Title
SCATTERING OF ALPHA PARTICLES BY 55Mn

Authors
Gabrielli, I.
Harvey, B. G.
Hendrie, D.L.
et al.

Publication Date
1968-09-01

University of California

Ernest O. Lawrence Radiation Laboratory

SCATTERING OF ALPHA PARTICLES BY ^{55}Mn

I. Gabrielli, B. G. Harvey, D. L. Hendrie, J. Mahoney,
J. R. Meriwether and J. Valentin

September 1968

To be submitted to:
Nuovo Cimento

UCRL-18488
Preprint

UNIVERSITY OF CALIFORNIA

Lawrence Radiation Laboratory
Berkeley, California

AEC Contract No. W-7405-eng-48

SCATTERING OF ALPHA PARTICLES BY ^{55}Mn

I. Gabrielli, B. G. Harvey, D. L. Hendrie, J. Mahoney,
J. R. Meriwether and J. Valentin

September 1968

SCATTERING OF ALPHA PARTICLES BY ^{55}Mn*

I. Gabrielli[+], B. G. Harvey, D. L. Hendrie, J. Mahoney,
J. R. Meriwether[++] and J. Valentin[+++]

Lawrence Radiation Laboratory
University of California
Berkeley, California

September 1968

Summary

The elastic and inelastic scattering of 50 MeV alpha particles by ^{55}Mn has been measured. The angular distributions of the scattered alphas from several excited levels were analyzed by means of the distorted-wave Born approximation. Transition strengths were determined for most of the levels observed. Energy resolution permitted the observation of the first excited state (0.126 MeV) separated from the elastic peak. Two single states previously observed in alpha scattering were each resolved into two states (2.25 and 3.37 MeV, probable transition, $\ell = 2$; 4.27 and 4.39 MeV, probable transition, $\ell = 3$).

---

*This work was performed under the auspices of the U. S. Atomic Energy Comission.

[+] NATO fellow. Present address: Istituto di Fisica dell'Universita
Trieste, Italy.

[++] Present address: University of Southwestern Louisiana, Lafayette, Louisiana.

[+++] Present address: Université de Grènoble, Grènoble, France.

Introduction

A number of studies have recently been performed on levels of ^{55}Mn. This nucleus has an unusual feature in that its ground state has five $(f_{7/2})$ protons coupled to give the spin of $5/2^-$(1). In addition to investigations of the excited states by inelastic scattering of protons(2,3,4) and neutrons(5), a measurement by means of 43 MeV alpha scattering has been reported(6). In the latter experiment, with a resolution of 280 keV, the first excited state (126 keV) could not be resolved from the elastic peak. The angular distribution of alphas elastically scattered from ^{55}Mn has been studied in terms of optical model parameters for a beam energy of 43 MeV(7), 22.2 MeV(8), and 24.7 MeV(9).

We have measured the scattering of 50 MeV alphas, with the improved resolution which is now available with cooled silicon counters, in order to obtain the angular distribution of alphas from the first excited state, to investigate the levels of a collective nature and to determine transition strengths. In addition, the availability of better alpha scattering data from ^{55}Mn, along with other experimental data, can be the basis for a description of the low-lying excited states of a quadrupole nature as a coupling of a proton to the quadrupole state of a ^{54}Cr core, or a hole to the ^{56}Fe(10,11).

Experimental Procedure

The beam of 50 MeV alphas, provided by the 88" cyclotron was focused onto a self-supporting evaporated foil of ^{55}Mn, which was 250 g/cm^2 thick. In addition to carbon and oxygen, a small amount of Al and Cl contaminants were present in the Mn target due to the method of target construction. Scattered particles were detected in four lithium-drifted silicon detectors, cooled to -25 °C, yielding resolutions of 50 to 75 keV depending on the scattering angle. The beam was collected in a Faraday cup and checked with a monitor counter placed at a fixed angle of 20° with respect to the beam. A sample spectrum is shown in Fig. 1, with an indication of the analyzed levels and the values of their excitation energies, computed with reference to the elastic peak and to the 1.884 MeV level. For the final extraction of the cross sections an IBM 7094 computer program(12) has been used, with which several levels not completely resolved in the spectra have been separated.

Results

Fig. 2 shows the experimental elastic angular distribution and its best fit to the optical model with four free parameters(13).

$$V_{opt} = (V_o + iW)\ (1 + \exp \frac{r - R}{a})$$

The values of the optical parameters (V = 198 MeV, W = 27.9 MeV, R = 1.35 Fm, and a = 0.59 Fm) are consistent with those of other alpha scattering experiments. The experimental inelastic angular distributions were compared with theoretical differential cross sections obtained from the collective model distorted-wave Born approximation (DWBA) using these optical parameters(14). By comparison of the experimental and theoretical differential cross sections at the first four diffraction maxima, the transition strengths were computed for most of the observed levels. The strengths are reported in terms of $B(E\ell)\uparrow$ which is independent of the spin of the initial and final states.

$$B(E\ell)\uparrow = \left[\frac{3}{4\pi} Z R_0^{\ell}\right]^2 \left[\left(\frac{d\sigma}{d\Omega}\right)_{exp} \Big/ \left(\frac{d\sigma}{d\Omega}\right)_{DWBA}\right]$$

where R_0 is the charge radius (= $1.2A^{1/3}$), ℓ is the angular momentum transfer, and Z is the charge of the target nucleus. In addition, the strengths are given in single particle units for the states of known spin(16):

$$G = \frac{2J_o+1}{2J+1} \quad \frac{(\ell+3)^2}{4\pi} \quad Z^2 \quad B(E\ell)\uparrow$$

where J_0 is the spin of the ground state and J the spin of the excited state. The estimated precision of the strengths is about 10%.

In Fig. 3 are given the experimental differential cross sections of alphas scattered from levels which are well represented by the theoretical distributions for an angular momentum transfer of two ($\ell = 2$). The latter are shown as the dashed curves which have been normalized to the data.

The transition strengths to these states are listed in Table 1. It should be noted that the sum of the observed $\ell = 2$ strengths in ^{55}Mn (sum of the β_c^2 values) is nearly equal that of the 0.847 MeV, 2+ state in ^{56}Fe (15,16) and in the range of values reported for the 0.835 MeV, 2+ state in ^{54}Cr (16). Nevertheless, it does not look appropriate to invoke the weak coupling model here. The $\ell = 2$ strength is spread over nearly 3 MeV and a disproportionate fraction of the strength goes to the 0.126 MeV state.

In Fig. 4 are shown the experimental angular distributions which appear to agree with a value of $\ell = 3$; the theoretical predictions of the DWBA analysis are shown as the dashed curves. Our data is not consistent with a negative parity assignment to the state at 1.289 MeV; it appears to be populated by reasonably strong $\ell = 3$ transition. Although the possibility of a double excitation process forming this state cannot be ruled out, it is interesting to note that an 11/2+ assignment is also consistent with the data of Ref. 5.

Peterson(4) has recently conjectured about the validity of the weak coupling model for states with octuple core excitations. In general our results are consistent with this view and with his spin assignments. Although we find the 4.27 MeV state slightly stronger than the 4.39 MeV states our uncertainties make it undesirable to reverse his assignments here. Although we were unable to reliably extract the 3.60 MeV level that Peterson saw, we were able to get an additional $\ell = 3$ transition to a level at 3.05 MeV. Comparing the relative strengths of the two states, we decided to assign $3/2^+$ to the 3.05 MeV state and to change Peterson's assignment to the 3.60 MeV state from $3/2^+$ to $1/2^+$. Table II reflects these assignments and their strengths compared with ^{56}Fe.

The 1.527 MeV, $3/2^-$ state is present at all angles, but with a low cross section (less than 1 mb/sr at the smallest measured angles). The hypothesis, that this is a single particle level, is consistent with our data. The angular distribution of the state at 5.04 MeV agrees fairly well with the DWBA curve for an $\ell = 4$ transition, but the oscillations are quite small and not well-defined.

References

(1) E. H. Schwarcz: Phys. Rev. 129, 727 (1963) with reported references.

(2) S. S. Vasil'ev, E. A. Romanovskii and G. F. Timushev: Zh. Eksperim. i Teor. Fiz. 42, 395 (1962) JETP 15, 274 (1962) and Vestnik Moscow Univers. Ser. III, no. 6, 90, (1961).

(3) M. Mazari, A. Sperduto and W. W. Buechner: Phys. Rev. 108, 103 (1957); J. H. Bjerregaard, P. F. Dahl, O. Hansen and G. Sidenius: Nucl. Phys. 51, 641 (1964).

(4) R. J. Peterson: Phys. Letters 27B, 446 (1968).

(5) R. C. Lamb and M. T. McEllistrem: Phys. Letters 4, 211 (1963); Nucl. Phys. A107, 153 (1968).

(6) H. W. Broek: Phys. Rev. 139, B1160 (1965).

(7) K. T. R. Davies, G. R. Satchler, R. M. Drisko and R. H. Bassel: Nucl. Phys. 44, 607 (1963).

(8) N. Takahashi, S. Kato, M. Takeda, T. Yamazaki and S. Yasukawa: J. Phys. Soc. Japan 20, 1544 (1965).

(9) L. McFadden and G. R. Satchler: Nucl. Phys. 84, 177 (1966).

(10) V. K. Thankappan and W. W. True: Phys. Rev. 137, B793 (1965).

(11) J. R. Meriwether, I. Gabrielli, D. L. Hendrie, J. Mahoney and B. G. Harvey: Phys. Rev. 146, 804 (1966).

(12) A. Springer (Ph.D. Thesis): University of California, Lawrence Radiation Laboratory Report UCRL-11681 (1965), unpublished.

(13) Code MERCY altered from SEEK written by Melkanoff, Raynal and Sawada: University of California at Los Angeles Report UCLA-66-10.

(14) Code JULIE by R. Drisko: Oak Ridge National Laboratory Report ORNL-3240.

(15) D. L. Hendrie, J. Valentin, I. Gabrielli, J. Mahoney, and J. R. Meriwether: to be published.

(16) R. H. Stelson and L. Grodzins: Nuclear Data 1, 42 (1965).

Table I. Transition strengths for the quadrupole levels of ^{55}Mn, ^{54}Cr, and ^{56}Fe

	Q	B(E2)↑ (fm^4)	J^π	G
^{55}Mn	-0.126	426.0	$7/2^-$	25.8
	-0.983	167.0	$(9/2^-)$	8.09
	-1.884	119.0	$(5/2^-)$	9.53
			$(7/2^-)$	7.15
	-2.25 ± .02	35.7		
	-2.37 ± .02	53.7		
	-2.82 ± .02	41.0		
total		843.0		
^{54}Cr	-0.835	570-1060[a]	2^+	
^{56}Fe	-0.847	875[b]	2^+	

[a] Ref. 16

[b] Ref. 15

Table II. Transition strengths for the octupole levels of ^{55}Mn and ^{56}Fe

	Q	B(E3)↑ (fm^6)	J$^\pi$	G
^{55}Mn	-1.289	586	$(11/2^+)$[a]	1.6
	-3.05 ± .02	647	$(3/2^+)$[b]	5.4
	-3.60 ± .02[c]	422[c]	$(1/2^+)$	7.6[c]
	-4.09 ± .02	765	$(5/2^+)$[b]	4.3
	-4.20 ± .02	3170	$(11/2^+)$[b]	8.8
	-4.27 ± .02	1537	$(7/2^+)$[b]	6.4
	-4.39 ± .02	1467	$(9/2^+)$[b]	4.9
total		8008		
^{56}Fe	-4.52	8216[d]	3^-	7.1[d]

[a] Ref. 5

[b] Ref. 4

[c] Taken from Ref. 4 and calculated from his strengths.

[d] Ref. 15

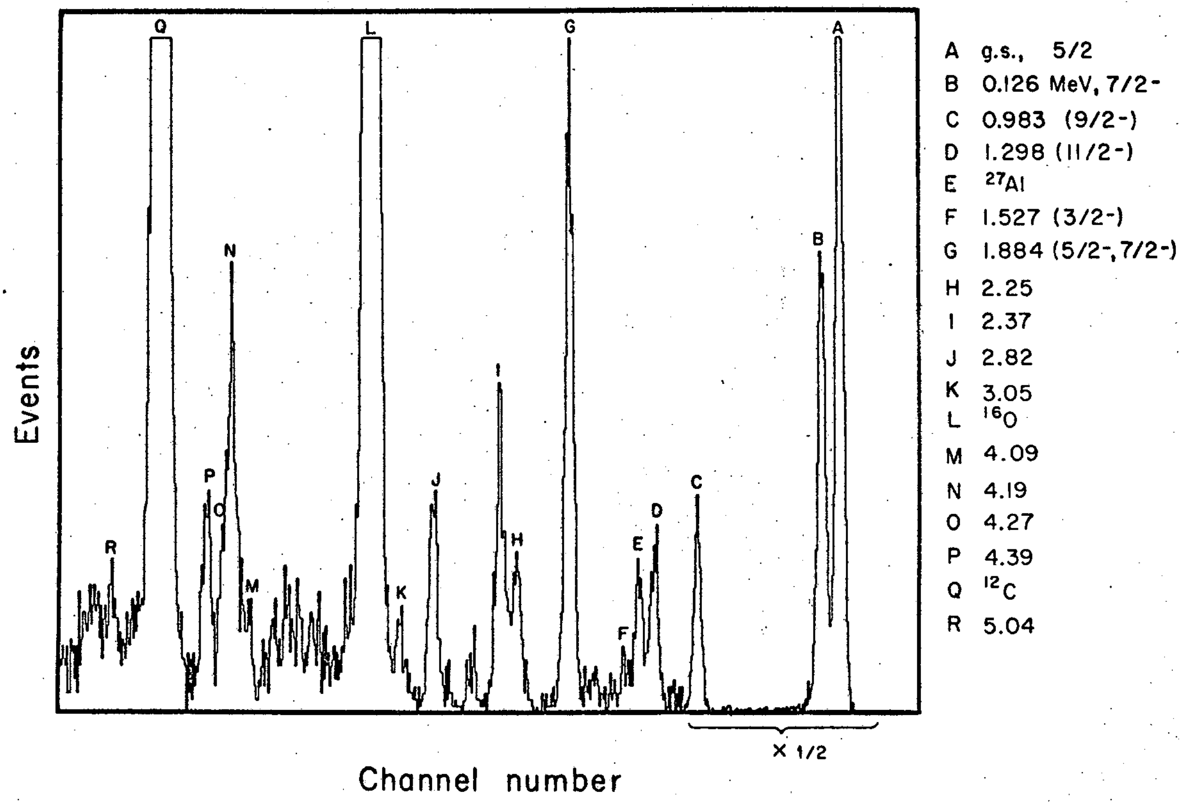
Figure Captions

Fig. 1. A sample energy spectrum at a laboratory angle of 36°.

Fig. 2. The elastic angular distribution in terms of the ratio of the experimental to the Rutherford cross section. The dashed curve is the optical model fit to the data.

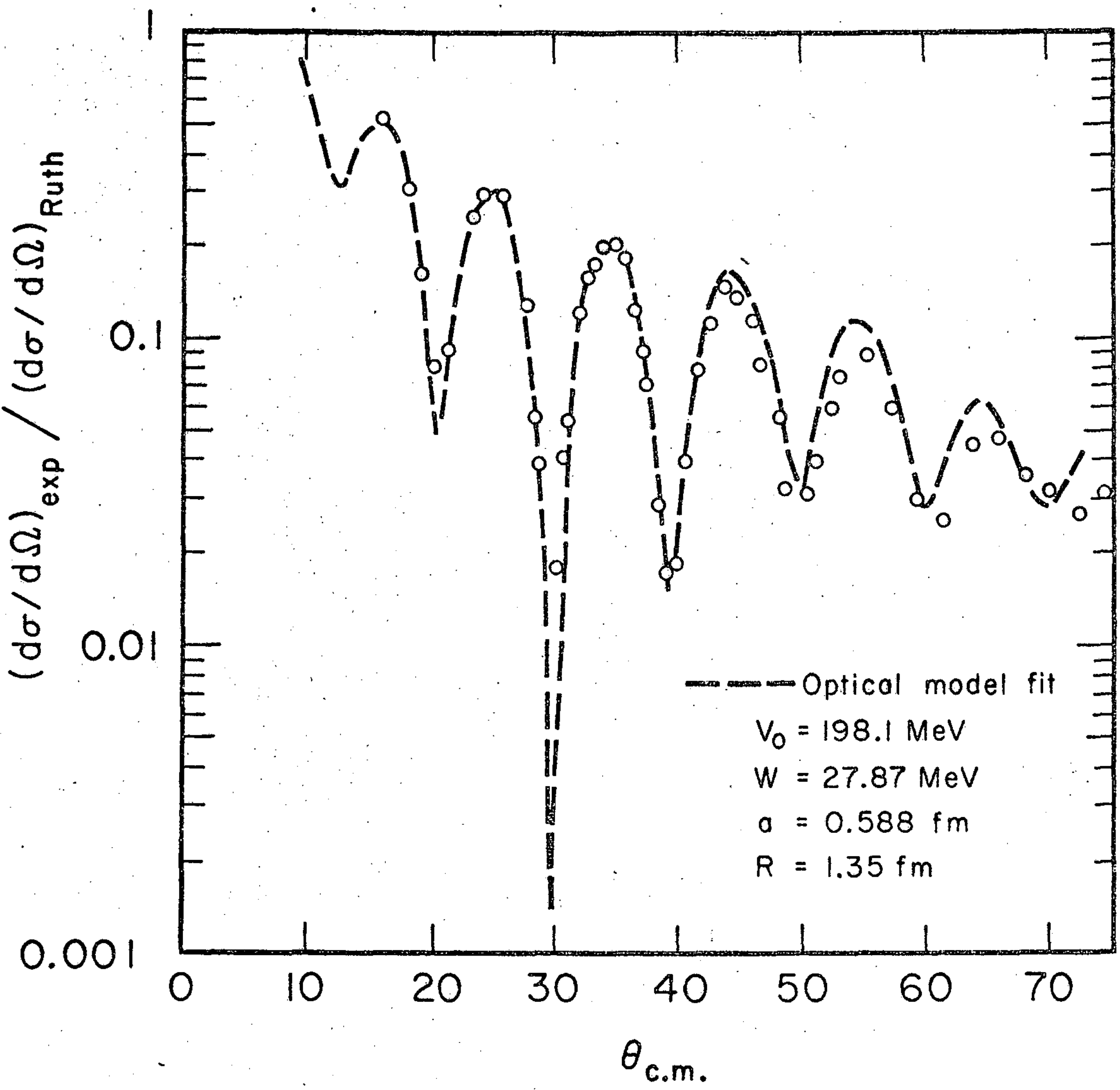
Fig. 3. The angular distributions from the levels which agree with an $\ell = 2$ distribution according to the DWBA analysis (dashed curve).

Fig. 4. The angular distributions from the levels which agree with an $\ell = 3$ distribution according to the DWBA analysis (dashed curve).



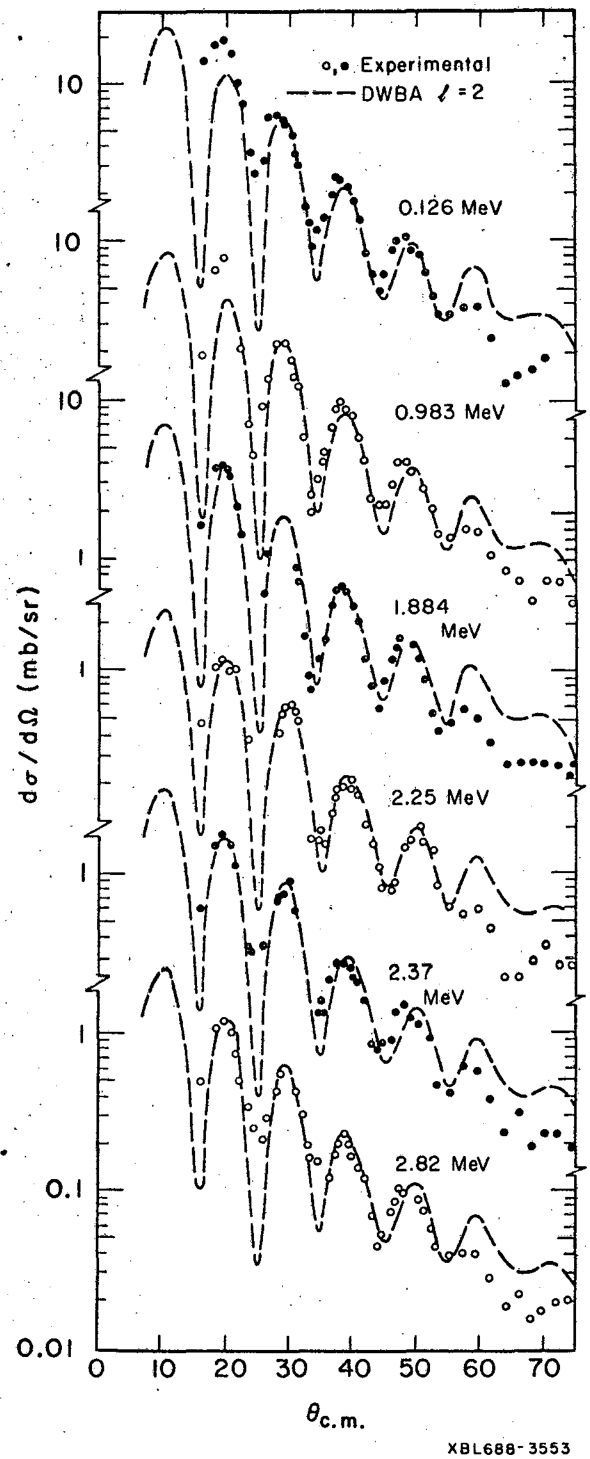
XBL688-3555

Figure 1



XBL688-3556

Figure 2



○, ● Experimental
DWBA ℓ = 2
0.126 MeV
0.983 MeV
1.884 MeV
2.25 MeV
2.37 MeV
2.82 MeV
10
10
10
1
1
1
1
0.1
0.01
0
10
20
30
40
50
60
70
dσ/dΩ (mb/sr)
θc.m.
XBL688-3553

Figure 3

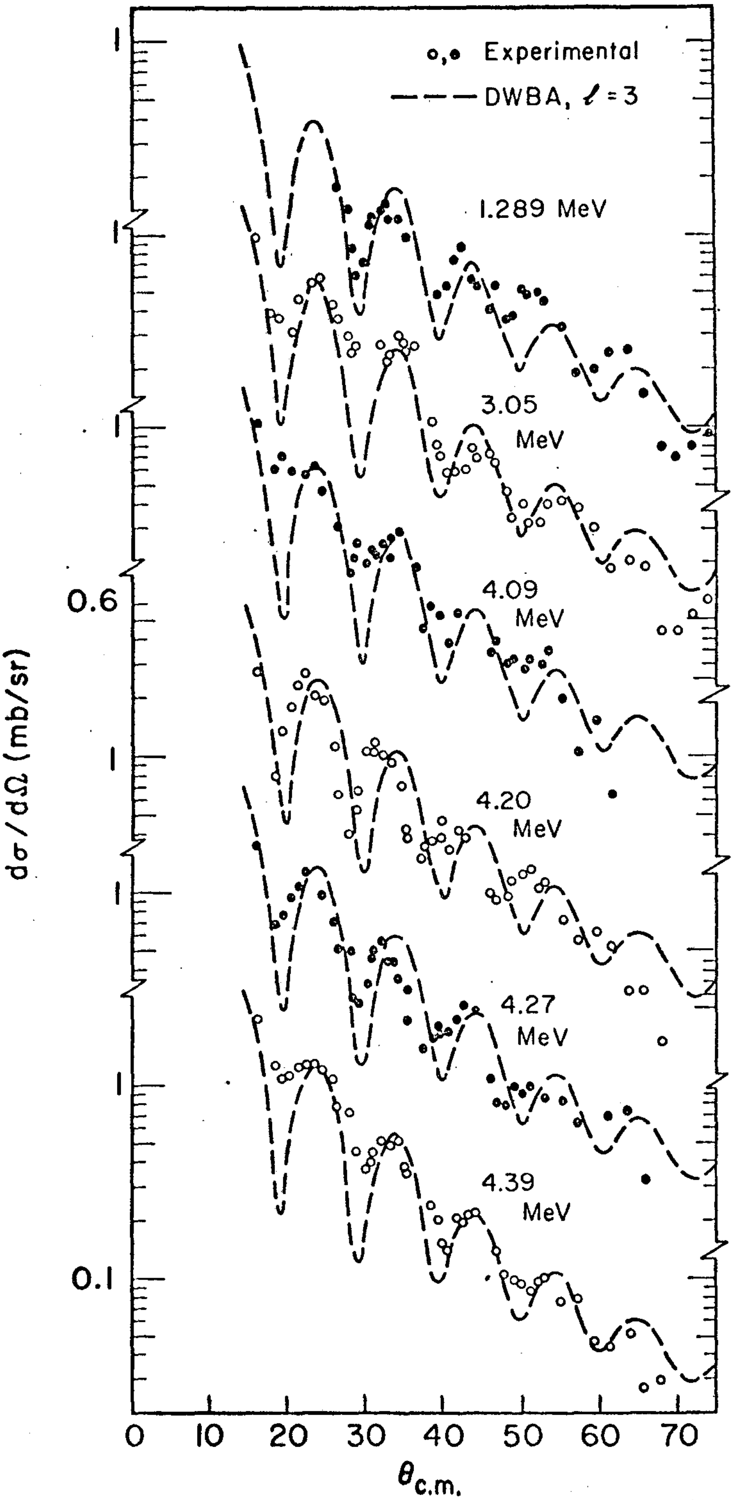

○,● Experimental
DWBA, ℓ=3
1.289 MeV
3.05 MeV
4.09 MeV
4.20 MeV
4.27 MeV
4.39 MeV
1
1
1
0.6
1
1
1
0.1
dσ/dΩ (mb/sr)
0
10
20
30
40
50
60
70
θc.m.
XBL688-3554

Figure 4