Study of ^{105}Ag and ^{107}Ag with the (p, t) reaction*

R. M. Del Vecchio, I. C. Oelrich, and R. A. Naumann
Joseph Henry Laboratories and Frick Chemical Laboratories, Princeton University, Princeton, New Jersey 08540
(Received 31 March 1975)

The ^{107,109}Ag$(p, t)^{105,107}$Ag reactions have been studied at 30 MeV bombarding energy. Tritons were detected with a 60 cm position-sensitive wire proportional counter backed by a plastic scintillator in the focal plane of a quadrupole-dipole-dipole-dipole (QDDD) spectrograph. Multiplet structure, interpretable as the coupling of a $2p_{1/2}$ proton to vibrational core states, was observed in both nuclei. In addition, some 50 levels in each nucleus were seen below about 3 MeV of excitation with a resolution of 10 keV. Distorted wave Born approximation calculations with simple two particle configurations worked rather well and permitted the determination of L transfers. A considerable amount of (p, t) strength in the region from 2–3 MeV of excitation in each nucleus was observed, not all of which could be associated with expected weak coupling to the 3^- core state.

[NUCLEAR REACTIONS ^{107}Ag, ^{109}Ag(p, t), $E = 30$ MeV; measured $\sigma(\theta)$ and level energies; DWBA analysis, deduced L, J^π. Resolution 10 keV. Enriched targets.]

I. INTRODUCTION

The odd-A silver isotopes have been regarded as interesting nuclei from the point of view of the weak coupling model[1,2] for some time. Above mass 103 their ground states have $J^\pi = \frac{1}{2}^-$ and may be considered, for simplicity, as consisting of a $2p_{1/2}$ proton (or proton hole) coupled to the 0^+ ground state of the adjacent even-even nucleus. One expects other states to arise from the coupling of this proton configuration to excited states of the even-even (core) nucleus. Since the spin of the proton configuration is $\frac{1}{2}$, these additional coupled states should occur as singlets or doublets. Their identification would be straightforward if the center of gravity (the $2J+1$ weighted energy average over the multiplet) is close to the excitation energy of the core state and if the energy splitting is not too severe, i.e. if the coupling is truly weak.

Previous attempts to observe this multiplet structure in ^{107,109}Ag via Coulomb excitation have met with some success.[3-6] The $\frac{3}{2}^-$, $\frac{5}{2}^-$ doublet arising from coupling to the first excited 2^+ core state has been well studied. The electromagnetic decay properties are consistent with a weak coupling interpretation of these levels, although small admixtures of other configurations in the wave functions are required to get detailed agreement with experiment. Since the even-even core nuclei (palladium or cadmium) exhibit vibrational type spectra, a quintet of levels (two doublets and a singlet) is expected to arise from the coupling to the two phonon 0^+, 2^+, 4^+ levels at about 1.0–1.5 MeV of excitation. (The term phonon is used loosely since these core states are not strictly harmonic in character.) Although the expected $\frac{3}{2}^-$, $\frac{5}{2}^-$ members of this quintet have been observed in ^{107,109}Ag, there is less certainty concerning the remaining three members.

The ^{107,109}Ag(p,p') reactions have also been employed to excite these core coupled states.[7,8] Such states were identified by comparing their angular distributions with those obtained from inelastic proton scattering on the neighboring even-even palladium nuclei. Absolute cross sections were also predicted within the framework of a particle-phonon coupling model and a coupled channels distorted wave Born approximation (DWBA) code. Although coupling to the 3^- vibrational mode was observed (as an unresolved doublet), the $\frac{1}{2}^-$, $\frac{7}{2}^-$, and $\frac{9}{2}^-$ members of the quintet were not unambiguously assigned in these previous studies.

Both in view of these experimental uncertainties and our previous success in exciting weak coupled states in ^{101}Rh with the (p, t) reaction,[9] we have performed the (p, t) reaction on ^{107}Ag and ^{109}Ag. Additionally this permitted the study of weak coupling states in ^{105}Ag where the present experimental information is scant.[10] A previous ^{109}Ag(p, t) experiment[11] at 19 MeV bombarding energy saw many new states in ^{107}Ag but did not resolve ambiguities concerning the quintet.

II. EXPERIMENTAL PROCEDURE

The ^{107,109}Ag$(p, t)^{105,107}$Ag experiments were performed at a proton energy of 29.7 ± 0.1 MeV. Tritons were detected with a 60 cm position sensitive wire proportional counter backed by a plastic scintillator in the focal plane of a quadrupole-dipole-dipole-dipole (QDDD) spectrograph. Figures 1 and 2 show spectra of ^{105}Ag and ^{107}Ag taken at $\theta_{lab} = 20°$. Three overlapping spectra were taken at each angle in order to cover excitation energies $\lesssim 3$ MeV. The resolution achieved averaged ~10 keV full width at half-maximum (FWHM) with a spectrograph solid angle of 10 msr. The corresponding angular acceptance was $\Delta\theta_{lab} = 5°$ but calculations showed that this had little effect on the shapes of the angular distributions except to fill in the deep minima in the theoretical $L=0$ shape. Cross sections were measured at $\theta_{lab} = 10$, 20, 30, 40, and 50°.

Excitation energies were determined from a calibration of the focal plane by means of known states in these nuclei and in ^{101}Rh from the ^{103}Rh-(p,t) reaction. The excitation energies listed in Tables I and II are averages over the angles at which cross sections were measured. A comparison with the ^{107}Ag data of Ref. 11 shows that there is a 2–4 keV systematic discrepancy between these two experiments. The energies of some of the low lying states are known to high precision from γ-ray work.[12] Since our energies are ~1 to 2 keV below these, it seems likely that ~2 keV should be added to our listed energies. The column labeled

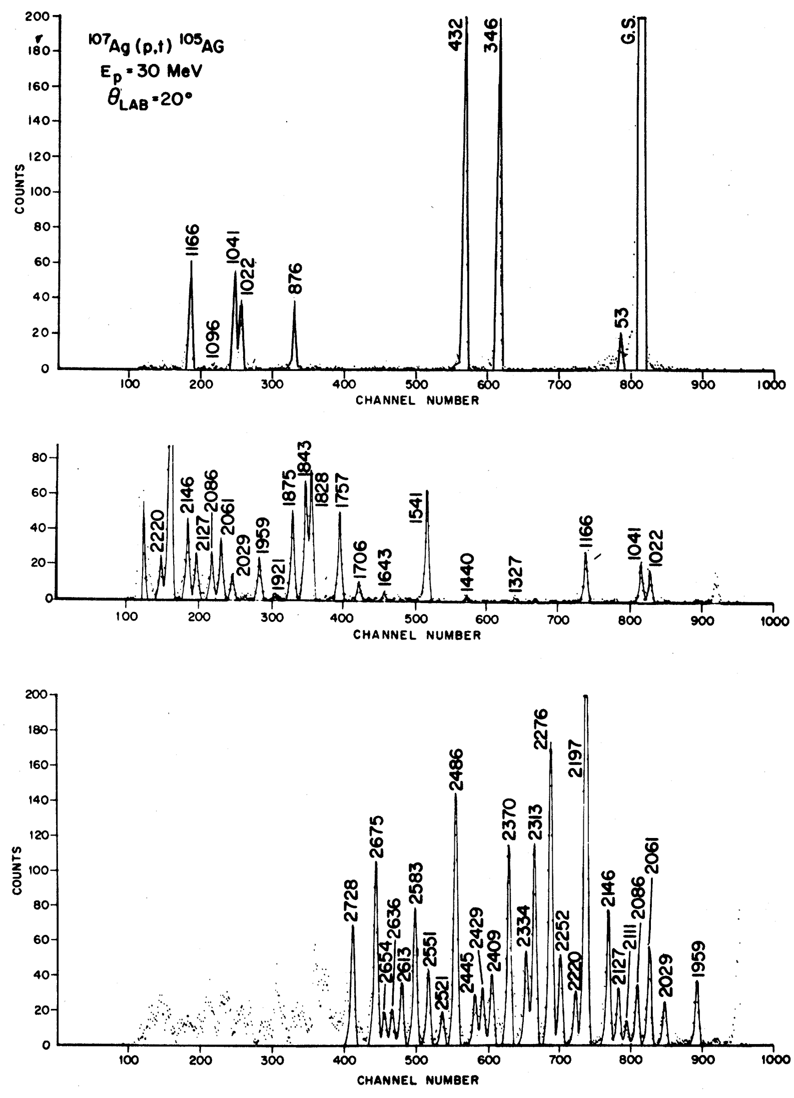

FIG. 1. The ^{107}Ag$(p,t)^{105}$Ag spectrum at $E_p = 30$ MeV and $\theta_{lab} = 20°$. Channel number refers to position along a 60 cm wire proportional counter in the QDDD focal plane.

"best energy" in Table II gives the adopted energy from Ref. 12 when available or an average of our (p, t) energy plus 2 keV and the energy of Ref. 11 when available. Perhaps a 2 keV addition to our ^{105}Ag energies is also in order, but this has not been done. The figures are labeled with the energies determined in this experiment.

The ^{107}Ag target was prepared from 98.8% isotopically pure metal by vacuum deposition onto a thin carbon foil which was subsequently reinforced with a thin layer of Formvar. The ^{109}Ag target was similarly prepared from 99.1% isotopically pure material. The thicknesses were ~60 μg/cm^2. Although relative cross sections were based on the charge collected during the run, absolute cross sections were obtained by normalizing the ground state transition to elastic scattering in a separate scattering chamber run. The presence of the ^{105}Ag ground state in the ^{107}Ag spectrum (Fig. 2) provided an independent check on the relative cross sections for ^{107}Ag(p, t) and ^{109}Ag(p, t). Using the assayed isotopic composition of the ^{109}Ag target, the calculated (p, t) cross section to the ^{105}Ag ground state differed by about 10% from that determined from the ^{105}Ag elastic scattering normalization. The expected error in the absolute cross sections determined here is about ±40% for both ^{105}Ag and ^{107}Ag states.

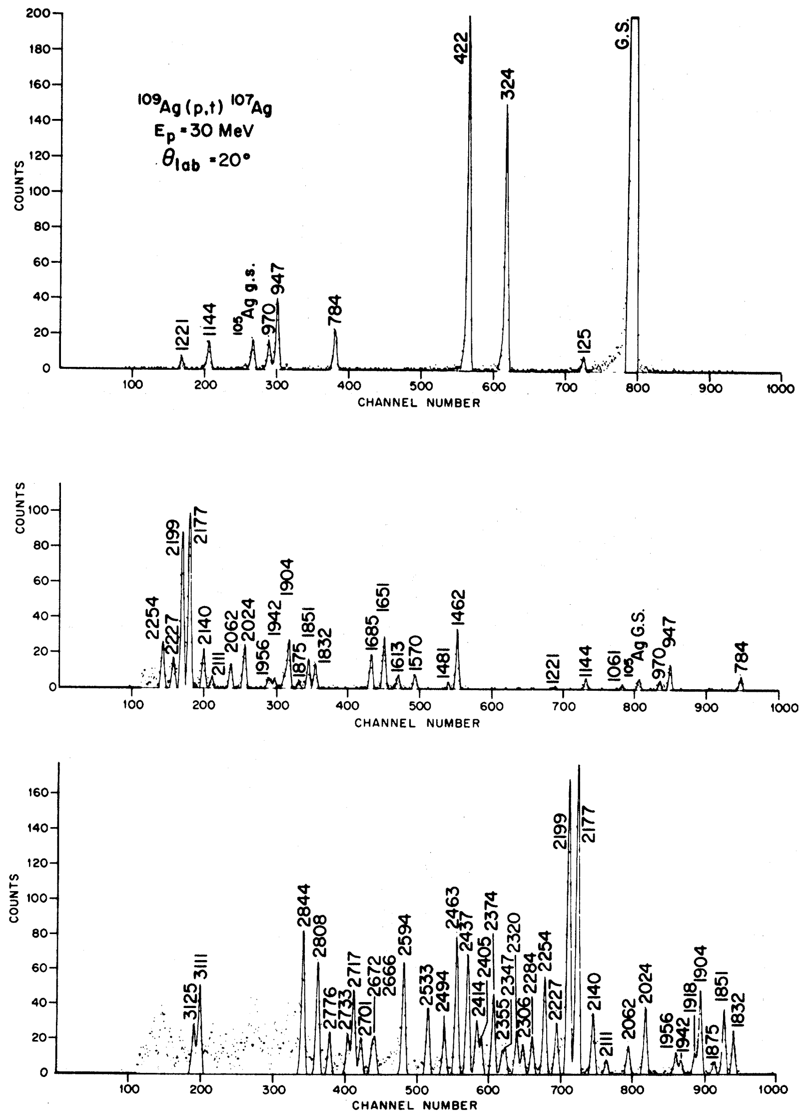

FIG. 2. The ^{109}Ag(p, t)^{107}Ag spectrum at E_p = 30 MeV and θ_{lab} = 20°. Channel number refers to position along a 60 cm wire proportional counter in the QDDD focal plane.

TABLE I. Properties of ^{105}Ag states seen in (p,t).

Exc.[a] (keV)	$\sigma(20°)$ μb/sr	L (p,t)	J^π
0	561	0	$\frac{1}{2}^-$
53	3		
346	30	2	$\frac{3}{2}^-$
432	43	2	$\frac{5}{2}^-$
876	5.6	2	$\frac{3}{2}^-$
1022	6.9	4	$\frac{7}{2}^-$
1041	9.0	2	$\frac{5}{2}^-$
1096	0.4		$(\frac{1}{2}^-)$
1166	10	4	$\frac{7}{2}^-, \frac{9}{2}^-$
1327	0.7	(6)	
1341	<0.7		
1440	1.2		
1541	24	2	$\frac{3}{2}^-, \frac{5}{2}^-$
1643	1.8	4	$\frac{7}{2}^-, \frac{9}{2}^-$
1669	~0.7		
1687	~0.7		
1706	4.0	2	$\frac{3}{2}^-, \frac{5}{2}^-$
1757	19	4	$\frac{7}{2}^-, \frac{9}{2}^-$
1828	28	4	$\frac{7}{2}^-, \frac{9}{2}^-$
1843	26	2	$\frac{3}{2}^-, \frac{5}{2}^-$
1875	20	4	$\frac{7}{2}^-, \frac{9}{2}^-$
1921	1.2	(6)	
1959	9.0	0	$\frac{1}{2}^-$
2029	6.0	4	$\frac{7}{2}^-, \frac{9}{2}^-$
2061	13	2	$\frac{3}{2}^-, \frac{5}{2}^-$
2086	9.5	2	$\frac{3}{2}^-, \frac{5}{2}^-$
2111	3.3	4	$\frac{7}{2}^-, \frac{9}{2}^-$
2127	9.0	0	$\frac{1}{2}^-$
2146	18	2	$\frac{3}{2}^-, \frac{5}{2}^-$
2157	b		
2197	74	2	$\frac{3}{2}^-, \frac{5}{2}^-$
2220	8.2	4	$\frac{7}{2}^-, \frac{9}{2}^-$
2252	13	(4)	
2276	42	3	$\frac{5}{2}^+, \frac{7}{2}^+$
2313	28	3	$\frac{5}{2}^+, \frac{7}{2}^+$
2334	13	(6)	
2359	b	2	$\frac{3}{2}^-, \frac{5}{2}^-$
2370	25	3	$\frac{5}{2}^+, \frac{7}{2}^+$
2409	10	3, 4	
2429	8.2	(6)	
2445	7.3	4	$\frac{7}{2}^-, \frac{9}{2}^-$
2486	34	4	$\frac{7}{2}^-, \frac{9}{2}^-$
2502	b		
2521	4.7	0	$\frac{1}{2}^-$
2551	10	2	$\frac{3}{2}^-, \frac{5}{2}^-$
2583	19	4	$\frac{7}{2}^-, \frac{9}{2}^-$
2602	b		
2613	9.0	2	$\frac{3}{2}^-, \frac{5}{2}^-$
2636	5.2	2	$\frac{3}{2}^-, \frac{5}{2}^-$
2654	4.7	4	$\frac{7}{2}^-, \frac{9}{2}^-$
2675	25	4	$\frac{7}{2}^-, \frac{9}{2}^-$
2728	~16		
2820	b		

[a] Statistical errors in the energies are about ±5 keV.

[b] Unresolved at this angle.

III. ANGULAR DISTRIBUTIONS AND J^π DETERMINATIONS

Peak areas and cross sections were determined by means of the computer code AUTOFIT.[13] Figure 3 shows the angular distributions for (p, t) transitions to corresponding low lying states in ^{105}Ag and ^{107}Ag. The states indicated in the figure are described further in Table III. The angular distributions to higher excited states in ^{105}Ag are shown in Figs. 4(a)–(e) while those to the remaining states measured in ^{107}Ag are given in Figs. 5(a)–(e). The error bars reflect only statistical errors. Due to spectrum overlaps, some of the cross section points were determined twice; the figures show the consistency in these separate determinations.

The DWBA curves were obtained from ^{103}Rh-$(p, t)^{101}$Rh calculations described elsewhere.[9] They include the effects of averaging over the 5°

TABLE II. Properties of ^{107}Ag states seen in (p, t).

This work				Ref. 11				
Exc. [a] (keV)	$\sigma(20°)$ μb/sr	L (p,t)	J^π	Exc. (keV)	L (p,t)	J^π	Ref. 10 J^π	Best energy (keV)
0	599	0	$\frac{1}{2}^-$	0	0	$\frac{1}{2}^-$	$\frac{1}{2}^-$	0
125	2.3			126			$(\frac{9}{2}^+)$	125.7
324	36	2	$\frac{3}{2}^-$	325	2	$\frac{3}{2}^-$	$\frac{3}{2}^-$	324.6
422	51	2	$\frac{5}{2}^-$	423	2	$\frac{5}{2}^-$	$\frac{5}{2}^-$	422.6
784	5.2	2	$\frac{3}{2}^-$	786	2	$\frac{3}{2}^-$	$\frac{3}{2}^-$	786.4
947	9.0	2	$\frac{5}{2}^-$	950	2	$\frac{5}{2}^-$	$\frac{5}{2}^-$	949.0
970	3.3	4	$\frac{7}{2}^-$	974				973.2
1061	1.2		$(\frac{1}{2}^-)$	1060				1061
1144	3.7	4	$\frac{9}{2}^-$	1147	3			1142.4
1221	1.0	(6)	$(\frac{11}{2}^-)$	1223			$(\frac{5}{2}^+)$	1222.4
1462	16	2	$\frac{3}{2}^-, \frac{5}{2}^-$	1465			$\frac{3}{2}^-$	1464.5
1481	1.5	6, 5	$(\frac{13}{2}^-)$	1482				1482
1570	4.7	4	$\frac{7}{2}^-, \frac{9}{2}^-$	1574				1573
1613	4.3	0	$\frac{1}{2}^-$	1615	0	$\frac{1}{2}^-$		1615
1651	15	0	$\frac{1}{2}^-$	1653	0	$\frac{1}{2}^-$		1653
1685	10	4	$\frac{7}{2}^-, \frac{9}{2}^-$	1688	(4)			1688
1832	7.3	2	$\frac{3}{2}^-, \frac{5}{2}^-$	1836				1835
1851	9.9	0	$\frac{1}{2}^-$	1854	0	$\frac{1}{2}^-$		1854
1875	2.5	2	$\frac{3}{2}^-, \frac{5}{2}^-$	1880	3	$(\frac{5}{2}^+)$		1878
1904	14	2	$\frac{3}{2}^-, \frac{5}{2}^-$	1911	3	$(\frac{5}{2}^+)$		1908
1918	4.1	4	$\frac{7}{2}^-, \frac{9}{2}^-$					1920
1942	2.9	2	$\frac{3}{2}^-, \frac{5}{2}^-$					1944
1956	3.7	4	$\frac{7}{2}^-, \frac{9}{2}^-$	1957				1957
2024	13	4	$\frac{7}{2}^-, \frac{9}{2}^-$	2030	3	$\frac{5}{2}^+$		2028
2062	6.4	3	$\frac{5}{2}^+, \frac{7}{2}^+$	2066	3	$(\frac{7}{2}^+)$		2065
2111	3.1	4, 3		2119				2116
2140	11	3, 2		2144	3	$(\frac{5}{2}^+)$		2143
2177	54	3		2182	3	$(\frac{7}{2}^+)$		2180
2199	50	3	$\frac{5}{2}^+, \frac{7}{2}^+$	2203	3	$(\frac{5}{2}^+)$		2202
2227	9.5	3	$\frac{5}{2}^+, \frac{7}{2}^+$	2229	(3)	$(\frac{7}{2}^+)$		2229
2254	16	2	$\frac{3}{2}^-, \frac{5}{2}^-$	2258				2257
2284	6.9	2	$\frac{3}{2}^-, \frac{5}{2}^-$					2286
2306	5.2	4	$\frac{7}{2}^-, \frac{9}{2}^-$					2308
2320	7.3	4	$\frac{7}{2}^-, \frac{9}{2}^-$					2322
2347	4.3							2349
2355	3.5	5	$\frac{9}{2}^+, \frac{11}{2}^+$					2357

TABLE II *(Continued)*

This work Exc.[a] (keV)	σ(20°) μb/sr	*L* (*p*, *t*)	J^π	Ref. 11 Exc. (keV)	*L* (*p*, *t*)	J^π	Ref. 10 J^π	Best energy (keV)
2374	14	2	$\frac{3}{2}^-, \frac{5}{2}^-$					2376
2405	6.4	2	$\frac{3}{2}^-, \frac{5}{2}^-$					2407
2414	9.0	4	$\frac{7}{2}^-, \frac{9}{2}^-$					2416
2437	21	2	$\frac{3}{2}^-, \frac{5}{2}^-$	2442				2439
2463	23	4	$\frac{7}{2}^-, \frac{9}{2}^-$	2467				2465
2494	7.3	4	$\frac{7}{2}^-, \frac{9}{2}^-$					2496
2533	12	4	$\frac{7}{2}^-, \frac{9}{2}^-$					2535
2588	b							2590
2594	19	4	$\frac{7}{2}^-, \frac{9}{2}^-$					2596
2666	5.6	4, 5						2668
2672	3.9							2674
2701	6.4	4	$\frac{7}{2}^-, \frac{9}{2}^-$					2703
2717	15							2719
2733	6.4	4	$\frac{7}{2}^-, \frac{9}{2}^-$					2735
2776	~6							2778
2808	19	4	$\frac{7}{2}^-, \frac{9}{2}^-$					2810
2844	24	4	$\frac{7}{2}^-, \frac{9}{2}^-$					2846
2887	b							2889
2902	b							2904
3111	~16							3113
3125	~10							3127

[a] Statistical errors in the energies are about ±5 keV.
[b] Unresolved at this angle.

acceptance angle of the spectrograph aperture. Sample ^{107,109}Ag(*p*, *t*) DWBA calculations were performed but differed negligibly from the Rh calculations. The *L*-transfer values obtained are listed in Tables I and II. Tentative values are enclosed in parentheses or several alternatives given.

The striking similarity in the angular distributions to corresponding low lying states is indicated in Fig. 3. The expected $L=2$ and $L=4$ doublets, comprising four of the members of the quintet, are seen around 1 MeV of excitation. The singlet $\frac{1}{2}^-$ member of this quintet is not so evident. It

TABLE III. Data on multiplets in ^{107}Ag and ^{105}Ag.

State J^π	Exc. (keV) ^{105}Ag	^{107}Ag	σ(J>)/σ(J<) ^{105}Ag	^{107}Ag	Doublet splitting (keV) ^{105}Ag	^{107}Ag	Center of gravity (keV) ^{105}Ag	^{107}Ag	C of G/core Exc. ^{105}Ag	^{107}Ag
$\frac{3}{2}^-$	346	324								
$\frac{5}{2}^-$	432	422	1.54	1.45	86	98	398	383	0.72	0.75
$\frac{3}{2}^-$	876	784								
$\frac{5}{2}^-$	1041	947	1.75	1.75	165	163	975	882	0.73	0.78
$\frac{7}{2}^-$	1022	970								
$\frac{9}{2}^-$	1166	1144	1.47	1.10	144	174	1102	1067	0.83	0.87
$(\frac{1}{2}^-)$	1096	1061					1096	1061	0.82	0.94

seems reasonable that the extra state seen in this same region of excitation in both nuclei is the missing singlet. The uncharacteristic angular distributions perhaps result from nondirect contributions to their cross sections, which are about an order of magnitude below those of neighboring states.

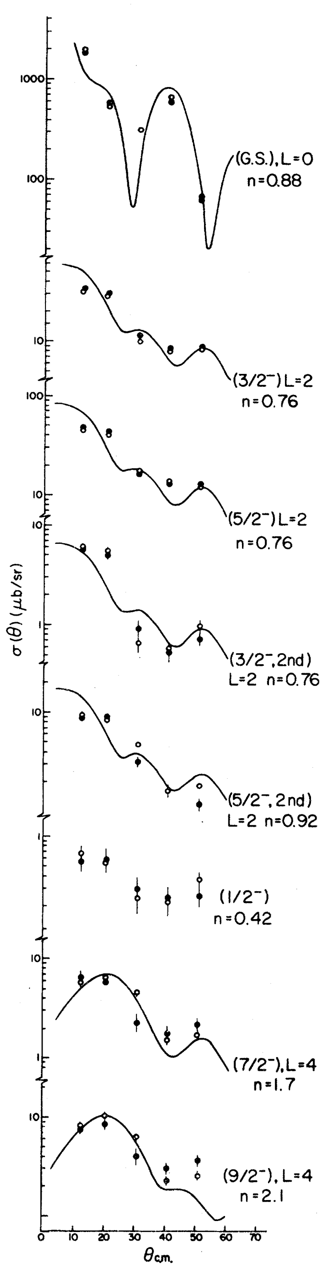

FIG. 3. Comparison of the (p, t) angular distributions to corresponding low lying states in ^{105}Ag and ^{107}Ag. The open circles refer to ^{107}Ag(p, t) states and the solid points to ^{109}Ag(p, t) states. n is the factor by which the ^{109}Ag(p, t) cross sections were multiplied. The solid lines are DWBA calculations.

In a one step (p, t) reaction without spin flip, the selection rules on the spin and parity of the final state, beginning with a $J=\frac{1}{2}$ target, are $J=L\pm\frac{1}{2}$ ($J=\frac{1}{2}$ for $L=0$) and no parity change if L = even and parity change for odd L. In addition, the members of a weak coupled doublet should have a cross section ratio, based on simple statistical considerations, of $(2J_1+1)/(2J_2+1)$ where J_1 and J_2 are the spins of the members. The cross section ratios given in Table III were used to make these spin assignments, although except for the first $L=2$ doublet, they differ somewhat from statistical expectations. There is no disagreement with what previous assignments have been made to these levels in ^{107}Ag as indicated in Table II. The ratio method was not applicable to the expected $L=3$ doublet since there appears to be a fragmentation of $L=3$ strength among more than two states.

The weak excitation of the low lying single particle $g_{9/2}$ states in ^{105}Ag and ^{107}Ag at 53 and 125 keV, respectively, is probably an indication of two step processes. Their angular distributions disagree with a direct one step calculation. The fact that these angular distributions are nearly identical suggests that the mechanism responsible for the excitation of these states is the same in the two reactions.

IV. DISCUSSION AND CONCLUSIONS

Figure 6 shows the multiplets observed which can be associated with vibrational type states in the cores. Only the two strongest $L=3$ states in ^{105}Ag and ^{107}Ag are shown. The corresponding ^{101}Rh spectrum is presented to point out the remarkable similarity in the multiplet structure of all three nuclei. Some information concerning centers of gravity and doublet splitting is indicated in Table III. The ratio of the center of gravity of the doublet to the excitation energy of the corresponding core state tends to increase with excitation energy. It becomes >1 for the $L=3$ multiplet in ^{107}Ag. The doublet splitting is a factor of 2–3 larger in the silvers than in ^{101}Rh.

Our assignment of the $L=4$ members of the quintet in ^{107}Ag disagrees with a suggestion made in a previous (p,p') study as to the location of this doublet.[7] It is consistent, however, with a Coulomb excitation study which saw states at 974 and 1147 keV in ^{107}Ag excited through multiple Coulomb excitation.[6] There are some disagreements between our (p, t) L-transfer assignments and those of the ^{109}Ag(p, t) experiment at $E_p=19$ MeV.[11] Our experience with the ^{103}Rh(p, t) reaction at $E_p=17$ MeV has been that the angular distributions are rather structureless except for

$L=0$ and difficult to fit with conventional DWBA.[9] Nevertheless, in view of the similarity between the $L=3$ and $L=4$ DWBA curves at 30 MeV proton energy there is certainly room for some doubt in our L assignments.

^{105}Ag has previously been investigated by means of the β decay of ^{105}Cd.[14,15] Employing a NaI-Ge(Li) coincidence experiment, Ref. 15 assigned two of the prominent γ rays to decays from states at 347 and 433 keV in ^{105}Ag. In view of the excellent agreement with the energies of our first excited $L=2$ doublet in ^{105}Ag, it seems likely that this aspect of the decay scheme is correct. Reference 14, however, performed a Ge(Li) singles experiment and tentatively assigned these γ rays to decays from other supposed states. This ap-

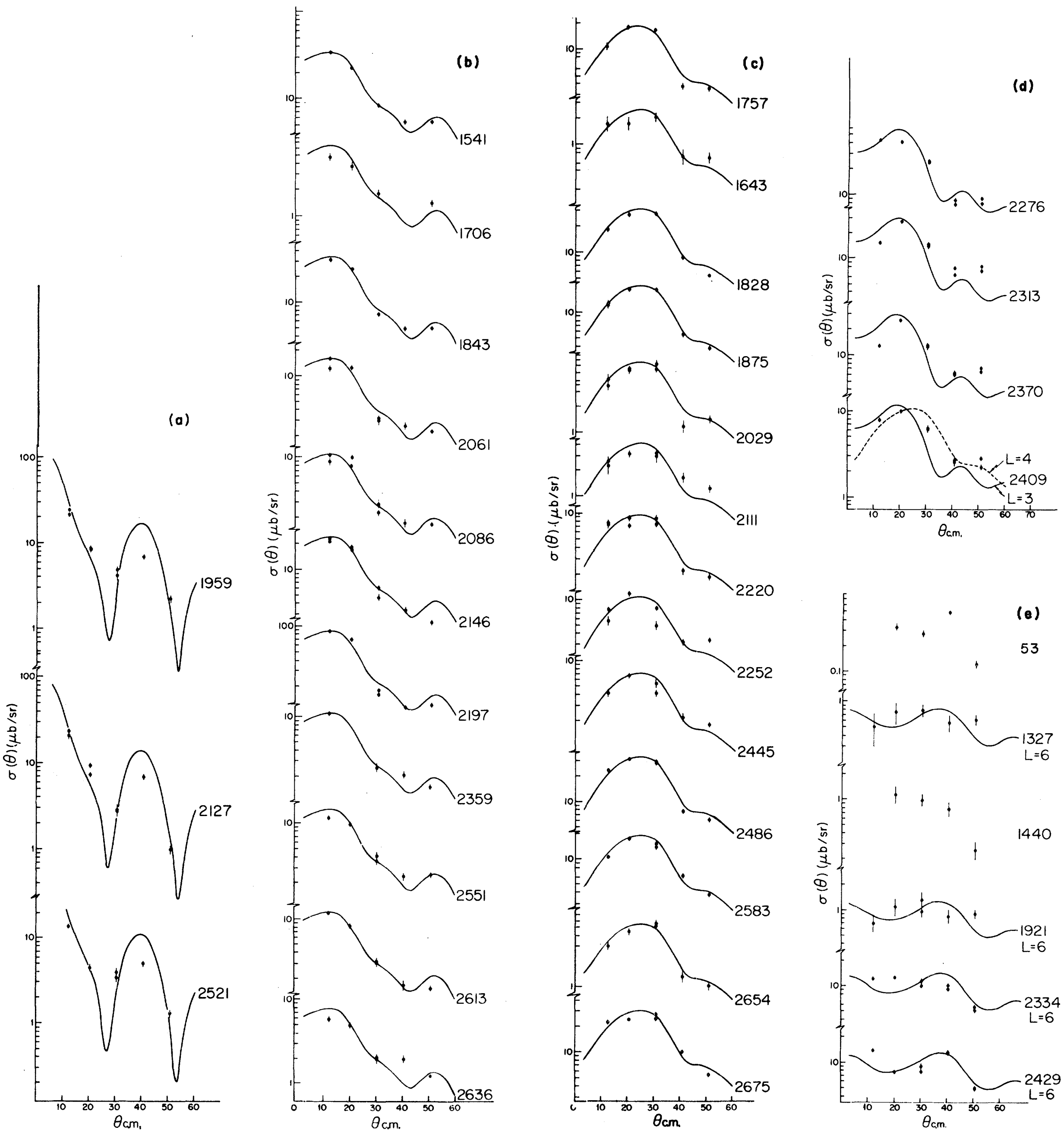

FIG. 4. ^{107}Ag$(p, t)^{105}$Ag angular distributions at $E_p = 30$ MeV. The solid lines are DWBA calculations. (a) $L=0$; (b) $L=2$; (c) $L=4$; (d) $L=3$; (e) extra or uncertain.

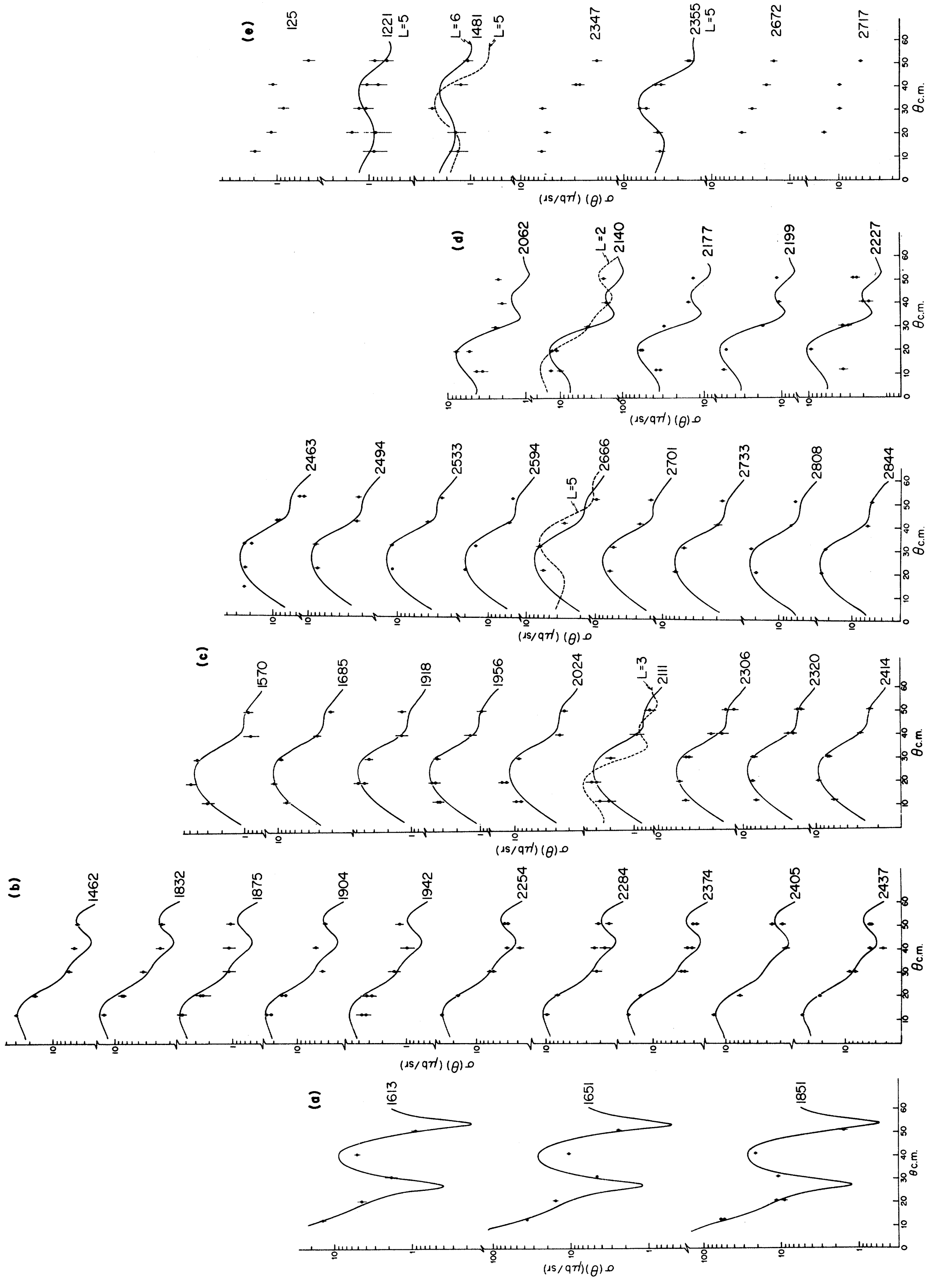

FIG. 5. ^{109}Ag(p, t)^{107}Ag angular distributions at $E_p = 30$ MeV. The solid lines are DWBA calculations. (a) $L=0$; (b) $L=2$; (c) $L=4$; (d) $L=3$; (e) extra or uncertain.

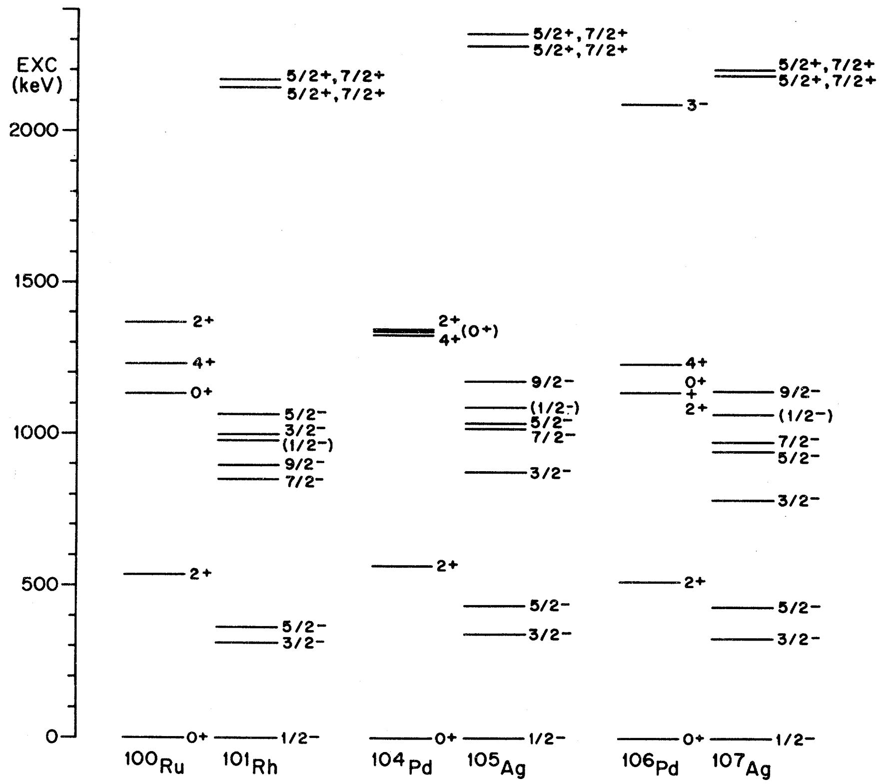

FIG. 6. Proposed multiplet structure in ^{103}Rh, ^{107}Ag, and ^{109}Ag associated with the coupling of a $2p_{1/2}$ proton onto vibrational core states.

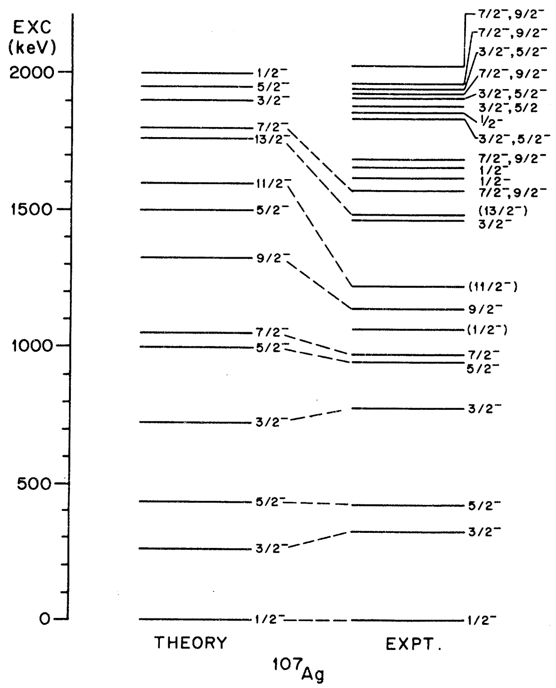

FIG. 7. A comparison of the theoretical spectrum of negative parity states in ^{107}Ag from Ref. 16 with the states seen in the (p, t) reaction below ~ 2 MeV of excitation.

parent misassignment would tend to distort other aspects of the decay scheme presented in Ref. 14 so that a reexamination of the ^{105}Cd decay scheme is evidently in order.

A theoretical treatment of the silver isotopes employing a basis of three proton holes in the $Z=50$ shell coupled to phonon states of a vibrational core has been given.[16] The Hamiltonian included particle-particle and particle-phonon interactions. The eigenstates which emerge are rather complicated but give a good account of the electromagnetic properties of ^{107}Ag and ^{109}Ag. Figure 7 shows a comparison of the theoretical spectrum of the negative parity states with our ^{107}Ag spectrum. The agreement is quite reasonable and shows that some aspects of weak coupling are preserved despite the complexity of the model. The interesting appearance of low lying $\frac{11}{2}^-$ and $\frac{13}{2}^-$ theoretical states seems to be a feature of the experimental spectrum as well. The states tentatively indicated by these spins proceeded by $L=(6)$ in (p, t). The spin order shown in Fig. 7 was based on the theoretical correspondence. The theory, however, does not give a good account of the $\frac{1}{2}^-$ states.

Reasonably large (p, t) strength to states other than those reached by $L=3$ transitions in the excitation region from 2–3 MeV is apparent in our data (Figs. 1 and 2). Such strength has been noticed previously in the ^{103}Rh(p, t) reaction[9] as well as in the even-even Cd(p, t) reaction,[17] although L transfers were not assigned in this latter work. A knowledge of where the (p, t) strength lies in the even-even (p, t) reaction should help explain the distribution of (p, t) strength among states in the odd-A nucleus, at least within the framework of a weak coupling description.[18,19] It appears that the (p, t) reaction can be a useful spectroscopic tool in the further elucidation of the weak coupling description of odd-A nuclei.

ACKNOWLEDGMENTS

We are grateful to C. Harrison for making the targets used in this work, to W. H. Moore for assistance in running the cyclotron, and to F. Loeser for help in taking the data.

*Work supported in part by the National Science Foundation under Grant No. GP32884 and Energy Research and Development Agency under Grant No. E(11-1)-2184.

[1]R. D. Lawson and J. L. Uretsky, Phys. Rev. 108, 1300 (1957).
[2]A. de-Shalit, Phys. Rev. 122, 1530 (1961).
[3]M. J. Throop, I. Hall, I. M. Naqib, D. J. Thomas, and B. Wakefield, Phys. Lett. 41B, 585 (1972).
[4]C. W. Cottrell, Nucl. Phys. A204, 161 (1973).
[5]T. R. Miller and M. Takeda, Nucl. Phys. A221, 392 (1974).
[6]R. L. Robinson, F. K. McGowan, P. H. Stelson, and W. T. Milner, Nucl. Phys. A150, 225 (1970).
[7]J. L. C. Ford, Jr., C.-Y. Wong, T. Tamura, R. L. Robinson, and P. H. Stelson, Phys. Rev. 158, 1194 (1967).
[8]J. L. C. Ford, Jr., R. L. Robinson, P. H. Stelson, T. Tamura, and C.-Y. Wong, Nucl. Phys. A142, 525 (1970).
[9]R. M. Del Vecchio, R. A. Naumann, J. R. Duray, H. Hübel, and W. W. Daehnick, Phys. Rev. C 12, 69 (1975).
[10]F. E. Bertrand, Nucl. Data B11, 449 (1974).
[11]A. Kuhfield and N. M. Hintz, John H. Williams Laboratory of Nuclear Physics, University of Minnesota, Annual Report No. COO-1265-126, 1972 (unpublished), p. 77.
[12]F. E. Bertrand and D. J. Horen, Nucl. Data B7, 1 (1972).
[13]J. R. Comfort, Physics Division, Argonne National Laboratory, Argonne, Illinois, Informal Report No. PHY-1970 B, 1970 (unpublished).
[14]C. L. Starke, E. A. Phillips, and E. H. Spejewski, Nucl. Phys. A139, 33 (1969).
[15]K. Okano, Y. Kawase, S. Uehara, T. Takeuchi, and T. Hayashi, Annual Reports of the Research Reactor Institute, Kyoto University, 1969 (unpublished), Vol. 2, p. 83.
[16]V. Paar, Nucl. Phys. A211, 29 (1973).
[17]J. R. Comfort, W. J. Braithwaite, and J. R. Duray (unpublished).
[18]Y. Iwasaki, M. Sekiguchi, F. Soga, and N. Takohashi, Phys. Rev. Lett. 29, 1528 (1972).
[19]K. A. Erb and T. S. Bhatia, Phys. Rev. C 7, 2500 (1973).