The speed of the transition in P^{30} is also much greater than can be accounted for by the spin component alone. Here, however, the relative importance of the orbital component can be attributed mainly to inhibition of the spin component. The reduced matrix element for the orbital component in P^{30} is only about a sixth of that in Al^{26} and thus the leading term in the wave function for the states in P^{30} could still correspond to two $s_{1/2}$ nucleons about a Si^{28} core. The lifetime measurements therefore point to a separation of the $d_{5/2}$ and $s_{1/2}$ subshells in the mass region near Si^{28}. The wave functions are certainly not pure; indeed, some valence nucleons in a d state are needed to account for the orbital component in P^{30}.

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Study of the (d,p) Reactions on $Zn^{64,66,68,70}$†

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Angular distributions from the (d,p) reactions on $Zn^{64,66,68,70}$ have been measured with 10.0-MeV deuterons from the Argonne Tandem van de Graaff accelerator. The energies, spins, parities, and spectroscopic factors of levels up to about 3.5-MeV excitation energy have been determined by use of distorted-wave Born-approximation calculations. Empirical J-dependence rules are used to distinguish between $\frac{3}{2}^-$ and $\frac{1}{2}^-$ states. The ground-state Q values of the $Zn^{64,66,68,70}(d,p)$ reactions, determined within ±10 keV, were 5.758, 4.827, 4.259, and 3.609 MeV, respectively. The sums of the spectroscopic factors are discussed briefly.

INTRODUCTION

INFORMATION on the energy levels in the odd-A zinc isotopes is available from β-γ decay studies,[1] the (d,p) and (p,d) reaction[2,3] for $A=65$, 67, and 69, and some Coulomb-excitation work[4] on Zn^{67}. In the present experiment we studied the (d,p) reaction with better energy resolution, statistically more accurate data, and more complete angular distributions than in past work. We have also obtained new information on the energy levels of Zn^{71}. Spins, parities, and spectroscopic factors for most states have been extracted from the data.

EXPERIMENTAL PROCEDURE

The 10.0-MeV deuteron beam from the Argonne Tandem Van de Graaff was used to obtain angular distributions between 25° and 165° in an 18-in.-diam scattering chamber.[5] Refrigerated surface-barrier Si detectors 2000 μ thick with a typical resolution of around 50 keV were used, subtending a solid angle of 10^{-3} sr. The targets were isotopically enriched[6] self-supporting metal foils ~0.5 mg/cm² in thickness. Beam currents ⩽0.2 μA were used with 100–200 μC of beam charge per point.

In order to be certain of resolving some closely spaced levels at the higher excitation energies and to avoid difficulties with the large number of elastically scattered deuterons at the extreme forward angles, the angular distributions between 5° and 40° were measured with the broad-range magnetic spectrograph.[7] The typical resolution was 10–15 keV. Here somewhat thinner targets evaporated on 20-μg/cm² carbon backings were used. The particles were detected in Kodak NTB emulsion 50 μ thick, covered with 10-mil acetate foils which stopped all particles except protons. The ground-state Q values of the $Zn^{70}(d,p)Zn^{71}$ reaction had not previously been determined. In addition to the data at

TABLE I. Ground-state Q values (MeV).

Reaction	$Zn^{64}(d,p)Zn^{65}$	$Zn^{66}(d,p)Zn^{67}$	$Zn^{68}(d,p)Zn^{69}$	$Zn^{70}(d,p)Zn^{71}$
Previous[a]	5.764±0.007	4.829±0.012	4.278±0.008	3.817±0.05
This experiment	5.758±0.01	4.827±0.01	4.259±0.01	3.609±0.01

[a] Reference 9.

† Work performed under the auspices of the U. S. Atomic Energy Commission.

[1] *Nuclear Data Sheets*, compiled by K. Way *et al.* (Printing and Publishing Office, National Academy of Sciences—National Research Council, Washington 25, D. C.), NRC 59-2-23.

[2] F. B. Shull and A. J. Elwyn, Phys. Rev. **112**, 1667 (1958); L. C. McIntyre, Phys. Rev. **152**, 103 (1966).

[3] E. K. Lin and B. L. Cohen, Phys. Rev. **132**, 2632 (1963).

[4] R. C. Ritter, P. H. Stelson, F. K. McGowan, and R. L. Robinson, Phys. Rev. **128**, 2320 (1962); D. G. Alkhazov, V. D. Vasil'ev, G. M. Gusinskii, I. K. Lemberg, and V. A. Nabichvrishvili, Izv. Akad. Nauk SSSR, Ser. Fiz. **28**, 1683 (1964) [English transl.: Bull. Acad. Sci. Phys. Ser. **28**, 1575 (1964)].

[5] J. T. Heinrich and T. H. Braid (to be published).

[6] The Zn^{64} target was enriched to 98.5%, the Zn^{66} to 97.8%, the Zn^{68} to 96.8%, and the Zn^{70} to 85.9%. The remainder of the Zn^{70} target consisted of 5.1% Zn^{64}, 3.7% Zn^{66}, 0.8% Zn^{67}, and 4.5% Zn^{68}.

[7] J. R. Erskine, Phys. Rev. **135**, B110 (1964).

TABLE II. Summary of results from $Zn^{64}(d,p)$ reactions.

E_x (MeV)	l	J^π	σ_{max} (mb/sr)	$(2J+1)S$ (Refs. 11, 12)	$(2J+1)S$ (Refs. 11, 13)
0.0	3	$\frac{5}{2}^-$	0.91	2.8	3.1
0.054	1	$\frac{1}{2}^-$	2.2	0.56	0.71
0.115	1	$\frac{3}{2}^-$	4.3	1.08	1.37
0.205	1	$(\frac{3}{2})^-$ [a]	0.25	0.06	0.08
0.865	1	$\frac{1}{2}^-$	2.4	0.54	0.71
0.908	1	$\frac{1}{2}^-, \frac{3}{2}^-$ [a]	0.63	0.14	0.19
1.064	4	$\frac{9}{2}^+$	1.0	4.9	7.8
1.370	2	$(\frac{5}{2})^+$	3.4	1.0	1.5
1.469	1	$\frac{1}{2}^-, \frac{3}{2}^-$ [a]	0.25	0.05	0.07
1.911	0	$\frac{1}{2}^+$	4.1[b]	0.10	0.13
2.054	…[c]		~0.2		
2.421	1	$\frac{1}{2}^-, \frac{3}{2}^-$ [a]	0.55	0.09	0.13
2.491	0	$\frac{1}{2}^+$	0.18[b]	~0.005	~0.006
2.532	2	$(\frac{5}{2})^+$	0.44	0.12	0.17
2.575	…[c]		0.14		
2.674	2	$(\frac{5}{2})^+$	0.3	0.07	0.10
2.811	…[c]		~0.2		
3.002	2	$(\frac{5}{2})^+$	0.3	0.07	0.10
3.054	0	$\frac{1}{2}^+$	1.9[b]	0.05	0.06
3.104	2	$(\frac{5}{2})^+$	0.5	0.12	0.16
3.207	…[c]		~0.2		
3.355	2	$(\frac{5}{2})^+$	0.36	0.09	0.11
3.409	…[c]		~0.2		
3.533	2	$(\frac{5}{2})^+$	1.2	0.27	0.36
3.618	2	$(\frac{5}{2})^+$	1.4	0.30	0.37
3.672	0	$\frac{1}{2}^+$	4.4[b]	0.13	0.14
3.822[d]			0.3		
3.857	0	$\frac{1}{2}^+$	1.2[b]	0.04	0.04

[a] No reliable data at backward angles.
[b] At $\theta_{lab}=7.5°$.
[c] No l assignment possible.
[d] Probably several unresolved levels.

forward angles, two long exposures at 130° and 147° were obtained to eliminate the ambiguity in the identification of the ground-state group.

The absolute cross sections were determined by reference to the elastic scattering of 7-MeV deuterons at 25°. An optical-model calculation[8] indicated that this cross section would be only 2% below Rutherford scattering.

RESULTS AND ANALYSIS

A typical spectrum obtained with the magnetic spectrograph is shown in Fig. 1. The ground-state Q values are given in Table I, where they are compared with previous values.[9] The excitation energies are listed in Fig. 2 and Tables II–V. The uncertainties are about ±5 keV for states below 1 MeV and about ±10 keV for the higher excitation energies. The absolute differential cross sections are given in Tables IX–XII in the Appendix. The error in the absolute cross sections is estimated to be around 10%; relative values are somewhat better.

Full angular distributions were obtained for all levels that could be well resolved with the solid-state counters. For the levels that could not be fully resolved in the solid-state detectors, only the data of the magnetic spectrograph were used, and these were obtained essentially in the forward direction only. Some of the angular distributions are displayed in Figs. 3–7, which also display distorted-wave Born-approximation (DWBA) curves calculated with the program of Macefield.[10] The

TABLE III. Summary of results from $Zn^{66}(d,p)$ reactions.[a]

E_x (MeV)	l	J^π	σ_{max} (mb/sr)	$(2J+1)S$ (Refs. 11, 12)	$(2J+1)S$ (Refs. 11, 13)
0.0	3	$\frac{5}{2}^-$	0.56	1.7	1.8
0.093	1	$\frac{1}{2}^-$	3.8	0.82	1.10
0.184	1	$\frac{3}{2}^-$	0.29	0.06	0.08
0.390	1	$\frac{3}{2}^-$	3.7	0.75	1.03
0.602	4	$\frac{9}{2}^+$	1.1	5.1	8.4
0.978	2	$(\frac{5}{2})^+$	3.7	1.1	1.55
1.142	1	$\frac{1}{2}^-$	1.5	0.26	0.37
1.444	1	$\frac{3}{2}^-$	0.26	0.04	0.06
1.542	1	$\frac{1}{2}^-, \frac{3}{2}^-$ [b]	0.12	0.02	0.03
1.642	…[c]		~0.09		
1.676	0	$\frac{1}{2}^+$	7.5[d]	0.2	0.23
1.782	…[c]		~0.07		
1.808[e]	(0)	$(\frac{1}{2}^+)$	~0.06[d]	(0.001)	(0.001)
1.842	(1)	$(\frac{1}{2}^-,\frac{3}{2}^-)$[b]	0.07	(0.01)	(0.015)
2.172[f]			~0.04		
2.246	…[c]		~0.06		
2.273	2	$(\frac{5}{2})^+$	0.66	0.16	0.22
2.407	2	$(\frac{5}{2})^+$	0.65	0.16	0.21
2.430	0	$\frac{1}{2}^+$	4.3[d]	0.11	0.12
2.609[e]	2	$(\frac{5}{2})^+$	0.19	0.04	0.06
2.648	…[c,e]		~0.1		
2.797	2	$(\frac{5}{2})^+$	0.88	0.19	0.25
2.849	0	$\frac{1}{2}^+$	0.2[d]	0.006	0.006
3.233	2	$(\frac{5}{2})^+$	0.33	0.07	0.09
3.295	0	$\frac{1}{2}^+$	1.4[d]	0.04	0.04
3.395	0	$\frac{1}{2}^+$	4.4[d]	0.12	0.13
3.480	2	$(\frac{5}{2})^+$	0.3	0.06	0.08
3.538	…[c,e,f]		(4)		
3.557	0	$\frac{1}{2}^+$	2[g]	~0.25	~0.27
3.607	0	$\frac{1}{2}^+$	0.85[g]	~0.1	~0.1
3.651	…[f,h]		(~0.1)		
3.67	…[f,h]		(~0.2)		
3.770	…[c,e,f]		~0.9		
3.822	…[f]		(~0.1)		
3.840	…[f]		(~0.3)		
3.863	(0)[f]	$(\frac{1}{2}^+)$	0.52[i]	(~0.09)	(~0.1)

[a] An additional level at 887.87±0.1 keV with $J^\pi=(3/2)^-$ (Ref. 16) is excited very weakly [$\sigma_{max}\approx 0.01$ (mb/sr)] in the present work.
[b] No reliable data at backward angles.
[c] No l assignment possible.
[d] At $\theta_{lab}=5°$.
[e] Probably several unresolved levels.
[f] Incomplete data.
[g] At $\theta_{lab}=15°$.
[h] Unresolved.
[i] At $\theta_{lab}=35°$.

[8] We are indebted to E. Auerbach for the ABACUS programs.

[9] C. Maples, G. W. Goth, and J. Cerny, University of California Lawrence Radiation Laboratory Report No. UCRL-16964, 1966 (unpublished).

[10] B. Macefield (private communication).

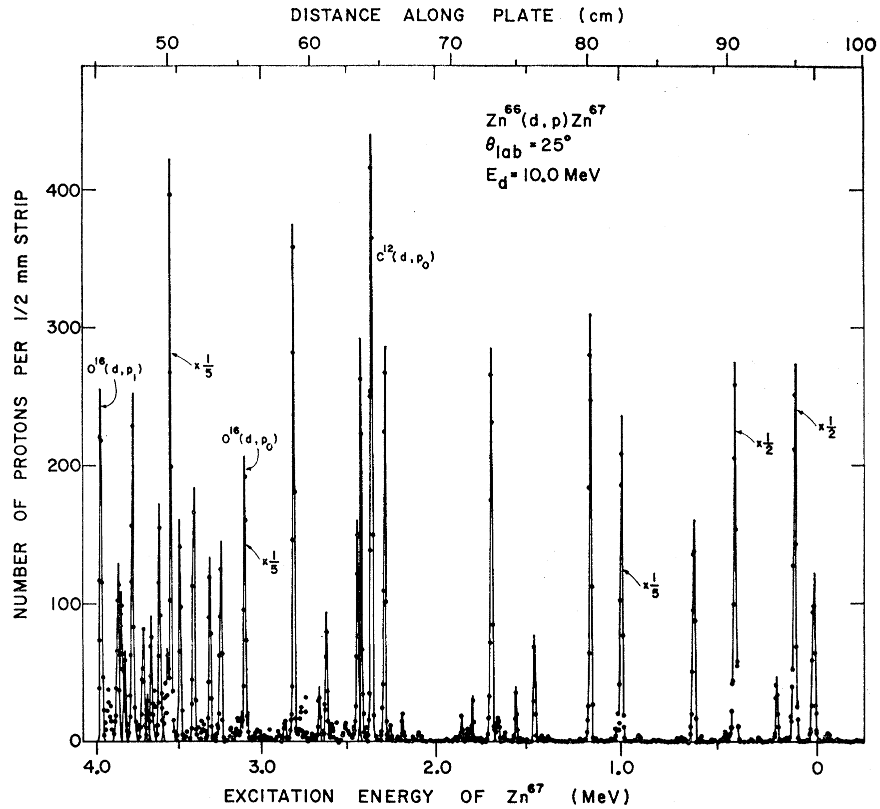

FIG. 1. Typical spectrum as obtained with the magnetic spectrograph.

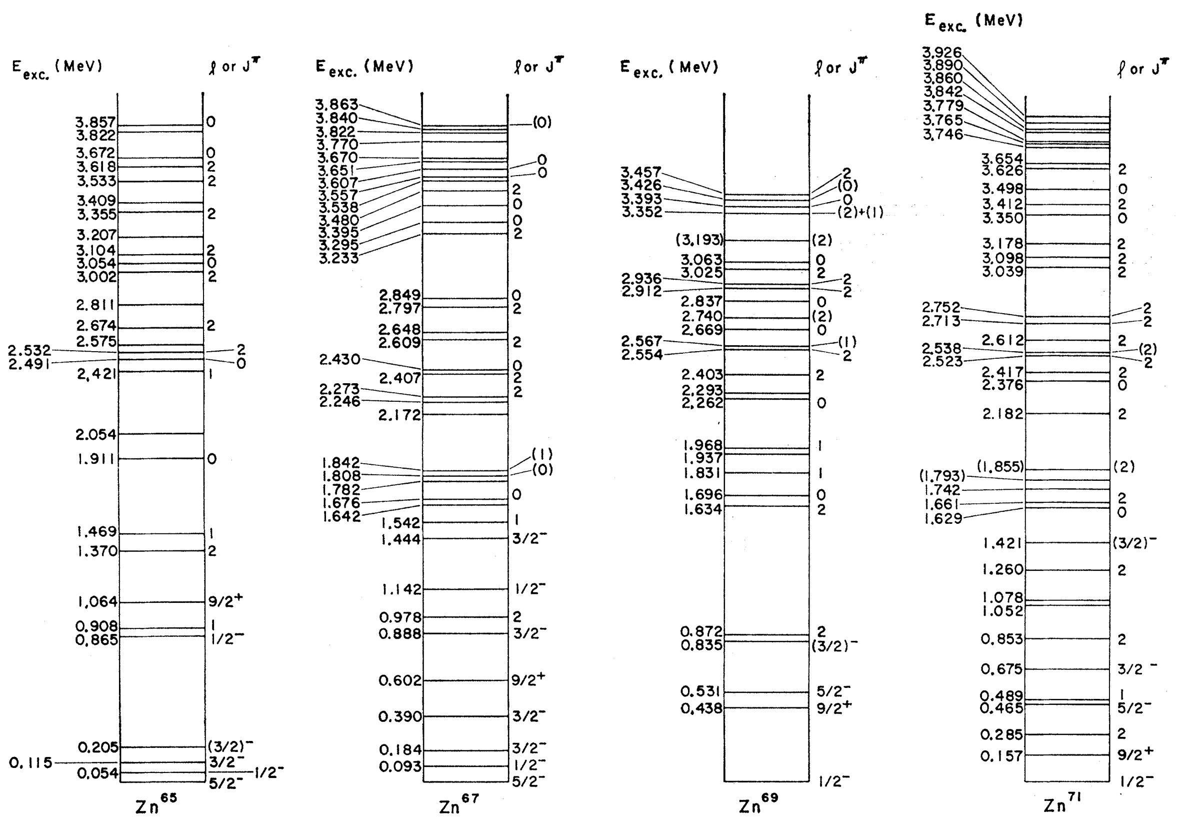

FIG. 2. Excitation energies and the values of J^π or l in the final nuclei. Uncertainties are about ±5 keV for the lower excitation energies and about ±10 keV for the higher. The 0.888-MeV level of Zn^{67} with $J^\pi = \frac{3}{2}^-$ is taken from Ref. 16. (For details, see the Discussion.)

distorting parameters, adapted from Perey,[11,12] are given in Table VI. Hulthén wave functions were employed. The DWBA curves were calculated without spin-orbit coupling and without cutoff. Introduction of spin-orbit coupling did not produce any appreciable change in the curves. A lower cutoff at $A^{1/3}\times 1.25$ F decreased forward maxima by $\lesssim 10\%$. The spectroscopic factor S multiplied by $(2J+1)$ was deduced from the peak cross sections as usual by use of the relation

$$\sigma(\max)_{\exp}/\sigma(\max)_{\mathrm{DWBA}}=(2J+1)S\,.$$

These values are included in column 5 in Tables II–IV.

To estimate the dependence of the DWBA results on the deuteron-potential parameters, an additional calculation was performed with a different set of parameters.[13] These parameters (line 2 of Table VI)

TABLE IV. Summary of results from $Zn^{68}(d,p)$ reactions.

E_x (MeV)	l	J^π	$\sigma_{\max}$ (mb/sr)	$(2J+1)S$ (Refs. 11, 12)	$(2J+1)S$ (Refs. 11, 13)
0.0	1	$\frac{1}{2}^-$	4.1	0.80	1.10
0.438	4	$\frac{9}{2}^+$	1.2	5.5	9.0
0.531	3	$\frac{5}{2}^-$	0.42	0.97	1.17
0.835	1	$(\frac{3}{2})^-$ [a]	2.2	0.37	0.53
0.872	2	$(\frac{5}{2})^+$	2.5	0.72	0.99
1.634	2	$(\frac{5}{2})^+$	1.8	0.45	0.61
1.696	0	$\frac{1}{2}^+$	6.3[b]	0.19	0.21
1.831	1	$\frac{1}{2}^-, \frac{3}{2}^-$ [a]	0.25	0.04	0.05
1.937	...[c,d]		~0.15		
1.968	1	$\frac{1}{2}^-, \frac{3}{2}^-$ [a]	0.15	0.02	0.03
2.262	0	$\frac{1}{2}^+$	1.0[b]	0.03	0.03
2.293	...[c]		~0.15		
2.403	2	$(\frac{5}{2})^+$	1.5	0.33	0.43
2.554[e]	2	$(\frac{5}{2})^+$	(0.35)	(0.07)	(0.1)
2.567[e]	(1)	$(\frac{1}{2}^-,\frac{3}{2}^-)$ [a]	(0.5)	(0.07)	(0.1)
2.669	0	$\frac{1}{2}^+$	4.8[b]	0.15	0.16
2.740	(2)	$(\frac{5}{2}^+)$	~0.1	(~0.02)	(~0.03)
2.837	0	$\frac{1}{2}^+$	1.0[b]	0.03	0.03
2.912	2	$(\frac{5}{2})^+$	0.73	0.14	0.18
2.936[f]	2	$(\frac{5}{2})^+$	0.64	0.12	0.16
3.025	2	$(\frac{5}{2})^+$	2.0	0.39	0.50
3.063[f]	0	$\frac{1}{2}^+$	1.0[b]	0.03	0.03
(3.193)[f]	(2)	$(\frac{5}{2}^+)$	0.18	(0.04)	(0.05)
3.352[e]	{ (2)	$(\frac{5}{2}^+)$	(0.18)	(0.03)	(0.04)
	(1)	$(\frac{1}{2}^-,\frac{3}{2}^-)$	(0.18)	(0.02)	(0.03)
3.393[f]	0	$\frac{1}{2}^+$	4.2[b]	0.13	0.15
3.426[f]	(0)	$(\frac{1}{2}^+)$	0.6[b]	0.02	0.02
3.457	(2)[d]	$(\frac{5}{2}^+)$	(~1.1)	(0.2)	(0.25)

[a] No reliable data at backward angles.
[b] At $\theta_{\mathrm{lab}}=5°$.
[c] No l assignment possible.
[d] Incomplete data.
[e] Not resolved.
[f] Probably several unresolved levels.

TABLE V. Summary of results from $Zn^{70}(d,p)$ reactions.[a]

E_x (MeV)	l	J^π	$\sigma_{\max}$ (mb/sr)	$(2J+1)S$ (Refs. 11, 12)	$(2J+1)S$ (Refs. 11, 13)
0.0	1	$\frac{1}{2}^-$	3.8	0.67	0.95
0.157	4	$\frac{9}{2}^+$	0.8	3.6	5.8
0.285	2	$(\frac{5}{2})^+$	0.45	0.14	0.19
0.465[b]	3	$\frac{5}{2}^-$	0.3	0.62	0.76
0.489[b]	1	$\frac{1}{2}^-, \frac{3}{2}^-$ [c]	0.34	0.06	0.08
0.675	1	$\frac{3}{2}^-$	1.0	0.16	0.23
0.853	2	$(\frac{5}{2})^+$	1.1	0.31	0.42
1.052[b]	...[d]		~0.2		
1.078[c]	...[d]		~0.15		
1.260	2	$(\frac{5}{2})^+$	0.24	0.06	0.08
1.421	1	$(\frac{3}{2})^-$ [c]	0.43	0.06	0.09
1.629	0	$\frac{1}{2}^+$	6.4[e]	0.27	0.29
1.661	2	$(\frac{5}{2})^+$	2.8	0.65	0.86
1.742	...[d]		~0.09		
(1.793)	...[d]		~0.12[e]		
(1.855)	(2)	$(\frac{5}{2}^+)$	~0.11	(0.02)	(0.03)
2.182	2	$(\frac{5}{2})^+$	0.9	0.18	0.23
2.376	0	$\frac{1}{2}^+$	5.7[e]	0.22	0.24
2.417	2	$(\frac{5}{2})^+$	0.34	0.07	0.09
2.523[b]	2	$(\frac{5}{2})^+$	1.3	0.25	0.32
2.538[b]	(2)	$(\frac{5}{2}^+)$	(0.5)	(0.09)	(0.1)
2.612	2	$(\frac{5}{2})^+$	0.39	0.08	0.1
2.713	2	$(\frac{5}{2})^+$	0.22	0.04	0.05
2.752	2	$(\frac{5}{2})^+$	1.0	0.19	0.24
3.039	2	$(\frac{5}{2})^+$	0.9	0.16	0.20
3.098	2	$(\frac{5}{2})^+$	0.44	0.07	0.09
3.178	2	$(\frac{5}{2})^+$	0.9	0.16	0.20
3.350	0[d]	$\frac{1}{2}^+$	0.66[e]	0.03	0.03
3.412	2[d]	$(\frac{5}{2})^+$	0.41	0.07	0.08
3.498	0[d]	$\frac{1}{2}^+$	1.89[e]	0.07	0.09
3.626	2[d]	$(\frac{5}{2})^+$	1.1	0.17	0.21
3.654	...[d]		~0.5		
3.746[a]	...[d]		0.25[e]		
3.765[a]	...[d]		0.40[e]		
3.779[a]	...[d]		0.77[e]		
3.842[a]	...[d]		0.56[e]		
3.860[a]	...[d]		0.62[e]		
3.890	...[d]		0.75[e]		
3.926	...[d]		0.35[e]		

[a] After completion of our work we learned about an investigation of the $Zn^{70}(d,p)Zn^{71}$ reaction by V. P. Bochin, K. I. Zherebtsova, V. A. Komarov, L. V. Krasnov, V. F. Litvin, and Y. A. Nemilov, [Vestn. Leningrad Univ. **10**, Ser. Fiz. i. Khim. **2**, 34 (1965)], with the following results; $E_x=0.0$ MeV ($l_n=1$); 0.67 MeV ($l_n=1$); 0.84 MeV; 1.29 MeV; 1.63 MeV ($l_n=0$); 2.34 MeV ($l_n=1$); 3.75 MeV.
[b] Unresolved.
[c] No angular distributions (or only unresolved ones) at backwards angles.
[d] Data incomplete or contaminated.
[e] At $\theta_{\mathrm{lab}}=7.5°$.

resulted in somewhat larger values of $(2J+1)S$, especially for $l=4$ transitions. They are listed in column 6 in Tables II–V.

DISCUSSION

Our improved energy resolution and statistics enabled us to observe quite a number of previously[3] unreported or unresolved levels in the spectra with Zn^{64}, Zn^{66}, and Zn^{68} as targets. The level scheme of $Zn^{70}(d,p)Zn^{71}$ is entirely new. Transferred orbital angular momenta

[11] F. G. Perey, Phys. Rev. **131**, 745 (1963).
[12] C. M. Perey and F. G. Perey, Phys. Rev. **132**, 755 (1963).
[13] Parameters obtained by G. R. Satchler (private communication) by fitting the elastic deuteron scattering from Fe^{54} [L. L. Lee, Jr., and J. P. Schiffer (to be published)]. The preference for such large imaginary radii was also found recently in the analysis of elastic scattering of 11.8-MeV deuterons by Fe, Ni, Cu, and Zn [F. G. Perey and G. R. Satchler, Nucl. Phys. **A97**, 515 (1967)].

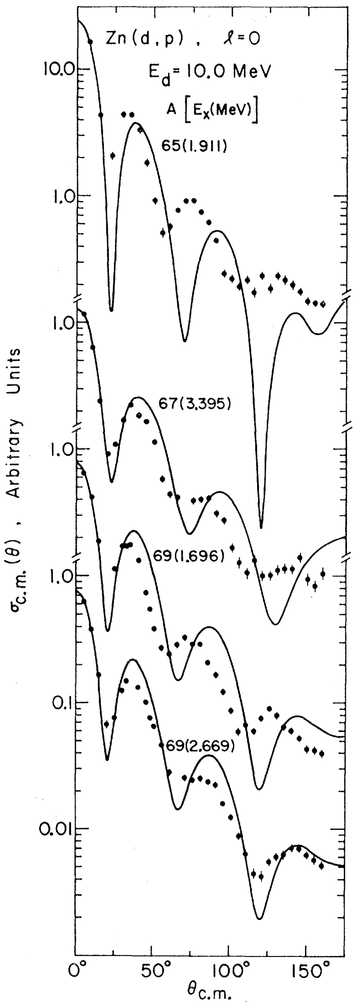

FIG. 3. Some angular distributions and DWBA calculations for $l=0$. The statistical errors are shown wherever they are greater than the diameters of the points. The values of A and the excitation energies E_x in the final nuclei are indicated.

could be assigned to most of the newly discovered levels; some of the previous (tentative) angular momentum assignments had to be corrected.

Apart from improved energy resolution and counting statistics, the main point of this investigation was to obtain complete angular distributions in order to distinguish between the spin assignments $\frac{1}{2}$ and $\frac{3}{2}$ in the $l=1$ transitions.[14] According to the empirical rules,

TABLE VI. Distorted-wave Born approximation DWBA parameters[a] used in the calculations.

Particle	V_S (MeV)	W (MeV)	r_{0S} (F)	a_s (F)	r_{0I} (F)	a_I (F)	r_{0c} (F)	Reference
d	94.0	19.0	1.15	0.81	1.34	0.68	1.30	12
	74.2	19.9	1.26	0.794	1.528	0.557	1.20	13
p	50.5 (Zn^{67}) 53.5 (Zn^{71})	13.4	1.25	0.65	1.25	0.47	1.30	11

[a] A surface-absorption Saxon-derivative potential was used. The notation is the same as in Ref. 12.

[14] L. L. Lee, Jr., and J. P. Schiffer, Phys. Rev. Letters **12**, 108 (1964); L. L. Lee, Jr., and J. P. Schiffer, Phys. Rev. **136**, B405 (1964); J. P. Schiffer, L. L. Lee, Jr., A. Marinov, and C. Mayer-Böricke, *ibid.* **147**, 829 (1966).

TABLE VII. J dependence effect for the $l=1$ levels. The ratio R (defined in the text) is a measure of the depth of the minimum ("dip") at backward angles.

A of final nucleus	Excitation (MeV)	S[a]	R	Spin
65	0.054	0.28	1.01	$\frac{1}{2}$
65	0.865	0.27	(0.77)[b]	$\frac{1}{2}$
67	0.093	0.41	1.29	$\frac{1}{2}$
67	1.142	0.13	0.97	$\frac{1}{2}$
69	0.0	0.40	1.2	$\frac{1}{2}$
71	0.0	0.34	0.93	$\frac{1}{2}$
65	0.115	0.27	0[c]	$\frac{3}{2}$
67	0.184	0.015	0[c]	$\frac{3}{2}$
67	0.390	0.19	0.45	$\frac{3}{2}$
71	0.675	0.04	0.4	$\frac{3}{2}$

[a] This spectroscopic factor S has been computed from the values $(2J+1)S$ in column 5, Tables II–V.
[b] The solid-state data from which R was calculated contain the unresolved level at 0.908 MeV.
[c] No "dip."

angular distributions of $\frac{1}{2}^-$ levels show a "dip" at medium or backward angles which is absent or much less pronounced in the angular distributions of $\frac{3}{2}^-$ levels.

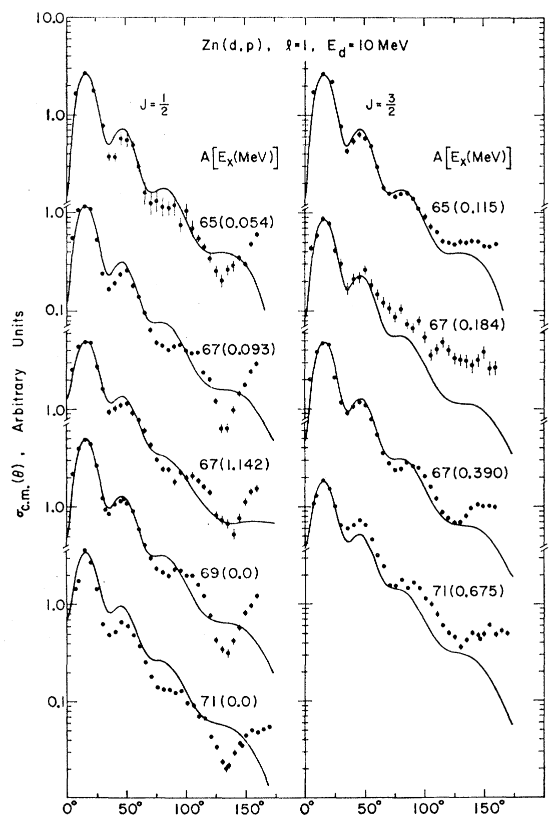

FIG. 4. Some angular distributions and DWBA calculations for $l=1$. The left-hand curves are for $J=\frac{1}{2}$; those at the right are for $J=\frac{3}{2}$. The statistical errors are shown wherever they are larger than the diameters of the points. The values of A and the excitation energies E_x in the final nuclei are indicated.

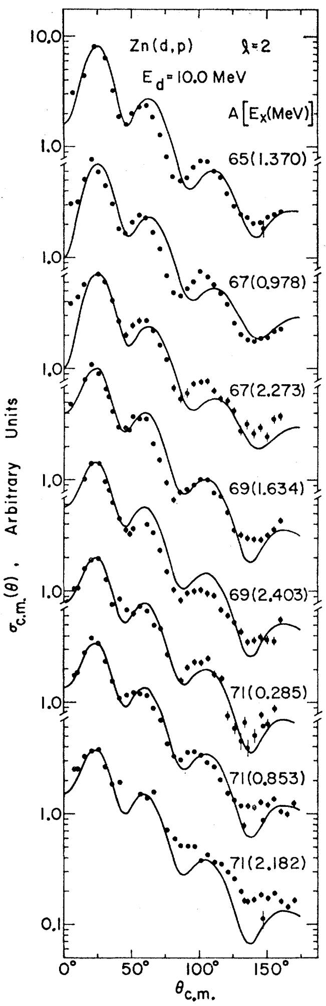

FIG. 5. Some angular distributions and DWBA calculations for $l=2$. The statistical errors are shown unless they are equal to or smaller than the diameters of the points. The values of A and the excitation energies E_x in the final nuclei are indicated.

To illustrate and apply this rule in the present case, full angular distributions of all the $l=1$ levels clearly resolved by solid-state detectors are displayed in Fig. 4 according to their J assignments.

To establish a quantitative value for this dip as a guide in the J assignment, the definition[15]

$$R=\frac{\bar{\sigma}_{\max}-\sigma_{\min}}{\frac{1}{2}(\bar{\sigma}_{\max}+\sigma_{\min})}$$

was recently introduced. Here $\sigma_{\min}$ is the cross section at the minimum of the dip and $\bar{\sigma}_{\max}$ is the average of the maximum cross sections on either side of the dip (or just the maximum behind the minimum). The latter definition of $\bar{\sigma}_{\max}$ was used in the present evaluation because of the steepness of the angular distributions. The results of this evaluation are summarized in Table VII. The $\frac{1}{2}^-$ assignments correspond to angular distributions with $R\gtrsim 0.8$. The two angular distributions for which R is 0.4 and 0.45 would have to be regarded as questionable $\frac{3}{2}^-$ states according to Ref. 15, but in the present case it is felt that even these two assignments are reasonable since the gap between the R values for $\frac{1}{2}^-$ levels and the R values for $\frac{3}{2}^-$ levels is very pronounced.

As an example of a correction on the basis of the J dependence rules, we would like to mention the reassignment of two levels in the Zn^{67} spectrum. The 0.093-MeV level, which in previous (d,p) work[3] was believed to be $\frac{3}{2}^-$ was reassigned $\frac{1}{2}^-$; and the 0.184-MeV level, previously believed to be $\frac{5}{2}^-$, was assigned as $\frac{3}{2}^-$. The present findings led Freedman *et al.*[16] to reinvestigate and reevaluate the β-γ decay of Ga^{67}. The resulting level scheme and spin assignments are in

TABLE VIII. Sums of the experimental values of $(2J+1)S$ for $l=1$, 3, and 4 for the measured $Zn(d,p)$ reactions.

Target nucleus	Zn^{64}		Zn^{66}		Zn^{68}		Zn^{70}	
Reference	a	b	a	b	a	b	a	b
$l=1$	2.52	3.26	1.96	2.70	1.32	1.84	0.95	1.35
$l=3$	2.8	3.1	1.7	1.8	0.97	1.17	0.62	0.76
$l=4$	4.9	7.8	5.1	8.4	5.5	9.0	3.6	5.8
Sum for $l=1$, 3, and 4	10.2	14.2	8.8	12.9	7.8	12.0	5.2	7.9
Expectation	16		14		12		10	

[a] These values were calculated with the deuteron parameters (Table VI) of Perey and Perey (Ref. 12).
[b] These values were calculated with the deuteron parameters (Table VI) of Satchler (Ref. 13).

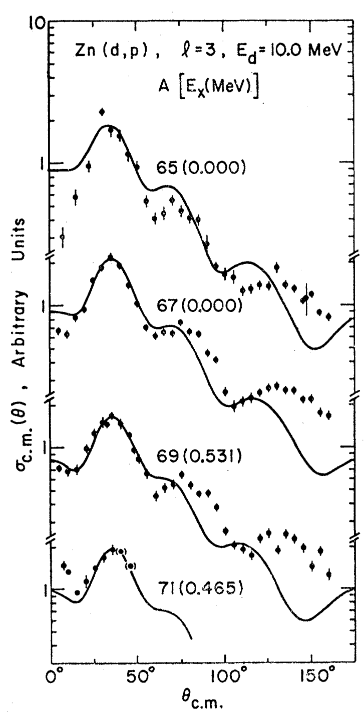

FIG. 6. The angular distributions for $l=3$, compared with DWBA calculations. The statistical errors are shown unless they are equal to or smaller than the diameters of the points. The values of A and the excitation energies E_x in the final nuclei are indicated. The points in parentheses in the curve for the 0.465-MeV level of Zn^{71} were obtained by subtracting the extrapolated $l=1$ distribution of the 0.489-MeV level from the unresolved data from the solid-state counter.

[15] L. L. Lee, Jr., and J. P. Schiffer, Phys. Rev. **154**, 1097 (1967).
[16] M. S. Freedman, F. T. Porter, and F. Wagner, Phys. Rev. **151**, 886 (1966).

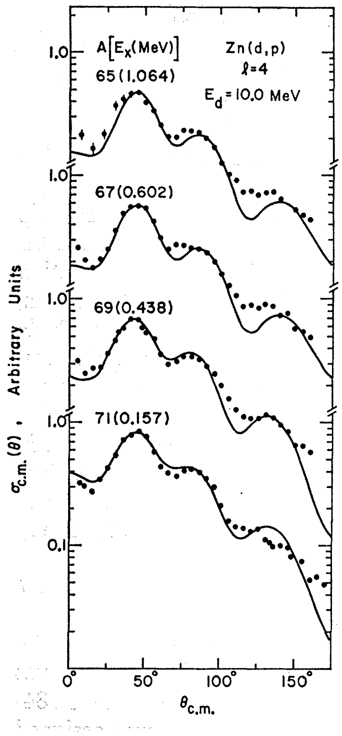

FIG. 7. The angular distributions for $l=4$, compared with DWBA calculations. The statistical errors are shown unless they are equal to or smaller than the diameters of the points. The A and the excitation energies E_x of the final nuclei are indicated.

agreement with this experiment and with earlier work[4] on the angular distributions of γ radiation following Coulomb excitation. Because of their use of Ge(Li) counters, Freedman *et al.* obtained much more accurate energy values for the observed lower levels than can be achieved with the present experimental method. In addition, they observed a level at $E_x=887.87\pm0.1$ keV with $J^\pi=\frac{3}{2}^-$, which we find to be populated very weakly [$\sigma(15°)\approx0.01$ mb/sr, $\sigma(40°)\approx0.005$ mb/sr] in this experiment. This level has been reported[3] to appear much more strongly ($\sigma_{\max}\approx0.5$ mb/sr) at $E_d=15$ MeV.

Thwaites and Pratt[17] investigated the β-γ decay of isomeric Zn^{71} and tentatively assigned a spin of $\frac{1}{2}^-$ to one state in Zn^{71} and a spin of $\frac{9}{2}^+$ to another state at 0.34±0.1-MeV higher excitation energy. They were unable to observe the transition between these two levels, although it would be expected to proceed with a reasonable intensity. In the light of the present work, these two levels are obviously the $\frac{1}{2}^-$ ground state and the $\frac{9}{2}^+$ first excited state at 0.157 MeV in the Zn^{71} spectrum.

Table VIII gives the sums of the experimental values of $(2J+1)S$ for the $l=1$, 3, and 4 levels. These l values are the orbital angular momenta of the neutrons filling the $2p_{3/2}$, $1f_{5/2}$, $2p_{1/2}$, and $1g_{9/2}$ states in the shell between $N=28$ and $N=50$. A total of $(2J+1)$ neutrons can be in each of these states. In a stripping reaction the sum of $(2J+1)S$ should be equal to the number of neutron holes present in the target for the state under consideration. In particular, Zn^{64} has $50-34=16$ neutrons less than would be needed to close the shell. Adding the sums of $(2J+1)S$ for $l=1$, 3, and 4 from Table VIII using the deuteron parameters of Perey and Perey,[12] one obtains only 10.2 instead of the expected 16. On the other hand, if one used DWBA calculations with the parameters of Satchler,[13] the sum in question is 14.2; within the experimental accuracy of about 10%, this is equal to the expected 16. The change is mostly in the $l=4$ strength, which seems to be the most sensitive to the choice of deuteron parameters. This result may indicate a slight preference for the deuteron parameters of Ref. 13 over those of Ref. 12. The same conclusion can be drawn from the results on the other isotopes.

Levels for the observed transitions with $l=0$ and $l=2$ must be attributed in this case to the shell above neutron number $N=50$; they usually were observed at higher excitation energies. Since the present investigation was limited to excitation energies below 4 MeV, it has to be expected that the full strength of the $l=0$ and the $l=2$ transitions is not exhausted here.

Another way of representing some of the gross features of the data is shown in Fig. 8, in which $\sum S_i$ is plotted as a function of the excitation energies of the centers of gravity of the observed levels. These centers

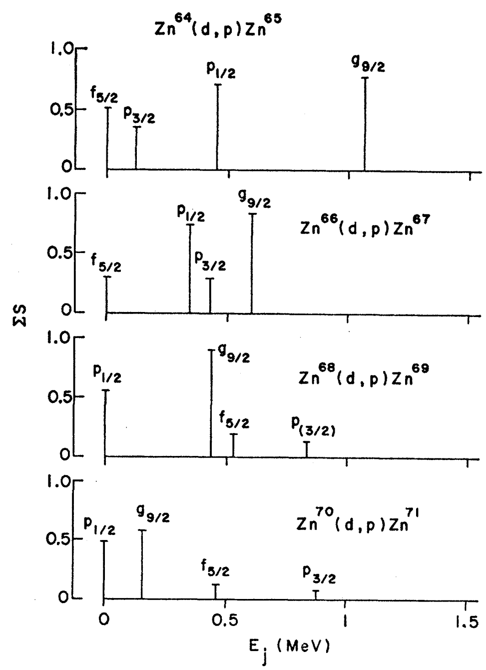

FIG. 8. The sums of the spectroscopic factors S calculated with the deuteron parameters of Ref. 13, plotted as a function of the center of gravity for the different isotopes and the indicated levels. For details and discussion see text.

[17] T. T. Thwaites and W. W. Pratt, Phys. Rev. **124**, 1526 (1961).

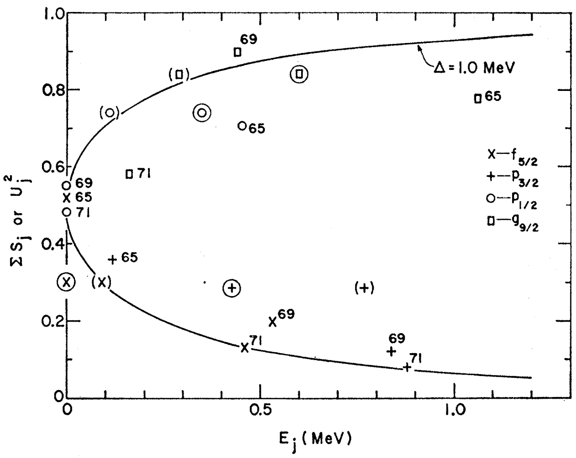

FIG. 9. Comparison of summed spectroscopic factors and center-of-gravity energies for the $1f_{5/2}$, $2p_{1/2}$, $2p_{3/2}$, and $1g_{9/2}$ states with the pairing theory. The curve was calculated by the method described in the text. Different Zn isotopes are identified by numbers next to the points except for Zn^{67}, for which the points are circled, and the recalculated points for Zn^{67} (with the Fermi surface above the ground-state quasiparticle energy by 0.43 MeV) which are in parentheses. Uncertainties in the points are $\sim$10% in $\sum S_i$ because of experimental uncertainties. Uncertainties from choice of optical-model parameters or possible missed levels at high excitation energies cannot be estimated reliably.

of gravity were calculated according to the relation

$$E(j)=\sum_i E_i(j)S_i(j)/\sum_i S_i(j),$$

where $E_i(j)$ and $S_i(j)$ are the energies and spectroscopic factors of the observed states with a given j. The second set of S_i (column 6) from Tables II–V were used. For the reasons given above, the values for $l=0$ and 2 are not included. This representation gives a qualitative picture of the degree of filling of the levels with $l=1$, 3, and 4 as one goes to heavier isotopes. The energy of the center of gravity should decrease in going to heavier isotopes if the subshell is less than half filled, and it should increase if the subshell is more than half filled. In this picture the $f_{5/2}$ subshell is about half-filled in the lighter isotopes (Zn^{64} and Zn^{66}); the $p_{1/2}$ subshell is about half-filled in the heavier isotopes (Zn^{68} and Zn^{70}); the $p_{3/2}$ subshell is already more than half filled in Zn^{64}; while the $g_{9/2}$ subshell is still less than half-filled in Zn^{70}. These statements are in agreement with the well-established shell-model sequence of these subshells.

The pairing theory predicts a relationship between the center-of-gravity energies and the extent of filling of single-particle states.[18,19] A comparison with the calculations from pairing theory is shown in Fig. 9.

[18] L. S. Kisslinger and R. A. Sorensen, Kgl. Danske Videnskab. Selskab, Mat. Fys. Medd. **32**, No. 9 (1960).

[19] B. L. Cohen and R. E. Price, Phys. Rev. **121**, 1441 (1961).

This gives the equation (U_j^2 is a measure of the "emptiness" of the state j)

$$\sum_i S_i(j)=U_j^2=\frac{1}{2}\left\{1+\frac{\epsilon_j-\lambda}{[(\epsilon_j-\lambda)^2+\Delta^2]^{1/2}}\right\}$$

and the center-of-gravity energies[19]

$$E(j)=[(\epsilon_j-\lambda^2+\Delta^2]^{1/2}+\text{const}, \qquad (1)$$

where Δ is the pairing energy, the ϵ_j are the single-quasiparticle energies, and λ is the mean energy of the Fermi surface. We set the constant in Eq. (1) equal to $-\Delta$; this corresponds to setting $E(j)=0$ for the single-quasiparticle state which is half filled ($U_j^2=0.5$, $\epsilon_j=\lambda$). Eliminating $\epsilon_j-\lambda$, we obtain

$$\sum_i S_i(j)=U_j^2=\frac{1}{2}\left\{1+\frac{\{[E(j)+\Delta]^2-\Delta^2\}^{1/2}}{E(j)+\Delta}\right\}.$$

The curve calculated from this equation with $\Delta=1$ MeV is displayed in Fig. 9. For all the isotopes except Zn^{67} (points in big circles) the single-quasiparticle state with the lowest excitation energy seems to have $U_j^2\approx0.5$ and thus $E(j)=0$ and $\epsilon_j\approx\lambda$. For Zn^{67} this was not adequate and therefore we recalculated the $E(j)$ from Eq. (1), with $\epsilon_{5/2}-\lambda=-0.43$ MeV chosen to give agreement for the $f_{5/2}$ ground state. These recalculated points are shown in parentheses in Fig. 9.

It should be noted that this form of comparison eliminates the ϵ_j from the pairing theory. The only parameter we chose was $\Delta=1$ MeV; a choice of $\Delta=2$ MeV made no great difference in the quality of fit to the data. The qualitative agreement with the pairing theory is reasonably good, the $S_i(j)$ are again those corresponding to the deuteron parameters of Ref. 13.

ACKNOWLEDGMENTS

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APPENDIX

The absolute differential cross sections are given in Tables IX–XII. Their statistical accuracy is roughly $0.04\sqrt{\sigma}$ for forward angles and $0.02\sqrt{\sigma}$ for backward angles, where σ is in mb/sr. There is an additional $\sim$10% uncertainty in the absolute cross section.

TABLE IX. Differential cross sections (mb/sr) for the reaction $Zn^{64}(d,p)Zn^{65}$.

θ_{lab} (deg) \ E_x (MeV) =	0.000	0.054	0.115	0.205	1.064	1.370	1.911	2.421
7.5	0.12	1.37	2.80	0.16	0.45	1.23	4.13	0.48
15	0.23	2.18	4.31	0.24	0.35	1.77	1.08	0.55
22.5	0.38	1.47	3.57	0.16	0.45	3.29	0.504	0.50
30	0.90	0.63	1.28	0.064	0.77	2.58	1.09	0.23
35	0.67	0.31	0.72	0.088	0.88	1.29	1.07	0.14
40	0.62	0.31	0.88	0.074	0.97	0.76	0.82	0.18
45	0.46	0.49	1.01	0.077	0.99	0.65	0.46	0.19
50	0.37	0.46	0.95	0.074	0.83	0.81	0.22	0.17
55	0.21	0.41	0.78	0.055	0.70	0.91	0.13	0.18
60	0.16	0.24	0.48	0.043	0.54	0.94	0.14	0.12
65	0.17	0.13	0.29	0.034	0.43	0.75	0.19	0.10
70	0.22	0.10	0.26	0.021	0.43	0.50	0.22	0.071
75	0.18	0.11	0.24	0.020	0.49	0.32	0.22	0.049
80	0.16	0.11	0.26	0.021	0.48	0.22	0.18	0.053
85	0.16	0.093	0.26	0.020	0.47	0.20	0.15	0.047
90	0.11	0.14	0.23	0.021	0.42	0.21	0.107	0.035
95	0.073	0.061	0.18	0.020	0.36	0.26	0.060	0.035
100	0.064	0.088	0.16	0.017	0.26	0.29	0.060	0.042
105	0.062	0.058	0.12	0.016	0.21	0.29	0.061	0.043
110	0.049	0.045	0.10	0.012	0.19	0.24	0.053	0.038
115	0.050	0.036	0.083	0.0073	0.15	0.21	0.042	0.034
120	0.054	0.028	0.080	0.0049	0.16	0.15	0.057	0.027
125	0.053	0.021	0.078	0.0081	0.14	0.12	0.045	0.039
130	0.067	0.0093	0.084	0.0059	0.12	0.088	0.057	0.029
135	0.055	0.022	0.080	0.0084	0.15	0.092	0.054	0.022
140	0.052	0.024	0.084	0.0073	0.14	0.081	0.048	0.040
145	0.042	0.028	0.082	0.0073		0.083	0.043	
147	0.044	0.018			0.082	0.073		
150	0.047	0.024	0.074	0.010	0.11	0.092	0.036	
155	0.035	0.039	0.073	0.0069	0.099	0.098	0.035	
160	0.032	0.049	0.077	0.011	0.091	0.102	0.035	

θ_{lab} (deg) \ E_x (MeV) =	2.054	2.674	2.811	3.207	3.355	3.409	3.533	3.618	3.672
7.5	0.062	0.041	0.10	0.078	0.18	0.070	0.48	0.43	4.36
15	0.055	0.16	0.046		0.15	0.180	0.82	0.80	1.42
20	0.17								
22.5	0.095	0.28	0.20		0.36	0.19	1.21	1.34	0.65
30	0.11	0.19	0.20	0.15		0.22	0.91	1.13	1.30
35	0.089	0.16	0.15	0.086	0.19	0.13	0.61	0.58	1.27
40	0.088	0.056	0.12	0.14	0.12	0.14		0.42	1.04
45	0.074	0.079	0.12	0.16	0.11	0.087	0.32	0.33	
50	0.070	0.062	0.10	0.12	0.14	0.12	0.28	0.30	0.44
55	0.043	0.092	0.10	0.12	0.12	0.10	0.35	0.33	0.29
60	0.057	0.092	0.082	0.076	0.12	0.067	0.33	0.28	0.22
65	0.049	0.091	0.072	0.070	0.090	0.077	0.29	0.33	0.19
70	0.045	0.056	0.062	0.060	0.11	0.080	0.24	0.23	0.22
75	0.056	0.043	0.048	0.082	0.054	0.047	0.19	0.17	0.24
80	0.053	0.024	0.058	0.077	0.060	0.058	0.16	0.14	0.23
85	0.036	0.026	0.045	0.070	0.050	0.043	0.095	0.094	0.21
90	0.033								
95	0.038								
130		0.0088		0.035		0.028	0.028	0.050	
147							0.029		0.044

θ_{lab} (deg) \ E_x (MeV) =	0.865	0.908	1.469	2.491	2.532	2.575	3.002	3.054
7.5	1.49	0.30	0.20	0.18	0.18	0.14	0.099	1.88
15	2.43	0.63	0.25	0.076	0.25	0.14	0.22	0.42
22.5	1.80	0.57	0.18	0.029	0.43	0.091	0.28	0.16
30	0.64	0.22		0.083	0.35	0.14	0.17	0.50
35	0.39	0.14	0.052	0.056	0.28	0.036	0.10	0.54
40	0.37	0.14			0.21	0.095	0.099	0.46
45	0.52	0.16	0.060	0.048	0.25	0.044	0.076	0.32
55	0.46	0.13	0.065	0.040	0.20	0.045	0.093	0.077
130	0.013	0.024	0.0088		0.013			
147	0.038	0.015			0.023	0.0058		

θ_{lab} (deg) \ E_x (MeV) =	3.104	3.822	3.857
7.5		0.22	1.24
15	0.30	0.29	0.53
22.5	0.48	0.28	0.17
30	0.41	0.21	0.46
35	0.26	0.12	0.48
40	0.16	0.13	0.35
45	0.13	0.17	0.33
55	0.17	0.13	0.10
130		0.029	0.042

TABLE X. Differential cross sections (mb/sr) for the reaction $Zn^{66}(d,p)Zn^{67}$.

θ_{lab} (deg) \ E_x (MeV) =	0.000	0.093	0.184	0.390	0.602	0.978	1.142	1.444	2.273	3.395
5	0.17	1.76	0.15	1.57	0.51	1.48	0.78	0.19	0.35	4.43
10	0.16	3.43	0.19	3.02	0.40	1.53	1.31		0.40	2.46
15	0.21	3.74	0.29	3.66	0.35	2.44	1.49	0.25	0.53	0.89
20	0.24	3.52	0.26	3.58	0.41	3.69	1.48			0.35
25	0.39	1.69	0.15	1.63	0.53	2.85	0.80	0.16	0.66	0.41
30	0.48	0.78	0.097	0.93	0.73	2.13	0.49	0.11	0.56	0.65
35	0.56	0.53	0.055	0.72	0.96	1.47	0.29	0.10	0.37	0.85
40	0.48	0.62	0.072	0.83	1.09	0.87	0.31	0.11	0.25	0.70
45	0.36	0.75	0.073	0.92	1.09	0.79	0.34	0.096	0.18	0.63
50	0.26	0.83	0.088	0.85	1.07	1.01	0.35	0.10	0.22	0.43
55	0.18	0.59	0.061	0.62	0.83	1.13	0.28	0.074	0.24	0.22
60	0.16	0.45	0.049	0.43	0.61	1.09	0.24	0.056	0.25	0.17
65	0.17	0.31	0.040	0.27	0.50	0.80	0.18	0.029	0.20	0.16
70	0.16	0.21	0.035	0.22	0.54	0.57	0.13	0.024	0.15	
75	0.20	0.15	0.029	0.19	0.53	0.32	0.092	0.019	0.11	0.15
80	0.17	0.14	0.034	0.19	0.50	0.23	0.074	0.029	0.061	0.15
85	0.16	0.13	0.024	0.22	0.50	0.22	0.073	0.023	0.049	0.15
90	0.12	0.14	0.022	0.20	0.47	0.25	0.055	0.031	0.055	0.12
95	0.11	0.15	0.026	0.19	0.39	0.29	0.068	0.024	0.066	0.10
100	0.063	0.13	0.018	0.16	0.31	0.36	0.060	0.018	0.069	0.063
105	0.049	0.12	0.012	0.13	0.25	0.31	0.064	0.016	0.071	0.047
110	0.053	0.12	0.013	0.095	0.21	0.27	0.056	0.013	0.058	0.040
115	0.057	0.075	0.015	0.068	0.17	0.23	0.049	0.012	0.049	0.051
120	0.062	0.064	0.013	0.059	0.17	0.18	0.043	0.015	0.046	0.038
125	0.067	0.038	0.011	0.053	0.16	0.12	0.025	0.011	0.038	0.038
130	0.069	0.020	0.010	0.054	0.18	0.096	0.022	0.010	0.025	0.042
135	0.065	0.020	0.010	0.063	0.17	0.085	0.020	0.0096	0.028	0.043
140	0.064	0.031	0.0092	0.076	0.14	0.083	0.016	0.011	0.023	0.043
145	0.055	0.046	0.010	0.084	0.15	0.089	0.023	0.018	0.027	0.052
150	0.056	0.057	0.012	0.079	0.12	0.090	0.034	0.0076	0.022	0.036
155	0.044	0.077	0.0084	0.079	0.11	0.10	0.044	0.0094	0.032	0.032
160	0.043	0.092	0.0087	0.078	0.094	0.11	0.048	0.016	0.034	0.040

θ_{lab} (deg) \ E_x (MeV) =	1.542	1.642	1.676	1.782	1.808	1.842	2.246	2.407
5	0.074	0.086	7.49	0.050	0.065	0.069		0.45
10		0.062	4.36	0.040	0.042	0.057	0.062	0.33
15	0.12	0.050	1.16	0.063	0.030	0.065		0.51
20	0.11	0.057	0.36	0.064	0.033	0.055		0.61
25	0.073	0.057	0.76	0.055	0.023	0.038	0.041	0.65
30	0.049	0.048	1.19	0.063	0.037	0.030	0.033	
35	0.051	0.059	1.44	0.053	0.063	0.020	0.018	0.42
40	0.037	0.034	1.10	0.037	0.062	0.021	0.027	0.31
45	0.037	0.041	0.56	0.041	0.065	0.015	0.032	0.30
55	0.025	0.058	0.14	0.027	0.044			0.27

θ_{lab} (deg) \ E_x (MeV) =	2.430	2.609	2.648	2.797	2.849	3.233	3.295	3.480
5	4.30	0.066	0.094	0.36	0.20	0.18	1.40	
10	2.28	0.10	0.079	0.45	0.15	0.21	0.92	0.17
15	0.89	0.14	0.11	0.61	0.079	0.26	0.44	0.23
20	0.29	0.16	0.11	0.86	0.038	0.32	0.30	
25	0.39	0.19	0.082	0.86	0.049	0.30	0.31	
30		0.13	0.071	0.66	0.064	0.25	0.40	0.22
35	0.74	0.089	0.076	0.51	0.071	0.30	0.39	0.17
40	0.61			0.37	0.055	0.14		0.14
45	0.40	0.048	0.040	0.25	0.062	0.099	0.20	0.10
55	0.17	0.052	0.041	0.26	0.039	0.11	0.14	0.12

θ_{lab} (deg) \ E_x (MeV) =	3.538	3.557	3.607	3.770	3.863
5					
10					
15	3.76	2.08	0.84	0.86	
20	3.58	0.67	0.27	0.53	0.32
25	4.04	0.72		0.56	0.35
30	2.60	1.05	0.53	0.54	0.45
35	1.63	1.30	0.60	0.55	0.52
40	0.79	1.18	0.58	0.36	0.48
45		0.78	0.41	0.24	0.32
55			0.19	0.25	0.18

TABLE XI. Differential cross sections (mb/sr) for the reaction $Zn^{68}(d,p)Zn^{69}$.

θ_{lab} (deg) \ E_x (MeV) = 0.000	0.438	0.531	1.634	1.696	2.403	2.669	2.837
5	1.74	0.54	0.17	0.77	6.30		4.83	0.97
10	3.21	0.44	0.17		4.09		2.92	0.63
15	3.98	0.48	0.17	1.26	1.81	1.03	1.28	0.23
20	3.57	0.49	0.24	1.72		1.42	0.51	0.098
25	2.18	0.63	0.31	1.43	1.08	1.43	0.59	0.14
30	0.98	0.80	0.37	1.04	1.69	0.98	1.00	0.21
32.5	0.76	0.95	0.35	0.89	1.63	0.82	1.13	0.25
35	0.69	1.02	0.41	0.65	1.63	0.64		0.22
40	0.87	1.21	0.35	0.47	1.30	0.45	0.98	0.18
45	0.94	1.18	0.29	0.46	0.71	0.36	0.78	
47.5	0.99	1.01	0.23	0.44	0.53	0.33	0.58	
50	0.88	0.93	0.20	0.58	0.37	0.37	0.50	
55	0.74	0.83	0.16	0.56	0.25		0.33	0.080
60	0.48	0.62	0.11	0.55	0.23	0.40	0.21	0.042
65	0.33	0.51	0.13	0.33	0.27	0.34		0.046
70	0.24	0.54	0.13	0.23	0.32	0.23	0.19	
75	0.19	0.59	0.16	0.15	0.28	0.15	0.19	0.036
80	0.17	0.59	0.13	0.10	0.28	0.10	0.19	0.033
85	0.16	0.56	0.11	0.12	0.20	0.084	0.18	0.034
90	0.18	0.50	0.12	0.13	0.16	0.098	0.17	0.027
95	0.18	0.43	0.091	0.14	0.12	0.099	0.12	0.022
100	0.16	0.34	0.062	0.16	0.083	0.10	0.094	0.012
105	0.16	0.27	0.050	0.16	0.057	0.098	0.068	0.0092
110	0.13	0.22	0.046	0.12	0.065	0.091	0.048	0.0076
115	0.098	0.19	0.042	0.11	0.058	0.069	0.034	0.0066
120	0.062	0.19	0.055	0.080	0.073	0.061	0.032	0.0097
125	0.034	0.19	0.061	0.055	0.086	0.053	0.042	0.013
130	0.028	0.20	0.045	0.050	0.078	0.044	0.046	0.0080
135	0.025	0.19	0.059	0.047	0.062	0.035	0.048	0.0086
140	0.034	0.16	0.055	0.046	0.058	0.037	0.054	
145	0.046	0.14	0.048	0.046	0.050	0.038	0.053	0.011
150	0.065	0.11	0.035	0.050	0.041	0.037	0.048	0.0089
155	0.078	0.11	0.044	0.057	0.041	0.036	0.043	0.0090
160	0.098	0.098	0.030	0.068	0.038	0.056	0.039	0.010

θ_{lab} (deg) \ E_x (MeV) = 0.835	0.872	1.831	1.937	1.968	2.262	2.293	2.740
5	1.02	1.13	0.15			0.98	0.14	
10	1.72	1.35	0.19	0.11	0.12	0.62	0.16	
15	2.13	1.68	0.20	0.060	0.14	0.24	0.12	0.056
20	1.94	2.27	0.23	0.072	0.11	0.084	0.13	0.11
25	1.27	2.41	0.17	0.095	0.095	0.13	0.11	0.097
32.5	0.65	1.37	0.062			0.23	0.095	0.055
40	0.69	0.75	0.057	0.15	0.047	0.21	0.097	
47.5	0.72	0.67	0.069	0.13	0.034			0.023
130	0.039							
147	0.058							

θ_{lab} (deg) \ E_x (MeV) = 2.912	2.936	3.025	3.063	3.193	3.352	3.393	3.426
5	0.42	0.38	1.02	0.95	0.12	0.14	4.19	0.59
10	0.46	0.46	1.25	0.68		0.25	3.11	0.49
15	0.62	0.56	1.54	0.39	0.16	0.27	1.70	0.42
20	0.68	0.59	1.91	0.27			1.11	0.34
25	0.69	0.61	1.82	0.24	0.17	0.27		0.41
32.5	0.43	0.45	1.12	0.24		0.19	1.22	0.22
40	0.26	0.33	0.67	0.21	0.094	0.10	1.19	0.20
47.5	0.21	0.28	0.53	0.15	0.077	0.076	0.80	0.15

TABLE XII. Differential cross sections (mb/sr) for the reaction $Zn^{70}(d,p)Zn^{71}$.

θ_{lab} (deg) \ E_x (MeV) =	0.000	0.157	0.285	0.46_5	0.48_9	0.675	0.853	2.182
7.5	1.50	0.32	0.23	0.23	0.27	0.59	0.52	0.61
10	1.82	0.30	0.24	0.20	0.28	0.71	0.56	0.61
15	3.79	0.27	0.36	0.14	0.33	1.01	0.85	0.79
20	2.84	0.34	0.43	0.17	0.33	0.82	1.15	0.88
25	1.51	0.42	0.44	0.21	0.24	0.54	1.04	0.90
30	0.66	0.54	0.28	0.26	0.16	0.35	0.70	0.64
35	0.50	0.71	0.17	0.29	0.12	0.32	0.47	0.46
40	0.55	0.78	0.19			0.35	0.33	0.47
45	0.69	0.84	0.15			0.39	0.35	
50	0.63	0.76	0.14			0.35	0.37	
55	0.51	0.58	0.16			0.25	0.36	0.36
60	0.39	0.44	0.15			0.17	0.35	0.33
65	0.26	0.38	0.11			0.13	0.27	0.38
70	0.19	0.37	0.10			0.084	0.21	
75	0.14	0.41	0.061			0.081	0.13	0.17
80	0.14	0.41				0.096	0.098	0.14
85	0.14	0.39	0.035			0.079	0.093	0.12
90	0.13	0.34	0.045			0.081	0.10	0.12
95	0.13	0.30	0.051			0.079	0.11	0.12
100	0.10	0.21	0.051			0.061	0.10	0.09
105	0.093	0.16	0.056			0.054	0.087	0.10
110	0.072	0.14	0.040			0.043	0.080	0.088
115	0.069	0.14	0.036			0.033	0.060	0.085
120	0.045	0.13	0.017			0.027	0.045	0.071
125	0.035	0.14	0.013			0.025	0.039	0.062
130	0.024	0.11	0.010			0.020	0.035	0.048
133	0.020	0.11	0.015		0.019	0.015	0.023	0.040
135	0.022	0.098	0.0086			0.023	0.035	0.039
140	0.030	0.10	0.011			0.028	0.034	0.041
145	0.038	0.095	0.017			0.026	0.038	0.044
147	0.036	0.080	0.014		0.0085	0.024	0.026	0.027
150	0.046		0.014			0.025	0.036	0.042
155	0.052	0.073	0.019			0.033	0.041	0.046
160	0.049	0.052				0.026	0.032	0.039
165	0.053	0.056				0.029	0.030	0.035
170	0.057	0.047				0.028	0.037	0.040

θ_{lab} (deg) \ E_x (MeV) =	1.260	1.421	1.629	1.661	1.742	2.376	2.417	2.523
7.5	0.16	0.30	6.37	0.98		5.67		
10	0.14	0.31	3.77	1.26		3.50	0.19	0.75
15	0.18	0.43	1.63	1.72		2.14	0.28	1.01
20	0.23	0.37	0.63	2.54	0.083	1.24	0.33	1.23
25	0.23	0.24	1.23	2.77		1.51	0.32	1.23
30	0.15	0.17	1.58	1.43	0.089	1.43	0.23	0.82
35	0.097	0.14	1.67	0.89	0.079	1.54	0.16	0.62
133	0.0079	0.0095			0.017	0.067		
147	0.0060	0.0084	0.033	0.049	0.0064			

θ_{lab} (deg) \ E_x (MeV) =	2.538	2.612	2.713	2.752	3.039	3.098	3.178
7.5			0.092	0.67	0.64		0.48
10	0.24	0.22	0.11	0.67	0.52	0.20	0.38
15	0.28	0.33	0.17	0.83	0.75	0.23	0.60
20	0.48	0.38		0.99	0.90	0.42	0.79
25	0.34	0.35	0.22	0.64	0.92	0.41	0.86
30	0.24	0.23	0.17	0.43	0.53	0.30	0.52
35	0.10	0.14	0.10		0.42	0.23	0.39
133		0.0077	0.0057	0.024	0.034		0.022
147		0.0011	0.0048	0.023		0.0094	0.018