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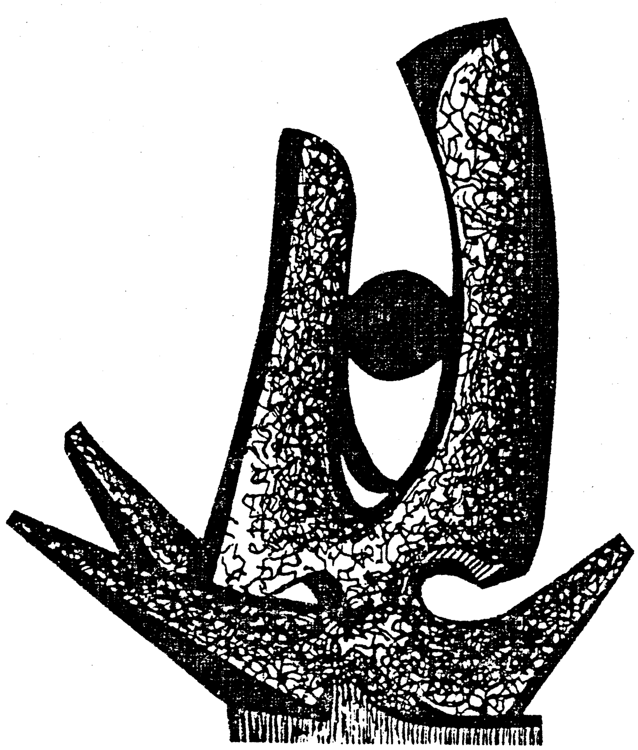

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OBSERVATION OF $\ell = 0$, SPIN-FLIP TRANSITIONS IN ^{48}Ca*

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Abstract

Observations down to 2^{o} in the $^{48}Ca(p,p')$ reaction at 201 MeV reveal 1^{+} strength with certainty only at the previously known excitation of 10.22 MeV. Compared to DWBA calculations, the strength of this state is only $\sim$ 30%.

An $\ell = 0$, spin flip transition is sensitive to the nuclear spin degrees of freedom, and its strength may give information on Δ particle-nucleon hole interactions in the nucleus. Our goals were: 1) to find all of the strength, often called M1 strength, via (p,p') in a nucleus with a simple shell model structure, namely, ^{48}Ca, and 2) to compare the strength with that observed in other reactions.

A strong M1 transition has already been observed[1] in (e,e') at an excitation energy of 10.2 MeV. The analogous Gamow-Teller transition has been seen in the (p,n) reaction.[2,3] Inelastic proton scattering has also been reported: in two of the experiments[4,5] the energy resolution was very good, but the bombarding energies were well below 100 MeV, where the reaction mechanism is not particularly selective of spin-flip transitions; in another (p,p') experiment[6] the bombarding energy was 160 MeV, but the most forward angle reached was only 6°, and the experimental background was too high to permit the study of smaller components of the 1^+ excitation.

In the present experiment, 201 MeV protons from the Orsay synchrocyclotron were used to study the $^{48}Ca(p,p')$ reaction at small angles. The experimental arrangement was very similar to that described in detail in some of our previous publications.[7-10] The target was a self-supporting foil of ^{48}Ca, 15 mg/cm^2 thick, and 1 cm^2 in area.

The absolute cross section was measured as described previously by using the known p-p scattering cross section at 15° to

determine the efficiency of the detector. In this experiment the measured efficiency was 94%. The fact that the specific yields for large and small beam spots were quite similar gives us confidence that the target was quite uniform and that the absolute cross section is accurate to ±10%.

Spectra taken with a small beam spot at 2°, 4°, 8°, and 12° and a spectrum at 6° taken with higher beam intensity are shown in Fig. 1. The ability of the high energy inelastic proton scattering reaction to select $\ell = 0$, spin-flip transitions at very forward angles is seen very clearly in this series of spectra. At very forward angles the 10.2 MeV, 1^+ state stands out very dramatically above the background, but even by 8° other states of comparable intensity are also present in the spectrum. By 12° the state is no longer the most prominent peak in the spectrum.

The angular distribution of the 10.2 MeV state is shown in Fig. 2. It is very sharply forward peaked, falling by an order of magnitude between 2° and 9°. This is characteristic of an orbital angular momentum transfer of zero at this bombarding energy.

In addition to the strong 10.2 MeV state, weak 1^+ states have been reported in the vicinity of the strong state. In the (p,p') experiments on ^{48}Ca at 65 MeV[4] and 44 MeV,[5] no other 1^+ states were reported. However, in a more recent measurement at 65 MeV[11] one additional 1^+ state was reported at 9.0 MeV with about 10% of the strength of the 10.2 MeV state. We do not see this state. In (e,e') eighteen additional states were observed[12] between 7.7 and 12.7 MeV. These raise the total value of B(M1) from $3.7 \pm 0.3\ \mu_k^2$ for the single state[1] to $\approx 5.0\ \mu_k^2$.

In the same interval of excitation energy we see fifteen additional states. Seven of these are within 42 keV of an (e,e') state (when we set the energy of the strong peak equal to their value of 10.225 MeV). The others, eight of ours and eleven of theirs, seem not to be correlated in energy. The angular distributions of most of our states have some forward peaking, but, possibly because of the presence of unresolved states of higher spin, none has a shape matching the shape of the strong state. The forward peaked part indicates 1^+ strength less than 5% of that in the 10.2 MeV state for a few of the peaks and less than 35% in toto. The latter estimate includes one peak below 7.7 MeV and five above 12.7 MeV. Of course, we cannot exclude the possibility of weak 1^+ strength spread over more states which we do not resolve.

Microscopic distorted wave calculations have been carried out using the computer codes RESEDA[14,7] and DWBA70.[15] An optical model parameter set from a fit to 201 MeV proton elastic scattering[16] on ^{40}Ca was used in both calculations. The parameters are given in Table 1. In addition, optical parameters obtained from systematic studies of data obtained with 80-180 MeV polarized protons[17] were also used in the DWBA70 calculations. These parameters gave angular distributions which had very similar shapes and were about 10% lower.

RESEDA uses phase shifts directly. Calculations were carried out with three sets of phase shifts.[18-20] All three calculations used a closed $\nu f_{7/2}$ shell for the 0^+ ground state, a simple $\nu f_{5/2} \nu f_{7/2}^{-1}$ configuration for the 1^+ state at 10.2 MeV, and a harmonic oscillator parameter $\alpha = 2.0$ fm. (Calculations

with different values of α have only slightly different shapes and all have the same absolute value around 5°.) The angular distributions have similar shapes but rather different normalizations. The calculation using the phase shifts from the Paris potential[20] is shown in Fig. 2. It gives a ratio of experimental to theoretical cross sections, N, of 0.24. Using the phase shifts of Bugg et al.,[19] which were also used by Love and Franey,[21] the value of N is 0.22. However, phase shifts of Arndt et al. give an N of 0.33.

In the DWBA70 calculation, the full Love-Franey parametrization of the interaction at 210 MeV[21] was used without alteration. Two different wave functions were tried in this case. First, a simple $\nu f_{5/2} \nu f_{7/2}^{-1}$ configuration was used as in RESEDA. This is shown as a short dashed line in Fig. 2. The second calculation, which used wave functions in a full f-p shell basis,[22] is shown as a long dashed line in Fig. 2.

All of the calculations give a reasonable fit to the shape of the experimental angular distribution out to about 12°. The RESEDA calculation matches the data very closely. However, none of the calculations, even though they include $\Delta\ell = 2$ components, reproduces the change in slope in the measured angular distribution which occurs near 12°. One possible explanation for this discrepancy is the presence of levels of higher ℓ, levels whose cross sections increase with angle, very close to the 10.2 MeV state. The existence of nearby levels has been demonstrated at, for example, 10.186, 10.152, and 10.126 MeV in lower energy experiments.[4,5]

The values of N for this and the other (p,p') experiments are listed in the top part of Table 2.

The operators for a $0^+ \rightarrow 1^+$ transition via (p,p'), (p,n), and (e,e') reactions share one component--the spin-flip, isospin-flip ($\sigma\tau$) component. For the two proton-induced reactions above 100 MeV and at small angles, it is the dominant component. In (e,e') it is also dominant in the present case where the excitation is almost entirely a neutron excitation. Any quenching of the $\sigma\tau$ operator should, under these conditions, appear in all three reactions, and in comparable proportions. Since only the sharp peak at 10.2 MeV is observed consistently in the different reactions, we will restrict our strength comparisons to this state.

A summary of the quenching in ^{48}Ca(p,n) to the T = 4, 1^+ state at 16.4 MeV in ^{48}Sc was given in a recent paper by Osterfeld et al.[23] The calculations include results obtained with three different sets of wave functions: pure particle-hole, standard RPA, and RPA including the Δ isobar. The N values obtained with the revised (p,n) cross section at 0° of Anderson et al.[24] are listed in Table 2. These N values are slightly higher than would be obtained by an overall comparison at all angles, since the calculation dips slightly towards 0°. The situation is slightly complicated by the fact that another, but unpublished,[25] experimental measurement with a 30% higher cross section was used by Osterfeld et al. to obtain the quenching values quoted in their paper.

Excitation of the 10.2 MeV state by (e,e')[1] gave a B(M1) value of 3.7 ± .3 μ_k^2. Calculations of B(M1) gave 12 μ_k^2 with the

simple f-shell wave functions and 8.6 μ_k^2 with a full f-p shell basis.[22] The corresponding N values, 0.31 and 0.43, respectively, are also listed in Table 2.

To summarize: the 10.2 MeV, 1^+ state in ^{48}Ca is very clearly seen in the inelastic scattering of 201 MeV protons at very forward angles. In spite of the strong selectivity of this process, little evidence is seen for other 1^+ states between 7.7 MeV and 12.7 MeV of excitation energy in ^{48}Ca, and an upper limit of about 5% of the 10.2 MeV strength can be placed on the strength present in any one level. Distorted wave calculations fit the shape of the angular distribution fairly well back to about 12° but then decrease rather more rapidly than the data. The absolute magnitude is always overpredicted by a factor of ~ 4, the exact value depending on the details of the wave functions used, but this factor is qualitatively consistent with that observed in (p,n), (e,e'), and two of the three previous (p,p') measurements.

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Table 2. Comparison of experimental cross sections with predictions for the 10.2 MeV 1^+ state of ^{48}Ca and the analogous 1^+ state in ^{48}Sc.

Reaction	Beam Energy	Reference	Wave Function	Reaction Code	$\frac{\sigma(exp)}{\sigma(theory)}$
(p,p')	201 MeV	Present Work	p-h	RESEDA[a]	0.24
	201 MeV	Present Work	p-h	DWBA70	0.21
	201 MeV	Present Work	full f-p[b]	DWBA70	0.30
	160 MeV	Ref. 6	full f-p[b]	DWBA70	0.50
	65 MeV	Ref. 4	p-h	DWBA74	0.25
	44.4 MeV	Ref. 5	RPA[c]	FROST-MARS	0.85-1.0
(p,n)	160 MeV	Refs. 2,24	p-h	FROST-MARS	0.27
		Refs. 2,24	RPA[d]	FROST-MARS	0.37
		Refs. 2,24	RPA + Δ[d]	FROST-MARS	0.56
					$\frac{B(M1)exp}{B(M1)theory}$
(e,e')	30-50 MeV	Ref. 1	p-h		0.31
		Ref. 1	full f-p[b]		0.43

[a]Using phase shifts from Paris potential of Ref. 20.

[b]From Ref. 22.

[c]From Ref. 26.

[d]From Ref. 23.

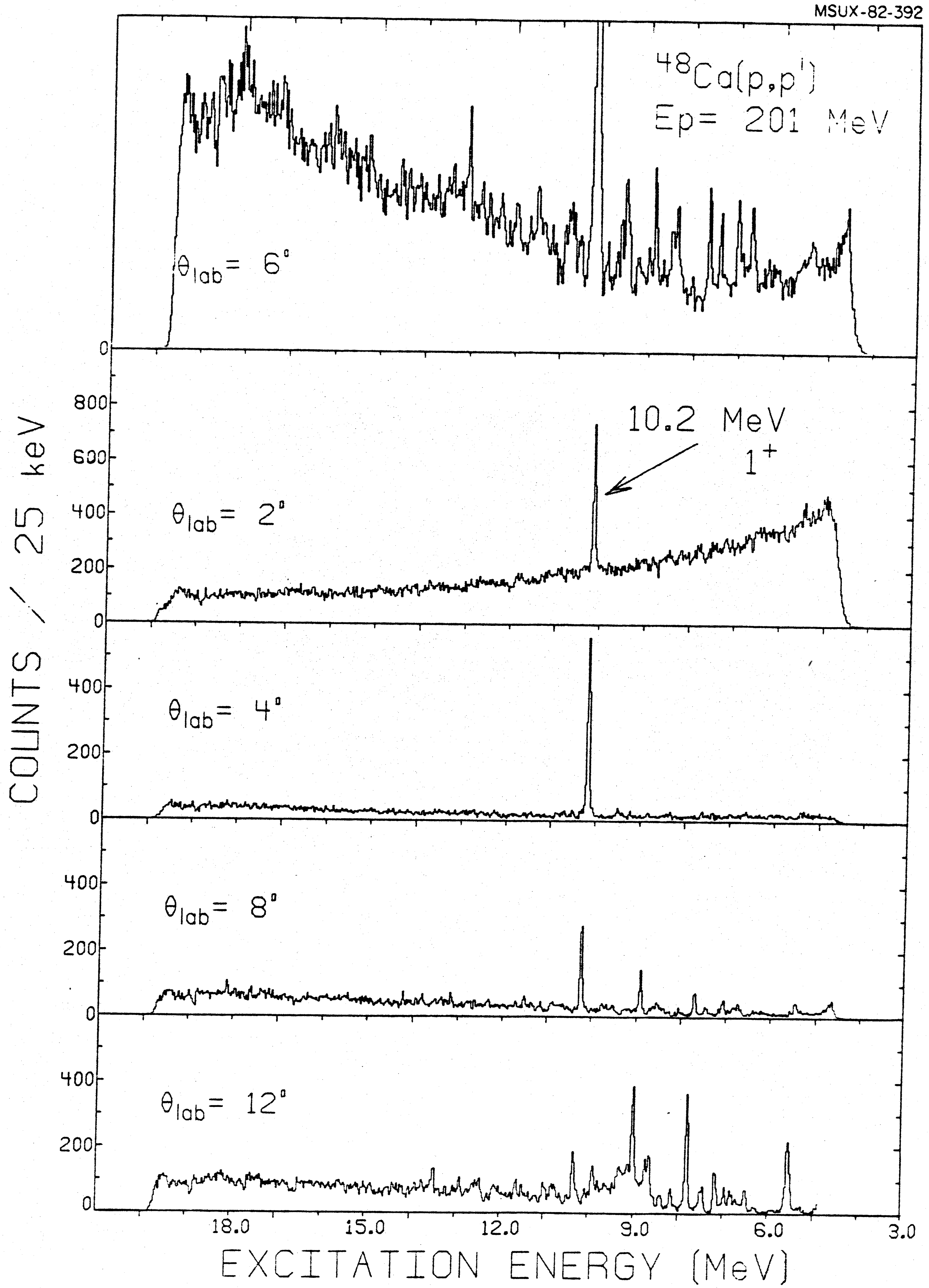
Figure Captions

Fig. 1. Spectra of protons inelastically scattered from ^{48}Ca. The uppermost spectrum has been scaled to show the weakly excited states; the 10.2 MeV state is off-scale here.

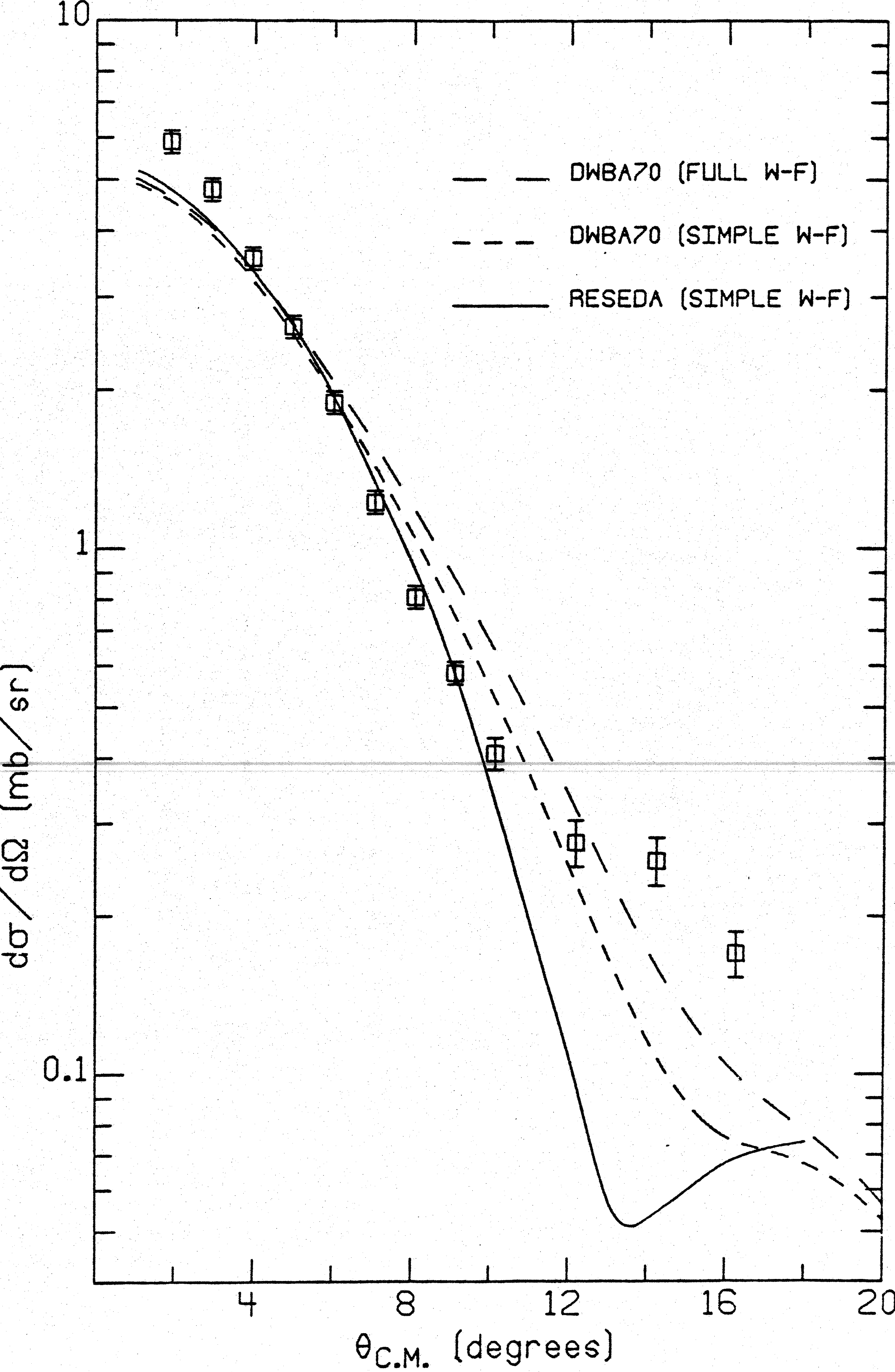
Fig. 2. Angular distribution for (p,p') to the 10.2 MeV state of ^{48}Ca. The points are the measured values, and the curves represent calculations discussed in the text.

Table 1. Optical-model parameters used in the distorted-wave analysis of the reaction $^{48}Ca(p,p')$ at E_p = 201 MeV.

V (MeV)	r_o (fm)	a_o (fm)	W_s (MeV)	r_w (fm)	a_w (fm)	V_{so} (fm)	r_{so} (fm)	a_{so} (fm)	W_{so} (MeV)	r'_{so} (fm)	a'_{so} (fm)	r_C (fm)
13.51	1.22	0.86	10.95	1.38	0.57	2.89	1.09	0.56	-1.48	1.09	0.56	1.24


MSUX-82-392
$^{48}Ca(p,p')$
Ep= 201 MeV
θlab= 6°
0
800
600
400
200
0
10.2 MeV
1+
θlab= 2°
400
200
0
θlab= 4°
400
200
0
θlab= 8°
400
200
0
θlab= 12°
18.0
15.0
12.0
9.0
6.0
3.0
COUNTS / 25 keV
EXCITATION ENERGY (MeV)

MSUX-82-390



10
1
0.1
4
8
12
16
20
$\theta_{C.M.}$ (degrees)
$d\sigma/d\Omega$ (mb/sr)
DWBA70 (FULL W-F)
DWBA70 (SIMPLE W-F)
RESEDA (SIMPLE W-F)