NASA TECHNICAL MEMORANDUM

NASA TM X-52912

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SCATTERING OF 42-MeV ALPHA PARTICLES FROM ^{45}Sc

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TECHNICAL PAPER proposed for presentation at
1970 Fall Meeting of the Division of Nuclear
Physics of the American Physical Society
Houston, Texas, October 15-17, 1970

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E-6009

Shell model calculations(1) have had some success in predicting the experimental results found in the (1f2p) shell, but the nucleus ^{45}Sc is an exception. The calculation predicted the lowest excited state to be at 1.5 MeV and several states below this energy have been experimentally measured. Malik and Scholz(2) have calculated the energy levels of ^{45}Sc using a rotational model with strong coriolis mixing. For a deformation parameter of B = +0.20, the correct ground state spin is obtained and the level at 0.375 MeV ($3/2^-$) is predicted.

This experiment was performed to obtain additional information about the collective behavior of ^{45}Sc. Inelastic alpha particle scattering is known to excite collective states, and the coupling of the f(7/2) proton to an excited ^{44}Ca core could describe some of the low lying negative parity states of ^{45}Sc. Particle-core coupling has been studied in heavier nuclei(3) with alpha particles and in ^{45}Sc with inelastic proton scattering(4).

The experiment was done using the 42 MeV alpha particle beam of the Lewis Research Center cyclotron. A schematic diagram of the scattering system is shown in figure 1. The scandium target was a self-supporting rolled target of thickness 0.50 mg/cm^2. The energy resolution of the experiment was 80-100 keV and angular distributions were measured for 10 to 50 degrees in the center of mass system. A typical energy spectrum of the first 10 excited states is shown in figure 2. The excitation energies shown in this figure are previously measured values(5). The data was reduced by fitting the peaks with a normal Gausian function using a least-squares computor program with a linear background subtraction. The relative cross sections are known to an accuracy of ±3% and the absolute cross sections to an accuracy of ±10%.

The elastic angular distribution is shown in figure 3. The six parameter optical model calculation was done using the computor program SCATLE(6). The four parameter potential (V = 200 MeV) of Priest and Vincent (7) was used as a starting point for the six parameter search. The resulting optical model parameters are listed on figure 3.

In figure 4 are shown the inelastic angular distributions of the five strongest excited states. The simple weak-coupling model predicts five states with an $\ell=2$ transfer angular distribution and the centroid of their excitation energies to be that of the ^{44}Ca 2^+ state. The five states shown in figure 4 do have the correct angular distributions for an angular momentum transfer of 2. Since the electromagnetic transition probability to the ground state should be equal to that for decay of the collective state of the core, this implies that the cross section for any member of the multiplet should be

$$\left(\frac{d\sigma}{d\Omega}\right)_{Jf} = \left[\frac{2Jf + 1}{(2Jc + 1)(2Ji + 1)}\right]\left(\frac{d\sigma}{d\Omega}\right)_{core} \qquad (1)$$

where $\left(\frac{d\sigma}{d\Omega}\right)_{core}$ is the cross section for excitation of the even-even core nucleus by the same process. Jc is the spin of the collective excitation in the core and Ji is the ground state spin of the odd nucleus. Assuming the weak-coupling model valid, the spin of the excited state in the odd nucleus (Jf) can be assigned on the basis of the strength of the excitation.

In figure 5 the total strength of these five angular distributions is compared to the strength of the 2^+ excitation in the ^{44}Ca core. The ^{44}Ca data is that of Peterson(8) measured at 42 MeV. The total strength of the five state multiplet is very close to that of the 2^+ state in ^{44}Ca. The center of gravity energy of the five state multiplet is 1.05 Mev as compared to the energy of 1.16 MeV for the core state in ^{44}Ca.

This would be a good description of the low lying negative parity states of ^{45}Sc if these five strongest excited states were the first five excited states. Unfortunately there is a state at excitation of 1.41 MeV that lies within the energy spread of the multiplet. The measured angular distribution for this state is shown in figure 6. It has the same angular distribution as the state at excitation energy of 2.09 MeV. The solid lines in figure 6 are DWBA calculations to the core states of ^{44}Ca and are labeled by their angular momentum transfer. If the 1.41 MeV state had an angular distribution for an $\ell=4$ transfer it could be explained as a member of a multiplet resulting from the f(7/2) proton coupling to the 2.28 MeV (4^+) core state of ^{44}Ca. Also, if the 2.09 MeV state had an angular distribution similar to an $\ell=0$ transfer it could be explained as the f(7/2) proton coupling to the 1.68 MeV (0^+) state of the ^{44}Ca core. However, as can be seen in figure 6, neither of these states have an angular distribution that allows a simple weak-coupling model description.

In figure 7 the results of this experiment are compared to those of Peterson and Perlman's(4) 17.5 MeV proton scattering. The same multiplet of five states were excited and with approximately the same strengths. As in this experiment, these states were not the five lowest excited states. The deformation parameters (β) listed in figure 7 are partial deformation parameters(3).

In figure 8 the results of this experiment are summarized. In the first column the levels of ^{44}Ca are shown. The relative strengths for excitation by 42 MeV alpha particles are given in parenthesis(8).

Since the 1.16 MeV (2^+) state is the strongest excited state below 2 MeV, one would expect a multiplet of five states below 2 MeV in ^{45}Sc. The five state multiplet seen in this experiment are shown as the solid lines in column 2. The spin assignments shown in this column are made on the basis of equation (1). The relative strengths of excitation are shown in parenthesis on each of the five states. The results of the 17.5 MeV proton scattering work of Peterson and Perlman(4) are shown in column 3 and the summary of the Nuclear Data Sheets(5) is shown in column 4.

The dotted lines in column 2 are the two states at 1.41 and 2.09 MeV that could not be matched to an $\ell=0^+$, 2^+ or 4^+ angular distribution of the ^{44}Ca core. As can be seen in column 4, these states are both unresolved doublets and this may explain the shapes of their angular distributions.

In column 5 is shown the predictions of Malik and Scholz's(2) rotational model with strong coriolis mixing. It reproduces the ground state spin and 0.375 MeV level and spin quits well, but is not too successful on the higher energy states.

The results for the simple weak-coupling model for the scattering of 42 MeV alpha particles are not too successful. It is successful in predicting the correct spin for the 1.065 MeV ($3/2^-$) state. The spins of the 1.237 MeV and 1.664 MeV states are unknown and the weak coupling model predicts $11/2^-$ and $7/2^-$ respectively.

The results found in scandium are similar to those found in antimony (3). The results are similar to a simple weak-coupling model, but are not exactly as the model predicts. These deviations from the simple model may be due in both scandium and antimony to the existence of a very low lying single particle state. The existence of this state could destroy the weak coupling between the core and the particle. This problem has been considered and calculations [9,10] have been made with some success, but no explicit calculations for scandium have been done.

REFERENCES

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EXPERIMENTAL ARRANGEMENT

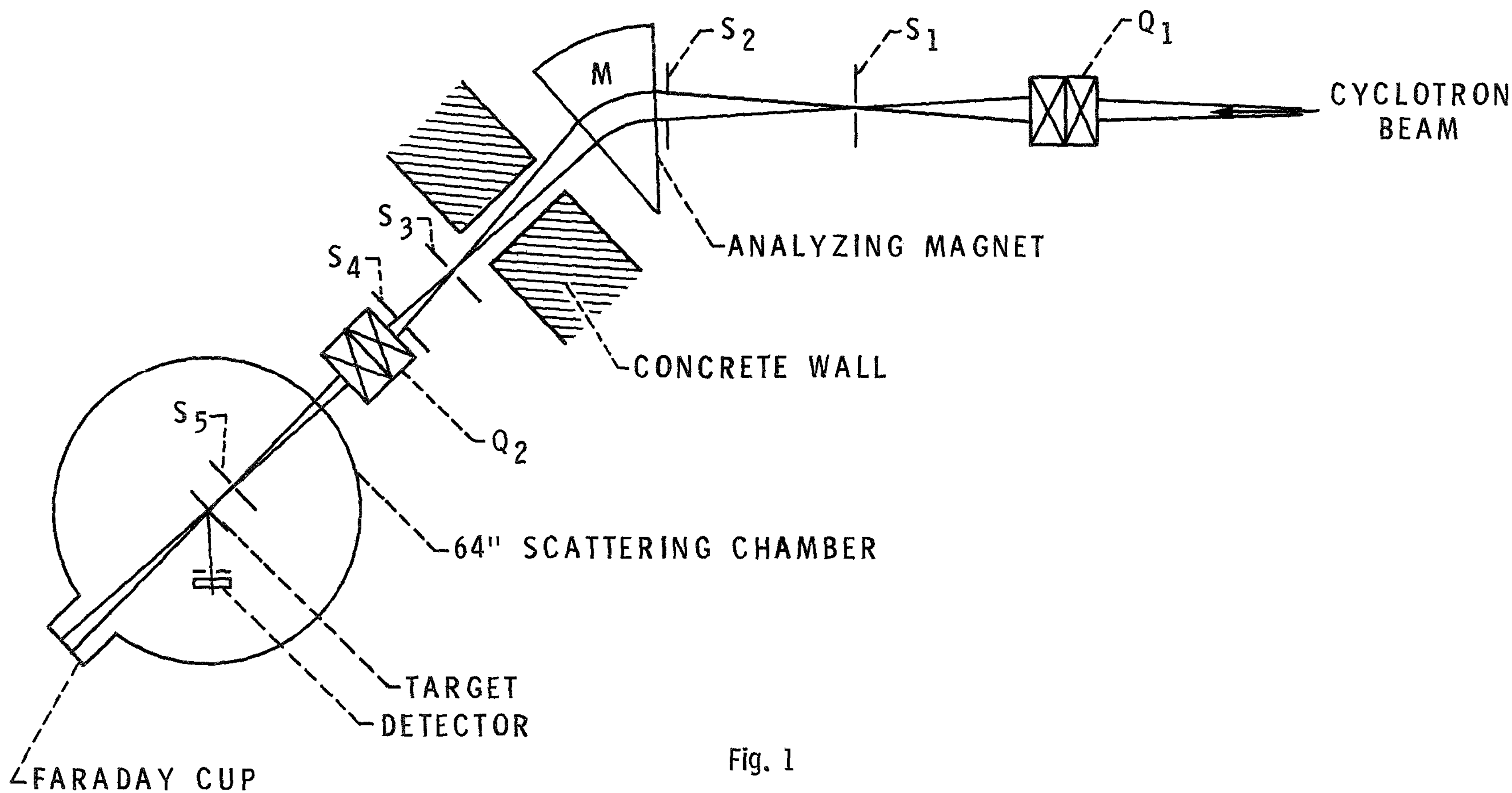


Fig. 1

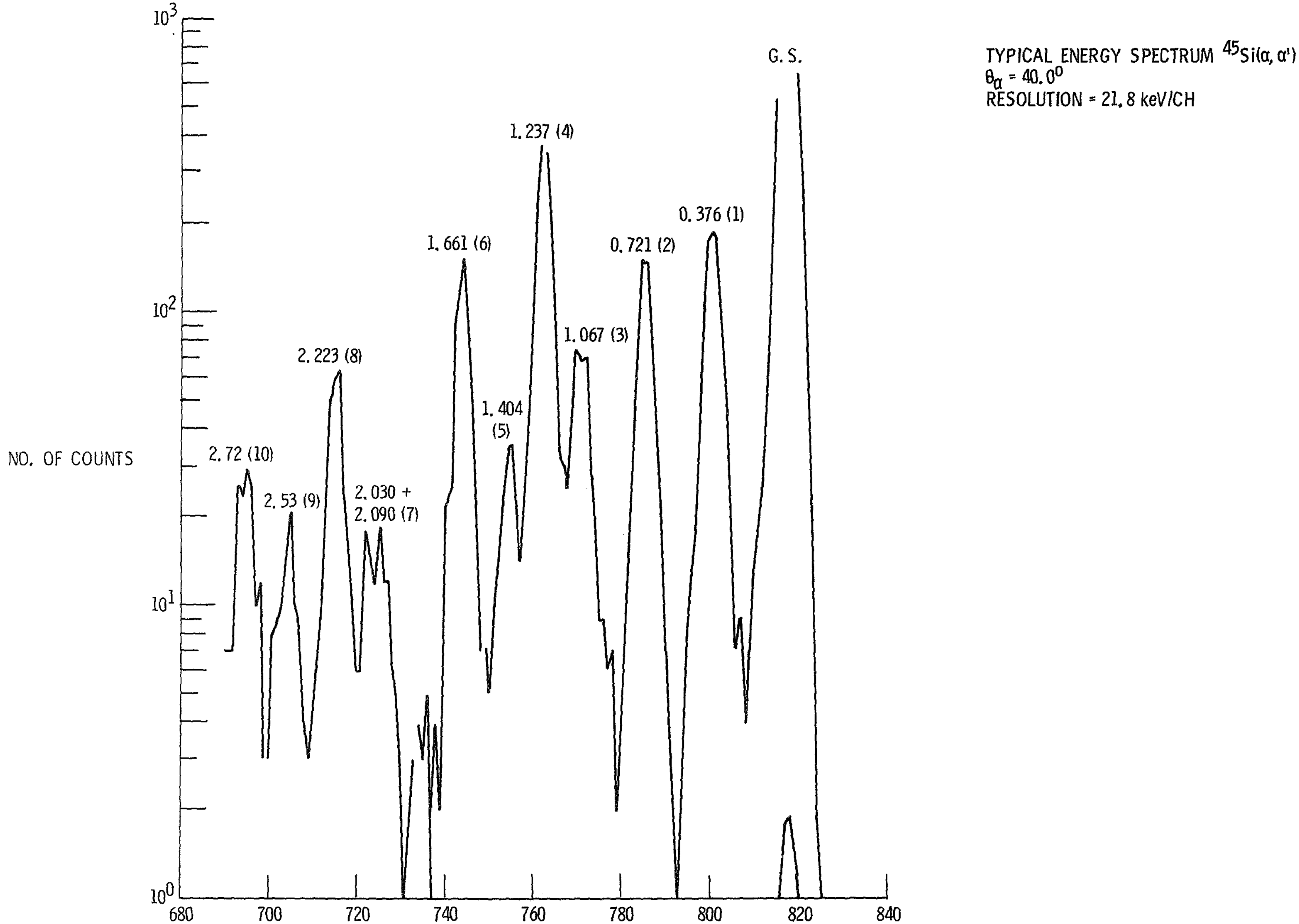
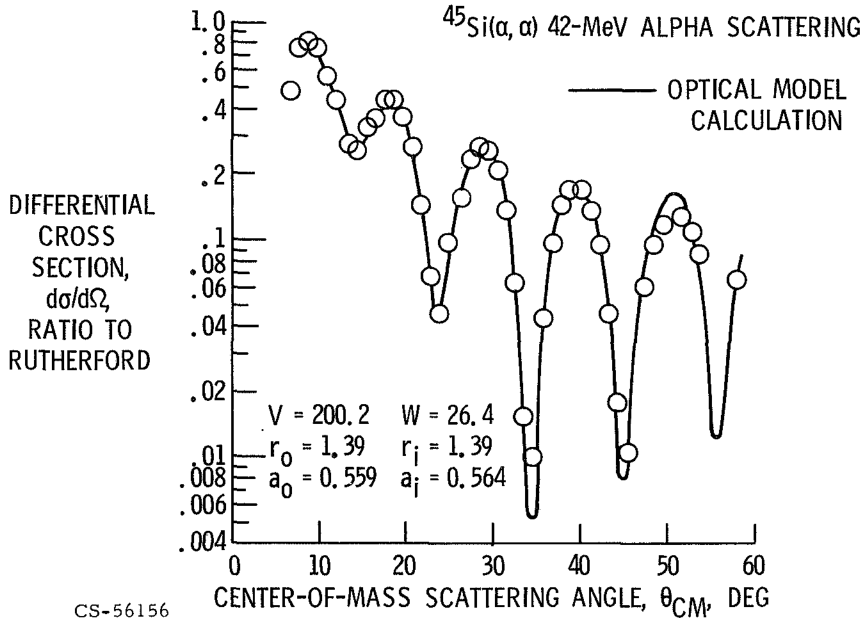


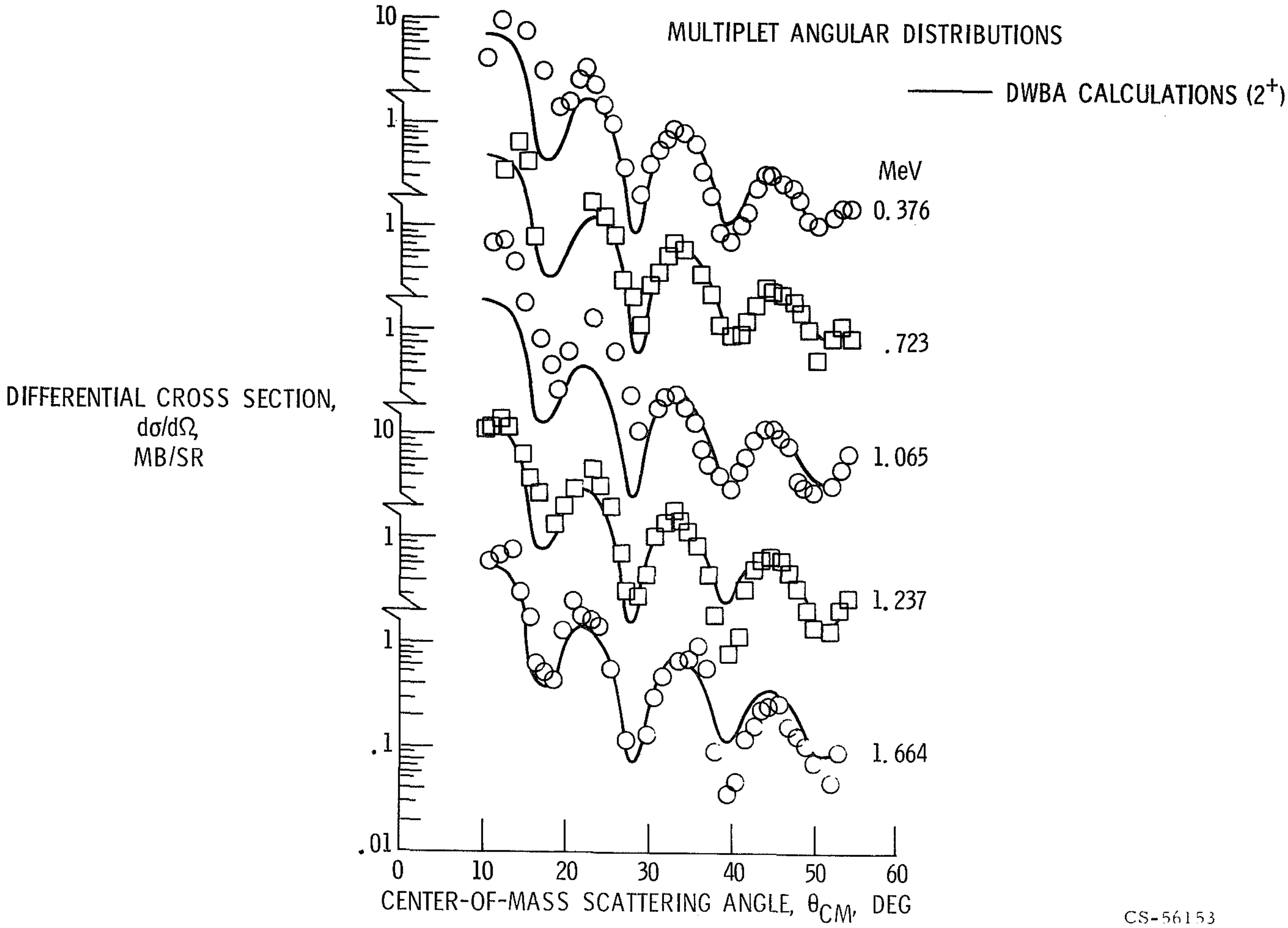
Fig. 2

CS-56151



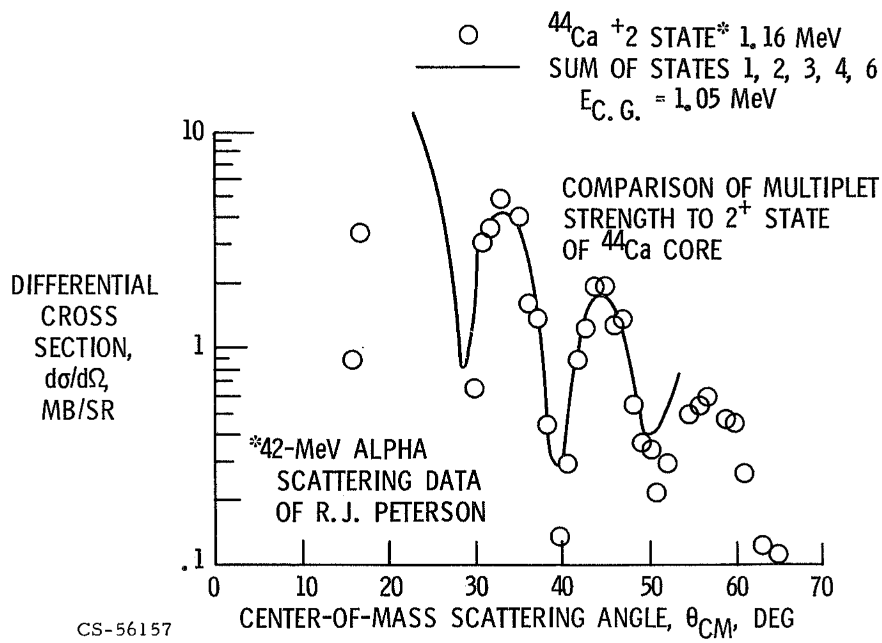
^{45}Si(α, α) 42-MeV ALPHA SCATTERING
OPTICAL MODEL CALCULATION
DIFFERENTIAL CROSS SECTION, dσ/dΩ, RATIO TO RUTHERFORD
V = 200.2 W = 26.4
r_0 = 1.39 r_i = 1.39
a_0 = 0.559 a_i = 0.564
CENTER-OF-MASS SCATTERING ANGLE, θ_{CM}, DEG
CS-56156

Fig. 3



MULTIPLET ANGULAR DISTRIBUTIONS
DWBA CALCULATIONS (2^+)
MeV
0.376
.723
1.065
1.237
1.664
DIFFERENTIAL CROSS SECTION, dσ/dΩ, MB/SR
CENTER-OF-MASS SCATTERING ANGLE, θ_{CM}, DEG
CS-56153

Fig. 4



CS-56157

Fig. 5

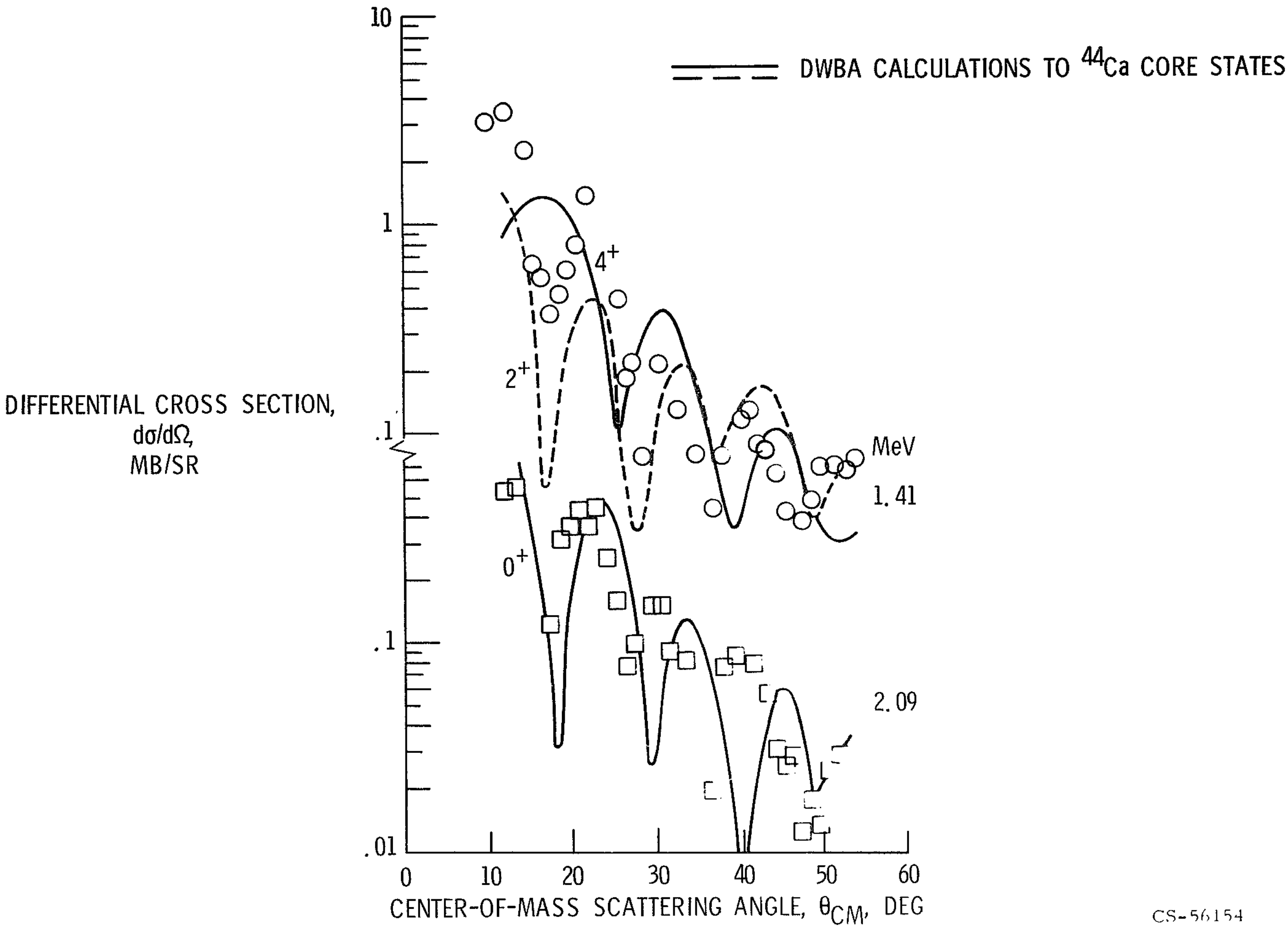


Fig. 6

CS-56154

STATE	ENERGY, MeV	PROTON SCATTERING*, βR, FM	ALPHA SCATTERING, βR, FM	PROTON SCATTERING*, β	ALPHA SCATTERING, β
1	0.376	0.45	0.48	0.10	0.098
2	.721	.38	.37	.085	.076
3	1.065	.27	.24	.06	.049
4	1.236	.61	.62	.14	.13
6	1.661	.38	.48	.085	.096

COMPARISON TO 17.5-MeV PROTON SCATTERING

*DATA OF PETERSON & PERLMAN.

CS-56155

Fig. 7

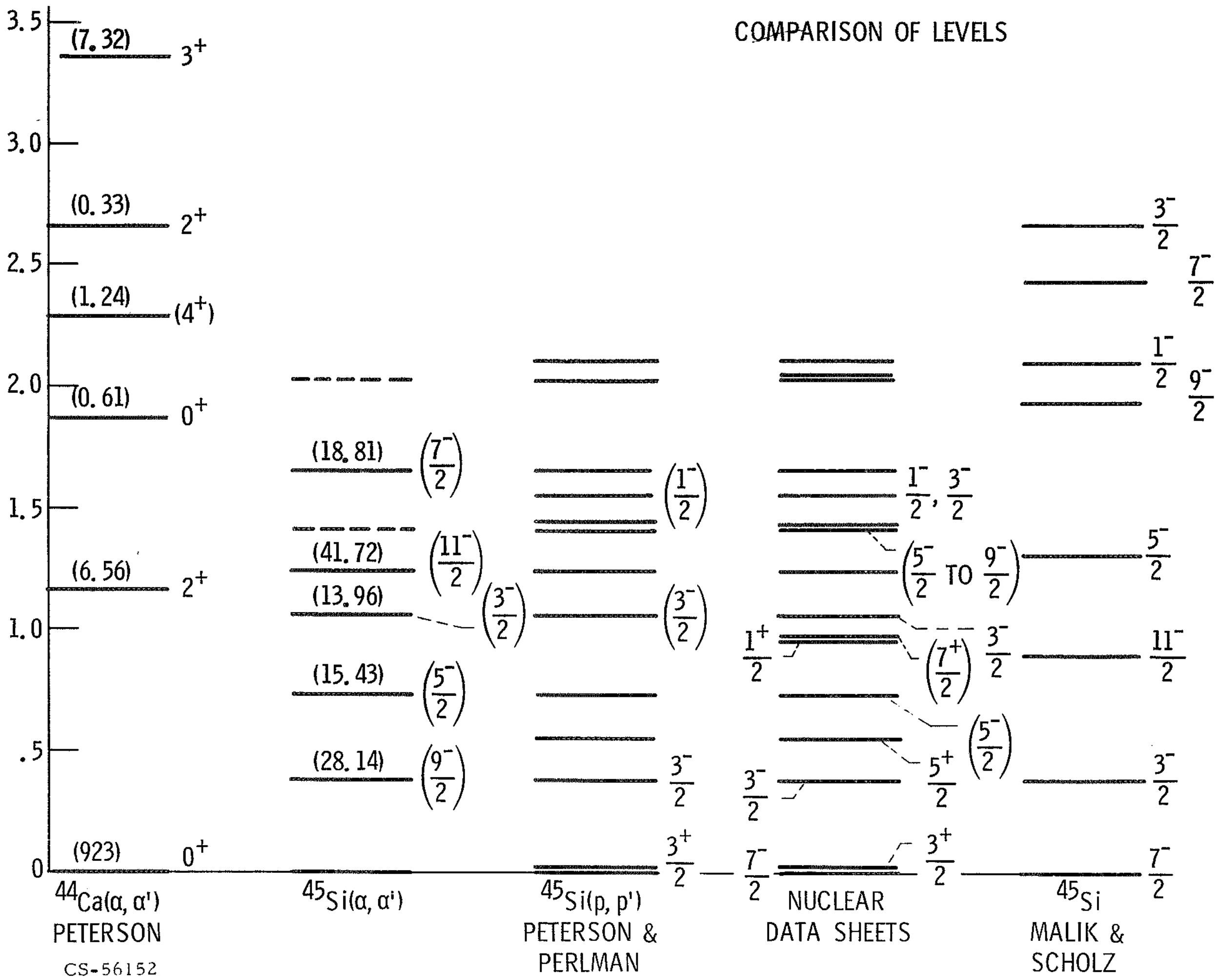


Fig. 8