[50]The values of Δ can be calculated (Ref. 45) from the separation energies $E_S(n)$ of the last neutron by use of the relation

$$\Delta(n) = \tfrac{1}{4}[|E_S(n) - E_S(n-1)| + |E_S(n) - E_S(n+1)|],$$

where n is the number of neutrons in the nucleus for which Δ is calculated. With the values of Q_0 obtained in the present work (Table II), this formula yields $\Delta(81) = 0.98$ MeV for Ba^{137} and $\Delta(80) = 1.09$ MeV for Ba^{136}.

[51]The length of the heavy bar representing the observed $\sum_j S_l(J^\pi) \approx 0.08$ for the $h_{11/2}$ level in Ba^{137} is very questionable because we could not identify an $l=5$ angular distribution at the known position (Ref. 43) of this level. This uncertainty in the spectroscopic factor is indicated by question marks next to this level in Figs. 10, 13, and 14. The single-particle energies, $\epsilon(\frac{1}{2}^+) - \epsilon(\frac{11}{2}^-) \approx 0.47$ MeV, however, are not affected by this uncertainty in the spectroscopic factor because they are obtained from Eq. (4).

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Nuclear-Structure Studies with (d, t) Reactions on Pd^{110}, Pd^{108}, and Ru^{104}†

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Seventeen-MeV deuteron-induced (d,t) reactions on Pd^{110}, Pd^{108}, and Ru^{104} are used to complement (d,p) studies exciting the same final nuclei. Many new states are reported, and in several cases previous I-π assignments are changed. The sum of spectroscopic factors gives roughly the same degree of filling as was found from the (d,p) work for the s and d states; further anomalous behavior was found for the $g_{7/2}$ and $h_{11/2}$ states. There is a tendency for the spectroscopic strength to be shifted to higher excitation energy in (d,t) reactions than in (d,p) reactions. There are strong similarities between the Pd and Ru isotopes as regards the number of nuclear states of each I-π and the degree of filling of s and d states, but the $g_{7/2}$ state seems to be much less full in Ru than in Pd. In both Pd isotopes, there is a low-energy state (0.671 MeV in Pd^{109} and 0.781 MeV in Pd^{107}) excited by $l=1$ transitions in both (d,p) and (d,t) reactions, indicating that they probably include components with $2p$ holes *and* $3p$ particles.

INTRODUCTION

For many reasons, it is useful to complement spectroscopic studies with (d,p) reactions by analogous measurements with (d,t) reactions. This gives checks on l-transfer determinations, gives the j transfer when this is ambiguous, gives independent determinations of occupation numbers and single quasiparticle energies, etc.

A spectroscopic study of Pd^{107} and Pd^{109} by use of (d,p) reactions was reported from this laboratory[1] some time ago; the $Pd^{108,110}(d,t)$ reactions reported here were undertaken to complement that work. The $Ru^{104}(d,t)$ study was intended to complement experiments on the $Ru^{102}(d,p)$ reaction reported in preliminary form,[2] although the complete results of the latter are not yet available.

EXPERIMENTAL

Incident 17-MeV deuterons were obtained from the University of Pittsburgh three-stage Van de Graaff accelerator. The tritons were magnetically analyzed with an Enge split-pole spectrograph and detected with photographic emulsion plates in the focal plane of the spectrograph. Angular distributions were measured over an angular range from 10 to 35°. A detailed description of the scattering chamber and the spectrograph system is given in Ref. 1.

The impinging beam was collimated by a 1-mm-wide by 3-mm-high target slit. The antiscattering slit was 3 mm wide by 5 mm high. The Faraday-cup to slit current ratio averaged 30:1. The reaction products entered the spectrograph through an entrance aperture of 1.4 msr and were detected at the focal plane by 25-μ Kodak NTB plates.

The product of the incident beam times target thickness was measured by counting elastically scattered deuterons with NaI(Tl) scintillation detectors mounted at 38° on each side of the beam. This dual arrangement eliminates errors due to shifts in the angle of the incident beam. Elastic deuteron cross sections at these angles were determined with targets of sufficient thickness to make direct thickness measurements feasible, and they were checked by using these targets to measure elastic deuteron scattering at 11.8 MeV, where they are known from other work,[3] and at 7 MeV, where they can be assumed to be Rutherford

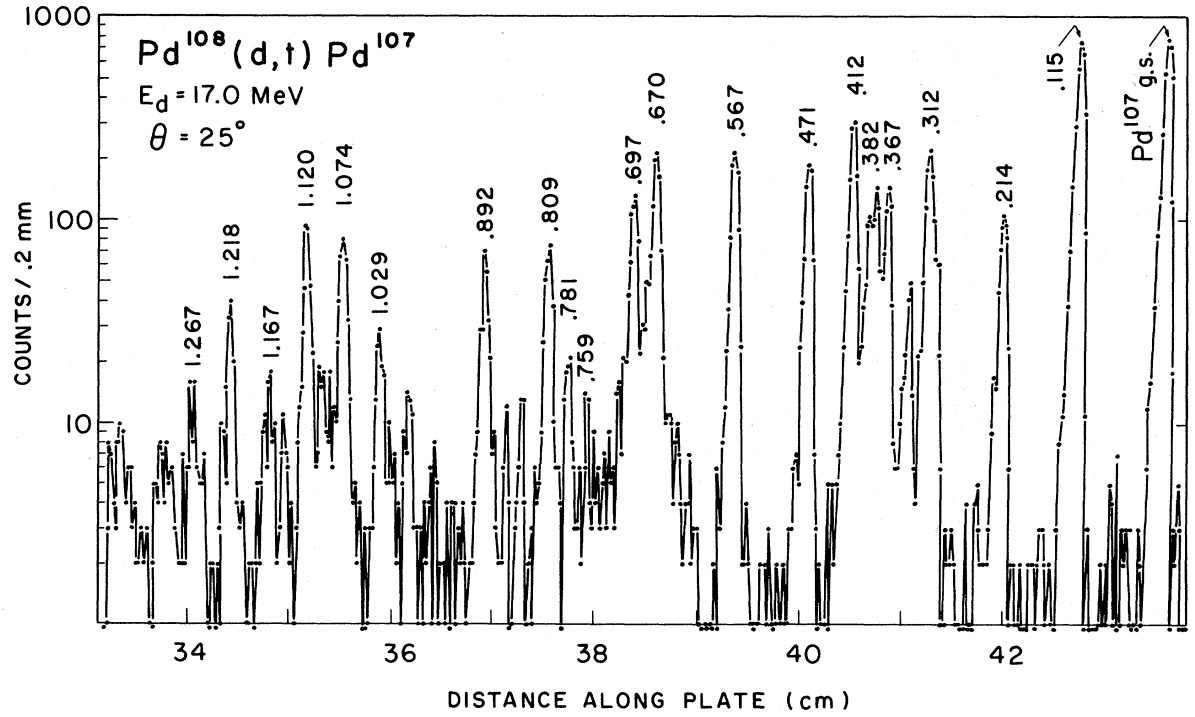

FIG. 1. Typical energy spectrum. This is the spectrum of tritons from $Pd^{108}(d,t)$ with tritons detected at 25°. Numbers above peaks are excitation energies of corresponding levels in the residual nucleus (Pd^{107}) in MeV. Unlabelled peaks are due to impurities.

cross sections. Absolute cross sections should be accurate to within 15%. Relative cross sections at different angles should be reliable to within 10%, where statistics are not a limitation and where there is no interference from particle groups arising from target impurities.

The targets of thickness between 50 and 100 $\mu g/cm^2$ were prepared by vapor deposition of the isotopes onto 30-$\mu g/cm^2$ carbon foils. In the (d,p) work,[1] the targets contained an uncomfortably large amount of tantalum impurity, picked up in the evaporation process. This problem was overcome in the present experiment, so there was much less difficulty with impurities. The Pd^{108}, Pd^{110}, and Ru^{104} targets are respectively 94, 88, and 99% isotopically pure.

A typical energy spectrum is shown in Fig. 1. The numbers attached to the peaks are the excitation energies in MeV. Peaks not so designated are due to impurities in the target. A (d,t) experiment was done on natural Pd and Ru targets at 15 and 30° to determine which triton groups are due to isotopes other than the one under study.

The over-all energy resolution was between 8 and 10 keV. In view of the discussion of this problem in Ref. 1, it would seem that there was an appreciable contribution from nonuniformities in target thicknesses.

RESULTS

Assignments of l values for transitions were made by comparing angular distributions with those obtained from distorted-wave Born-approximation (DWBA) calculations. In these calculations, the Perey "average" (or "compromise") optical-model parameters[4] were used, but other reasonable parameter sets gave very similar angular distributions. It was previously found[5] that the introduction of nonlocality and finite-range effects caused almost no differences in either angular distributions or absolute cross sections in these reactions, so those complications were ignored here.

Spectroscopic factors S were calculated from the relation[6]

$$d\sigma/d\Omega = 5\times\tfrac{2}{3}\times S_j^{(l)}\sigma_{DW}(j), \quad (1)$$

where the left side is the measured cross section for excitation of the state i by pickup of a neutron with orbital and total angular momentum l and j, and σ_{DW} is the cross section obtained from the DWBA calculation. Since all targets are even-even, the "spin" of the state excited, I, is equal to j and its parity is $(-1)^l$.

If the state i is assumed to include a fraction f_l

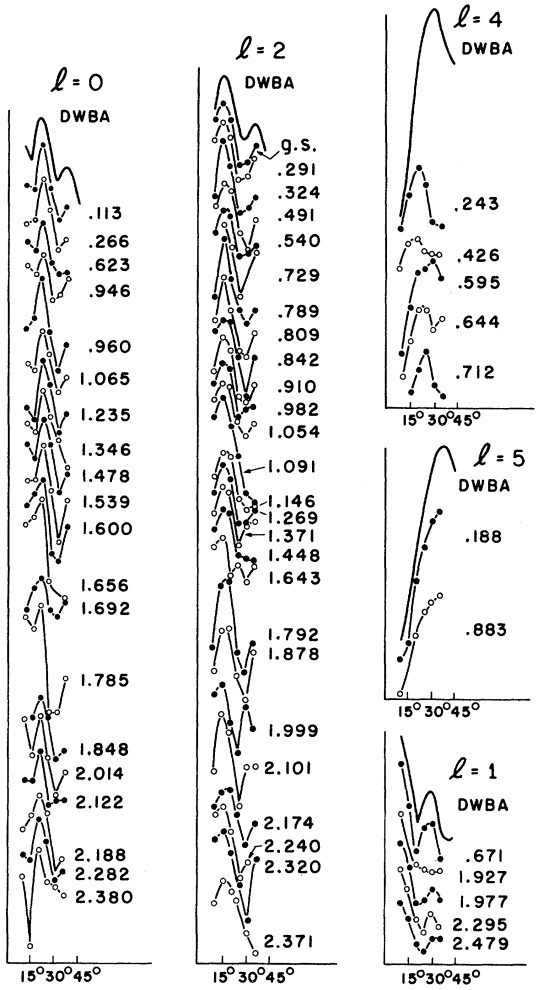

FIG. 2. Angular distributions of tritons from $Pd^{110}(d, t)Pd^{109}$. Groupings are in accordance with l-value assignments. Figures are excitation energies of corresponding levels of Pd^{109} in MeV. Further information on these levels is listed in the Tables.

of the single-quasiparticle (SQP) state, we have

$$\frac{S^{(l)}(d,t)}{S^{(l)}(d,p)}=\frac{f_l(2j+1)V_j^2}{f_l(1-V_j^2)}=\frac{(2j+1)V_j^2}{1-V_j^2}, \qquad (2)$$

where the V_j^2 are the occupation numbers. Since V_j^2 is always larger for $j=l+\frac{1}{2}$ than for $j=l-\frac{1}{2}$ SQP states, the ratio in (2) is larger, usually by a large factor, for the former than for the latter. This ratio was therefore used to determine j and thence I.

$l=4$ Transitions

The angular distributions of tritons from reactions on the three targets are shown in Figs. 2, 3, and 4, and the results are summarized in Tables I, II, and III. One important difficulty concerns transitions assigned as $l=4$ from the (d,p) experiments.[1] Most of the useful data are in Fig. 2, where we see that the angular distributions for the various transitions are not very similar to each other or to the DWBA prediction for $l=4$ or for any other l. "On an average" they peak at about 20°, whereas the DWBA prediction is 28°. There is one case in $Pd^{108}(d,t)$ and two in $Ru^{104}(d, t)$ where $l=4$ assignments were made from (d,p) reactions; in the former the peak is at 25°, and in the latter the peaks are at 28 and 35°. (The last case is the 0.235-MeV transition shown as $l=5$ in Fig. 4.)

In order to test whether this is a general failing of the DWBA, measurements were made for the well-known $l=4$ transition in (d,t) reactions on Sn^{118} and In^{115}; in both cases the peaks are at 28° and the angular distributions agree well with DWBA predictions. New measurements were then made for the $Pd^{110}(d,t)$ reaction, but they agreed with the original ones shown in Fig. 2.

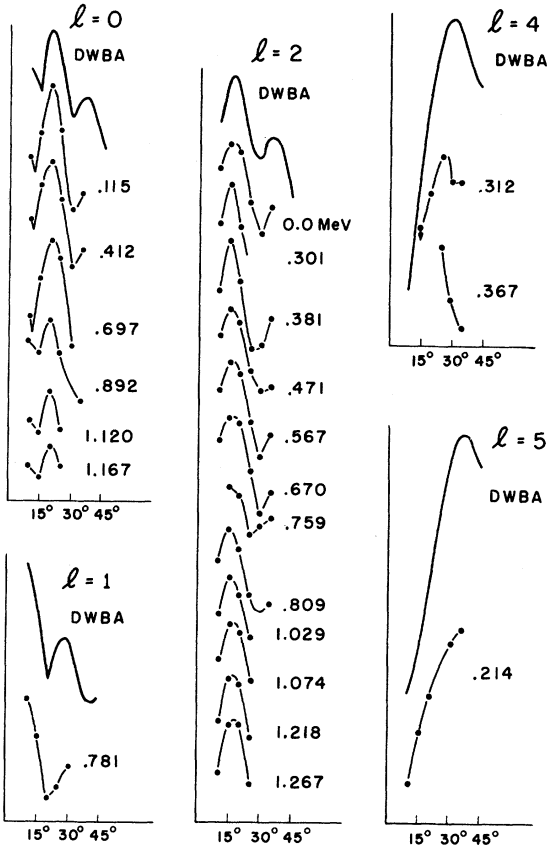

FIG. 3. Angular distributions of tritons from $Pd^{108}(d, t)Pd^{107}$. See caption for Fig. 2.

TABLE I. Results for $Pd^{110}(d,t)Pd^{109}$. The (d,p) data are from Ref. 1. Spectroscopic factors are calculated from (1) with σ_{DW} calculated with "average" optical-model parameters from Ref. 4.

$Pd^{110}(d,t)Pd^{109}$						$Pd^{108}(d,p)Pd^{109}$			
Excitation energy (MeV)	σ_{max} (μb/sr)	l	I^π	$S(d,t)$ JULIE	$\frac{S(d,t)}{S(d,p)}$	Excitation energy (MeV)	l	I^π	$S(d,p)$
0.0	3473	2	$5/2^+$	1.16	6.6	0.0	2	$5/2^+$	0.176
0.113	2481	0	$1/2^+$	0.43	1.4	0.112	0	$1/2^+$	0.30
0.188	367	5	$11/2^-$	2.6	9.1	0.188	5	$11/2^-$	0.28
0.243	366	4	$7/2^+$	2.3	5.3	0.245	4	$7/2^+$	0.44
0.266	868	0	$1/2^+$	0.156	2.8	0.262	0	$1/2^+$	0.055
0.291	1216	2	$3/2^+$	0.60	1.8	0.291	2	$3/2^+$	0.33
0.324	126	2	$3/2^+$	0.063	1.4	0.324	2	$3/2^+$	0.045
							0	$1/2^+$	0.009
0.339	48	...							
						0.370	(1)	$(3/2^-)$	0.0021
				(<0.002)	<0.7	0.382	0	$1/2^+$	0.0032
				(<0.003)	<0.5		2	$(3/2^+)$	0.0088
						0.404	0	$1/2^+$	0.0040
0.426	587	4	$7/2^+(9/2^+)$	4.0	20	0.427	4	$7/2^+(9/2^+)$	0.20
0.491	528	2	$3/2^+(5/2^+)$	0.28	2.7(4.6)	0.489	2	$3/2^+$	0.104
0.540	1100	2	$5/2^+$	0.47	17	0.539	2	$5/2^+$	0.027
0.596	68	4	$7/2^+(9/2^+)$	0.4	≥13				(≤0.03)
0.623	280	0	$1/2^+$	0.056	1.1	0.623	0	$1/2^+$	0.053
0.644	61	4	$7/2^+$	0.46	3.8	0.644	4	$7/2^+$	0.12
0.671	189	1	$(3/2^-)(1/2^-)$	0.049	5.9	0.671	1	$(3/2^-)(1/2^-)$	0.0096
0.712	30	(4)	$7/2^+$ $(9/2^+)$	0.2	≥5				(≤0.04)
						0.719	2	$(3/2^+)$	0.017
0.729	59	2	$5/2^+$	0.035	≥12				≤0.003
	Blocked by another isotope					0.742	0	$1/2^+$	0.0062
0.789	378	2	$(5/2^+)$	0.179	4.4	0.788	2	$3/2^+$	0.053
0.809	565	2	$5/2^+$	0.27	12	0.808	2	$(5/2^+)$	0.022
0.842	160	(2)	$(3/2^+)$	0.10	1.6	0.844	2	$3/2^+$	0.062
0.883	35	5	$11/2^-$	0.31					≲.04
0.910	390	2	$5/2^+$	0.195	13	0.908	2	$5/2^+$	0.015
						0.940	1	$3/2^-$	0.014
0.946	150	0	$1/2^+$	0.034					
						0.954	0	$1/2^+$	0.0104
0.960	218	(0)	$(1/2^+)$	0.050	>12				(<0.004)
0.982	235	2	$5/2^+$	0.122	15	0.981	...	...	(0.008)
						1.006	...	...	...
1.054	130	2	$(3/2^+)$	0.092	3.7	1.051	2	$(3/2^+)$	0.025
1.065	190	0	$1/2^+$	0.046	>11				(<0.004)
1.091	143	2	$5/2^+$	0.079	6.4	1.093	2	$3/2^+$	0.016
1.146	98	2	$3/2^+$	0.073	1.1	1.145	2	$3/2^+$	0.066
						1.176	3	$(7/2^-)$	0.0066
1.235	83	0	$1/2^+$	0.022	2.5	1.231	0	$1/2^+$	0.0088
						1.241	3	$(7/2^-)$	0.0065
1.269	188	2	$5/2^+$	0.114	17	1.263	2	$(3/2^+)$	0.0088
						1.308	...	...	...
						1.329	1(?)	$(3/2^-)$	0.031
1.346	120	0	$1/2^+$	0.033	1.57	1.344	0	$1/2^+$	0.021
1.371	98	2	$5/2^+$	0.076	15				(0.005)
1.448	85	2	$(3/2^+, 5/2^+)$	0.058		Blocked by impurity			
1.478	145	0	$1/2^+$	0.043	3.9	1.474	0	$1/2^+$	0.011
						1.424	2(1)	$3/2^+(3/2^-)$	0.016(0.0048)
						1.449	...		
1.539	162	0	$1/2^+$	0.049	>12				(<0.004)
						1.541	(3)(2)	$(7/2^-)(3/2^+)$	(0.0080)(0.011)
						1.561	...		

TABLE I (*Continued*)

$Pd^{110}(d,t)Pd^{109}$						$Pd^{108}(d,p)Pd^{109}$			
Excitation energy (MeV)	σ_{max} (μb/sr)	l	I^π	$S(d,t)$ JULIE	$\frac{S(d,t)}{S(d,p)}$	Excitation energy (MeV)	l	I^π	$S(d,p)$
						Blocked by impurity			
1.600	29	(0)	$(1/2^+)$	0.009		1.644	...		($\lesssim$0.008)
(1.643)	16	(2)	$(3/2^+, 5/2^+)$	0.012	$\lesssim$1.5	1.664	2(1)	$(3/2^+)(3/2^-)$	0.021(0.0072)
(1.656)	19	(0)	$1/2^+$	0.006	>2				(<0.003)
						1.682	0	$1/2^+$	0.034
1.692	50	0	$1/2^+$	0.017	>8				(<0.002)
						1.737	2(1)	$3/2^+(3/2^-)$	0.017(0.056)
						1.773	3	$(7/2^-)$	0.0046
(1.785)	16	(0)	$1/2^+$	0.006	>1.2				
1.792	18	(0)(2)	$(1/2^+)(3/2^+)$	(0.006)(0.019)	~1	1.789	(1)(2)	$(3/2^-)(3/2^+)$	0.0053(0.018)
						1.800	0	$1/2^+$	0.0088
						1.819	...	...	
						1.836	3	$(7/2^-)$	0.0072
						1.846	(1)(2)	$(3/2^-)(3/2^+)$	0.0076(0.028)
1.848	110	0	$1/2^+$	0.040	>5				(<0.008)
						1.863	(3)	$(7/2^-)$	0.0063
						1.877	1	$(3/2^-)$	0.0075
1.878	27	2	$3/2^+$	0.030	1.4				
						1.915	1	$(3/2^-)$	0.0088
1.927	118	1	$(1/2^-)$	0.056		1.923	1	$(3/2^-)$	0.022
						1.941	3	$(7/2^-)$	0.018
						1.954	...		
						1.972	3	$(7/2^-)$	0.030
1.977	138	1	$(1/2^-)$	0.063					
1.999	37	(1)(2)	$(1/2^-)(3/2^+)$	(0.018)(0.033)					
						2.021	1	$(3/2^-)$	0.014
2.014	133	0	$1/2^+$	0.052	>5				(<0.01)
						2.053	...	...	...
						2.091	2	$(3/2^+)$	0.030
2.101	31	(2)	$(3/2^+)$	0.029	>2.9				($\lesssim$0.010)
						2.117	1	$(3/2^-)$	0.018
2.122	108	0	$1/2^+$	0.046	>3				(<0.015)
						2.135	(1)	$(3/2^-)$	0.0044
						2.160	1	$(3/2^-)$	0.016
2.174	24	2	$(3/2^+)$	0.025		Blocked by impurity			
2.188	25	0	$1/2^+$	0.011	>1.3				(<0.008)
						2.209	3	$(7/2^-)$	0.018
						2.245	1	$(3/2^-)$	0.011
2.240	29	(2)	$3/2^+$	0.030	1.6				(0.019)
						2.259	1	$(3/2^-)$	0.0096
						2.280	2	$3/2^+$	0.021
2.282	37	0	$1/2^+$	0.018	>2				(<0.008)
2.295	104	1	$(1/2^-)$	0.063					
						2.301	(1)	$(3/2^-)$	0.0039
2.320	30	2	$3/2^+$	0.033	2.7				(0.012)
						2.346	(3)	$(7/2^-)$	0.014
						2.357	1	$(3/2^-)$	0.0096
						2.371	3	$(7/2^-)$	0.021
2.371	25	2	$3/2^+$	0.029	1.5				(0.019)
2.380	27	0	$1/2^+$	0.014	>7				(<0.002)
						2.391	3	$(7/2^-)$	0.011
						2.415	1	$(3/2^-)$	0.0074
						2.465	3	$(7/2^-)$	0.028
						2.473	1	$(3/2^-)$	0.018
2.479	55	1	$(1/2^-)$	0.038					
						2.493	(3)	$(7/2^-)$	0.022

TABLE II. Results for $Pd^{108}(d,t)Pd^{107}$. The (d,p) data are from Ref. 1. Spectroscopic factors are calculated from (1) with σ_{DW} calculated with "average" optical-model parameters from Ref. 4.

$Pd^{108}(d,t)Pd^{107}$						$Pd^{106}(d,p)Pd^{107}$			
Excitation energy (MeV)	σ_{max} (μb/sr)	l	I^π	$S(d,t)$	$\frac{S(d,t)}{S(d,p)}$	Excitation energy (MeV)	l	I^π	$S(d,p)$
0.0	3425	2	$5/2^+$	1.388	6.61	0.0	2	$5/2^+$	0.21
0.115	1900	0	$1/2^+$	0.370	0.95	0.115	0	$1/2^+$	0.39
0.214	205	5	$11/2^-$	1.67	5.8	0.214	5	$11/2^-$	0.29
0.301	340	2	$5/2^+$	0.157	16	0.302	2	$5/2^+$	0.010
0.312	360	(4)	$(7/2^+)(9/2^+)$	2.78(1.60)	11	0.311	4	$7/2^+(9/2^+)$	0.26
0.367	234	(4)	$(7/2^+)$	1.82	4.1	0.364	4	$7/2^+$	0.45
0.381	922	2	$3/2^+$	0.569	1.9	0.380	2	$3/2^+$	0.29
0.412	680	0	$1/2^+$	0.148	3.6	0.412	0	$1/2^+$	0.041
0.471	600	2	$3/2^+$	0.387	2.8	0.469	2	$3/2^+$	0.14
0.567	620	2	$(5/2^+)(3/2^+)$	(0.323)(0.419)	3.8	0.566	2	$5/2^+(3/2^+)$	(0.058)(0.11)
0.670	795	2	$5/2^+$	0.438	36	(0.670)	2	$5/2^+$	(0.012)
						0.685	3(?)	$(7/2^-)(?)$	0.0072
0.697	268	0	$1/2^+$	0.066	1.1	0.698	0	$1/2^+$	0.059
0.759	27	2	$3/2^+$	0.020	0.5	0.759	2	$3/2^+$	0.040
0.781	116	1	$(1/2^-)$	0.038		0.781[a]	1	$(3/2^-)$	0.011
0.809	250	2	$5/2^+$	0.148	12	0.806	1(2)	$(3/2^-)(3/2^+)$	(0.0039)(0.016)
0.892	162	0	$1/2^+$	0.044		0.889	0	$1/2^+$	0.018
1.029	103	2	$(5/2^+)(3/2^+)$	(0.070)(0.091)	3.8	1.023	2	$3/2^+$	0.024
1.074	300	2	$5/2^+$	0.203	14	1.071	2	$3/2^+$	0.019
						1.113	2	$3/2^+$	0.018
1.120	228	0	$1/2^+$	0.069	$\gtrsim$8.6				$\lesssim$0.008
1.167	27	0	$1/2^+$	0.008		1.160	2	$(3/2^+)$	0.059
1.218	100	2	$(5/2^+)(3/2^+)$	(0.074)(0.097)	4.4	1.214	2(?)	$3/2^+(?)$	0.022
						1.221	4	$7/2^+$	0.072
1.267	54	2	$(5/2^+)$	0.041	>24				$\lesssim$0.0017

[a] Listed as 0.791 in Ref. 1 because of misprint.

TABLE III. Results for $Pd^{104}(d,t)Ru^{103}$. The (d,p) data are from Ref. 2. Spectroscopic factors are calculated from (1) with σ_{DW} calculated with "average" optical-model parameters from Ref. 4.

$Ru^{104}(d,t)Ru^{103}$						$Ru^{102}(d,p)Ru^{103}$			
Excitation energy (MeV)	σ_{max} (μb/sr)	l	I^π	$S(d,t)$ JULIE	$\frac{S(d,t)}{S(d,p)}$	Excitation energy (MeV)	l	j	$\frac{d\sigma}{d\Omega}$(Rel.)
0.0	4293	2	$5/2^+$	1.973	2.0	0.0	2	$5/2^+$	1
0.133	233	2	$(3/2^+)(5/2^+)$	(0.141)(0.109)					
0.171	1799	0	$1/2^+$	0.431	0.5	0.17	0	$1/2^+$	0.85
							(4)	$(7/2^+)$	
0.210	295	4	$7/2^+$	2.36		0.21			0.12
							0	$(1/2^+)$	
0.235	201	5	$11/2^-$	1.92		0.24	4	$7/2^+$	0.12
0.294	323	(0)	$1/2^+$	0.080					
0.343	304	2	$(5/2^+)$	0.164					
0.402	914	2	$(3/2^+)$	0.621	1	0.40	2		0.6
0.428	463	0	$1/2^+$	0.118	2.4	0.43	0	$1/2^+$	0.05
0.497	450	2	$(5/2^+)$	0.257					
							0	$1/2^+$	0.07
0.545	205	1	$(1/2^-)$	0.068		0.55			
							2		0.026
0.587	514	2	$3/2^+$	0.377	0.8	0.59	2		0.3
0.658	47	(2)	$(5/2^+)(3/2^+)$	(0.029)(0.036)	1–1.2	0.66	2		0.03
0.693	49	4	$(7/2^+)$	0.47					
0.731	509	0	$1/2^+$	0.146	0.3	0.74	0	$1/2^+$	0.45
0.902	105	2	$(5/2^+)$	0.071	2.0	0.91	2		0.035

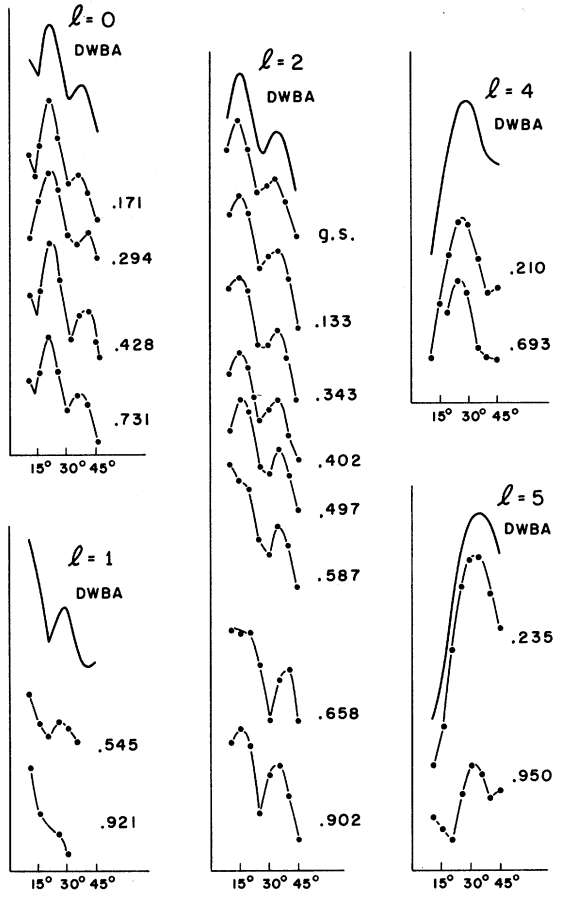

FIG. 4. Angular distributions of tritons from $Ru^{104}(d, t)Ru^{103}$. See caption for Fig. 2.

This raised the possibility that the (d,p) measurements were wrong, so a new set was made; the results agreed well with those of Ref. 1. It may be recalled that those angular distributions agreed well with angular distributions for known $l=4$ transitions in Sn^{116} and In^{115}. Since the (d,p) results seem to give definite $l=4$ assignments and the (d,t) results do not suggest any other assignment, there is no reason to change the assignments from $l=4$. Some of the many other peculiarities of these $l=4$ transitions were discussed by Cohen *et al.*[7] In spite of very extensive efforts to understand these problems as outlined above and by Diehl, Cohen, and Moyer,[8] we can still only say that the one-nucleon-transfer theory seems to break down rather seriously but unpredictably in these transitions.

To add slightly to the complication, there are two additional states, not observed in the (d,p) work, that are excited by $Pd^{110}(d,t)$ with angular distributions resembling the DWBA predictions for $l=4$ and one additional state of this nature excited by $Ru^{104}(d,t)$. They are so weakly excited that it is not surprising that they were not observed by (d,p) reactions, as can be seen from the $S(d,t)/S(d,p)$ ratios, and they do not appreciably enhance the anomalies.

$Pd^{110}(d, t)Pd^{109}$

Among the strongly excited states in this reaction, there is complete agreement between the l-value assignments from (d,p) and (d,t) reactions. One surprising case of this type is the $l=1$ transition at 0.671 MeV. The energies from the two experiments agree exactly, and, judging from the energy agreements for neighboring levels, the uncertainty here is not more that 1 or 2 keV. The angular distributions give excellent fits to the DWBA for $l=1$ and have no resemblance to those for other l. If these transitions are to the same state of Pd^{109}, there are two reasonable but unprecedented explanations: (1) Either the $N=28-50$ shell is not full or the $N=82-126$ shell is not empty in Pd^{110}, which has 64 neutrons; or (2) there is n-mixing in that a single state contains components of both a $2p$-hole and a $3p$-particle configuration. The second explanation seems to be more likely. A similar but less unambiguous situation of this type was reported in $Si^{28}(d, He^3)$ reactions by Wildenthal and Newman,[9] and an analogous case in Pd^{107} will be pointed out.

There are numerous cases where states have been observed in one of the two reactions but not in the other. In general, the limits these nonobservations put on the ratio $S(d,p)/S(d,t)$ are not unreasonable, especially when we realize that this ratio is known to vary considerably for very weakly excited states. In several cases, assignments have been changed from $\frac{3}{2}^+$ to $\frac{5}{2}^+$ or vice versa; the assignment from the current work is always more reliable, since the $S(d,t)/S(d,p)$ ratios are determined much more carefully here than in Ref. 1.

The very wide variations of $S(d,t)/S(d,p)$, especially for some of the $l=0$ transitions, may be indicative of misassignments, perhaps due to impurities or other Pd isotopes. On the other hand, this ratio is rather unpredictable for very weakly excited states.

Among the more highly excited states, most transitions are $l=1$ or $l=3$, indicating that holes are being made in the $N=28-50$ shell. As expected, these states are not excited by (d,p) reactions; and $l=1$ and $l=3$ transitions that are excited by (d,p) reactions, indicating that they consist of configurations with a particle in the $N=82-126$ shell, are not excited by (d,t). The only clear exception to this rule is the above-mentioned case of the 0.671-MeV state.

$Pd^{108}(d,t)Pd^{107}$

In the $Pd^{110}(d,t)$ reaction, all of the more interesting results were obtained from the first 1 MeV of excitation energy, while the vast majority of the labor was expended in analyzing the higher-energy region, in spite of which, the results there have an uncomfortable degree of uncertainty. For this reason, and also because the corresponding $Pd^{106}(d,p)$ reaction was done with less attention to detail because of the poor isotopic purity of the Pd^{106} target, the $Pd^{108}(d,t)$ study was limited to the region below 1.27-MeV excitation. Again here there is essentially perfect agreement in l values, although a few I assignments have been shifted between $\frac{3}{2}^+$ and $\frac{5}{2}^+$ because of the more careful $S(d,t)/S(d,p)$ ratio determinations in the present work. (In Ref. 1, (d,t) cross sections were measured only up to 0.6 MeV). Unfortunately, some of the ratios lie between the ranges that clearly determine I as $\frac{3}{2}$ or $\frac{5}{2}$, so the assignments are uncertain. The 0.791-MeV $l=1$ transition is completely analogous to the 0.671-MeV transition in $Pd^{110}(d,t)$ discussed above.

There seems to be a discrepancy between the state excited by (d,t) at 1.167 MeV as $l=0$ and one excited by (d,p) as $l=2$ at 1.160 MeV. The difference in energy and l values would seem to indicate that this is an unresolved doublet. The $S(d,t)/S(d,p)$ ratio for the 1.267-MeV state is unusually large, which may be indicative of an error, but systematics is not always reliable for such weakly excited states.

$Ru^{104}(d,t)Ru^{103}$

The data available from the $Ru^{102}(d,p)$ reaction,[2] as listed in Table III, is rather sketchy, as energies are given to only two significant figures and there are no absolute cross sections. The six states identified in the (d,p) work are also excited by (d,t), and five additional states are found in the same energy region. Among the states identified in the (d,p) work, there are three discrepancies in l assignments. In two of these, the (d,p) measurements indicate that there are doublets, but no indication of them was found here, although the energy resolution was about twice as good. The 0.133- and 0.343-MeV states reported here would seem to correspond to the 0.135- and 0.35-MeV state known from decay-scheme studies.[10]

There was an unusual amount of difficulty in assigning I values to states excited by $l=2$ transitions, because the $S(d,t)/S(d,p)$ ratio did not vary appreciably. No explanation for such behavior can be offered, unless all five states excited by $l=2$ in both reactions are $\frac{5}{2}^+$, a most unexpected situation.

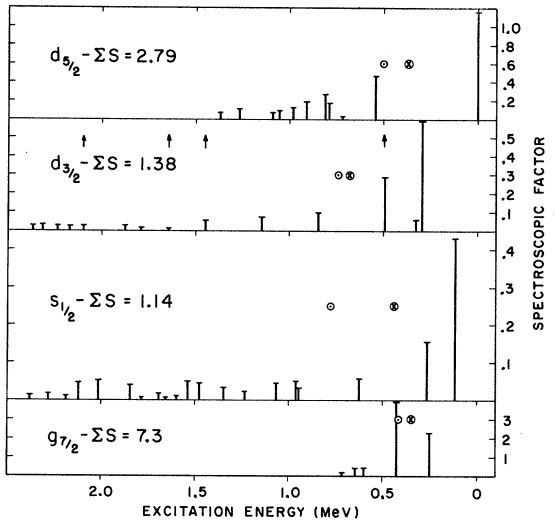

FIG. 5. Summary of results for $Pd^{110}(d,t)Pd^{109}$. Levels are grouped according to the SQP state to which they are assigned. Vertical arrows above $d_{3/2}$ states indicate that they may be $d_{5/2}$. Horizontal scale is excitation energy and vertical scales are spectroscopic factors S. Where I-π assignments are uncertain, states are included with the most probable SQP state. The circles and crosses give the location of the "center of gravity" (see text) from (d,t) and (d,p) reactions, respectively.

DISCUSSION AND CONCLUSIONS

The distribution of Pd^{109} states of various I-π and their spectroscopic factors in $Pd^{110}(d,t)$ reactions are shown in Fig. 5. The low-energy states have by far the largest spectroscopic factors, and in all cases well over half of the strength is below 0.55 MeV. The remainder, however, is highly fragmented and spread over a wide energy region. The "center of gravity" in these diagrams, obtained as $\sum S_f E_f / \sum S_f$, is approximately equal to the single quasiparticle energy E_j. These are shown by the circles in Fig. 5 and analogous determinations from (d,p) reactions are shown by the encircled crosses. The discrepancies are due to shifts in spectroscopic factors; there is a con-

TABLE IV. Percentage of $\sum S$ in lowest-energy nuclear state of correct I-π.

	$Pd^{108}(d,p)$	$Pd^{110}(d,t)$
$d_{5/2}$	73	42
$d_{3/2}$	41	43
$s_{1/2}$	57	38
$g_{7/2}$	58	32

sistent tendency for higher energy levels to contain more of the strength in (d,t) reactions than in (d,p) reactions. The fraction of the total strength contained in the lowest-energy nuclear state from the two reactions is shown in Table IV; here again we see evidence for the above-mentioned tendency.

The sum of the spectroscopic factors for each j transfer is related to the fullness V_j^2, of the SQP state j by

$$\sum S(d,p) = (1 - V_j^2),$$

$$\sum S(d,t) = (2j+1)V_j^2.$$

While these V_j^2 are for the target nucleus which is Pd^{108} in (d,p) and Pd^{110} in (d,t), we ignore the difference between the two targets and give the results for V_j^2 in columns 2 and 4 of Table V, as obtained from the data of Table II. We see there the large discrepancy between the two determinations for $g_{7/2}$ and $h_{11/2}$ states, which was considered in great detail in Ref. 7; we will not discuss it further here.

However, we also see a discrepancy between the two determinations for the $d_{5/2}$ SQP state. When confronted with a problem of this type, one usually explores the effect of changing the optical-model parameters. Indeed, one might well argue that specific parameters fitted to elastic scattering data for the nucleus under study should be used in preference to "average" parameters. This is done to obtain the results in columns 3 and 5 of Table V; since the (d,p) work was done at 12 MeV, the Perey B parameters[4] for Pd from 11.8-MeV elastic scattering are used in column 5; and since there are no elastic scattering studies at 17 MeV, where the (d,t) work was done, parameters from 15-MeV studies[11] were used for column 3.

In addition, there are four states for which the $S(d,t)/S(d,p)$ ratio does not give a clear choice between $\frac{3}{2}^+$ and $\frac{5}{2}^+$, but the former assignment was chosen; these are designated by vertical arrows in Fig. 5. In the most important of these, the 0.491-MeV state, the ratio is 2.7 for $I = \frac{3}{2}$ and 4.6 for $I = \frac{5}{2}$, whereas the principal $\frac{3}{2}^+$ and $\frac{5}{2}^+$ SQP states have ratios of 1.8 and 6.6, respectively. If V_j^2 for Pd^{108} and Pd^{110} are taken to be the same as for their Sn isotopes,[12] the ratios from 2 should be 1.4 and 12, whence a $\frac{3}{2}^+$ assignment seemed most likely, but there are cases where V_j^2 are different in isotonic nuclei[5], so this argument is not very strong. If the assignment for the 0.491-MeV state is switched to $\frac{5}{2}^+$ along with those of the other three states with even more uncertain I assignments, the results for V_j^2 are listed in columns 6, 7, 8, and 9 of Table V.

Of the various possibilities presented in Table V, the best over-all agreement for the s and d states is obtained with columns 6 and 8. Columns 7 and 8 are a little better for the d states but considerably worse for the s states. Our "best estimate" of V_j^2, obtained by taking a weighted average of the results, is given in column 10.

The V_j^2 for the isotonic[12] nuclei Sn^{112} and Sn^{114} are listed in column 11 of Table V. The largest difference between Pd and Sn isotones appears to be in the $s_{1/2}$ state, but this is to some extent deceiving, since $V_{1/2}^2$ for the next heavier Sn isotopes Sn^{116} and Sn^{118} are 0.51 and 0.60, respectively; apparently the $s_{1/2}$ state begins to fill a little sooner in Pd than in Sn isotopes. This may be responsible for the difference between the $V_{1/2}^2$ results in columns 2 and 4, since these are actrally $V_{1/2}^2$ in Pd^{110} and Pd^{108}, respectively.

The $d_{5/2}$ state is less full and the $d_{3/2}$ is more full in Pd than in Sn; this is what one would expect if the single-particle energies were closer together. It appears from the Sn results that the (d,t) is more reliable than (d,p) for determining V_j^2 for the $g_{7/2}$ and $h_{11/2}$ states.

The results for $Pd^{108}(d,t)$ are summarized in Fig. 6; they are very similar to those for Pd^{110} (d,t). The lowest-energy states of each j are at about the same energy and are excited with very similar spectroscopic factors. The $\sum S$ in the energy region investigated are also quite similar between Pd^{107} and Pd^{109} – 2.84 vs 2.71 for $d_{5/2}$, 0.98 vs 1.11 for $d_{3/2}$, and 0.60 vs 0.79 for $s_{1/2}$, respectively. In view of the fact that the (d,p) results

TABLE V. V_j^2 (occupation numbers) for $Pd^{108,110}$ from (d,p) and (d,t) reactions. Results from the two isotopes are averaged.

SQP state	(d,t) Average parameter	(d,t) 15-MeV parameter	(d,p) Average parameter	(d,p) Perey B	Doubtful $d_{5/2} \rightarrow d_{3/2}$ (d,t)		(d,p)		Best estimate	Sn^{112} Sn^{114}
$d_{5/2}$	0.47	0.62	0.68	0.76	0.52	0.69	0.59	0.69	0.57	0.65
$d_{3/2}$	0.34	0.43	0.26	0.43	0.25	0.32	0.36	0.51	0.30	0.24
$s_{1/2}$	0.57	0.76	0.48	0.59					0.52	0.20
$g_{7/2}$	0.91	1.10	0.24	0.42					?	0.78
$h_{11/2}$	0.24	0.31	0.72	0.80					?	0.15

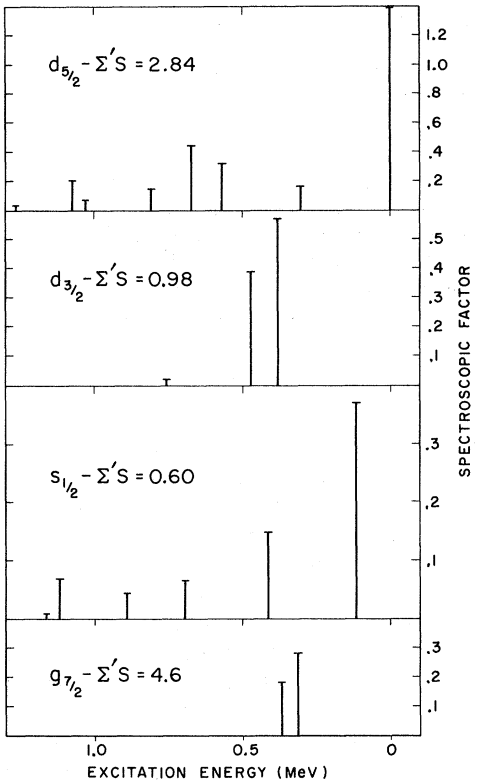

FIG. 6. Summary of results for $Pd^{108}(d,t)Pd^{107}$. See caption for Fig. 5. $\sum'$ indicates the sum up to 1.3 -MeV excitation energy.

for these nuclei are also very similar,[1] the structure of these two nuclei must be very analogous.

The results for Ru^{103} are summarized in Fig. 7. While the data are more limited and the detailed differences are greater, Ru^{103} also has much in common with these Pd isotopes. In the energy region investigated, the number of energy levels of each I-π is about the same, and $\sum S$ for Ru^{103} and Pd^{109} are, respectively, 2.49 vs 2.36 for $d_{5/2}$, 1.14 vs 1.04 for $d_{3/2}$, and 0.78 vs 0.64 for $s_{1/2}$.

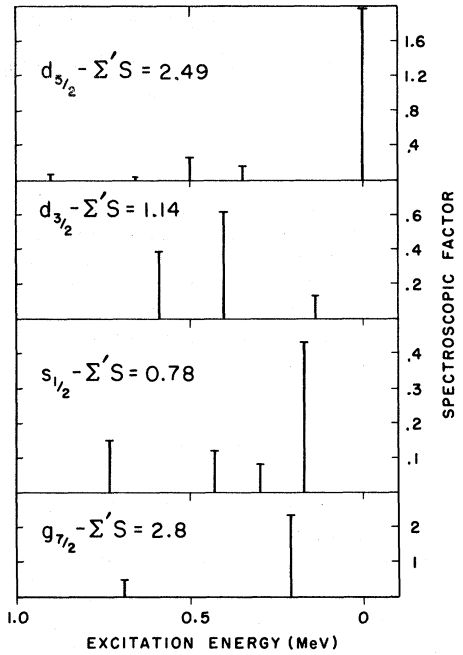

FIG. 7. Summary of results for $Ru^{104}(d,t)Ru^{103}$. See caption for Fig. 5. $\sum'$ indicates the sum up to 0.92 -MeV excitation energy.

While these numbers are remarkably similar, we may note that the s and d states are slightly more full in Ru^{104} than in Pd^{110}, even though the former nucleus has four less neutrons. We may therefore conclude that the $g_{7/2}$ state is considerably less full in Ru. There is direct evidence for this from the small $\sum S$ for $g_{7/2}$ in Ru^{103}, 2.8 vs 6.1 for Pd^{109}. This effect can be explained as due to a lowering of the $g_{7/2}$ neutron single-particle state between Ru and Pd because of the filling of the $g_{9/2}$ proton single-particle state in this region.[13]

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