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Fragmentation of $L = 0$ transfer strength in the ^{195}Pt(t,p)^{197}Pt reaction

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The ^{195}Pt(t,p)^{197}Pt reaction has been measured with a 17 MeV triton beam. Excitation energies and angular distributions of states below 2.2 MeV have been obtained. Three sizable $L = 0$ transitions were observed to states below 1 MeV, in contrast to earlier Pt(t,p) and (p,t) reaction measurements where essentially all of the $L = 0$ strength was in the ground-state transition.

NUCLEAR REACTIONS ^{195}Pt(t,p), $E = 17$ MeV; enriched target; measured energy levels, $\sigma(\theta)$ in ^{197}Pt; DWBA.

I. INTRODUCTION

Two-neutron transfer reactions on odd-mass targets have frequently been a very sensitive test of the transitional character of a region of nuclei. The most striking example occurs in the $N = 88-90$ nuclei which undergo a rapid change from a predominantly spherical ground state in ^{150}Sm to a predominantly prolate deformed ground state in ^{152}Sm. This rapid change is seen in the ^{150}Sm(t,p)^{152}Sm reaction,[1] where the $L = 0$ strength is fragmented into three sizable pieces, with the ground-state receiving about 40% of the total strength. However, in the odd target reaction ^{151}Eu(t,p)^{153}Eu the $L = 0$ strength is more severely fragmented with numerous states receiving $L = 0$ strength and the ground state receiving almost none.[2] Another region where considerable fragmentation of $L = 0$ strength shows a clear indication of a rapid change in deformation is in the Ge-Ga region.[3]

The Os-Pt-Hg nuclei are in another region undergoing a shape transition, although rather gradually from the well deformed prolate shapes of the rare-earth nuclei to the spherical structure of the Pb isotopes. Recent two-neutron transfer studies[4-6] in this region, however, show very smooth systematics of the $L = 0$ strengths. The details of these trends in the Pt(t,p) reactions[4] are actually in very good agreement with the predictions of the O(6) limit of the interacting boson approximation (IBA) model[7] and the boson expansion (BET) model.[8] Given the smoothness of the even-A (t,p) and (p,t) strengths,[4-6] one might expect the odd-A two-neutron transfer strengths to be characteristic of rather spherical weak-coupling systems. This has been observed in ^{107,109}Ag(t,p) reactions,[9] for example, where the two-neutron transfer induced excitation pattern in the odd-A nucleus tracks the pattern in the even-A core.

Since two-neutron transfer reactions on odd-A targets have frequently been a more sensitive tool in probing nuclear shape changes than the reactions on even-A targets, we have initiated a study of the distribution of $L = 0$ strength in (t,p) and (p,t) reactions on $A = 190-200$ odd-mass targets. The initial study reported here is the ^{195}Pt(t,p)^{197}Pt reaction; a brief report of this has been previously presented.[10]

II. EXPERIMENTAL PROCEDURES

The ^{195}Pt(t,p) reaction was investigated at the Los Alamos National Laboratory Van de Graaff Accelerator Facility using a 17 MeV triton beam and an enriched ^{195}Pt (97.3%) target. The reaction protons were momentum analyzed using the Q3D spectrometer[11] and detected by a helical proportional counter[12] in the focal plane. Typical FWHM resolutions of 15 keV were obtained. A typical spectrum obtained at 25° is shown in Fig. 1. Our experimental results are summarized in Table I. Angular distributions were taken in 5° intervals from 10°–60° and are summarized in Fig. 2. Absolute cross sections were determined by measuring the elastically scattered tritons in a surface-barrier

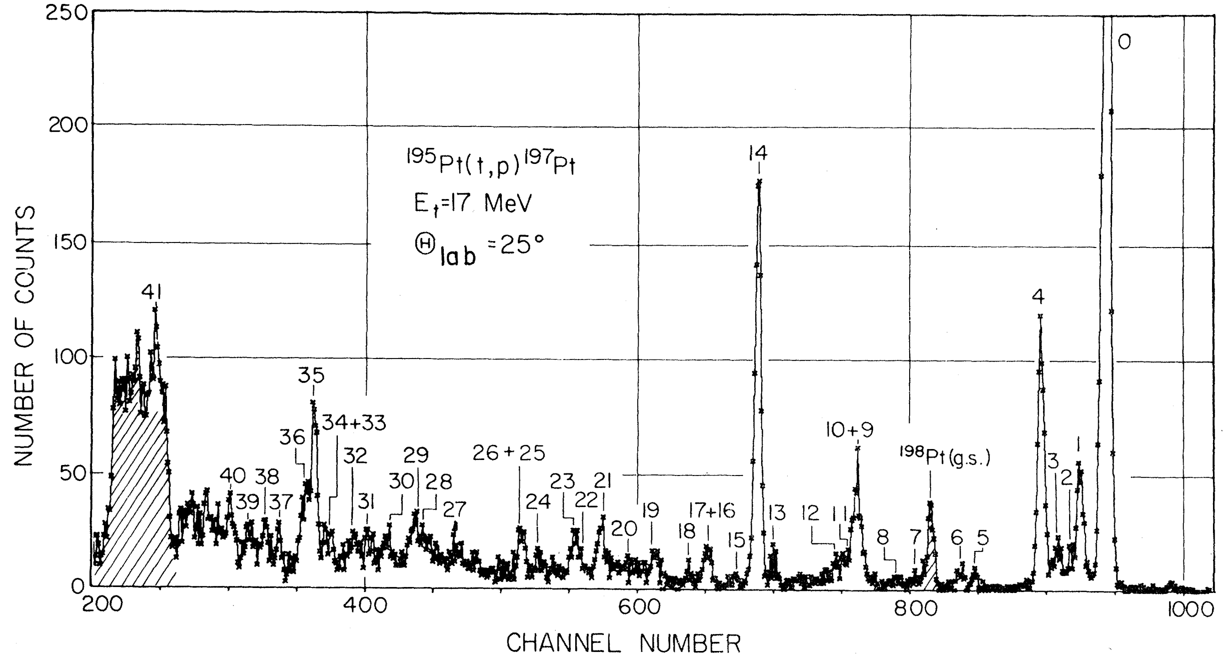

FIG. 1. Spectrum of the ^{195}Pt$(t,p)^{197}$Pt reaction measured at 25° with 17 MeV tritons. The numbering of the peaks corresponds to the levels in Table I.

detector placed at 30° relative to the beam and comparing the elastic yield to predictions from optical model calculations using the parameters of Table II. Cross section measurements relative to the $^{\text{even}}$Pt(t,p) reactions were obtained from $^{\text{natural}}$Pt(t,p) measurements reported in Ref. 4.

The measured angular distributions were compared with DW predictions obtained from the code[13] DWUCK and using the standard optical parameters[14,15] given in Table II. DW calculations for $L=0$ and $L=2$ transfer are indicated in Fig. 2. As was seen in the $^{\text{even}}$Pt(t,p) measurements,[4] the DW predictions for $L=4$ transfer show less structure than observed for transfer to known 4^+ states. We have adopted and indicated in Fig. 2 the same empirical shape for $L=4$ transfer used in the $^{\text{even}}$Pt(t,p) study of Ref. 4, which is reasonable given the identical beam energy and similar Q values, etc., between the reactions.

Table I compares our present results with earlier measurements of ^{197}Pt and the compilation of Ref. 16. Yamazaki and co-workers[17] probed ^{197}Pt via the (d,p), (d,t), and (n,γ) reactions, and ranges of J^π values can be obtained for many states based on these measurements and are given in Table I. Combining our present measurements with the earlier results allows more restrictive assignments to be made, since for two neutron transfer from a spin-$\frac{1}{2}$ target, the J^π value is given by[18]

$$J^\pi = \frac{(L+l)^{(-)^l}}{2},$$

where L is the angular momentum transfer in the (t,p) reaction and l is the angular momentum transfer observed in a (d,p) or (d,t) reaction. As given in Table I definitive assignments can be made based on the clear signature of an $L=0$ transition; less definitive assignments are based on other L transfers.

III. DISCUSSION

The systematics of low-lying negative-parity states in ^{193,195,197}Pt is summarized in Fig. 3. The most striking characteristic of ^{197}Pt, which is evident in Fig. 2 and Table I, is that three states below 1 MeV are populated with sizable $L=0$ strengths. This is in contrast to $^{\text{even}}$Pt(t,p) measurements,[4] where excited 0^+ states are populated with less than 5% of the ground-state strength and in contrast to Pt(p,t) reactions[5,6] where essentially all of the $L=0$ strength again is concentrated in the ground-state transition, even in the ^{195}Pt$(p,t)^{193}$Pt reaction.[6] A comparison of even- and odd-mass (t,p) and (p,t) $L=0$ strengths is summarized in Table III.

In both the (t,p) and (p,t) reactions on the ^{195}Pt

TABLE I. Excited states in ^{197}Pt.

	Present work[a]			Earlier work[b]		Adopt[c]
	E_x	$\frac{d\sigma}{d\Omega}(25°)$		E_x		
Level No.	(keV)	(μb/sr)	L	(keV)	J^π	J^π
0	0	103(2)	0	0.0	$\frac{1}{2}^-$	$\frac{1}{2}^-$
1	52	10.1(9)	2	53.1	$\frac{5}{2}^-$	$\frac{5}{2}^-$
2	72	2.8(5)	2	71.6	$(\frac{3}{2})^-$	$\frac{3}{2}^-$
3	99	4.0(6)	2	98.6	$\frac{1}{2}^-,\frac{3}{2}^-$	$\frac{3}{2}^-$
4	131	20.3(13)	0	131.0	$\frac{1}{2}^-,\frac{3}{2}^-$	$\frac{1}{2}^-$
5	271	1.2(3)	2	269.1	$\frac{1}{2}^-,\frac{3}{2}^-$	$\frac{3}{2}^-$
6	301	1.5(3)	2	299.3	$(\frac{1}{2}^-,\frac{3}{2}^-)$	$\frac{3}{2}^-$
7	394	1.0(3)		399.6	$\frac{13}{2}^+$	$\frac{13}{2}^+$
				425.7	$\frac{1}{2}^-,\frac{3}{2}^-$	$\frac{1}{2}^-,\frac{3}{2}^-$
8	455^{d}	0.9(4)		456.8	$(\frac{5}{2}^-,\frac{7}{2}^-)$	$(\frac{5}{2}^-,\frac{7}{2}^-)$
				481	$(\frac{1}{2}^-,\frac{3}{2}^-)$	$(\frac{1}{2}^-,\frac{3}{2}^-)$
				502.4	$\frac{1}{2}^-,\frac{3}{2}^-$	$\frac{1}{2}^-,\frac{3}{2}^-$
9	520$\}^{e}$	3.8(7)		529	$\frac{5}{2}^-,\frac{7}{2}^-$	
10	531	7.1(9)	(2)			
11	(561^{d}	2.4(5)	)^{f}			
12	590	2.0(5)	4	595.3	$\frac{1}{2},\frac{3}{2},\frac{5}{2}^-$	h
13	707	2.5(10)	2	708.4	$\frac{1}{2}^-,\frac{3}{2}^-$	$\frac{3}{2}^-$
14	744	30.0(13)	0	747.8	$\frac{1}{2}^-,\frac{3}{2}^-$	$\frac{1}{2}^-$
15	797	1.0(3)				
16	847$\}^{e}$	1.5(5)		853	$\frac{5}{2}^-,\frac{7}{2}^-$	
17	859	2.2(5)	2			$(\frac{3}{2}^-,\frac{5}{2}^-)$
18	896	0.9(3)		897		
19	978	2.8(7)		977.9	$\frac{1}{2}^-,\frac{3}{2}^-$	$(\frac{3}{2})^-$
				1029		
20	1055	2.0(4)		1060	$(\frac{1}{2}^-,\frac{3}{2}^-)$	$(\frac{3}{2}^-)$
21	1099	5.2(8)		1107	$\frac{1}{2}^-,\frac{3}{2}^-$	$(\frac{3}{2})^-$
22	1144	1.5(6)		1135	$(\frac{1}{2}^-,\frac{3}{2}^-)$	$(\frac{3}{2}^-)$
23	1162	4.3(8)	(0)	1158	$(\frac{1}{2}^-,\frac{3}{2}^-)$	$(\frac{1}{2})^-$
				1214		
24	1243	1.6(5)		1249		
25	1276$\}^{e}$	1.5(8)	2	1290		$(\frac{3}{2}^-,\frac{5}{2}^-)$
26	1292	2.7(9)	4			$(\frac{7}{2}^-,\frac{9}{2}^-)$
				1297	$\frac{5}{2}^-,\frac{7}{2}^-$	
				1330	$\frac{1}{2}^-,\frac{3}{2}^-$	$\frac{1}{2}^-,\frac{3}{2}^-$
27	1439	2.1(7)				
28	1507	3.4(9)		1516		
29	1540	4.7(9)				
30	1608	3.2(7)				

TABLE I. (*Continued.*)

	Present work[a]			Earlier work[b]		Adopt[c]
Level No.	E_x (keV)	$\frac{d\sigma}{d\Omega}(25°)$ (μb/sr)	L	E_x (keV)	J^π	J^π
				1634	$(\frac{1}{2}^-,\frac{3}{2}^-)$	$(\frac{1}{2}^-,\frac{3}{2}^-)$
31	1657	3.4(8)				
32	1687	3.9(9)				
				1706		
33	1743[e]	2.8(6)		1754		
34	1761	2.8(5)				
35	1787	13.7(14)	(4)	1797	$(\frac{7}{2}^+,\frac{9}{2}^+)$	h
36	1812	7.3(11)		1822	$(\frac{1}{2}^-,\frac{3}{2}^-)$	$(\frac{3}{2}^-)$
37	1874	3.5(7)				
38	1908	4.5(7)	4			$(\frac{7}{2}^-,\frac{9}{2}^-)$
39	1947[d]	3.8(7)				
40	1999[d]	4.9(9)				
41	2186[g]	7.7(18)		2176		

[a] Excitation energies, cross sections at 25° and angular momentum transferred as measured in the present (t,p) study. Errors on energies are typically less than 5 keV. Differential cross section errors given in parentheses on the last digit(s) are only relative errors. Absolute errors would typically be at least 15%.

[b] Excitation energies and J^π values that can be obtained from the measurements of Ref. 17 and the compilation of Ref. 16.

[c] J^π values that can be adopted from combining the earlier values and our present L-transfer measurements. No values were adopted when the correspondence between the earlier and present measurements was ambiguous.

[d] Broad peak, probably a doublet.

[e] Resolution of multiplet structure.

[f] Tentatively assigned to ^{197}Pt.

[g] Partially obscured by contaminant at 25°. It was difficult to unambiguously assign higher lying peaks to ^{197}Pt, so no other levels are quoted.

[h] The J^π values implied by the present work and earlier measurements are not consistent.

targets, the $L=0$ ground state strength is considerably less than the even-A ground-state strength. This is expected because the odd-particle in the target prohibits this orbital from participating in the pairing correlations, due to the Pauli principle blocking. The spectroscopic factor for the two nucleon transfer on an odd-mass target is[22]

$$B_j(\text{odd})=(-)^l\left[1-\frac{\sqrt{2}}{\sqrt{j+(1/2)}\,(2j+1)}\right]B_j(\text{even})\,.$$

For two-neutron transfer on a ^{195}Pt target, the $\frac{1}{2}^-$ orbital is blocked. Therefore, $B_{1/2}(\text{odd})=0.29B_{1/2}(\text{even})$; that is almost all of the $\frac{1}{2}^-$ component of the two-nucleon transfer amplitude is blocked. To actually calculate the effect on the ground state cross section requires a knowledge of the occupation probabilities for all of the orbitals involved in the two-neutron transfer mechanism. Unfortunately, the necessary spectroscopic strengths have not been determined with sufficient accuracy. Empirically, the two-neutron transfer strength on odd-A collective targets is typically reduced by ~50% compared to even-A (t,p) and (p,t) ground-state transitions. However, in the ^{195}Pt(t,p) reaction the ground-state strength is ~35% of the even-A strength, and only by summing the strength observed in the three fragments can ~50% of the

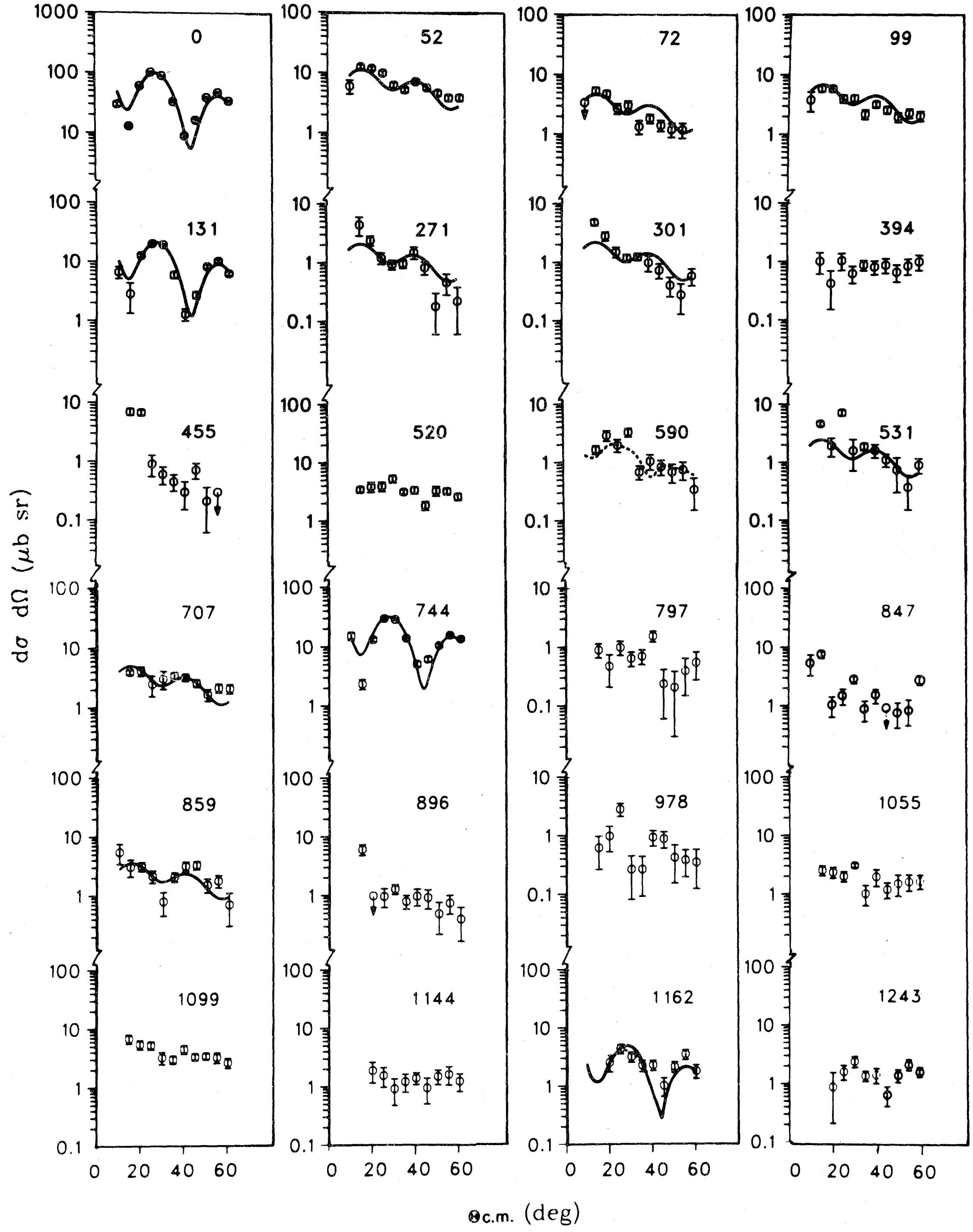

FIG. 2. Angular distributions for the states populated in ^{197}Pt. The solid curves are DWBA calculations for $L=0$ and $L=2$ transitions; the dashed curves represent an empirical $L=4$ shape.

even-A strength be attained. If the three $L=0$ transitions in ^{197}Pt were due to the fragmentation of the ground-state pairing correlation of the even cores, then the two neutron separation energy, $S(2n)$, should be a smooth function of A that went through the centroid at ~ 160 keV of the $L=0$ strength in ^{197}Pt. However, the ground state $S(2n)$ of ^{197}Pt is only ~ 50 keV from the even-A systematics, so that

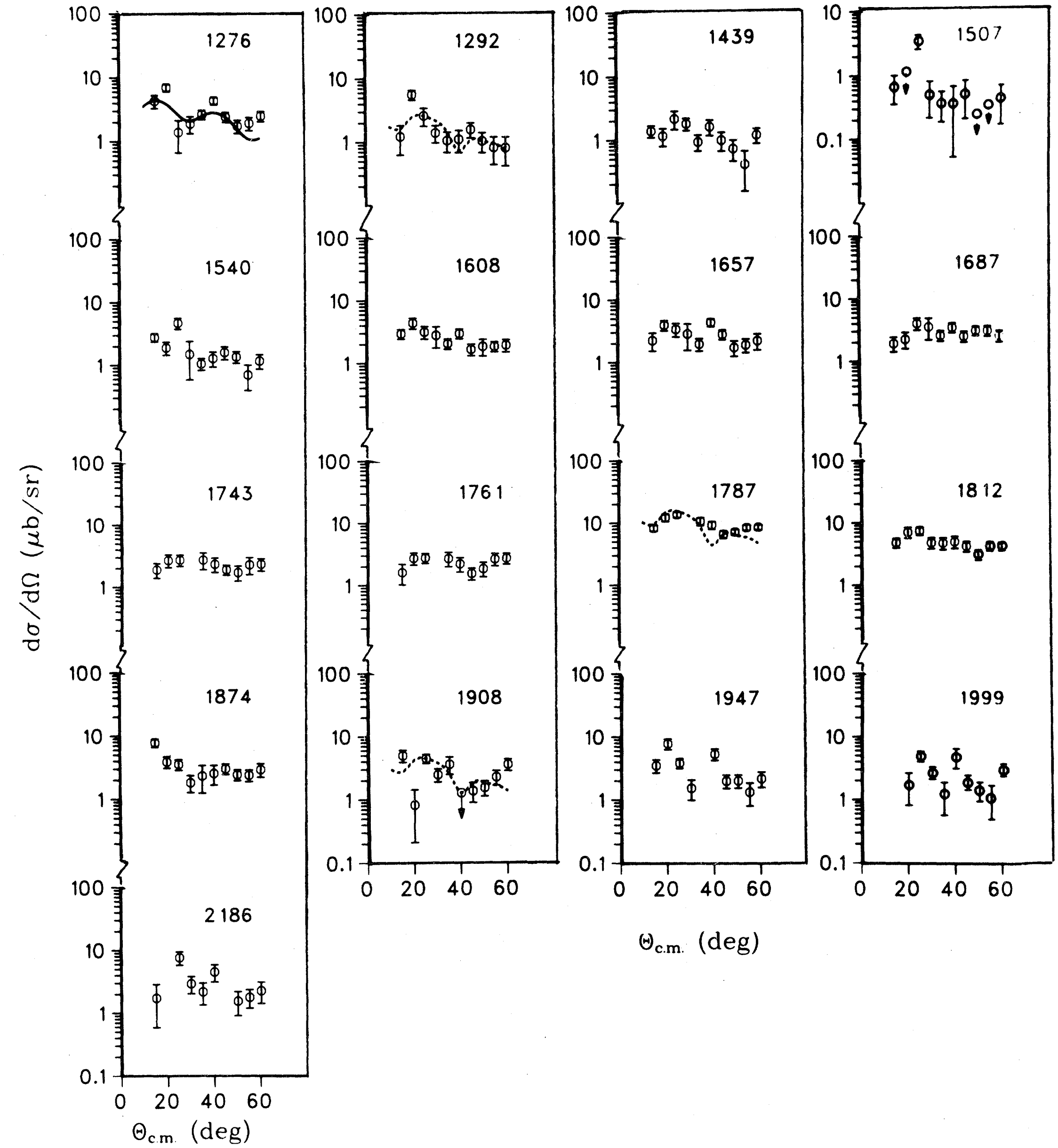

FIG. 2. (*Continued.*)

the centroid of the $L=0$ strength deviates by ~ 110 keV from the systematics. Therefore, the observed fragmentation is probably not a simple fragmentation of the ground-state pairing correlations in the even core.

In ^{197}Pt we are observing a fragmentation of $L=0$ strength and three low-lying $\frac{1}{2}^-$ states. Given the rather weak population and high excitation energies of excited 0^+ states in the $^{\text{even}}$Pt cores, ^{197}Pt does not exhibit the simple structure of cou-

TABLE II. Optical model parameters used in distorted wave calculations.

Particle	V (MeV)	r_r (fm)	a_r (fm)	W (MeV)	W_D (MeV)	r_w (fm)	a (fm)	V_{so} (MeV)	r_{so} (fm)	a_{so} (fm)	Ref.
t	166.7	1.16	0.752	12.0	0	1.498	0.817				14
p	50.9	1.25	0.650	0	13.5	1.25	0.47	7.5	1.25	0.47	15

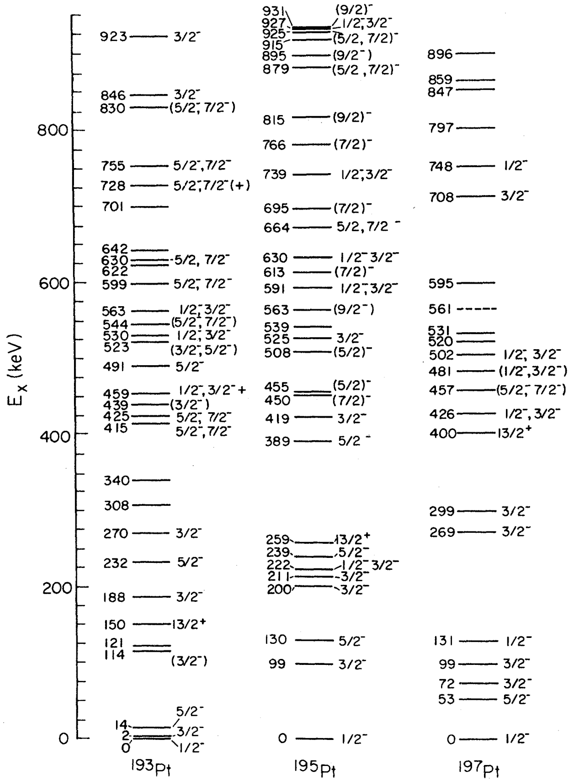

FIG. 3. Systematics of negative-parity states in ^{193,195,197}Pt below 1 MeV. The data are taken from Refs. 6, 16, 17, 19–21, and the present study.

pling an odd particle to the even O(6) or γ-unstable core. In such a coupling the ground state would receive essentially all of the $L=0$ strength and excited $\frac{1}{2}^-$ states could only arise by coupling to excited 0^+ states which lie at ~ 1 MeV in excitation.

An alternate possibility for understanding the origin of the level structure of ^{197}Pt comes from geometrical models. Boson expansion calculations[8] predict that ^{192}Pt is a good γ-unstable rotor, with equal prolate and oblate minima in the potential energy surface. However, as one goes to the heavier Pt isotopes, the prolate minimum gets smaller more rapidly than the oblate minimum, yielding an essentially pure oblate shape for ^{198}Pt. Possibly the two-neutron transfer reaction is quite sensitive to this γ-unstable→oblate shape transition. However, as seen in a Nilsson scheme for this region in Fig. 4, one can only construct two low-lying $\frac{1}{2}^-$ states, an insufficient number to explain the data. Recently, 11 $\frac{1}{2}^-$, $\frac{3}{2}^-$ states have been identified below 1 MeV in excitation in ^{195}Pt via neutron average resonance capture (ARC).[20] The shell model negative-parity orbitals near the Fermi surface are $p_{1/2}$, $p_{3/2}$, and $f_{5/2}$ and only eight $\frac{1}{2}^-$ or $\frac{3}{2}^-$ states can be formed from these configurations, taking into account the five $K=\frac{1}{2}$ or $\frac{3}{2}$ bandheads and the three $J^\pi K=\frac{3}{2}^-\frac{1}{2}$ states. This leaves ^{193}Pt as the nucleus in which relatively few $\frac{1}{2}^-$ and $\frac{3}{2}^-$ states have been identified; ARC measurements will be crucial here in mapping out the systematics of the low-spin excitations.

TABLE III. Relative ground state cross sections for two-neutron transfer studies on Pt nuclei.

	Target				
	^{192}Pt	^{194}Pt	^{195}Pt	^{196}Pt	^{198}Pt
(p,t)[a]	111	100	50	97	98.5
(t,p)[b]	92	100	36[c] (49)	97	88

[a] Taken from Ref. 6.

[b] Obtained from natural target Pt(t,p) measurements.

[c] For the ^{195}Pt target the summed (t,p) $L=0$ strength below 1 MeV is given in parentheses.

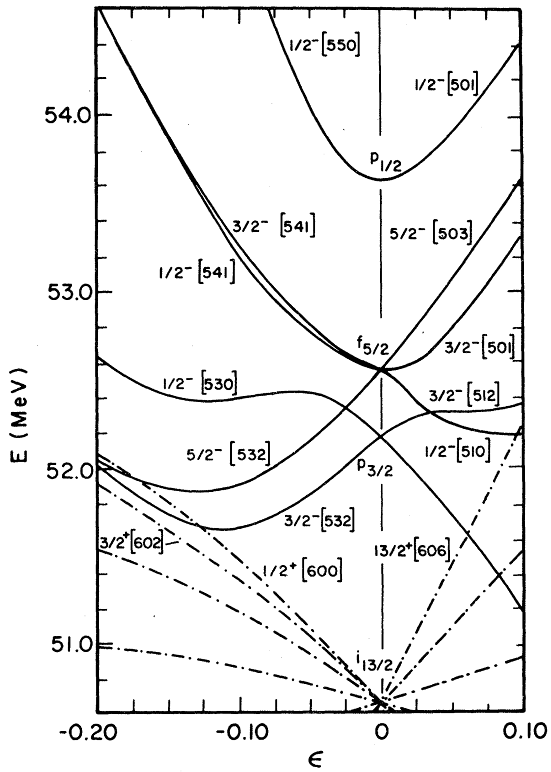

FIG. 4. Nilsson level scheme for ^{197}Pt for small deformations. The Fermi surface would be near the $\frac{1}{2}^-$ [530] orbital for $\epsilon = \sim -0.10$. The calculations were done with the code DIET of Ref. 23.

A recent survey of the fragmentation of single-particle strengths in the Hf-W-Os nuclei[24] was able to understand the systematics of this strength as due to the changing hexadecapole and quadrupole deformations in these nuclei. In the earlier study the gross trends of the single-particle strengths followed the changes in hexadecapole deformation, which fragmented and pushed up in energy the $L=1$ single-particle strength due to $\Delta N=2$ mixing and the changes in quadrupole deformations which tracked the $L\neq 1$ strength. Effects of asymmetric shapes were not found to be important. However, many of the specific details of the number of states and how the strength was distributed probably could not be reproduced without doing a rather complicated particle-vibration coupling calculation. Since the hexadecapole degree of freedom is not as important in the Pt nuclei as it is in the W region, where β_4 values[25] as large as -0.08 have been measured, this degree of freedom is probably not the clue to the fragmentation of $L=0$ strength in ^{197}Pt. However, a change in the asymmetric degree of freedom, either as a change from rigid to soft asymmetric shapes or as a change from γ unstable to oblate shapes, may be a clue to understanding the complicated patterns of two-neutron transfer strengths in odd-Pt and other $A=190$ nuclei.[26]

IV. CONCLUSIONS

We have investigated the ^{195}Pt$(t,p)^{197}$Pt reaction and have observed three sizable $L=0$ transitions to states below 1 MeV in excitation. This is in contrast to the ^{195}Pt$(p,t)^{193}$Pt reaction and other $^{\text{even}}$Pt(t,p) and (p,t) reactions where essentially all of the $L=0$ strength goes to the ground state. The explanation of this phenomenon is probably not due to changing hexadecapole deformations, but may be due to a change in the nonaxial components of the nuclear shapes in this region. We are in the process of investigating further the systematics of $L=0$ strengths in (t,p) reactions on ^{191,193}Ir and ^{197}Au targets and the (p,t) reaction on ^{197}Au. These results will be combined with earlier (p,t) measurements in this region in order to map out the systematics of this fragmentation and, hopefully, to find an explanation of these trends.

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