value of 14. It is clear that the photon intensity of the 229-keV transition will have to be remeasured. Part of the problem, however, may be due to an incomplete and inaccurate knowledge of the ^{147}Gd decay scheme.

The measured decay energy of ^{147}Gd was used to predict the electron-capture decay energy of ^{151}Dy and the α-decay energy of ^{147}Gd by means of closed energy cycles. The method consists of constructing an energy-balance cycle from two α- and two β-decay energies. If three of the four pieces of information that constitute a cycle are known, then the fourth can be calculated. Figure 4 shows the two cycles used. The α-decay energies of ^{151}Dy, ^{151}Tb, and ^{147}Eu were taken from the work of Golovkov *et al.*[14] The ^{143}Sm electron-capture decay energy is the one adopted in the Nuclear Data Sheets.[15] α-decay energies used in the cycles are total disintegration energies of the bare nuclei. They are equal to the energy in the laboratory system plus the recoil energy plus the oribital electron screening correction, which is about 20 keV for the rare-earth nuclides. In this way the ^{151}Dy electron-capture decay energy and the ^{147}Gd α-decay energy were calculated to be 3001 ± 35 and 1847 ± 60 keV, respectively. The latter decay energy is of particular interest because it shows the influence of the 82-neutron closed shell on the α-decay energies of nuclides in its vicinity. Thus, ^{147}Gd, an 83-neutron isotope, according to the cycle shown in Fig. 4, has an α-decay energy 1.45 MeV less than that of the 84-neutron isotope, ^{148}Gd.[16] This drop in energy is similar to the values of 1.39 and 1.52 MeV previously noted in closed-cycle calculations[17] for the differences between the α-decay energies of the 84- and 83-neutron nuclides of samarium and neodymium, respectively.

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Spectroscopic-Factor Ratios for States of the Same l-π from (d, p) Reactions at Different Energies*

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In a previous study, ratios of spectroscopic factors from (d, p) reactions for $l=4$ transitions to various $\frac{7}{2}^+$ states were found to vary strongly with bombarding energy in the Pd isotopes. As this represents a breakdown in basic one-nucleon-transfer theory, the possibility that this breakdown extends to $l=0$ and $l=2$ transitions was investigated in these isotopes. Measurements of ratios of spectroscopic factors for various transitions were made at 8-, 12-, and 17-MeV bombarding energies. The results at the three energies agree within experimental error, which indicates that the theory does not break down for these transitions. Differences in angular distributions for transitions with the same (n, l, j) to different nuclear states were noted in three cases. There is evidence that the ratio of cross sections for $d_{5/2}$ and $d_{3/2}$ excitations may vary much more between 8 and 12 MeV than is predicted by distorted-wave Born-approximation calculations.

In a recent study of stripping and pickup reactions, it was found[1] that (d, p) reactions leading to $g_{7/2}$ and $h_{11/2}$ states behave very anomalously in the isotopes of $_{46}$Pd, $_{48}$Cd, $_{49}$In, and $_{44}$Ru[2] but not in the $_{50}$Sn isotopes. Spectroscopic factors (S) vary widely from the values determined with (d, t) reactions and from theoretical expectations, and $S(d, p)/S(d, t)$ for exciting the same state varies much more strongly than usual among the various levels. But the most surprising result

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TABLE I. Ratios of spectroscopic factors for various (d, p) transitions with the same l value as measured at different energies and different angles near the peak of the angular distributions.

Target	j	Excitation energy of states (keV)	$E_d=8$ MeV 10°	$E_d=8$ MeV 12.5°	$E_d=12$ MeV 15°	$E_d=12$ MeV 30°	$E_d=17$ MeV 28°	$E_d=17$ MeV 32°
			(A) $l=0$ transitions					
Pd^{106}	$\frac{1}{2}$	115/412	8.5±1.0	8.4±1.2	9.2±1.3	9.3±0.6	10.5±1.2	7.7±0.7
		115/698	7.1±0.8	6.3±1.3	7.5±1.0	6.7±0.5	6.8±0.6	5.3±0.9
		115/889	29±9	22±10	18±8	20.5±2.5	18.5±4	11.0±2
Pd^{108}	$\frac{1}{2}$	112/262	7.6±1.1	7.7±1.1	6.5±3.0	5.9±0.8	5.9±0.8	6.0±0.6
		112/623	5.7±0.7	4.7±0.5	6.1±1.0	6.1±0.6	4.0±0.5	5.0±0.5
		112/742	39±10	...	29±6	43±8	31±4	32±4
			(B) $l=2$ transitions					
			37°	41°	45°	20°	19°	22°
Pd^{106}	...	$0(\frac{5}{2})/380(\frac{3}{2})$	0.58±0.07	0.54±0.04	0.64±0.06	0.70±0.08	0.71±0.07	0.70±0.07
	$\frac{5}{2}$	0/566	2.9±0.4	3.6±0.5	3.0±0.6	3.6±0.3	3.2±0.3	2.9±0.3
	$\frac{3}{2}$	380/469	1.66±0.17	2.25±0.28	1.77±0.18	2.00±0.25	1.84±0.15	1.80±0.20
	$\frac{3}{2}$	380/566	2.95±0.35	3.9±0.6	2.71±0.50	2.75±0.50	2.54±0.25	2.30±0.25
	$\frac{3}{2}$	380/759	...	8.3±2.1	7.1±1.1	6.8±1.8	8.4±1.0	6.5±0.9
Pd^{108}	...	$0(\frac{5}{2})/291(\frac{3}{2})$	0.43±0.05	0.43±0.05	0.52±0.06	0.54±0.05	0.53±0.05	0.56±0.05
	$\frac{5}{2}$	0/539	6.8±1.4	6.3±1.0	5.7±0.8	6.9±0.6	5.2±0.6	8.0±1.2
	$\frac{5}{2}$	0/808	6.1±0.8	5.7±0.9	6.5±0.9	8.0±2.0	8.2±1.0	8.6±1.1
	$\frac{5}{2}$	0/908	...	...	...	10.5±2	10.5±1.3	10.8±1.5
	$\frac{3}{2}$	291/324	7.1±1.0	6.7±1.0	4.3±0.5	6.7±0.6	6.5±0.7	6.5±0.7
	$\frac{3}{2}$	291/489	3.8±0.5	3.9±0.6	3.3±0.4	3.2±0.2	3.2±0.3	3.2±0.4
	$\frac{3}{2}$	291/788	7.2±0.9	7.0±1.0	5.6±0.7	6.2±1.2	6.0±0.7	6.0±0.7
	$\frac{3}{2}$	291/844	...	4.9±0.6	4.1±0.5	5.4±0.6	4.4±0.5	3.9±0.5

was that the ratio of $S(d, p)$ for different $\frac{7}{2}^+$ states in the same nucleus varies by more than a factor of 2 between 12- and 17-MeV bombarding energy.

It is conventional to blame most difficulties in the results of (d, p) reactions on the vagaries of the distorted-wave Born-approximation (DWBA) calculations used in the analysis. But this last variation is essentially independent of DWBA. The states in question are within 50–250 keV of one another and there is no way to make DWBA calculations change drastically in such a small energy interval. These results can only be explained as a breakdown of the basic one-nucleon-transfer reaction theory.

Since (d, p) reactions are so widely used in nuclear-structure studies, it is important to investigate the extent of this breakdown as a function of A and of the l value. It seems not to occur in the nearby closed-shell nuclei, the $_{50}$Sn and $_{40}$Zr isotopes, so its occurrence is limited to a rather restricted region of A. The other l values encountered in this mass region are 0 and 2, corresponding to the insertion of neutrons into the $3s_{1/2}$, $2d_{5/2}$, and $2d_{3/2}$ states. In this paper we investigate the question of whether there is a similar breakdown in reactions leading to these states.

There is a rather large number of $\frac{1}{2}^+$, $\frac{3}{2}^+$, and $\frac{5}{2}^+$ states excited by (d, p) reactions on Pd^{106} and Pd^{108}, so these target nuclei were chosen for the study. Weakly excited or difficult to resolve states were disregarded, and careful measurements were made on some 23 states which are relatively strongly excited and clearly resolved. Measurements were made at 17, 12, and 8 MeV at angles near the peaks of the angular distributions. At 17 and 8 MeV, these angles were known in advance only from DWBA calculations, so runs were made at two or three angles in the vicinity.

The experimental method has been described previously.[3,4] Protons from (d, p) reactions were magnetically analyzed with an Enge split-pole spectrograph and detected with photographic plates on its focal plane. Intensities of proton groups were obtained by

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counting tracks under microscopes. Corrections for the Q value dependence of the ratio of cross sections to spectroscopic factors were made with DWBA calculations, but these were never more than a few percent and they are insensitive to the choice of parameters used in the calculations. Ratios of spectroscopic factors between each transition and the transition to the lowest-energy state of the same l, j were then obtained from each run. These are listed in Table I and they will be referred to in the following discussion as "peak ratios." Table I also includes the peak ratios of the lowest energy $d_{5/2}$ and $d_{3/2}$ states in each isotope; since they should have very similar angular distributions, this provides a test of the variation of j dependence with energy.

All track counting was done independently by two different microscopists and where there were appreciable deviations in the results, third and even fourth countings were carried out. The average deviation between two countings was 5.6%; 20% of the deviations were as large as 10%, and only 1% of the deviations was as large as 14%. These deviations are partly due to differences in judgement between different microscopists over what represents an acceptable track. Since ratios between the track counts in two peaks were generally taken between readings by the same microscopist, these judgement errors partly cancel in the ratios; the average deviation between *ratios* as obtained by different microscopists was 5.3%. By taking averages and making repeated readings where deviations were large, it is believed that the average error in peak ratios was reduced to about 4%.

A most puzzling discrepancy arose when measurements were repeated by exposing different plates on different dates. Ratios obtained from the two differed by an average of 9.0%, whereas the average standard deviation from statistics was 6.3%. The number of carefully studied cases was sufficient to rule out unusual statistical fluctuations as a cause of this discrepancy and readings by separate microscopists agreed well. The simplest reason why differences might arise is that the angle of the incident beam changed between the two runs. But this change could not be more than 1° and it would be surprising if ratios between two peaks which have the same angular distributions differ very much in 1°. In some cases, differences in background might be important, but no such cases were included here. The different plates did have rather different track densities, and there is some tendency for tracks to be missed by the microscopists when track densities are high. However, the disagreements in the peak ratios could not be explained by this effect; high track density peaks just as often had too many tracks as too few. In order to take the discrepancies under discussion into account we assign an 8% uncertainty to all ratios due to unexplained sources.

The errors listed in Table I combine this error with the statistical uncertainty (one standard deviation) as the square root of the sum of squares. In a few cases the error was further increased due to the sources of uncertainty such as the interpretation of a possible "shoulder" on a peak, unusually large discrepancies between readings by different microscopists or between results from separate exposures, uncertainty in background (background was appreciable in only two cases, both at 8 MeV), etc.

Where there are different results at different angles but at the same bombarding energy, the angular distribution of the two peaks must be different. An example of this is seen in the 8 MeV, $l=2$ data from $Pd^{108}(d, p)$; the angular distribution for the transition to the 291 keV state decreases more between 41° and 45° than does that for transitions to any other $l=2$ state, $\frac{3}{2}^+$ or $\frac{5}{2}^+$. Another case of this type is seen in the 17-MeV data for transitions to the 115-keV $\frac{1}{2}^+$ state in Pd^{106} and a third occurs in the 17-MeV data for transitions to the 539-keV $\frac{5}{2}^+$ state in Pd^{108}. We can offer no explanation for these differences, but extensive efforts were made to eliminate the possibility of experimental explanations. In these cases, a good estimate of the true ratio of spectroscopic factors is probably obtained by averaging over angles, since the angles chosen span the peak of the angular distribution.

If this procedure is accepted, there is very little evidence in Table I for variation of peak ratios with bombarding energy. The only case where there seems to be a discrepancy outside of the combined experimental errors is for the 0/808 peak ratio in $Pd^{108}(d, p)$, where the 8-MeV data give about 6.1 ± 0.7 and the 17-MeV data give 8.4 ± 1.0 for this ratio. In view of the method of assigning errors, it is perhaps not unexpected statistically that one case should fall outside of the combined assigned errors, so we attribute no great significance to this single discrepancy.

The conclusion of this work is then that if there are differences in ratios of spectroscopic factors from determinations at different energies, they are generally not more than about 15% in the energy range between 8 and 17 MeV bombarding energy. In view of the factor of two discrepancies among $g_{7/2}$ states, we may conclude that the breakdown in reaction theory indicated there does not extend to s and d states. Moreover, since spectroscopic factors cannot be determined with better than about 20% absolute accuracy, there is no need to worry over the energy at which these are determined within the range studied here.

The entries in Table I for the peak ratio of the lowest energy $\frac{5}{2}^+$ and $\frac{3}{2}^+$ states provides a test of the manner in which DWBA calculations handle the j dependence of absolute cross sections. These calculations predict differences in the $d_{5/2}/d_{3/2}$ ratio to be less than 3% at the three energies. The data, however, show an 18% increase in the ratio between 8 MeV and either 12 or 17 MeV for Pd^{106} and a 16% increase for Pd^{108}. While these differences are not completely outside the limits of experimental uncertainty, the effect is probably real and represents a failure in the DWBA calculations.