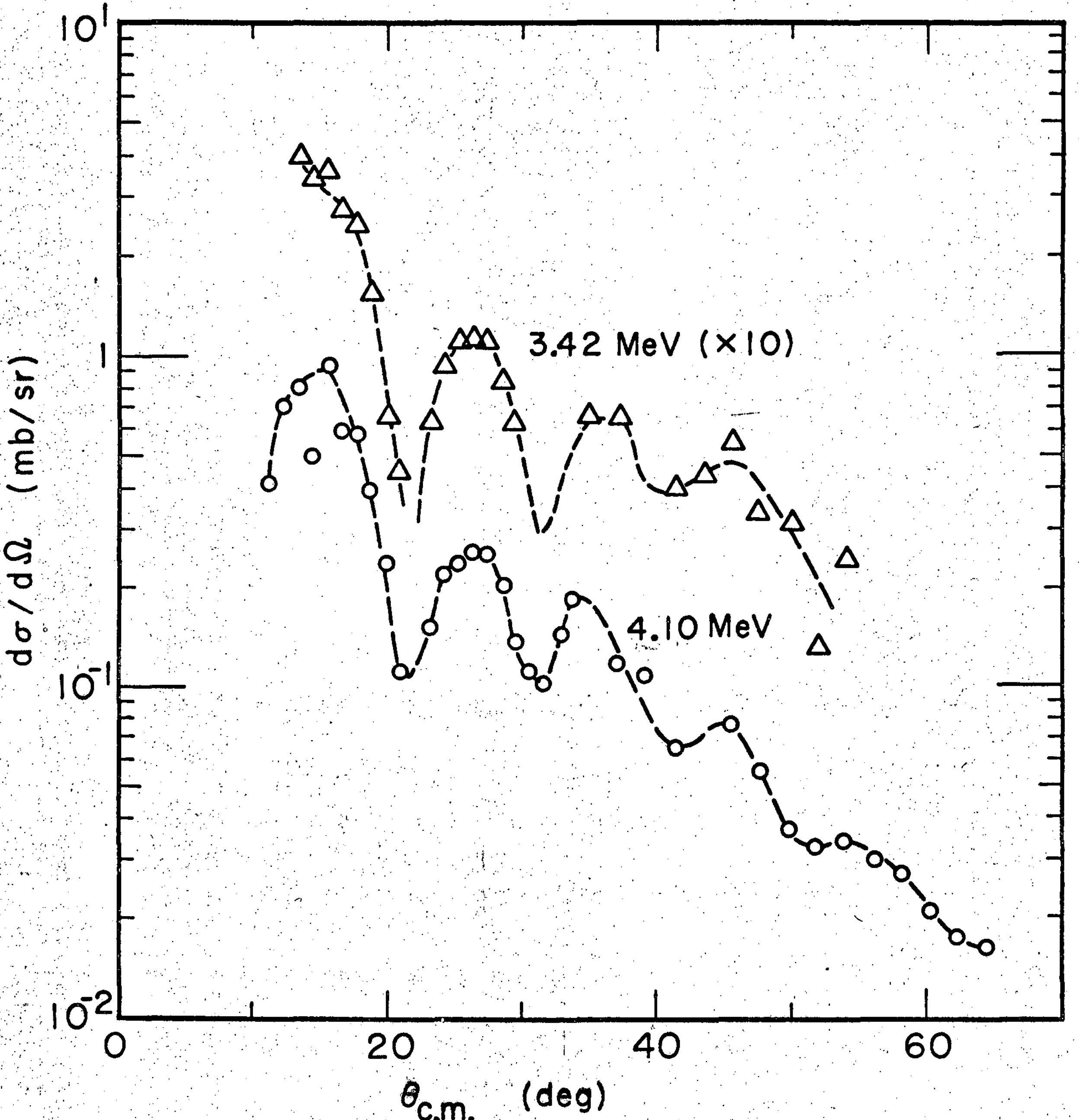
Fig. 3

Fig3



MUB-8642

Fig. 4



10^1
1
10^{-1}
10^{-2}
0
20
40
60
$d\sigma/d\Omega$ (mb/sr)
$\theta_{c.m.}$ (deg)
3.42 MeV (×10)
4.10 MeV
MUB-8641

Fig. 5

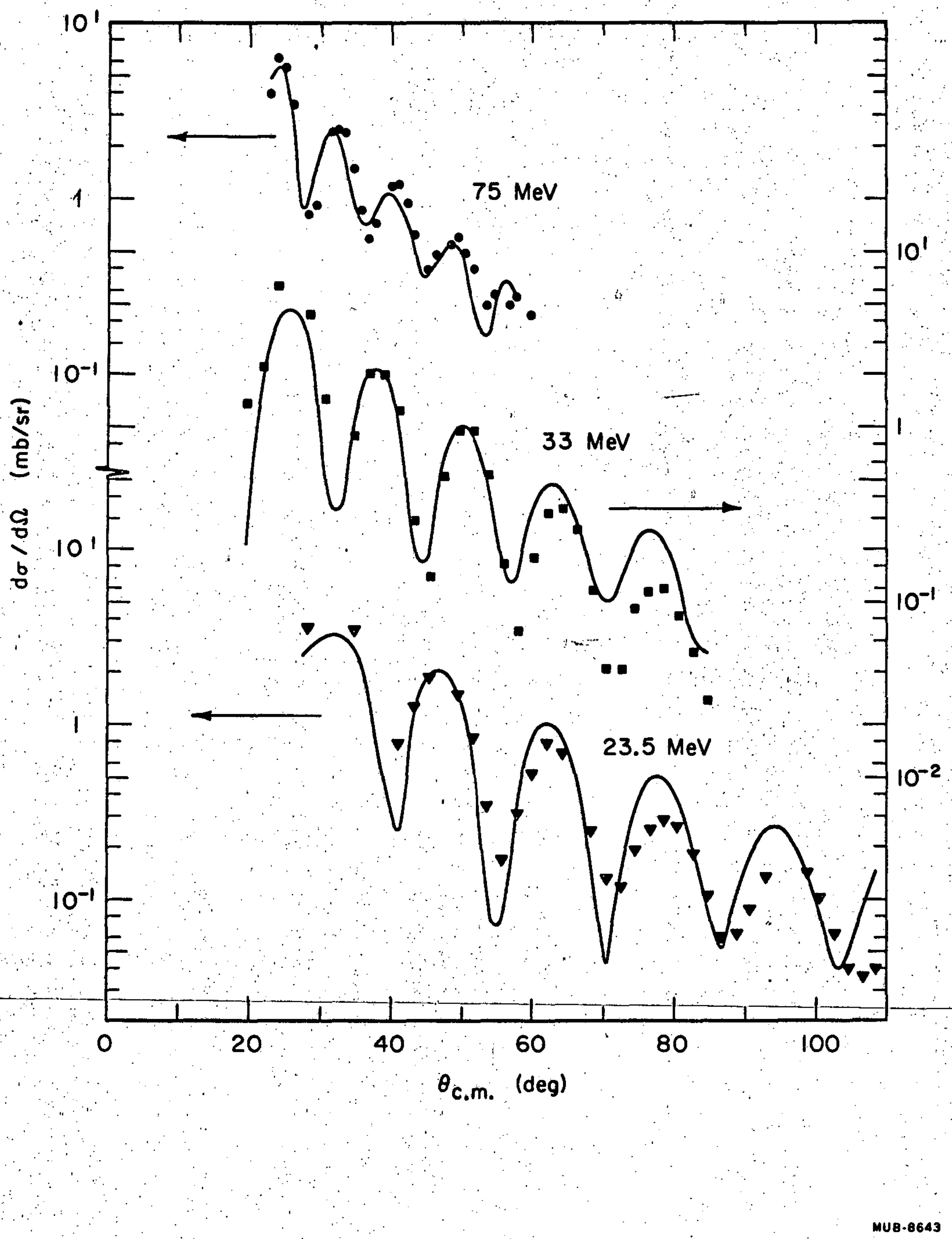

10¹
1
10⁻¹
10¹
1
10⁻¹
dσ / dΩ (mb/sr)
75 MeV
33 MeV
23.5 MeV
10¹
1
10⁻¹
10⁻²
0
20
40
60
80
100
θc.m. (deg)
MUB-8643

Fig. 6

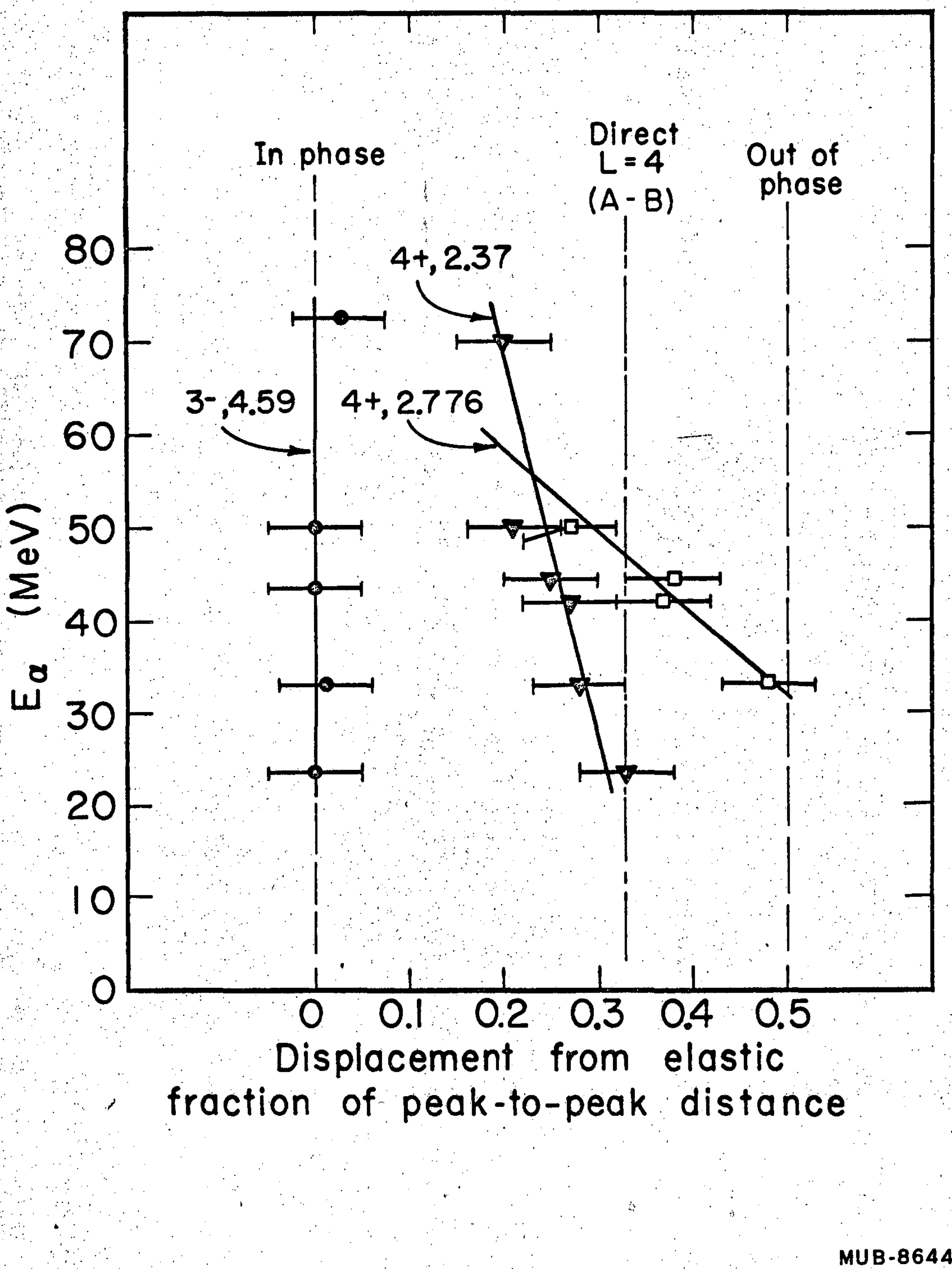

In phase
Direct
L = 4
(A - B)
Out of
phase
4+, 2.37
3-, 4.59
4+, 2.776
80
70
60
50
40
30
20
10
0
Eα (MeV)
0
0.1
0.2
0.3
0.4
0.5
Displacement from elastic
fraction of peak-to-peak distance
MUB-8644

Fig. 7

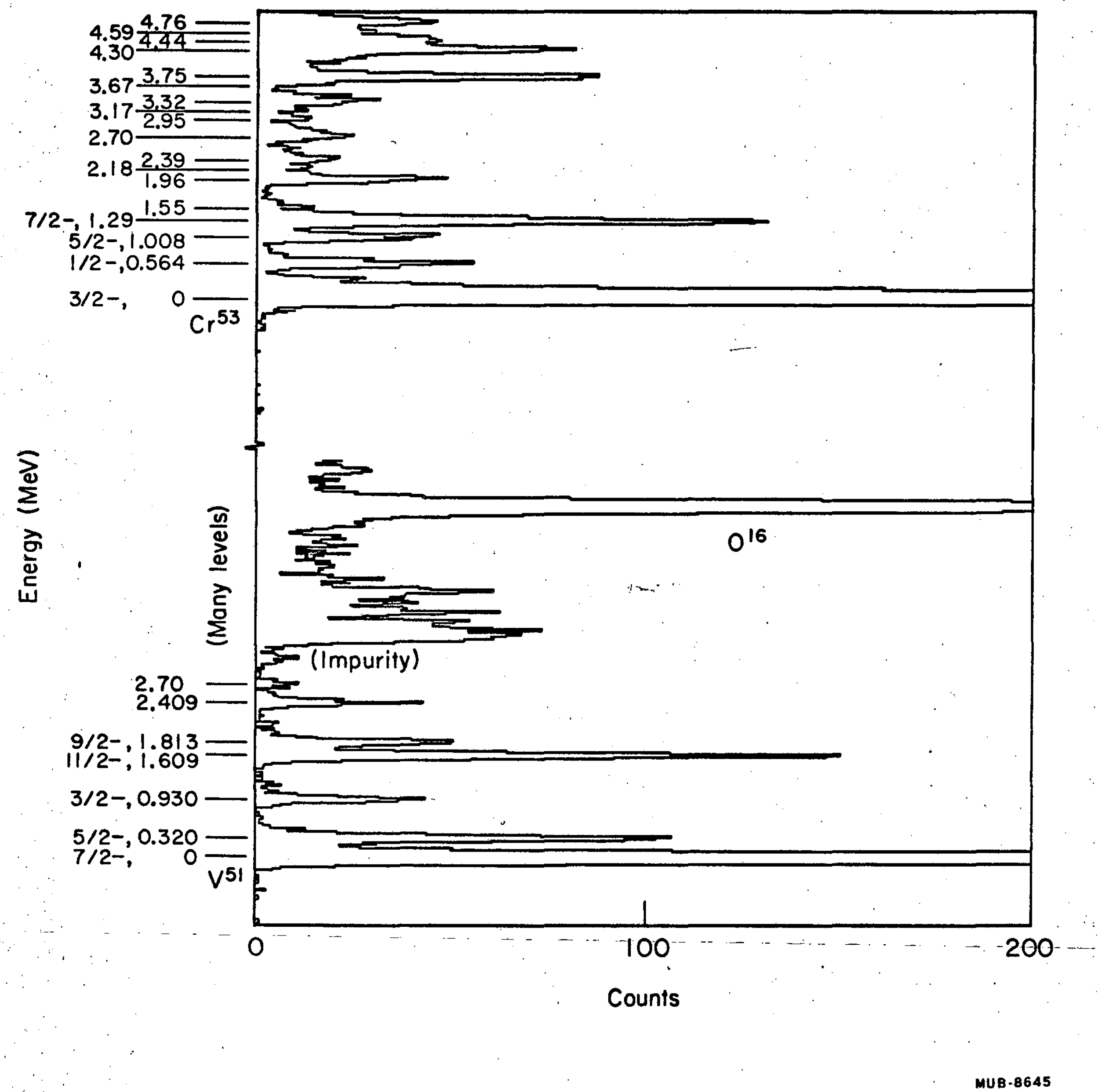
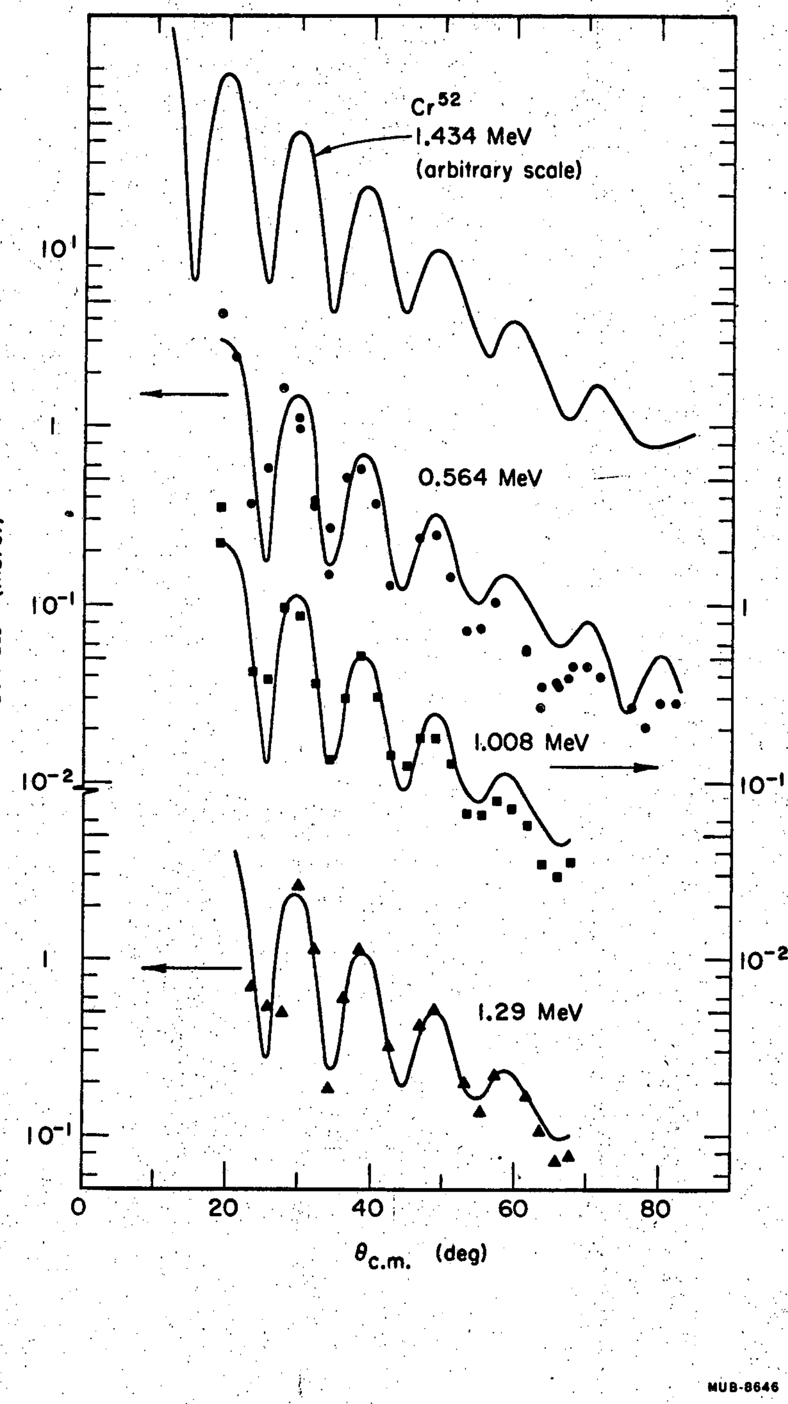

4.76
4.59
4.44
4.30
3.75
3.67
3.32
3.17
2.95
2.70
2.39
2.18
1.96
1.55
7/2-, 1.29
5/2-, 1.008
1/2-, 0.564
3/2-, 0
Cr53
Energy (MeV)
(Many levels)
O16
(Impurity)
2.70
2.409
9/2-, 1.813
11/2-, 1.609
3/2-, 0.930
5/2-, 0.320
7/2-, 0
V51
0
100
200
Counts
MUB-8645

Fig. 8



Cr52
1.434 MeV
(arbitrary scale)
0.564 MeV
1.008 MeV
1.29 MeV
dσ/dΩ (mb/sr)
θc.m. (deg)
10¹
1
10⁻¹
10⁻²
1
10⁻¹
10⁻¹
10⁻²
0
20
40
60
80
MUB-8646

Fig. 9

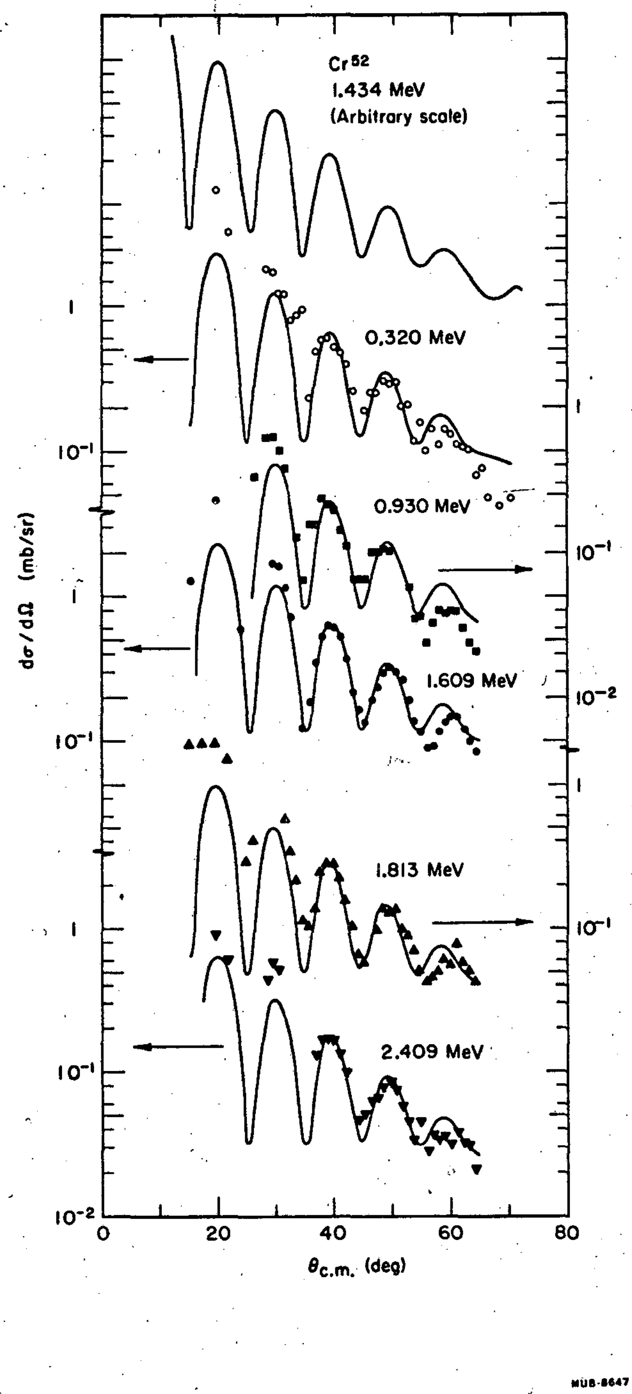

Cr52
1.434 MeV
(Arbitrary scale)
0.320 MeV
0.930 MeV
1.609 MeV
1.813 MeV
2.409 MeV
dσ/dΩ (mb/sr)
θc.m. (deg)
MUB-8647

Fig. 10

Cr^{52}

Elastic

$E_\alpha = 23.5$ MeV

θ_{cm}	dσ/dΩ (mb/SR)	Statistical Error (mb/SR)	θ_{cm}	dσ/dΩ (mb/SR)	Statistical Error (mb/SR)
28.4	701.7	1.4	55.9	14.4	0.1
30.5	376.4	1.0	58.0	8.57	0.05
32.6	194.2	0.7	60.1	3.61	0.03
34.8	131.9	0.6	62.2	1.66	0.01
36.9	121.0	0.4	64.3	1.96	0.02
39.0	111.9	0.3	66.3	3.23	0.02
41.1	85.2	0.3	68.4	3.91	0.02
43.4	49.0	0.2	70.6	3.72	0.02
45.5	24.3	0.1	72.5	2.73	0.02
47.5	13.9	0.1	74.6	1.38	0.01
49.5	13.6	0.1	76.6	0.400	0.006
51.7	16.1	0.1	78.7	0.098	0.003
53.8	17.8	0.1	80.7	0.316	0.002

Cr^{52}

E_α = 23.5 MeV

2.37 MeV		2.65 MeV		2.776 MeV		2.956 MeV	
θ cm	dσ/dΩ(mb/SR)	θ cm	dσ/dΩ(mb/SR)	θ cm	dσ/dΩ(mb/SR)	θ cm	dσ/dΩ(mb/SR)
28.5	.577	28.5	.147	28.5	.933	28.5	.122
30.6	.396	30.6	.066	30.6	.590	30.7	.086
32.8	.252	32.8	.072	32.8	.344	32.8	.042
34.9	.083	34.9	.058	34.9	.234	34.9	.035
41.3	.963	37.1	.069	37.1	.159	37.1	.035
43.4	.173	39.2	.019	39.2	.147	39.2	.031
45.6	.182	47.7	.119	41.3	.189	41.3	.055
47.7	.165	56.1	.007	47.7	.214	43.5	.048
54.0	.032	60.3	.018	49.8	.241	52.0	.044
56.1	.035	62.4	.013	52.0	.127	54.1	.049
58.2	.045	64.5	.019	56.1	.026	58.3	.020
60.3	.044	66.6	.015	58.2	.034	68.7	.010
62.4	.042	68.7	.005	60.3	.029	70.8	.022
64.5	.027	70.7	.005	62.4	.058	72.8	.016
66.6	.028	72.8	.006	64.5	.059	74.9	.012
68.6	.015	74.8	.004	66.6	.059	76.9	.010
70.7	.009	76.9	.004	68.7	.046	81.0	.005
72.8	.012	81.0	.004	70.7	.032	83.1	.008
74.8	.012	83.0	.002	72.8	.016	85.1	.007
76.9	.014	87.1	.015	74.9	.024	87.1	.027
81.0	.013			76.9	.015	89.1	.011
83.0	.013			81.0	.022		
85.0	.015			83.0	.021		
87.0	.010			85.1	.016		
89.1	.011			87.1	.008		
				89.1	.013		

Cr^{52}

E_α = 23.5 MeV

3.16 MeV		3.46 MeV		3.78 MeV		4.050 MeV	
θ cm	dσ/dΩ(mb/SR)	θ cm	dσ/dΩ(mb/SR)	θ cm	dσ/dΩ(mb/SR)	θ cm	dσ/dΩ(mb/SR)
28.5	.498	28.5	.235	28.6	.547	28.6	.398
30.7	.466	30.7	.063	30.7	.698	30.7	.171
32.8	.493	32.8	.042	32.9	.779	32.9	.146
35.0	.374	35.0	.039	35.0	.658	35.0	.066
37.1	.378	37.1	.046	37.1	.449	37.2	.080
39.2	.290	39.3	.038	39.3	.275	39.3	.077
41.4	.242	41.4	.045	41.4	.218	41.4	.076
43.5	.169	43.5	.067	43.5	.252	43.6	.063
45.6	.333	45.6	.054	45.7	.343	45.7	.107
49.9	.190	47.8	.099	47.8	.355	47.8	.102
52.0	.088	52.0	.064	49.9	.373	50.0	.055
54.1	.069	56.2	.025	56.3	.073	52.0	.067
56.2	.057	64.6	.017	58.4	.105	58.4	.033
60.4	.091	66.7	.028	60.4	.122	60.5	.028
62.5	.130	68.7	.033	62.5	.178	62.6	.038
64.6	.137	70.8	.031	66.7	.151	64.7	.034
66.6	.100	72.9	.030	68.8	.083	70.9	.023
68.7	.047	74.9	.015	70.9	.047	73.0	.017
70.8	.028	77.0	.010	72.9	.030	74.9	.015
72.8	.018	81.1	.008	74.9	.032	77.1	.013
74.9	.020	83.1	.007	77.0	.058	81.2	.012
77.0	.026	85.2	.005	81.1	.073	83.2	.010
81.0	.046	87.2	.036	83.2	.065	85.2	.017
83.1	.037	89.2	.008	85.2	.048	89.3	.012
85.1	.034			87.2	.008		
87.1	.010			89.2	.025		
89.2	.024						

Cr^{52}

E_{α} = 23.5 MeV

4.59 MeV

θ cm	dσ/dΩ(mb/SR)
28.6	1.05
30.8	.760
32.9	.591
35.1	.528
39.4	.724
41.5	.719
43.6	.399
45.8	.177
47.9	.173
52.1	.196
54.2	.181
62.6	.232
64.7	.088
66.8	.115
68.9	.085
79.2	.094
83.3	.053
85.3	.040
87.3	.045
89.3	.037
91.4	.047
93.4	.051
95.4	.055
97.4	.066
101.4	.038
103.3	.023

Cr^{53}

Elastic

E_α = 50 MeV

θ_{cm}	dσ/dΩ (mb/SR)	Statistical Error (mb/SR)	θ_{cm}	dσ/dΩ (mb/SR)	Statistical Error (mb/SR)
19.3	244.0	1.28	44.9	8.40	0.076
21.5	62.6	0.649	47.0	4.53	0.056
23.6	149.6	1.00	49.1	1.57	0.033
25.8	135.5	0.956	51.2	1.46	0.032
27.9	43.5	0.172	53.3	2.45	0.025
30.0	2.36	0.040	55.4	2.47	0.026
32.2	19.4	0.115	57.5	1.49	0.020
34.3	30.8	0.145	59.6	0.642	0.013
36.4	19.0	0.106	61.7	0.500	0.016
38.6	3.90	0.048	63.8	0.745	0.019
40.7	2.42	0.038	65.9	0.801	0.020
42.8	7.82	0.068	67.9	0.577	0.017

Cr^{53}

E_{α} = 50 MeV

0.564 MeV, 1/2-		1.008 MeV, 5/2-		1.29 MeV, 7/2-		1.96 MeV	
θ cm	dσ/dΩ(mb/SR)	θ cm	dσ/dΩ(mb/SR)	θ cm	dσ/dΩ(mb/SR)	θ cm	dσ/dΩ(mb/SR)
19.4	4.41	19.4	3.60	21.5	5.16	19.4	1.47
21.5	2.46	23.6	.424	23.7	.705	21.5	1.25
23.6	.374	25.8	.358	25.8	.531	23.7	.830
25.8	.591	27.9	.961	27.9	2.48	25.8	.352
27.9	1.66	30.1	.889	30.1	2.64	27.9	.493
30.1	1.17	32.2	.364	32.2	1.14	32.2	.476
32.2	.362	34.3	.136	34.3	.184	34.4	.128
34.3	.150	36.5	.300	36.5	.610	36.5	.068
36.4	.523	38.6	.375	38.6	1.17	38.6	.140
38.6	.578	40.7	.303	40.7	.921	40.7	.247
40.7	.373	42.8	.141	42.8	.323	42.9	.140
42.8	.129	44.9	.124	45.0	.204	45.0	.035
44.9	.131	47.1	.177	47.1	.423	47.1	.046
47.0	.238	49.2	.176	49.2	.518	49.2	.110
49.2	.246	51.3	.126	51.3	.368	51.3	.114
51.3	.145	53.4	.067	53.4	.197	53.4	.062
53.4	.073	55.5	.065	55.5	.135	55.5	.034
55.5	.076	57.6	.078	57.6	.210	57.6	.033
57.5	.107	59.7	.071	59.7	.204	59.7	.046
59.6	.098	61.7	.057	61.7	.163	61.8	.045
61.7	.056	63.8	.035	63.8	.105	63.9	.033
63.8	.027	65.9	.030	65.9	.072	65.9	.030
65.9	.038	68.0	.036	68.0	.077	68.0	.014
67.9	.040						

Cr^{53}

E_{α} = 50 MeV

3.67 MeV θ cm	3.67 MeV dσ/dΩ(mb/SR)	4.30 MeV θ cm	4.30 MeV dσ/dΩ(mb/SR)
19.4	.932	19.4	.721
21.5	1.40	21.6	.565
23.7	1.82	23.7	.727
25.8	.914	25.9	.781
28.0	.328	28.0	.264
30.1	.325	30.1	.160
32.3	.692	32.3	.207
36.5	.351	34.4	.363
38.5	.140	36.0	.411
40.8	.226	38.7	.165
42.9	.309	40.8	.120
45.0	.201	42.9	.099
47.2	.138	47.2	.109
51.4	.092	51.4	.050
53.5	.130	53.5	.063
55.6	.085	55.6	.065
57.7	.078	57.7	.065
59.8	.055	59.8	.047
61.8	.062	61.9	.027
63.9	.055	64.0	.033
66.0	.065	66.0	.040

V^{51}

Elastic

E_α = 50 MeV

θ_{cm}	dσ/dΩ (mb/SR)	Statistical Error (mb/SR)	θ_{cm}	dσ/dΩ (mb/SR)	Statistical Error (mb/SR)
15.5	1996	3.8	43.3	11.4	0.066
17.7	1000	2.7	44.4	13.5	0.042
19.8	177	0.74	45.4	12.3	0.069
19.8	162	1.1	46.5	9.49	0.035
22.0	84.2	0.51	47.6	6.74	0.051
24.1	208	0.81	48.6	3.48	0.021
25.2	196	0.38	49.7	2.23	0.029
26.3	156	0.70	50.7	1.84	0.012
28.4	38.1	0.13	51.8	2.22	0.029
29.5	6.53	0.07	52.8	3.24	0.016
30.5	1.01	0.21	53.9	3.82	0.027
31.6	12.5	0.097	54.9	4.03	0.018
32.7	29.1	0.111	56.0	3.86	0.028
33.8	40.2	0.12	57.0	2.91	0.015
34.8	40.4	0.13	58.1	2.27	0.021
35.9	34.5	0.11	59.1	1.42	0.011
37.0	22.0	0.092	60.2	1.03	0.014
38.0	10.5	0.063	61.2	0.746	0.008
39.1	3.75	0.038	62.3	0.859	0.009
40.1	1.77	0.026	63.3	0.985	0.009
41.2	4.05	0.039	64.3	1.18	0.011
42.2	8.69	0.033	65.4	1.21	0.010

V^{51}

Elastic

E_α = 50 MeV

θ_{cm}	$d\sigma/d\Omega$ (mb/SR)	Statistical Error (mb/SR)
66.4	1.27	0.011
68.5	0.918	0.010
70.5	0.605	0.008
72.6	0.496	0.007
74.7	0.574	0.008
76.7	0.652	0.008
78.8	0.628	0.007
80.8	0.544	0.007
82.8	0.430	0.006
84.9	0.363	0.006
86.9	0.377	0.004
88.9	0.402	0.004
90.9	0.397	0.004
92.9	0.339	0.003
94.9	0.291	0.003
96.9	0.242	0.003
98.9	0.206	0.003
100.9	0.189	0.003
106.8	0.128	0.002
108.8	0.092	0.002
110.7	0.071	0.001

V^{51}

E_α = 50 MeV

.320 MeV level

θ cm	dσ/dΩ(mb/SR)	θ cm	dσ/dΩ(mb/SR)	θ cm	dσ/dΩ(mb/SR)
19.8	6.37	56.0	.104	100.9	.022
22.0	3.45	57.0	.151	104.9	.017
28.4	1.89	58.1	.115	106.8	.014
29.5	1.80	59.1	.149	108.8	.014
30.6	1.31	60.2	.137	110.7	.012
31.6	1.28	61.2	.120		
32.7	.842	62.3	.114		
33.8	.902	63.3	.108		
34.8	.983	64.3	.072		
35.9	.243	65.4	.081		
37.0	.510	66.4	.051		
38.0	.604	68.5	.045		
39.1	.620	70.6	.051		
40.2	.540	72.6	.054		
41.2	.512	74.7	.043		
42.3	.413	76.7	.032		
43.3	.273	78.8	.027		
45.5	.201	80.8	.028		
46.5	.266	82.8	.032		
47.6	.267	84.9	.029		
48.6	.317	86.9	.032		
49.7	.309	88.9	.025		
50.7	.316	90.2	.026		
51.8	.221	92.9	.024		
52.8	.222	94.9	.028		
53.9	.127	96.9	.027		
54.9	.167	98.9	.024		

V^{51}

E_{α} = 50 MeV

.930 MeV level

θ cm	dσ/dΩ(mb/SR)	θ cm	dσ/dΩ(mb/SR)	θ cm	dσ/dΩ(mb/SR)
26.3	.345	56.0	.025	106.8	.005
28.4	.655	57.1	.034	108.8	.005
29.5	.660	58.1	.041	110.7	.004
30.6	.535	59.2	.040		
31.6	.402	60.2	.041		
32.7	.190	61.2	.041		
33.8	.129	62.3	.031		
34.8	.065	63.3	.025		
35.9	.161	64.4	.022		
37.0	.161	65.4	.017		
38.0	.241	66.4	.015		
39.1	.222	68.5	.015		
40.2	.202	70.6	.018		
41.2	.146	72.6	.018		
42.3	.115	74.7	.014		
43.5	.069	76.8	.012		
44.4	.069	78.8	.011		
45.5	.069	80.8	.011		
46.5	.103	82.9	.013		
47.6	.105	84.9	.012		
48.7	.111	86.9	.011		
49.7	.105	88.9	.010		
50.8	.099	90.9	.009		
51.8	.074	92.9	.010		
52.9	.059	94.9	.008		
53.9	.036	96.9	.007		
55.0	.038	98.9	.006		

$V^{51}(\alpha,\alpha') V^{51}$

E_α = 50 MeV

1.609 MeV level

θ cm	dσ/dΩ(mb/SR)	θ cm	dσ/dΩ(mb/SR)	θ cm	dσ/dΩ(mb/SR)
15.5	1.343	55.0	.115	100.9	.023
17.7	3.182	56.1	.093	104.8	.019
19.9	4.90	57.1	.096	106.8	.017
24.2	.630	58.2	.120	108.8	.013
29.5	1.757	59.2	.140	110.8	.014
30.6	1.698	60.2	.148		
31.7	1.227	61.3	.152		
32.7	0.757	62.3	.125		
33.8	0.309	63.4	.104		
34.9	0.128	64.4	.086		
35.9	.194	65.5	.058		
37.0	.357	66.5	.049		
38.1	.545	68.6	.045		
39.1	.651	70.6	.051		
40.2	.636	72.7	.062		
41.3	.541	74.7	.046		
42.3	.387	76.8	.035		
43.3	.220	78.8	.029		
44.4	.171	80.9	.030		
45.5	.138	82.9	.037		
46.6	.198	85.0	.036		
47.6	.244	87.0	.032		
48.7	.305	89.0	.029		
49.7	.335	90.9	.028		
50.8	.316	92.9	.025		
51.9	.273	94.9	.030		
52.9	.199	96.9	.028		
54.0	.140	98.9	.029		

$V^{51}(\alpha,\alpha')\ V^{51}$

E_α = 50 MeV

1.813 MeV level

θ cm	dσ/dΩ(mb/SR)	θ cm	dσ/dΩ(mb/SR)	θ cm	dσ/dΩ(mb/SR)
15.6	1.896	55.0	.052	100.9	.009
17.7	1.988	56.1	.043	104.8	.007
19.9	1.958	57.1	.047	106.8	.007
22.0	1.49	58.2	.052	108.8	.007
25.2	.289	59.2	.062	110.8	.007
26.3	.411	60.3	.057		
31.7	.588	61.3	.080		
32.7	.344	62.3	.059		
33.8	.220	63.4	.052		
34.9	.117	64.4	.044		
35.9	.104	65.5	.034		
37.0	.140	66.5	.029		
38.1	.251	68.6	.021		
39.1	.287	70.6	.026		
40.2	.284	72.7	.024		
41.3	.231	74.8	.026		
42.3	.159	76.8	.018		
43.4	.107	78.9	.012		
44.6	.067	80.9	.013		
45.5	.058	82.9	.014		
46.6	.088	84.9	.013		
47.6	.098	87.0	.012		
48.7	.140	89.0	.010		
49.7	.131	90.9	.011		
50.8	.138	92.9	.009		
51.9	.102	94.9	.010		
52.9	.090	96.9	.010		
54.0	.071	98.9	.012		

$V^{51}(\alpha,\alpha')\,V^{51}$

E_α = 50 MeV

2.409 MeV level				2.699 MeV level			
θ cm	dσ/dΩ(mb/SR)	θ cm	dσ/dΩ(mb/SR)	θ cm	dσ/dΩ(mb/SR)	θ cm	dσ/dΩ(mb/SR)
17.7	.959	60.3	.032	17.7	.820	83.0	.006
19.9	.951	61.3	.039	19.9	.492	85.0	.005
22.0	.619	62.4	.033	22.0	.260	90.9	.004
28.5	.451	63.4	.032	25.3	.259	92.9	.004
29.5	.602	64.4	.022	26.3	.265	94.9	.004
30.6	.527	65.5	.019	30.6	.174	96.9	.004
37.0	.133	66.5	.020	38.1	.087	98.9	.003
38.1	.170	68.6	.018	39.2	.063	104.9	.003
39.2	.173	70.7	.018	40.2	.050	106.8	.002
40.2	.173	72.7	.017	41.3	.038	108.8	.002
41.3	.135	74.8	.015	44.5	.034		
42.4	.101	76.8	.014	45.5	.040		
43.4	.049	78.9	.010	46.6	.042		
44.5	.047	80.9	.009	47.7	.038		
45.5	.052	83.0	.010	48.7	.046		
46.6	.064	85.0	.009	49.8	.025		
47.6	.067	87.0	.010	56.1	.015		
48.7	.080	89.0	.007	58.2	.014		
49.8	.087	90.9	.007	59.2	.022		
50.8	.075	92.9	.007	60.3	.016		
51.9	.060	94.9	.008	62.4	.010		
52.9	.047	96.9	.007	64.5	.008		
54.0	.035	98.9	.006	66.5	.008		
55.0	.046	100.9	.006	68.6	.008		
56.1	.029	104.9	.005	70.7	.009		
57.1	.038	106.8	.004	72.7	.008		
58.2	.034	108.8	.005	76.9	.006		
59.2	.037	110.8	.004	78.9	.005		

Cr^{52}

Elastic

E_α = 33 MeV

θ_{cm}	dσ/dΩ (mb/SR)	Statistical Error (mb/SR)	θ_{cm}	dσ/dΩ (mb/SR)	Statistical Error (mb/SR)
13.5	8220	43.4	68.5	1.04	0.017
17.2	1449	18.3	70.6	1.11	0.012
19.9	988	15.1	70.6	1.09	0.033
19.9	1056	5.2	72.6	0.791	0.010
22.1	678	4.2	72.6	0.80	0.028
24.2	281	2.7	74.7	0.344	0.006
26.3	90.7	1.5	74.7	0.354	0.019
28.5	70.5	0.30	76.7	0.101	0.004
30.6	94.4	0.35	76.7	0.104	0.010
32.7	83.9	0.33	78.8	0.147	0.004
34.9	42.3	0.23	80.8	0.357	0.007
37.0	10.8	0.19	82.8	0.511	0.008
39.1	3.30	0.065	84.9	0.511	0.008
41.3	11.3	0.12	86.9	0.432	0.008
43.4	17.1	0.15	88.9	0.267	0.006
45.5	14.5	0.10	90.9	0.158	0.005
47.6	6.93	0.067	92.9	0.124	0.004
49.7	1.14	0.027	94.9	0.178	0.004
51.8	0.226	0.012	96.9	0.253	0.004
53.9	2.64	0.034	98.9	0.274	0.005
56.0	4.15	0.0435	100.9	0.240	0.004
58.1	3.62	0.0400	102.9	0.194	0.004
60.2	1.77	0.0288	104.9	0.147	0.004
62.3	0.361	0.010	106.8	0.105	0.003
64.3	0.064	0.004	108.8	0.080	0.003
66.4	0.554	0.012			

Cr^{52}

E_α = 33 MeV

1.434 MeV, 2+				2.37 MeV, 4+			
θ cm	dσ/dΩ(mb/SR)	θ cm	dσ/dΩ(mb/SR)	θ cm	dσ/dΩ(mb/SR)	θ cm	dσ/dΩ(mb/SR)
15.6	14.3	76.8	.114	17.8	1.99	83.0	.009
17.8	6.62	78.9	.119	20.0	1.83	85.1	.006
19.9	1.36	80.9	.085	22.1	1.35	87.1	.007
19.9	1.30	82.9	.052	24.3	1.07	89.1	.008
22.1	2.23	85.0	.028	26.4	.355	91.1	.009
24.2	6.44	87.0	.034	28.6	.111	93.1	.008
28.5	4.39	89.0	.051	30.7	.114	95.1	.007
30.7	1.46	91.0	.069	32.8	.243	97.1	.008
34.9	.891	93.0	.078	34.9	.278	99.1	.008
37.1	2.04	95.0	.069	37.1	.205	101.1	.007
39.2	2.04	97.0	.054	39.2	.135	103.1	.007
41.3	1.24	99.0	.042	41.4	.141	105.0	.006
43.5	.294	101.0	.030	45.6	.052	107.0	.008
45.6	.137	103.0	.033	47.7	.086	109.0	.008
47.7	.520	105.0	.044	49.9	.078		
49.8	.954	106.9	.055	52.0	.046		
51.9	.940	108.9	.058	54.1	.018		
54.0	.537			56.2	.014		
56.1	.165			58.2	.020		
58.2	.068			62.4	.033		
60.3	.179			64.5	.020		
62.4	.320			66.6	.013		
64.4	.342			68.7	.005		
66.5	.256			70.7	.015		
68.6	.115			72.8	.010		
70.6	.042			74.9	.013		
72.7	.041			76.9	.011		
74.8	.092			79.0	.010		
				81.0	.008		

Cr^{52}

E_{α} = 33 MeV

2.650, MeV, 0+				2.776 MeV, 4+			
θ cm	dσ/dΩ(mb/SR)	θ cm	dσ/dΩ(mb/SR)	θ cm	dσ/dΩ(mb/SR)	θ cm	dσ/dΩ(mb/SR)
19.9	.258	97.1	.001	17.8	1.660	87.1	.005
22.1	.141	99.1	.001	20.0	1.52	89.1	.006
26.4	.184	101.1	.002	22.1	1.39	91.1	.005
28.6	.116	103.1	.003	24.3	.967	93.2	.005
30.7	.047	105.1	.004	26.4	.621	95.2	.007
32.9	.036	107.0	.004	28.6	.278	97.1	.006
35.0	.060	109.0	.002	30.7	.194	99.1	.005
47.7	.037			32.9	.183	101.1	.005
49.9	.018			35.0	.216	103.1	.005
52.0	.020			39.3	.215	105.1	.003
54.1	.011			43.5	.095	107.0	.004
56.2	.015			47.8	.063	109.0	.006
58.3	.023			49.9	.093		
60.4	.036			52.0	.069		
62.5	.023			54.1	.069		
64.5	.026			56.2	.036		
66.6	.012			58.3	.020		
68.7	.006			60.4	.012		
70.8	.011			62.5	.020		
72.8	.013			64.5	.022		
74.9	.015			66.6	.020		
76.9	.006			68.7	.017		
79.0	.005			70.8	.008		
81.1	.004			74.9	.007		
85.1	.003			76.9	.013		
87.1	.003			79.0	.003		
91.1	.002			81.0	.008		
93.1	.002			83.1	.008		

Cr^{52}

E_{α} = 33 MeV

2.97 MeV				3.16 MeV, (2+)			
θ cm	dσ/dΩ(mb/SR)	θ cm	dσ/dΩ(mb/SR)	θ cm	dσ/dΩ(mb/SR)	θ cm	dσ/dΩ(mb/SR)
17.8	.455	93.2	.007	17.8	.973	81.1	.019
20.0	.417	95.2	.007	20.0	.686	83.1	.026
22.1	.198	97.2	.006	22.1	.669	85.1	.012
26.4	.089	99.2	.007	24.3	.740	89.2	.016
28.6	.099	101.1	.008	26.4	.806	91.2	.015
30.7	.107	103.1	.008	28.6	.624	93.2	.013
32.9	.069	105.1	.007	30.7	.293	95.2	.014
35.0	.033	107.1	.009	32.9	.246	97.2	.013
43.5	.951	109.2	.007	35.0	.226	99.2	.011
47.8	.043			37.2	.295	101.2	.007
52.0	.009			41.4	.156	103.1	.008
54.1	.008			43.5	.071	105.1	.007
56.2	.019			45.7	.049	107.1	.007
58.3	.014			47.8	.118	109.0	.008
60.4	.004			52.0	.109		
64.6	.011			54.1	.067		
66.6	.008			56.2	.025		
68.7	.015			58.3	.024		
70.8	.015			60.4	.042		
72.8	.009			62.5	.063		
74.9	.005			64.6	.057		
77.0	.004			66.7	.041		
79.0	.021			68.7	.022		
81.0	.014			70.8	.013		
83.1	.011			72.9	.018		
85.1	.011			74.9	.024		
87.1	.011			77.0	.030		
89.1	.009			79.0	.026		
91.2	.007						

Cr^{52}

E_{α} = 33 MeV

3.45 MeV				3.78 MeV			
θ cm	dσ/dΩ(mb/SR)	θ cm	dσ/dΩ(mb/SR)	θ cm	dσ/dΩ(mb/SR)	θ cm	dσ/dΩ(mb/SR)
17.8	.674	87.2	.011	17.8	1.94	83.1	.051
20.0	.521	89.2	.008	20.0	.946	85.2	.032
22.1	.329	91.2	.006	22.2	1.022	87.2	.030
24.3	.098	93.2	.004	24.3	1.41	89.2	.037
26.5	.072	95.2	.006	26.5	1.67	91.2	.042
28.6	.053	97.2	.006	28.6	1.22	93.2	.049
30.7	.058	99.2	.003	30.8	.498	95.2	.046
32.9	.081	101.2	.004	32.9	.189	97.2	.042
35.0	.070	103.2	.004	35.0	.320	99.2	.035
37.2	.032	105.1	.003	37.2	.632	101.2	.027
39.3	.031	107.1	.004	39.8	.735	103.2	.025
47.8	.036	109.1	.003	41.4	.419	105.2	.026
54.1	.020			45.7	.117	107.1	.027
56.2	.023			47.8	.148	109.1	.027
58.3	.019			49.9	.241		
60.4	.016			52.0	.243		
62.5	.017			54.5	.074		
64.6	.018			60.4	.104		
66.7	.009			62.5	.161		
68.8	.011			64.6	.180		
70.8	.013			66.7	.138		
72.9	.009			68.8	.084		
74.9	.011			70.8	.049		
77.0	.008			72.9	.040		
79.0	.008			75.0	.053		
81.1	.009			77.0	.064		
83.1	.009			79.1	.072		
85.1	.008			81.1	.063		

Cr^{52}

E_{α} = 33 MeV

4.03 MeV

θ cm	dσ/dΩ(mb/SR)	θ cm	dσ/dΩ(mb/SR)
17.9	.998	91.3	.008
20.0	1.06	93.3	.009
22.2	.727	95.3	.012
24.3	.371	97.3	.012
26.5	.216	99.2	.010
28.6	.119	101.2	.004
30.8	.142	103.2	.008
32.9	.161	105.2	.006
35.1	.128	107.2	.007
37.2	.118	109.1	.006
39.3	.058		
47.8	.061		
58.4	.025		
60.5	.017		
62.6	.027		
64.6	.031		
66.7	.027		
68.8	.018		
70.9	.017		
72.9	.019		
75.0	.015		
77.0	.015		
79.1	.014		
81.1	.014		
83.2	.009		
85.2	.008		
87.2	.009		
89.2	.010		

4.59 MeV, 3-

θ cm	dσ/dΩ(mb/SR)	θ cm	dσ/dΩ(mb/SR)
20.0	4.54	85.2	.036
22.2	3.11	87.3	.041
24.3	.612	89.3	.045
26.5	.718	91.3	.039
28.6	1.01	93.3	.032
30.8	1.46	95.3	.032
32.9	1.65	97.3	.027
35.1	1.01	99.3	.027
37.2	.560	101.3	.023
39.4	.345	103.3	.031
41.5	.317	105.2	.032
43.6	.464	107.2	.034
45.8	.567	109.2	.030
47.9	.453		
54.2	.118		
56.3	.234		
58.4	.332		
62.6	.195		
64.7	.137		
66.7	.064		
68.8	.050		
70.9	.074		
73.0	.092		
75.0	.095		
77.1	.078		
81.2	.045		
83.2	.037		

Cr^{52}

E_{α} = 33 MeV

4.73 MeV				5.12 MeV			
θ cm	dσ/dΩ(mb/SR)	θ cm	dσ/dΩ(mb/SR)	θ cm	dσ/dΩ(mb/SR)	θ cm	dσ/dΩ(mb/SR)
20.0	.435	87.3	.014	22.2	.761	99.3	.012
22.2	.420	89.3	.009	24.4	.445	101.3	.008
24.3	1.31	91.3	.015	26.5	.259	103.3	.008
26.5	.667	93.3	.018	28.7	.110	105.3	.008
28.6	.440	95.3	.013	30.8	.106	107.2	.008
30.8	.212	97.3	.013	33.0	.146	109.2	.006
32.9	.123	99.3	.010	35.11	.175		
35.1	.362	101.3	.011	37.3	.152		
37.2	.717	103.3	.009	39.4	.136		
39.4	.243	105.2	.012	41.52	.097		
41.5	.154	107.2	.014	43.6	.037		
43.6	.052	109.2	.014	45.8	.045		
45.8	.056			47.9	.050		
47.9	.094			50.0	.070		
56.3	.037			66.8	.024		
58.4	.054			68.9	.020		
62.6	.086			71.0	.017		
64.7	.076			73.0	.014		
66.8	.066			75.1	.013		
68.9	.042			77.1	.014		
70.9	.029			79.2	.015		
73.0	.029			81.2	.016		
75.0	.029			83.3	.013		
77.1	.033			85.3	.016		
79.1	.038			87.3	.016		
81.2	.037			89.3	.009		
83.2	.019			93.4	.007		
85.3	.017			97.4	.010		

Cr^{52}

E_α = 33 MeV

5.45 MeV

θ cm	dσ/dΩ(mb/SR)
24.4	.887
28.7	.501
30.8	.386
33.0	.371
35.1	.343
37.3	.291
39.4	.274
41.5	.179
43.6	.140
45.8	.130
47.9	.134
50.0	.149
68.9	.048
71.0	.044
73.1	.040
75.1	.033
77.2	.033
79.3	.041
81.3	.038
83.3	.029
85.3	.020
87.4	.022
89.4	.023
93.4	.028
97.4	.023
101.4	.016
105.3	.014
109.2	.014

Cr^{52}

Elastic

$E_{\alpha} = 50$ MeV

θ_{cm}	$d\sigma/d\Omega$ (mb/SR)	Statistical Error (mb/SR)	θ_{cm}	$d\sigma/d\Omega$ (mb/SR)	Statistical Error (mb/SR)
9.1	1967	19.7	41.3	4.35	0.057
11.2	4283	17.1	43.4	9.57	0.086
12.3	2282	22.8	45.5	8.52	0.068
13.4	1882	18.9	47.6	3.57	0.043
14.4	1762	14.1	49.7	1.13	0.023
15.5	1567	7.8	51.8	1.94	0.021
16.5	1128	11.3	54.0	2.90	0.026
17.7	703.5	7.0	56.0	2.52	0.017
18.7	277	2.8	58.1	1.35	0.013
19.9	101	0.40	60.2	0.645	0.009
20.9	49.4	0.25	62.3	0.592	0.009
23.0	123	0.49	64.4	0.844	0.010
24.2	149	0.60	66.5	0.828	0.019
26.3	106	0.42	68.5	0.556	0.016
27.3	47.0	0.23	70.6	0.356	0.012
28.5	18.2	0.13	72.7	0.333	0.025
30.6	3.68	0.18	74.7	0.395	0.013
31.6	16.6	0.10	76.8	0.447	0.013
32.8	27.6	0.17	78.7	0.388	0.013
33.7	31.7	0.19	80.7	0.338	0.012
34.9	30.0	0.18	82.8	0.242	0.010
37.0	11.8	0.094	84.8	0.232	0.010
39.1	1.17	0.030			

Cr^{52}

E_α = 50 MeV

1.434 MeV, 2+ (ℓ=2)				2.37 MeV, 4+			
θ cm	dσ/dΩ(mb/SR)	θ cm	dσ/dΩ(mb/SR)	θ cm	dσ/dΩ(mb/SR)	θ cm	dσ/dΩ(mb/SR)
11.3	29.5	58.2	.359	11.3	.820	62.4	.019
12.3	21.7	60.3	.416	12.3	1.33	64.5	.020
13.5	12.2	62.4	.325	13.5	1.50		
14.4	1.67	64.4	.188	14.5	1.19		
15.6	1.27	66.5	.125	15.6	1.61		
16.6	3.33	68.5	.119	16.6	1.48		
17.8	7.99	70.7	.170	17.8	1.37		
18.7	12.8	72.7	.150	18.8	.862		
23.0	2.96	74.8	.125	19.9	.450		
24.2	.655	76.8	.082	20.9	.124		
27.3	3.83	78.8	.074	23.1	.293		
28.5	5.21	80.8	.088	24.2	.337		
29.5	5.35	82.8	.087	25.2	.521		
30.7	4.58	84.9	.097	27.4	.586		
31.6	2.79			28.5	.440		
32.8	1.45			29.5	.334		
33.8	.481			30.7	.216		
34.9	.333			35.0	.139		
37.1	1.41			37.1	.196		
39.2	2.08			39.2	.127		
41.3	1.45			41.3	.042		
43.4	.504			43.5	.025		
45.6	.383			49.8	.037		
47.7	.853			51.9	.030		
49.8	1.02			54.0	.044		
51.9	.706			56.1	.032		
54.0	.334			58.2	.037		
56.1	.256			60.3	.024		

Cr^{52}

E_α = 50 MeV

2.776 MeV, 4+				3.16 MeV, 2+	
θ cm	dσ/dΩ(mb/SR)	θ cm	dσ/dΩ(mb/SR)	θ cm	dσ/dΩ(mb/SR)
11.3	.832	56.1	.009	11.3	2.10
12.3	1.28	58.2	.011	12.3	1.11
13.5	1.42	60.3	.016	13.5	.748
14.5	.951	62.4	.011	15.6	.307
15.6	1.55	64.5	.007	16.6	.555
16.6	1.61			17.8	.866
17.8	1.55			18.8	1.21
18.8	1.172			20.0	1.27
20.0	.748			20.9	.620
20.9	.264			23.1	.326
23.1	.170			24.3	.243
24.2	.177			25.2	.226
25.2	.174			26.4	.310
26.4	.330			27.4	.489
27.4	.569			28.6	.473
28.6	.563			29.5	.549
30.7	.300			32.8	.154
31.6	.208			35.0	.095
32.8	.152			41.4	.041
37.1	.114			45.6	.038
39.2	.142			47.7	.078
41.4	.079			49.8	.072
43.5	.047			52.0	.059
45.6	.033			54.1	.025
47.7	.046			56.2	.022
49.8	.046			58.3	.032
51.9	.038			60.3	.036
54.0	.017			62.4	.028
				64.5	.025

Cr^{52}

E_α = 50 MeV

3.42 MeV				3.78 MeV, 2+ (ℓ=2)			
θ cm	dσ/dΩ(mb/SR)	θ cm	dσ/dΩ(mb/SR)	θ cm	dσ/dΩ(mb/SR)	θ cm	dσ/dΩ(mb/SR)
11.3	1.64	62.5	.012	11.3	5.88	58.3	.148
12.3	.590	64.5	.009	12.3	4.25	60.4	.159
13.5	.403			13.5	2.83	62.5	.139
15.7	.364			15.7	.736	64.5	.103
16.6	.277			16.6	1.28		
17.8	.250			17.8	2.28		
18.8	.151			18.8	2.94		
20.0	.067			20.0	2.98		
20.9	.045			20.9	1.50		
23.1	.065			23.1	.600		
24.3	.093			24.3	.282		
25.2	.110			25.2	.309		
26.4	.112			26.4	.642		
27.4	.111			27.4	1.26		
28.6	.083			28.6	1.45		
29.5	.063			29.5	1.53		
30.7	.132			30.7	1.27		
35.0	.065			31.7	.823		
41.4	.040			32.9	.461		
43.5	.043			35.0	.221		
45.6	.054			37.1	.478		
47.7	.033			39.3	.666		
49.9	.031			43.5	.218		
52.0	.013			45.6	.166		
54.1	.024			47.8	.265		
56.2	.018			52.0	.230		
58.3	.019			54.1	.138		
60.4	.014			56.2	.118		

Cr^{52}

E_{α} = 50 MeV

4.05 MeV				4.59 MeV, 3-			
θ cm	dσ/dΩ(mb/SR)	θ cm	dσ/dΩ(mb/SR)	θ cm	dσ/dΩ(mb/SR)	θ cm	dσ/dΩ(mb/SR)
11.3	.412	56.2	.030	12.3	9.07	50.0	.183
12.3	.715	58.3	.027	13.5	9.64	52.0	.159
13.5	.811	60.4	.021	14.5	7.68	54.2	.233
15.7	.926	62.5	.017	15.7	5.88	56.3	.246
16.6	.590	64.6	.016	16.7	4.43	58.4	.202
17.8	.586			17.9	2.57	60.5	.157
18.8	.396			18.8	1.15	62.6	.103
20.0	.238			20.0	.885	64.6	.103
20.9	.111			21.0	1.276		
23.1	.151			22.2	2.06		
24.3	.223			23.1	2.43		
25.2	.238			24.3	2.81		
26.4	.256			25.3	2.72		
27.4	.253			26.5	2.26		
28.6	.203			27.4	1.45		
29.6	.137			28.6	.876		
30.7	.112			29.6	.539		
31.7	.101			30.8	.491		
32.9	.145			31.7	.686		
33.8	.183			32.9	.985		
37.1	.117			33.9	1.079		
39.3	.107			35.1	1.131		
41.4	.065			37.2	.796		
45.6	.076			39.3	.345		
47.8	.055			41.5	.231		
49.9	.037			43.6	.408		
52.0	.033			45.7	.492		
54.1	.034			47.8	.374		

Cr^{52}

E_α = 50 MeV

4.73 MeV				5.1 MeV			
θ cm	dσ/dΩ(mb/SR)	θ cm	dσ/dΩ(mb/SR)	θ cm	dσ/dΩ(mb/SR)	θ cm	dσ/dΩ(mb/SR)
15.7	1.214	60.5	.103	12.3	.729	56.3	.027
17.9	1.219	62.6	.077	15.7	1.07	58.4	.022
18.8	1.134	64.6	.060	16.7	.956	60.5	.029
20.0	.946			17.9	.917	62.6	.019
21.0	.691			18.8	.419	64.6	.019
22.2	.481			20.0	.334		
23.1	.341			21.0	.178		
24.3	.352			22.2	.133		
25.3	.435			23.1	.164		
26.5	.589			24.3	.180		
27.4	.654			25.3	.248		
28.6	.621			26.5	.275		
29.6	.526			27.4	.261		
30.8	.363			28.6	.240		
31.7	.187			29.6	.154		
32.9	.135			30.8	.125		
33.9	.163			31.7	.083		
35.0	.212			32.9	.072		
37.2	.319			33.9	.072		
39.3	.265			35.0	.089		
41.5	.144			37.2	.114		
43.6	.101			39.3	.097		
45.7	.177			41.5	.054		
50.0	.164			43.6	.045		
52.1	.099			45.7	.049		
54.2	.094			47.8	.052		
56.3	.110			52.0	.035		
58.4	.202			54.2	.022		

Cr^{52}

E_{α} = 50 MeV

5.45 MeV

θ cm	dσ/dΩ(mb/SR)	θ cm	dσ/dΩ(mb/SR)
12.3	1.95	56.3	.057
13.5	2.03	58.4	.058
14.5	1.95	60.5	.056
15.7	1.95	62.6	.046
17.9	2.30	64.6	.035
18.8	1.36		
20.0	1.04		
21.0	.800		
22.2	.645		
23.1	.517		
24.3	.494		
25.3	.524		
26.5	.520		
27.4	.524		
28.6	.480		
29.6	.437		
30.8	.328		
31.7	.273		
32.9	.236		
33.9	.218		
35.1	.204		
37.2	.260		
39.3	.231		
43.6	.122		
45.7	.129		
47.8	.129		
50.0	.130		
54.2	.069		

E_α = 50 MeV

Cr^{52}

dσ/dΩ (mb/SR)

θ cm	5.62	5.96	6.16	6.30	6.54	6.77	7.04
12.3	-	1.74	2.00	-	-	-	4.04
13.5	-	0.969	1.60	-	-	-	-
14.5	-	-	1.26	-	-	-	-
15.7	-	-	0.864	-	1.97	-	2.64
16.7	0.458	0.549	0.703	0.506	1.35	-	1.97
17.9	0.613	0.594	0.617	0.512	0.954	-	1.44
18.8	-	0.642	0.440	0.343	0.563	-	-
20.0	0.568	0.627	0.476	0.286	0.597	-	-
21.0	0.284	-	0.506	0.291	0.797	0.447	-
22.2	0.206	-	0.651	0.268	1.07	0.515	0.867
23.1	0.122	0.167	-	-	1.09	0.532	1.067
24.3	-	-	0.518	-	1.09	0.465	1.113
25.3	0.124	0.132	0.457	-	-	0.470	1.085
26.5	0.168	0.197	0.315	0.162	-	0.468	0.879
27.4	0.204	-	-	0.177	0.436	-	0.638
28.6	0.218	0.217	0.155	0.155	0.320	0.223	-
29.6	0.189	0.315	0.203	0.160	0.340	0.239	0.312
30.8	0.113	0.223	0.177	0.126	0.319	0.206	0.291
31.7	0.101	-	0.202	-	0.418	0.221	0.387
32.9	0.065	0.099	0.220	0.095	0.447	0.234	0.496
33.9	0.068	-	0.222	0.104	0.430	0.221	0.503
35.0	0.070	-	0.153	0.076	0.382	0.184	0.479
37.2	0.119	0.085	0.113	0.086	0.242	0.145	0.375
39.3	0.118	0.093	0.070	0.103	0.177	0.103	0.189
41.6	0.062	0.099	0.070	-	0.164	0.106	0.163
43.6	-	-	0.095	0.051	0.185	0.111	0.119
45.7	0.064	0.042	-	-	0.170	0.101	0.255
47.8	0.063	0.061	0.056	-	0.106	-	-
50.0	0.054	0.066	0.052	0.045	0.084	0.082	0.107
52.1	-	-	0.045	0.030	0.088	0.077	0.102
54.2	0.036	-	-	0.029	0.081	0.067	0.124
56.3	0.036	0.033	-	-	-	0.067	0.119
58.4	0.034	0.037	0.031	0.023	-	-	0.101
60.5	0.030	0.024	0.023	0.023	0.057	0.048	-
62.6	0.020	0.039	-	0.021	0.050	0.042	0.062
64.6	0.021	0.028	0.024	0.016	0.045	0.034	0.056

Cr^{52}

Elastic

E_α = 75 MeV

θ_{cm}	dσ/dΩ (mb/SR)	Statistical Error (mb/SR)	θ_{cm}	dσ/dΩ (mb/SR)	Statistical Error (mb/SR)
16.5	83.3	0.616	40.0	2.56	0.034
19.7	159.3	0.435	41.1	2.13	0.025
20.8	184.8	0.918	42.1	2.37	0.026
22.9	56.7	0.509	43.2	2.86	0.029
24.0	16.5	0.140	45.3	3.44	0.026
25.1	1.67	0.043	46.4	3.52	0.032
26.1	10.2	0.110	48.5	1.70	0.022
28.3	34.5	0.242	49.5	1.51	0.017
27.3	29.5	0.185	50.6	1.26	0.016
31.5	7.84	0.094	51.6	1.29	0.016
32.6	2.97	0.071	53.7	1.22	0.015
33.6	2.76	0.035	54.8	1.28	0.016
34.7	5.24	0.095	56.9	0.712	0.012
35.7	8.14	0.047	57.9	0.612	0.010
36.8	9.00	0.052	60.0	0.404	0.009
37.9	7.70	0.059			

Cr^{52}

E_α = 75 MeV

1.434 MeV, 2+		2.37 MeV, 4+		2.776* MeV, 4+		3.12 MeV, 2+	
θ cm	dσ/dΩ(mb/SR)	θ cm	dσ/dΩ(mb/SR)	θ cm	dσ/dΩ(mb/SR)	θ cm	dσ/dΩ(mb/SR)
22.9	4.02	16.5	0.763	16.5	0.904	16.5	1.44
24.0	6.46	17.6	0.200	17.6	0.646	17.6	1.56
25.1	5.70	19.7	1.136	19.7	0.410	19.7	0.486
26.2	3.54	20.8	1.495	20.8	0.436	20.8	0.298
28.3	0.826	24.0	0.574	23.0	0.790	23.0	0.510
29.4	0.913	29.4	0.243	26.2	1.73	24.0	0.704
31.5	2.41	31.5	0.233	31.5	0.203	28.3	0.851
32.6	3.14	32.6	0.151	32.6	0.231	29.4	1.254
33.6	2.41	33.7	0.095	33.7	0.136	33.7	0.270
34.7	1.49	34.7	0.083	35.8	0.066	34.7	0.183
35.8	0.864	35.8	0.102	36.9	0.130	35.8	0.111
36.8	0.589	36.9	0.130	37.9	0.101	36.9	0.147
37.9	0.725	37.9	0.141	40.1	0.098	37.9	0.114
40.0	0.991	40.0	0.094	41.1	0.084	40.1	0.108
41.1	1.21	41.1	0.076	42.2	0.062	41.1	0.105
42.2	0.947	42.2	0.059	43.2	0.056	42.2	0.091
43.2	0.636	43.2	0.113	45.4	0.053	43.3	0.079
45.3	0.405	45.3	0.097	46.4	0.060	45.4	0.050
46.4	0.485	46.4	0.061	48.5	0.080	46.4	0.043
48.5	0.557	48.5	0.040	49.6	0.068	48.5	0.033
49.6	0.610	49.6	0.049	50.6	0.039	49.6	0.044
50.6	0.491	50.6	0.039	51.7	0.039	50.7	0.081
51.7	0.407	51.7	0.030	53.8	0.033	51.7	0.044
53.8	0.250	53.8	0.029	54.9	0.031	53.8	0.024
54.8	0.285	54.8	0.031	57.0	0.029	54.9	0.020
56.9	0.250	56.9	0.024	58.0	0.025	57.0	0.024
57.9	0.294	58.0	0.027	60.1	0.020	58.0	0.032
60.1	0.222	60.1	0.017			60.1	0.029

*Unresolved from the 2.65 MeV, 0+ state.

Cr^{52}

E_{α} = 75 MeV

3.78 MeV, 2+		4.59 MeV, 3-	
θ cm	dσ/dΩ(mb/SR)	θ cm	dσ/dΩ(mb/SR)
16.5	2.03	16.5	4.65
17.6	2.70	17.6	3.60
19.7	0.909	19.7	3.93
20.8	0.237	20.8	3.98
23.0	1.23	23.0	1.96
24.0	1.70	24.1	1.55
25.1	1.63	25.1	1.25
26.2	1.08	26.2	1.20
31.5	0.842	28.3	1.89
32.6	0.895	29.4	4.81
33.7	0.996	32.6	0.811
35.8	0.358	33.7	0.659
36.9	0.237	34.8	0.650
38.0	0.276	35.8	0.753
40.1	0.368	36.9	0.916
41.1	0.397	40.1	0.451
42.2	0.331	41.2	0.398
42.2	0.318	42.2	0.339
43.3	0.184	43.3	0.296
45.4	0.167	45.4	0.398
46.4	0.168	46.4	0.437
48.6	0.152	48.6	0.364
49.6	0.168	49.6	0.345
50.7	0.140	50.7	0.296
51.7	0.125	51.7	0.267
53.8	0.099	53.9	0.240
54.9	0.106	54.9	0.242
57.0	0.097	57.0	0.215