States in ^{193}Pt using the (p,t) reaction

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Levels in ^{193}Pt were populated by the (p,t) reaction using 25 MeV protons and an isotopically enriched ^{195}Pt target. A number of low-lying negative parity states are observed. By far the most strongly populated is the $1/2^-$ ground state. Some of these states are qualitatively interpreted assuming Coriolis coupling and rotation-vibration coupling between the $1/2^-|530|$, $3/2^-|532|$, and $5/2^-|532|$ Nilsson states and an oblate core. $L=0$ angular distributions for states in ^{193}Pt appear to be associated with the excited $J^\pi=0^+$ states in the even-even Pt cores.

[NUCLEAR REACTION ^{195}Pt$(p,t)^{193}$Pt, $E(p)=25$ MeV, excitation energies, $\sigma(E_t,\theta)$ $\theta=5°-55°$, ^{193}Pt l, J, π, deduced; enriched target; magnetic spectrograph; analyses, strong coupling model, oblate shape.]

I. INTRODUCTION

The platinum nuclei reside in the interesting transitional region between the strongly prolate rare earth nuclei and the spherical nulcei in the vicinity of the doubly closed shell at ^{208}Pb. As predicted originally by Kumar and Baranger,[1] a shape transition from prolate to oblate seems to occur as one goes from the neutron deficient lighter Pt isotopes to the stable heavier Pt isotopes. The general experience in transitional nuclei in which shape transitions are occurring is that the nuclear potentials are quite soft. In odd-A nuclei the nature of the nucleon can exert a considerable polarizing influence on the soft core. This can lead to quite different coexisting nuclear shapes.

Indeed, in ^{193}Pt, the $\frac{1}{2}^-$ ground state and other low spin low-lying negative parity states are believed to involve Coriolis coupled Nilsson bands arising from an oblate potential. On the other hand, the $\frac{13}{2}^+$ state and the decoupled band built on it has been convincingly characterized[2] as an $i_{13/2}$ neutron hole coupled to a triaxially deformed core.

The goal of the present (p,t) experiment is to relate states in the residual ^{193}Pt nucleus to the ground state configuration in the ^{195}Pt target. For superfluid nuclei, most of the two-neutron transfer strength populates states in the produce nucleus closely related to the ground state of the target. When the target and residual nuclei have approximately the same shape and there is very little Coriolis coupling, most of the two nucleon strength should appear in the ground state or the ground state band. Thus the (p,t) reaction is a sensitive method of searching for deviations from the strong-coupling model and is therefore of particular value in studying nuclei like ^{193}Pt.

Previous research on ^{193}Pt includes high spin studies[2] utilizing the $(\alpha,3n\gamma)$ reaction, neutron pickup studies involving the (p,d) reaction[3,4] and decay scheme studies.[5] These earlier studies complement the present (p,t) studies effectively.

In Sec. II we describe the experimental procedure, while the experimental results are presented in Sec. III. Section IV contains a discussion and interpretation of results, while Sec. V is a brief summary and conclusion.

II. EXPERIMENTAL PROCEDURE

Targets of ^{195}Pt, 65 μg/cm^2 thick, were prepared by slow (~24 h per target) evaporation of separated platinum metal onto 79 μg/cm^2 carbon foil using focused electron bombardment. Target thicknesses were measured with a Sloan thickness gauge and are believed accurate to ±25%. The ^{195}Pt isotope, which was obtained from the Stable Isotopes Division of the Oak Ridge National Laboratory, was enriched to 97.28%.

A 25 MeV proton beam from the Orsay MP tandem accelerator was used to study simultaneously the (p,d) and (p,t) reactions. Emitted particles were analyzed by a split pole magnetic spectrometer and detected in the focal plane with solid state position sensitive detectors. The experimental setup was the same as the one used for the previous study of the (p,d) reactions on even Pt targets.[4] Only the results of the analysis of the (p,t) reaction will be presented here. Absolute cross sections were deduced using the target thickness indicated above.

III. RESULTS

Figure 1 presents a triton spectrum taken at $\theta_{lab}=5°$ with respect to the beam, for ^{193}Pt. In

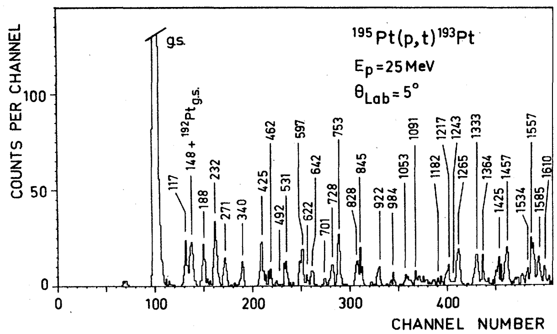

FIG. 1. The triton spectrum from the reaction ^{195}Pt$(p,t)^{193}$Pt. The levels are labeled with the excitation energy in keV.

Table I the excitation energies intensities and L values of levels in ^{193}Pt obtained in the (p,t) reaction are compared with data for ^{193}Pt obtained from gamma ray spectroscopy[2,5] following decay or (α,xn) reactions and neutron pickup reaction spectroscopy.[3,4] The intensities for the (p,t) reaction presented in Table I $(\sum\sigma)$ are obtained by summing the differential cross sections.

In the present experiment the angular distributions of the g.s. → g.s., $L=0$ transitions were taken simultaneously at 25 MeV for the various isotopes using a natural Pt target. The relative strengths, in agreement within error limits with those previously determined in the same way at 26 MeV (Ref. 6), are given in Table II. From this direct comparison the ^{195}Pt (p,t) ^{193}Pt strength is shown to be about 50% of that observed for the even isotopes. This unambiguously determined value is in disagreement with the 20% value which would be obtained by comparing the absolute cross sections from the present work (odd Pt) and from Ref. 6 (even Pt). The discrepancy may be partly due to the energy difference between the two studies (25 and 26 MeV) but could be partly due also to an error in the estimation of one of the target thicknesses. It should therefore be stressed that there are potential uncertainties of the order of a factor of 2 in the absolute normalization of the cross sections, either in the present study or in the preceding work[6] at 26 MeV on the even Pt isotopes.

Angular distributions for some of the levels observed in the ^{195}Pt(p,t) ^{193}Pt reaction are presented in Figs. 2 and 3. The characteristic, forward peaked, oscillatory, angular distributions of Fig. 2, with a minimum at 15°, correspond to an $L=0$ transfer and the final levels have therefore $J^\pi=\frac{1}{2}^-$. The ^{196,194}Pt$(p,t)^{194,192}$Pt $(0^+_{1,2,3})$ $L=0$ angular distributions measured[6] at 26 MeV are also presented for comparison.

Levels populated in the ^{194}Pt$(p,d)^{193}$Pt reaction by an $l=1$ transfer have either $J^\pi=\frac{1}{2}^-$ or $J^\pi=\frac{3}{2}^-$. In the (p,t) reaction with a $J^\pi=\frac{1}{2}^-$ target, a level with $J^\pi=\frac{1}{2}^-$ is necessarily populated by a pure $L=0$ transition, a level with $J^\pi=\frac{3}{2}^-$ by a pure $L=2$ transition. In the upper part of Fig. 3, $L=2$ angular distributions observed in the ^{195}Pt$(p,t)^{193}$Pt reaction for known $J^\pi=\frac{3}{2}^-$ or $\frac{5}{2}^-$ final levels are shown. For comparison the ^{196,194}Pt$(p,t)^{194,192}$Pt $(2^+_{1,2})$ angular distributions measured[6] at 26 MeV are shown just below. The (p,t) angular distributions for the ^{193}Pt levels at 841, 922, and 1182 keV, populated in the (p,d) reaction by $l=1$ transfer are shown in the lower part of Fig. 3. The clear fact that these distributions are not $L=0$ (see Fig. 2 for comparison) and have a reasonable similarity with the known $L=2$ distributions of Fig. 3, permit a unique assignment $J^\pi=\frac{3}{2}^-$ for the three levels.

Very close to the $J^\pi=\frac{1}{2}^-$, ground state, two states with $J^\pi=\frac{3}{2}^-$ and $\frac{5}{2}^-$, respectively, were observed[5] at 1.64 and 14.27 keV in ^{193}Pt. The 14 keV resolution (full width at half maximum) of the present experiment does not permit the resolution of the 1.64 keV state from the ground state. Even the 14.27 keV state can be resolved from the two other states only when the cross sections are of the same order of magnitude, which happens at the angle $\theta_{lab}=15°$, corresponding to the deep minimum of the ground state $L=0$ angular distribution. At this angle the ratio $|\sigma(\text{g.s.})+\sigma(1.64)|/\sigma(14.27)$ is equal to 3. If the angular distribution for the 14.27 keV state is assumed to be identical to those observed for the other $J^\pi=\frac{5}{2}^-$ states, the summed cross section is estimated to be about 6% of that for the ground state.

Although the 1.64 keV state cannot be resolved from the ground state an evaluation of its summed cross section may be attempted from a comparison of the shapes of all the angular distributions corresponding to ground state transitions, measured simultaneously with a natural Pt target. These angular distributions are very similar for all the even Pt ground states. Only in the case of ^{195}Pt$_{g.s.}$ → ^{193}Pt$_{(g.s.)}$ transition, where the ground state is not resolved from the first excited state, the relative cross section at $\theta_{lab}=15°$ is appreciably larger (by a factor of 4 if the 14.27 keV state cross section is not subtracted, by a factor of 3 if it is) than in the case of the even isotopes. The summed cross section corresponding to the 1.64 keV is estimated from this evidence to be about two times larger than that of the 14.27 keV state, assuming similar angular distributions for the two levels.

IV. DISCUSSION

The (p,t) reaction selects those states in the

TABLE I. Comparison of ^{193}Pt levels observed in the ^{195}Pt$(p,t)^{193}$Pt reaction with those observed in gamma spectroscopy and the neutron pickup reaction.

Gamma spectroscopy [a,b]		^{194}Pt$(p,d)^{193}$Pt Energies (keV)			^{195}Pt$(p,t)^{193}$Pt (This research)			
E (keV)	J^π	Ref. c	Ref. d	l	E (keV) [f]	$\sum\sigma$	L	J^π
0	$\frac{1}{2}^-$	0	0	1	0	100	0	$\frac{1}{2}^-$
1.64	$\frac{3}{2}^-$					[(12)]		
14.27	$\frac{5}{2}^-$	14	20	3	(14)	[(6)]		
114.15	$(\frac{3}{2}^-)$	114	111	1	117	1.9		
121.3		121						
149.78	$\frac{13}{2}^+$	148	192	6	(^{192}Pt$_{g.s.}$)	weak		
187.81	$(\frac{3}{2}^-)$	189			188	2.7	2	$\frac{3}{2}^-$
199.0	$\frac{11}{2}^+$							
232.15	$(\frac{3}{2},\frac{5}{2}^-)$	233		(3)	232	4.9	2	$\frac{5}{2}^-$
269.84	$(\frac{3}{2},\frac{5}{2}^-)$	271	265	1	271	1.9	2	$\frac{3}{2}^-$
		308	303	(4,5)	(307)	(0.15)		
		340	330	(4,5)	340	2		
			415	3				
		423	425	3	425	4.6		
439.06	$(\frac{3}{2}^-)$							
		459 [e]	450	1 + (3)	462	2		
491.0	$\frac{17}{2}^+$							
491.25	$(\frac{3}{2},\frac{5}{2}^-)$	491	486	3	492	0.7	2	$(\frac{5}{2}^-)$
519.6	$\frac{15}{2}^+$							
522.54	$(\frac{3}{2},\frac{5}{2}^-)$							
		530	524	1	531	1.8		
		544	545	(3)				
		563		1				
		599	587	3	597	4.2		
603.3	$\frac{15}{2}^+$							
					622	0.9		
		630	616	3				
					642	1.2		
		675	665	6				
		701	692	(3), (6)	701	0.5		
		728	718 [e]	3(+0)	728	1.5		
		755	743	3	753	3.3		
		830		(3)	828	2.1		
		846	832	1	841	4.3	2	$\frac{3}{2}^-$
907.4	$(\frac{17}{2}^+)$							
		923	910	1	922	3	2	$\frac{3}{2}^-$
		969	960	X				

TABLE I. (*Continued*.)

Gamma spectroscopy[a,b]		^{194}Pt$(p,d)^{193}$Pt Energies (keV)			^{195}Pt$(p,t)^{193}$Pt (This research)			
E (keV)	J^π	Ref. c	Ref. d	l	E (keV)[f]	$\sum\sigma$	L	J^π
980.5	$\frac{19}{2}^+$							
					984	1.1		
1003.4	$\frac{21}{2}^+$	1014		(4,5)				
		1042	1025	6				
					1053	2.5		
		1069		(3)				
		1099	1086	(3)X	1091	1		
1103.5								
		1130		(3)				
1159.9	$\frac{19}{2}^+$							
		1168		(1)				
		1188	1169	1	1182	1	2	$\frac{3}{2}^-$
		(1225)			1217	1.9		
		1245	1222[e]	3,3+1	1243	0.8		
					1265	2.9		
1320.8	$\frac{21}{2}^{(-)}$							
					1333	2.8		
					1364	1.9		
					1425	2		
1454.7	$\frac{25}{2}^{(-)}$							
					1457	3	0	$\frac{1}{2}^-$
1510.3								
					1534	1.4	0	$\frac{1}{2}^-$
					1557	3.5	0	$\frac{1}{2}^-$
					1585	1.6		
					1610	0.9		
1631.8	$\frac{25}{2}^+$							

[a]Reference 2.
[b]Reference 5.
[c]Reference 4.
[d]Reference 3.
[e]Unresolved doublet.
[f]The uncertainties in excitation energies are ±4 keV up to 1 MeV and ±8 keV above 1 MeV.

TABLE II. Relative g.s. → g.s. transition strengths in the (p,t) reaction for all the Pt isotopes at 25 MeV, see Ref. 6.

190 ← 192	192 ← 194	193 ← 195	194 ← 196	196 ← 198
111	100	50	96.8	98.5

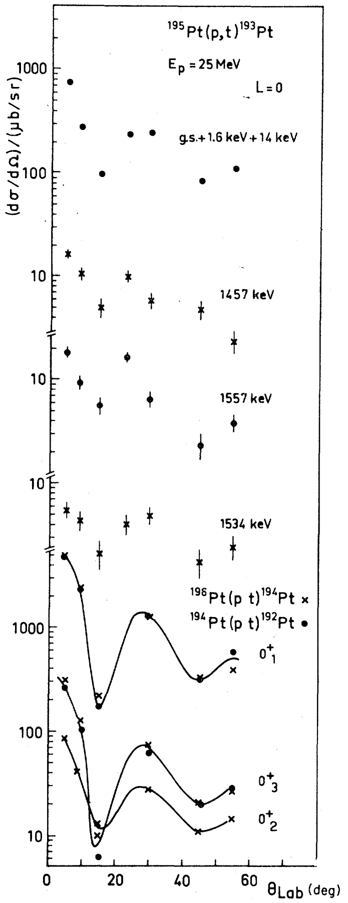

FIG. 2. Angular distributions of the states with $L=0$ from the reaction ^{195}Pt$(p,t)^{193}$Pt. The corresponding angular distributions for the reactions ^{196,194}Pt$(0^+_{g.s.})(p,t)^{194,192}Pt(0^+_{1,2,3})$ at 26 MeV are presented for comparison.

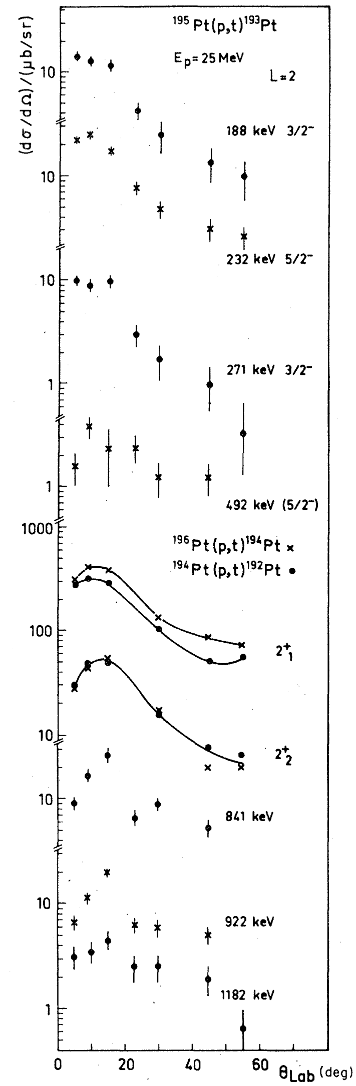

FIG. 3. In the upper part: Angular distributions of the states with known spins of $3/2^-$ or $5/2^-$. The corresponding angular distributions for the reactions ^{196,194}Pt$(0^+_{g.s.})$ $(p,t)^{194,192}$Pt$(2^+_{1,2})$ at 26 MeV are presented for comparison. In the lower part: Angular distributions of states with $l=1$ in the ^{194}Pt$(p,d)^{193}$Pt reaction. Cross sections as a function of angle for seven angles of a number of states whose angular distributions were not presented in this paper though seen in reaction ^{195}Pt$(p,t)^{193}$Pt and are available through the Physics Auxiliary Publication Service (Ref. 12).

residual nucleus which are closely related to the ground state of the target nucleus for preferential population. It is therefore of considerable value to discuss the nature of the $\frac{1}{2}^-$ target ground state in ^{195}Pt.

A. Nature of the $\frac{1}{2}^-$ ^{195}Pt ground state

Both the studies of the reorientation effect in Coulomb excitation[7-9] on the neighboring even-even Pt isotopes and the observation[2] of decoupled bands built on the $i_{13/2}$ hole orbital in the lighter odd-A Pt isotopes strongly suggest that ^{195}Pt must be oblate, Indeed, the study of ^{195}Pt with (d,p) and (d,t) reactions[10] has led to a qualitative interpretation of the ground state as the $\frac{1}{2}^-$ band head of the $\frac{1}{2}^-|530|$ Nilsson band with an oblate deformation $\beta \simeq -0.13$. A more qualitative interpretation[10] of the observed spectroscopic factors requires that the nuclear potential be extremely soft in the gamma (γ) degree of freedom—actually approaching γ instability. Both the extremely low second 2^+ state in even-even Os, Pt, and Hg isotopes and the calculations of potential energy surfaces[1] in this transition region, which show only shallow minima in the β-γ plane, are consistent with this interpretation.

Thus although the $\frac{1}{2}^-|530|$ band head served as a convenient label for the ^{195}Pt ground state and undoubtedly represents a wave function component >50%, it must be recognized that, in view of strong Coriolis and important rotation-vibration coupling, this state has indeed a complex configuration.

B. The $\frac{1}{2}^-$ $|530|$ band in ^{193}Pt

It has been pointed out in Sec. III that the strength for the $^{195}Pt_{g.s.} \rightarrow {}^{193}Pt_{g.s.}$ transition, obtained directly with a natural Pt target, is about 50% of that observed for the even isotopes (Table II). This effect is well known for superfluid nuclei and has been explained[11] by the "blocking" of the "hot" $J=\frac{1}{2}$ orbital by a neutron in the odd target.

In spite of the complexity of the $\frac{1}{2}^-$ ground state of ^{195}Pt detailed in the previous section it is obvious that the ground state of ^{193}Pt is very similar. Not only does the (p,t) reaction populate it with an $L=0$ transition, but it is populated extremely strongly. No more than 12% of the g.s. strength goes to any other state. Thus the $\frac{1}{2}^-$ ground state of ^{193}Pt can be qualitatively identified as the band head of the $\frac{1}{2}^-|530|$ Nilsson state arising from an oblate potential with, however, considerable rotation-particle and vibration-rotation coupling. Reasonable but very tentative higher rotational members of the $\frac{1}{2}^-|530|$ band are the possible $\frac{3}{2}^-$ state at 188 keV and the $\frac{3}{2}^-$ or $\frac{5}{2}^-$ state at 232 keV assumed here to be $\frac{5}{2}^-$.

C. The $\frac{3}{2}^-$ $|532|$ and $\frac{5}{2}^-$ $|532|$ bands

The two states with $J^\pi=\frac{3}{2}^-$ and $\frac{5}{2}^-$ at 1.64 and 14.27 keV appear as discussed before to be the most strongly populated states except for the ground state. The most reasonable interpretation of these states is as the lowest members of the $\frac{3}{2}^-|532|$ and $\frac{5}{2}^-|532|$ bands. Their energy of excitation is too low for interpretation as band members of the $\frac{1}{2}^-|530|$ band. However, through first and second order Coriolis coupling, these states should mix with the ground state band. Furthermore, their Nilsson configurations relative to the ground state, $|Nn_3\Lambda\pm 2|$, stamps them as the states which will mix readily with the $K\pm 2$ gamma vibrations. These admixtures explain the relatively intense population of the observed states in the (p,t) reaction. In view of the uncertainty, no attempt has been made to assign higher band members.

D. The $\nu i_{13/2}$ decoupled band

Unfortunately, a small amount of ^{194}Pt contamination in our target gives rise to a triton group from the ^{194}Pt$(p,t)^{192}$Pt(g.s.) which obscures the 150 keV energy region of excitation in ^{195}Pt where the $i_{13/2}$ decoupled band head is observed.[5] Even though the observed peak is very weak (Table I), we are unable either to confirm or deny the population of the $\nu i_{13/2}$ band head. We can, however, set a firm limit, 1.5% of the g.s. strength, as the maximum population of this state.

E. Other $L = 0$ states

In addition to the $L=0$ angular distributions populating the ground state of ^{193}Pt, a number of other $L=0$ angular distributions populate states at 1457, 1534, and 1557 keV. Interestingly these are the only $L=0$ angular distributions and lie in a narrow energy band quite close to known[6] $J^\pi=0^+$ states in ^{192}Pt and ^{194}Pt at 1617 and 1546 keV respectively. It should be noted that these are the second excited 0^+ states in ^{192,194}Pt, which are appreciably more populated than the first excited 0^+ states in the (p,t) reaction on these even-even nuclei.[6] It seems, therefore, that these states in ^{193}Pt correspond mainly to the $\frac{1}{2}^-|530|$ particle (hole) state coupled to the second excited 0^+ core in ^{192}Pt(^{194}Pt). The observed fragmentation into two or three states in ^{193}Pt is expected in going from an even-even nucleus to an odd-A nucleus.

F. $L = 2$ states in ^{193}Pt

In the simplest weak coupling description of the data we would expect to see $\frac{3}{2}^-$ and $\frac{5}{2}^-$ states built on the $\frac{1}{2}^-$ g.s. at 322 keV with $L=2$ angular distributions and with ~13% of the g.s. strength divided between them. We might have expected this because the 2^+ states in ^{192}Pt and ^{194}Pt lie at 316 and 328 keV with 11% and 14.5% of the g.s. strength respectively. However, in view of the high density of states near the ground state, here interpreted as $\frac{1}{2}|530|$, $\frac{3}{2}^-|532|$, and $\frac{5}{2}^-|532|$ configurations, each of which can give rise to $\frac{3}{2}^-$ and $\frac{5}{2}^-$ states when coupled to a one-phonon vibration, we might expect to see three sets of $\frac{3}{2}^-$ and $\frac{5}{2}^-$ states with ~13% of the g.s. strength divided between them.

Four states, two with $J^\pi=\frac{3}{2}^-$ and two with $J^\pi=\frac{5}{2}^-$ and $L=2$ angular distributions, are observed at 188, 232, 271, and 492 keV, respectively (see Fig. 3). The combined strength of these states is 10.2% of the ground state. Thus, although none of the energies is close to 320 keV, their average is reasonably close. Furthermore, the summed cross section for all four states is quite reasonable. Thus if one is willing to assume severe fragmentation of the type described here, the weak coupling model seems to be crudely appropriate in explaining the band of $\frac{3}{2}^-$ and $\frac{5}{2}^-$ states of ^{193}Pt. Indeed there are other states at 425 and 462 keV which may even be the missing $\frac{5}{2}^-$ and $\frac{3}{2}^-$ states. The angular distributions of the (p,d) reaction (Table I) are suggestive of this, although the (p,t) angular distributions measured here are not consistent with any simple angular distribution for these states.

States in ^{193}Pt populated in the (p,t) reaction with $L=2$ angular distributions are also observed at 841, 922, and 1182 keV (see Sec. III). These states lie higher in energy than the weakly populated[6] second 2^+ (611 keV, 1.7% and 622 keV, 1.6%, respectively) of the possible even-even cores. There is no evidence for any simple relationship between these higher lying $L=2$ states and the 2^+ states of the even-even Pt cores.

V. CONCLUSION

The (p,t) reaction has permitted the population of levels in ^{193}Pt, many of which were previously unknown. In particular, the reaction populates a number of low-lying negative parity states in ^{193}Pt which are related to the ^{195}Pt ground state. Some of these low-lying states have been associated with the $\frac{1}{2}^-|530|$, $\frac{3}{2}^-|532|$, and $\frac{5}{2}^-|532|$ Nilsson bands assuming an oblate deformation. In view of the fact that ^{193}Pt lies in the transition region and because of the related nature of the three Nilsson bands, considerable particle-rotation and rotation-vibration coupling must be operative. Thus the Nilsson assignments should be thought of as labels rather than assignments to relatively pure states.

The states with $L=0$ angular distributions observed in a narrow excitation energy band in ^{193}Pt seem quite clearly related to the excited 0^+ states of the even neighboring Pt nuclei. A band of $L=2$ states is crudely but appropriately described in terms of a one-phonon vibration built on the configurational triplet of states near the ground state. Higher lying $L=2$ states and other states evidence no simple model relationships (like weak coupling between the even cores and the odd particles). Instead, the strength is split among many levels and no special selectivity is apparent. This is clearly a consequence of the complicated nature of the $J^\pi=\frac{1}{2}^-$ target ground state and of the striking proximity of all the single particle levels in ^{193}Pt.

This study again demonstrates both the complexity and the richness of detail of the spectroscopy of the transitional nuclei.

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[12]See AIP document no. PAPS PRVCA-21-1232-2 for 2 pages of cross sections as a function of angle for seven angles of a number of states whole angular distributions were not presented in this paper though seen in the reaction ^{195}Pt$(p,t)^{193}$Pt. Order by PAPS number and journal reference from American Institute of Physics, Physics Auxiliary Publication Service, 335 East 45th Street, New York, N.Y. 10017. The price is $1.50 for microfiche or $5 for photocopies. Airmail additional. Make checks payable to the American Institute of Physics. This material also appears in Current Physics Microfilm, the monthly microfilm edition of the complete set of journals published by AIP, on the frames immediately following this journal article.