PHYSICAL REVIEW VOLUME 142, NUMBER 3 FEBRUARY 1966

Studies of (d,d') Reactions on Sn, Cd, Te, and Mo Isotopes*

Y. S. Kim† and B. L. Cohen
University of Pittsburgh, Pittsburgh, Pennsylvania
(Received 6 October 1965)

Energy spectra were obtained from inelastic scattering of 15-MeV deuterons by various isotopes of Sn, Cd, Te, and Mo. The 2^+ and 3^- collective states are located, and the systematics of their excitation energies and cross sections are studied. Crude estimates are obtained for the octupole vibrational deformation parameter β_3 for these isotopes and for isotopes of Zn, Se, Zr, and Pd studied previously. Many other (noncollective) levels are catalogued, and some information is obtained on their parities.

INTRODUCTION AND EXPERIMENTAL

For the past several years, there has been a continuing program of studies of stripping reactions induced by 15-MeV deuterons from the University of Pittsburgh cyclotron using a magnetic spectrograph and photographic-plate detection. This program requires thin targets of a large variety of separated isotopes, so that in the course of using these targets, exposures are also made routinely for inelastic deuteron scattering. The purpose of this paper is to report an analysis of these exposures made over the past three years. Unfortunately, the data are not as complete as one might hope, and it is impossible to extend them since the targets are no longer available. However, there are sufficient data to locate the collective 2^+ and 3^- states in these isotopes, to study their vibrational amplitudes, and to obtain some information on other states.

The experimental method has been described previously.[1] Briefly it consists of bombarding thin targets with 15-MeV deuterons, passing the reaction products through a 60° wedge-magnet spectrograph, and detecting them by the tracks they produce in a photographic plate on the focal plane. The photographic plates are covered with an aluminum absorber of sufficient thickness to stop all particles but deuterons and protons; even the highest energy protons produced (about 20 MeV) have the magnetic rigidity of only 10-MeV deuterons, so that deuterons of higher energy can be studied without proton contamination. After the bombardment, the plates are developed and scanned

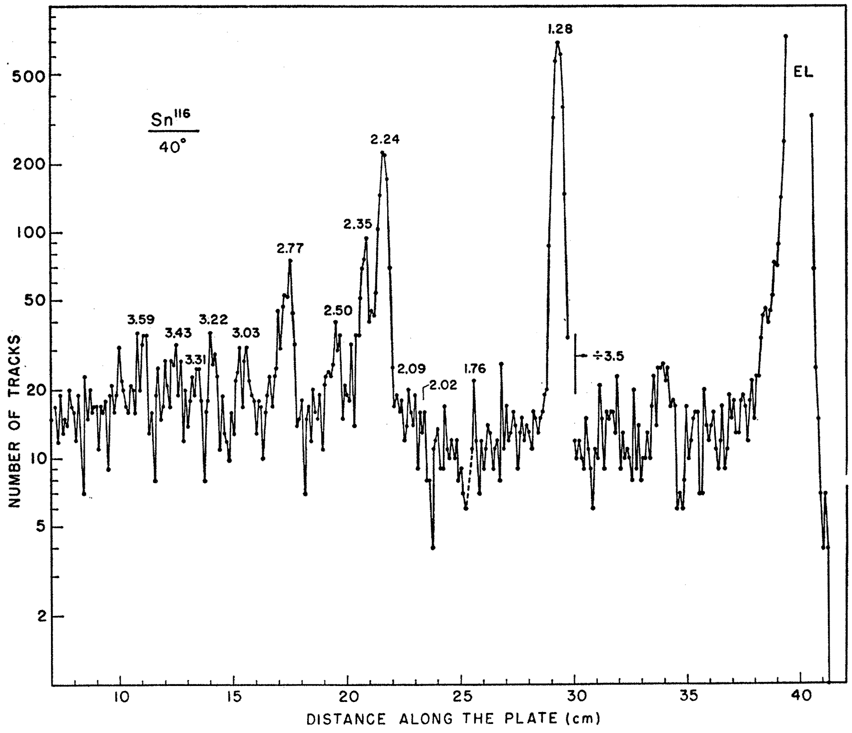

Fig. 1. Energy spectrum for $Sn^{116}(d,d')$ at 40°. Figures above peaks are excitation energies in MeV. EL denotes elastic-scattering peak. This is typical of most of the Sn and Cd isotope data.

---

* This work was supported by the National Science Foundation under Grant No. GP-2211.

† Present address: Department of Physics, University of Connecticut, Storrs, Connecticut.

[1] B. L. Cohen, J. B. Mead, R. E. Price, K. S. Quisenberry, and C. Martz, Phys. Rev. **118**, 449 (1960); B. L. Cohen, R. H. Fulmer, and A. L. McCarthy, *ibid.* **126**, 698 (1962).

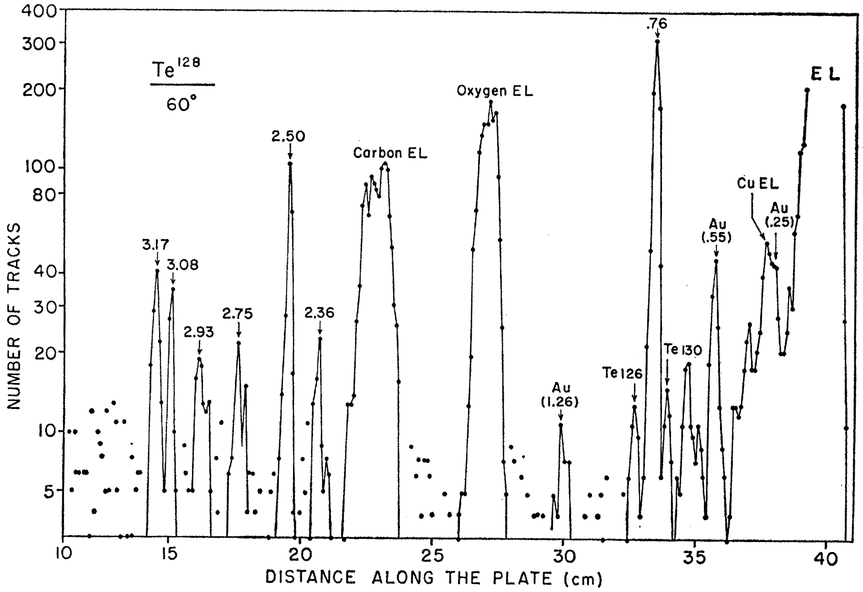

FIG. 2. Energy spectrum for $Te^{128}(d,d')$ at 60°. See caption for Fig. 1. This is typical of most Te isotope data. Note that the interference from the Au backing is not important beyond 0.6 MeV.

under microscopes to determine the track density as a function of position. Typical data are shown in Figs. 1, 2, and 3.

The target thicknesses and isotopic compositions are listed in Table I. As is evident from Table I, the isotopic purity of many of the targets left much to be desired, so that careful corrections for contributions from other isotopes were often necessary. The Sn and Cd targets were self-supporting, but the Te targets were on a thin gold backing, and the molybdenum targets were alloyed with approximately equal amounts of copper. The gold interference with the tellurium data was not serious, but the nonuniformity of the gold backing made target-thickness determinations unreliable. The spectra for the molybdenum isotopes were very heavily contaminated with background from copper, so that even after careful subtraction of the copper contribution only a few peaks due to molybdenum could be studied (cf. Fig. 3). The energy resolution in these experiments was about 40–50 keV. The absolute cross sections should be accurate to about 20% except where target thickness is a dominating uncertainty.

Exposures were made at two angles so as to distinguish peaks due to light-element impurities. Carbon and oxygen peaks were particularly prominent. The angles were chosen in accordance with the prescription developed by Jolly *et al.*[2] for giving an indication of the parity of the final state. It was found in Ref. 2 that in the Sn region angular distributions for transitions leading to the 2^+ first excited states were falling rapidly between 40° and 60°, whereas those leading to the 3^- collective states were rising in this angular region. Since theoretical studies of direct interaction inelastic scattering[3] predict that transitions leading to states of the same parity should have angular distributions whose maxima and minima are in phase with one another, but out of phase with those of opposite parity, it was pre-

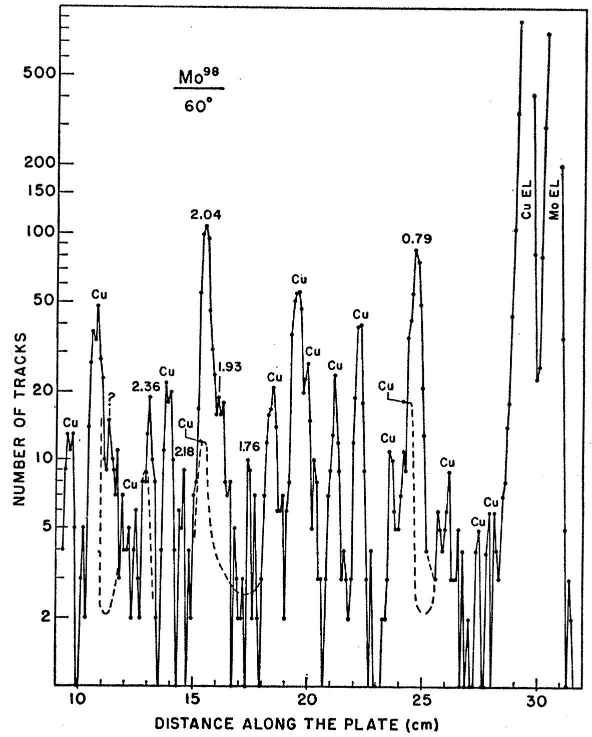

FIG. 3. Energy spectrum for $Mo^{98}(d,d')$ at 60°. Target was a Mo-Cu alloy, so that most peaks are due to Cu; they are so labeled. The peaks labeled by figures only are from Mo^{98}; figures are excitation energies; dashed curves under them are copper background in that region. The peak at 11.4 cm is not due to Cu, but there was no evidence for it in the 45° spectrum.

---

[2] R. K. Jolly, E. K. Lin, and B. L. Cohen, Phys. Rev. **128**, 2292 (1962).

[3] J. S. Blair, Phys. Rev. **115**, 928 (1959).

TABLE I. Isotopic composition (in %) and thickness of targets.

(a) Cadmium targets

Target \ Isotope	110	112	116	Thickness (mg/cm²)
Cd^{110}	95.6	2.62	0.06	2.90
Cd^{112}		98.8		2.55
Cd^{116}			94.6	1.80

(b) Molybdenum targets[a]

Target \ Isotope	92	94	95	96	97	98	100	Thickness (mg/cm²)
Mo^{92}	93.0	1.55	1.06	1.21	0.62	1.61	0.98	0.83
Mo^{94}	2.2	79.6	9.6	3.8	1.3	2.7	0.8	1.0
Mo^{96}	0.5	0.6	3.2	89.2	3.3	2.7	0.5	1.43
Mo^{98}	0.3	0.3	0.5	0.8	1.0	96.4	0.7	1.0
Mo^{100}	0.9	0.6	1.2	1.5	1.1	4.7	90.0	1.17

(c) Tin targets

Target \ Isotope	112	114	115	116	117	118	119	120	122	124	Thickness (mg/cm²)
Sn^{112}	74.7	1.9		4.7	1.9	4.6	1.6	5.6	2.0	2.6	2.36
Sn^{114}	1.9	60.1	2.0	13.4	3.5	6.8	2.0	6.5	1.8	2.0	2.23
Sn^{116}				97.0							2.77
Sn^{117}				2.8	85.4	7.8	1.0	1.6	0.3		3.30
Sn^{118}						97.1	1.1	1.2			2.71
Sn^{119}						3.6	85.9	8.5			2.54
Sn^{120}								96.0			4.73
Sn^{122}							0.75	6.2	88.9	2.1	2.84
Sn^{124}						0.5	0.2	1.2	1.2	96.0	2.37

(d) Tellurium targets[b]

Target \ Isotope	122	124	125	126	128	130	Thickness (mg/cm²)
Te^{124}	1.4	84.0	4.7	4.5	2.92	1.7	0.456
Te^{125}		1.4	87.9	6.8	2.4	1.1	0.568
Te^{126}		0.4	1.9	91.2	1.6		1.00
Te^{128}				1.0	96.5	2.5	0.50
Te^{130}	0.4		3.6			96.0	0.568

[a] All targets are alloyed with approximately equal amounts of copper.

[b] All targets mounted on 0.2 mg/cm² Au.

sumed that this behavior of transitions to the 2^+ and 3^- states is typical to those to other states of the same parity. Thus the ratio of intensities at 40° and 60° might serve as an indicator of the parity of final states. This presumption was tested in Ref. 2, and found to be reasonably valid except for two-phonon states. This anomalous behavior of two-phonon states has been well known for some time and is theoretically understandable. The prescription developed in Ref. 2 for the Sn region was

$$\frac{d\sigma/d\Omega(60°)}{d\sigma/d\Omega(40°)}<0.49, \quad \text{even parity,}$$

$$\frac{d\sigma/d\Omega(60°)}{d\sigma/d\Omega(40°)}>0.63, \quad \text{odd parity.}$$

These indications are probably about 75% accurate

TABLE II. Results for Sn^{112}.

This work		(d,d′)	
$E(d,d')$ (MeV)	$\frac{d\sigma}{d\Omega}(60°)$ (mb/sr)	$\frac{(d\sigma/d\Omega)(60°)}{(d\sigma/d\Omega)(40°)}$	Parity
1.25	0.70	0.34	+
2.26	0.25	0.99	
2.36	0.51	1.11	−
2.53	0.014	0.85	−
2.80	0.034	1.56	
2.97	0.023	0.66	−
3.15	0.067	0.67	−
3.43	0.030	0.71	−

TABLE III. Results for Sn^{114}.

This work (d,d′)				Ref. 5 (d,t)		
$E(d,d')$ (MeV)	$\frac{d\sigma}{d\Omega}(60°)$ (mb/sr)	$\frac{(d\sigma/d\Omega)(60°)}{(d\sigma/d\Omega)(40°)}$	Parity	$E(d,t)$ (MeV)	$\frac{d\sigma}{d\Omega}(45°)$ (mb/sr)	J^π
1.30	0.59	0.35	+	1.31	0.331	2^+
				1.58	~0.06	0^+
1.97	0.037	0.83		1.95	0.180	0^+
2.18	0.15	1.26		2.20	0.260	
2.27	0.89	1.60	−			
2.39	0.12	0.89	−	2.42	0.079	
				2.55	0.198	
				2.68	0.059	
2.82	0.014	1.38	−	2.84	0.04	
2.87	0.086	1.75	−			

TABLE IV. Results for Sn^{116}.

This work (d,d')				(d,p) Ref. 5			(d,t)		Ref. 7 β^-		Ref. 6 β^+	
$E(d,d')$ (MeV)	$\frac{d\sigma}{d\Omega}(60°)$ (mb/sr)	$\frac{(d\sigma/d\Omega)(60°)}{(d\sigma/d\Omega)(40°)}$	Parity	$E(d,p)$ (MeV)	$\frac{d\sigma}{d\Omega}(\max)$ (mb/sr)	J^π	$E(d,t)$ (MeV)	$\frac{d\sigma}{d\Omega}(45°)$ (mb/sr)	$E(\beta^-)$ (MeV)	J^π	$E(\beta^+)$ (MeV)	J^π
1.28	0.53	0.34	+	1.30	0.329	2^+	1.28	0.364	1.29	2^+	1.29	2^+
1.76	0.16	?		1.76	0.554	0^+	1.73	0.243	1.72	0^+		
2.02	0.027	1.22		2.03	0.623	0^+	1.99	0.290				
2.09	0.019	0.64							2.12	2^+		
				2.23	1.409	$1^+, 2^+, 3^+$	2.18	0.305				
2.24	0.75	1.44	−								2.25	3^-
2.35	0.14	0.76	−								2.35	5^-
				2.37	0.242	$1^+, 2^+, 3^+$	2.34	0.311	2.38	4^+		
2.50	0.054	1.33	−				2.53	0.678	2.53	4^+		
				2.62	1.62	0^+						
2.77	0.14	1.13	−								2.76	6^-
				2.78	2.19	2^+	2.76	0.251	2.78	4^+		
				2.95	0.405	$1^+, 2^+, 3^+$	2.96	0.184			2.90	7^-
3.03	0.063	1.70	−	3.10			3.06	0.226	3.06	4^+		
3.15	0.019	1.85	−	3.17	0.254	$1^+, 2^+, 3^+$	3.18	0.274				
3.22	0.026	0.59	?									
3.31	0.039	1.15	−	3.35	1.495							
3.43	0.044	1.01	−				3.39	0.657				

away from the two-phonon energy region. Their reliability should be better for more strongly excited levels.

While such a reliability is so poor that it might be called useless (except for the collective 2^+ and 3^- states), this unhappy situation is caused by the unreliability of the direct interaction inelastic scattering process as a tool for determining spins and parities, rather than by the two-angle method used here. In fact, if complete angular distributions were measured with very high accuracy, the reliability of parity determinations would not be very much better.

RESULTS

The results as listed in Tables II–XXII are far from complete. In many cases, weakly excited states are missed, and in others, they are masked at one of the angles by carbon and oxygen impurity peaks. In the latter cases, the levels are not listed unless they are very clear and unmistakable at the other angle, or are known from other experiments. In general, states with cross sections less than 0.03 mb/sr should be viewed with some suspicion.

In all isotopes, the first excited state is strongly excited and of positive parity and there is a strongly excited state of negative parity at about 2.1 MeV. These are assumed to be the collective 2^+ and 3^- states, respectively.

Even-Mass Tin Isotopes

The results for the even tin isotopes are listed in Tables II to VII. For Sn^{112}, only the 1.25-MeV state was listed in the Nuclear Data Sheets.[4] It is the collective 2^+ state, and the collective 3^- state is at 2.36 MeV. The

TABLE V. Results for Sn^{118}.

This work (d,d')				(d,p) Ref. 5			(d,t)		Ref. 6 β^+		Ref. 8 β^-	
$E(d,d')$ (MeV)	$\frac{d\sigma}{d\Omega}(60°)$ (mb/sr)	$\frac{(d\sigma/d\Omega)(60°)}{(d\sigma/d\Omega)(40°)}$	Parity	$E(d,p)$ (MeV)	$\frac{d\sigma}{d\Omega}(\max)$ (mb/sr)	J^π	$E(d,t)$ (MeV)	$\frac{d\sigma}{d\Omega}(45°)$ (mb/sr)	$E(\beta^+)$ (MeV)	J^π	$E(\beta^-)$ (MeV)	J^π
1.22	0.54	0.29	+	1.22	0.489	2^+	1.218	0.289	1.23	2^+	1.228	2^+
1.74	0.023	0.57		1.75	0.207	0^+	1.742	0.135				
1.99	0.033	1.15		2.05	0.178	0^+	2.033	0.192			2.04	(2^+)
							2.124	0.026				
				2.32	1.745	$1^+, 2^+, 3^+$	2.302	0.354	2.28	4^+	2.28	4^+
									2.32	5^-	2.32	5^-
2.33	0.74	0.97	−									
2.49	0.034	1.15	−	2.49	1.135	0^+	2.468	0.719			2.48	(4^+)
									2.57	7^-		
2.74	0.072	1.01	−	2.72	2.318	2^+	2.716	0.416			2.72	?
											2.77	?
2.96	0.044	0.73	−								2.96	(4^+)
3.06	0.013	0.53	?	3.06	0.094	$1^+, 2^+, 3^+$	3.044	0.325				

---

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

TABLE VI. Results for Sn^{122}.

	This work (d,d')			Ref. 8 β^-		Ref. 10
$E(d,d')$ (MeV)	$\frac{d\sigma}{d\Omega}(60°)$ (mb/sr)	$\frac{(d\sigma/d\Omega)(60°)}{(d\sigma/d\Omega)(40°)}$	Parity	$E(\beta^-)$	J^π	$E(p,p')$ (MeV)
1.15	0.55	0.27	+	1.14	2^+	1.141
2.15	~0.04	~0.3		2.14	(4^+)?	2.147
2.25	0.071	0.60				2.247
2.34	0.078	1.29		2.30		
2.42	0.095	0.45				2.414
2.50	~0.40	~1.0	−			2.494
3.15	0.038	0.98	−			
3.26	0.058	1.22	−			
3.33	0.033	0.91	−			
3.49	0.012	0.73	−			
3.56	0.014	0.51	?			
3.71	0.012	0.68	−			
3.85	0.014	0.85	−			
3.92	0.016	0.52	?			

TABLE VII. Results for Sn^{124}.

	This work (d,d')			Ref. 10
$E(d,d')$ (MeV)	$\frac{d\sigma}{d\Omega}(60°)$ (mb/sr)	$\frac{(d\sigma/d\Omega)(60°)}{(d\sigma/d\Omega)(40°)}$	Parity	$E(p,p')$ (MeV)
1.13	0.54	0.39	+	1.131
2.13	0.075	0.57		2.101
2.21	0.081	0.77		2.200
2.41	0.060	0.46		2.428
2.59	0.30	0.90	−	2.604
2.85	0.006	0.35	+	
2.98	0.009	0.52	?	
3.13	0.014	0.73	−	
3.19	0.028	0.36	+	
3.35	0.053	0.64	−	

2.26-MeV state is unusually strongly excited for a noncollective state; its nature should be further investigated. The levels in Sn^{114} shown in Table III, agree well with those found in the $Sn^{115}(d,t)$ reaction[5]; it is interesting to note that the collective 3^- state is not excited in that reaction.

For Sn^{116}, there are data from the beta decay[6,7] of both In^{116} and Sb^{116} as well as from $Sn^{115}(d,p)$ and $Sn^{117}(d,t)$ reactions[5] to compare with, as shown in Table IV. In the higher energy region, the energy uncertainties make it difficult to ascertain that levels from different experiments are the same. The 2.24-MeV state

TABLE VIII. Results for Sn^{117}.

	This work (d,d')				(d,p) Ref. 5		(d,t)	
$E(d,d')$ (MeV)	$\frac{d\sigma}{d\Omega}(60°)$ (mb/sr)	$\frac{(d\sigma/d\Omega)(60°)}{(d\sigma/d\Omega)(40°)}$	Parity	$E(d,p)$ (MeV)	$\frac{d\sigma}{d\Omega}(\max)$ (mb/sr)	J^π	$E(d,t)$ (MeV)	$\frac{d\sigma}{d\Omega}(45°)$ (mb/sr)
				0.16	3.715	$\frac{3}{2}^+$	0.16	0.695
				0.32	0.800	$11/2^-$	0.31	0.212
				0.72	0.166	$\frac{7}{2}^+$	0.71	
1.04	0.38	0.34	+	1.03	0.875	$\frac{5}{2}^+$	1.01	1.15
1.26	0.052	0.25	+	1.19	0.490	$\frac{5}{2}^+$	1.18	0.526
1.34	0.040	0.26	+	1.31	0.226	$\frac{7}{2}^-$		
1.46	~0.070	0.31	+	1.51	0.315	$\frac{5}{2}^+$	1.50	0.173
1.60	0.029	0.69	−	1.59	0.098	$\frac{5}{2}^+$		
1.65	0.020	0.50	?	1.67	0.106	$\frac{5}{2}^+$		
2.00	~0.029	~0.48	+	1.96	0.040 0.020	$\frac{3}{2}^-$ $\frac{7}{2}^-$		
2.07	~0.064	~1.03	−	2.05	0.277	$\frac{7}{2}^-$		
2.15	~0.20	~2.11	−					
2.22	0.017	0.26	+	2.24				
2.28	0.12	1.13	−					
				2.31	0.205	$\frac{5}{2}^+$		
2.33	0.14	2.10	−					
2.41	0.048	0.86	−	2.38				
2.47	0.064	1.42	−	2.47	0.293	$\frac{7}{2}^-$		
2.59	0.023	0.88	−	2.54	0.167	$\frac{7}{2}^-$		
2.67	0.033	0.92	−	2.68	0.134	$\frac{7}{2}^-$		
2.77	0.024	1.33						
2.87	0.008	0.46	+	2.83				
				2.92	1.076	$\frac{3}{2}^-$		
2.97	0.040	0.22	+					
3.16	0.014	0.52	?	3.22	1.413	$\frac{7}{2}^-$		
3.26	0.019	0.85	−	3.33	0.538	$\frac{3}{2}^-$		

---

[5] E. J. Schneid, A. Prakash, and B. L. Cohen, Phys. Rev. (to be published).
[6] H. H. Bolotin, Phys. Rev. (to be published).
[7] H. H. Bolotin, Phys. Rev. 138, B795 (1965).

TABLE IX. Results for Sn^{119}.

This work (*d*,*d'*)				(*d*,*p*) Ref. 5 (*d*,*t*)				
$E(d,d')$ (MeV)	$\frac{d\sigma}{d\Omega}(60°)$[a] (mb/sr)	$\frac{(d\sigma/d\Omega)(60°)}{(d\sigma/d\Omega)(40°)}$	Parity	$E(d,p)$ (MeV)	$\frac{d\sigma}{d\Omega}(\max)$ (mb/sr)	J^π	$E(d,t)$ (MeV)	$\frac{d\sigma}{d\Omega}(45°)$ (mb/sr)
				0.024	3.63	$\frac{3}{2}^+$	0.03	
				0.08	0.522	$11/2^-$	0.08	
				0.79	0.166	$\frac{5}{2}^+$	0.78	0.304
0.90	0.39	0.34	+	0.93	0.085	$\frac{5}{2}^+$	0.92	0.174
1.06	0.097	0.28	+	1.10	1.29	$\frac{5}{2}^+$	1.08	1.618
1.21	~0.016	?		1.22	0.127	$\frac{5}{2}^+$	1.24	0.067
1.34	0.039	0.26	+	1.37	0.216	$\frac{5}{2}^+$	1.36	0.436
1.51	(0.036)							
1.59	(0.028)			1.59	0.114	$\frac{5}{2}^+$	1.56	0.074
							1.64	0.038
1.73	0.012	0.37	+	1.74	0.209	$\frac{5}{2}^+$	1.73	0.105
1.90	0.027	0.40	+	1.95	0.214	$\frac{3}{2}^-$		
2.24	0.27	1.39	−					
2.36	0.12	2.00	−					
2.75	(0.058)			2.58	0.119 0.369	$\frac{5}{2}^+$ $\frac{3}{2}^-$		
2.70	0.029	0.52	?	2.68	1.25	$\frac{7}{2}^-$		
2.77	0.022	0.69	−					
2.89	(0.031)			2.92	1.02	$\frac{3}{2}^-$		
2.94	0.016	0.86	−					
3.06	0.012	0.46	+					
3.13	0.016	1.57	−	3.13	0.070	$\frac{3}{2}^-$		

[a] Parentheses indicate $d\sigma/d\Omega$ at 40°.

observed here as the 3^- collective state is very close in energy to a positive parity state ($l=2$) found in the stripping experiments; these must be different states.

In Sn^{118}, there are again data from both positive[6] and negative[8] beta decay and from (*d*,*p*) and (*d*,*t*) reactions[5] to compare with, but the correspondence is difficult to make except for the lowest energy levels. There are apparently separate levels at 2.28 (4^+), 2.31 (1^+, 2^+, 3^+), 2.32 (5^-), and 2.33 (3^-) MeV. This is indicative of the problems involved in comparing results of the different experiments.

The $Sn^{120}(d,d')$ reaction was studied extensively by Jolly,[9] so that no new measurements were made here.

TABLE X. Results for Cd^{110}.

This work				Ref. 4		Ref. 14	
$E(d,d')$ (MeV)	$\frac{d\sigma}{d\Omega}(59°)$ (mb/sr)	$\frac{(d\sigma/d\Omega)(59°)}{(d\sigma/d\Omega)(40°)}$	Parity	E_{known} (MeV)	J^π	E (MeV)	J
0.65	0.89	~0.25	+	0.656	2^+	0.657	2
1.18	0.035	1.05					
1.47	0.14	0.70		1.474	2^+	1.476	2
1.54	0.028	0.31		1.541	4^+	1.544	4
2.09	0.55	1.24	−	2.160	3^-	2.082	3
2.23	0.091	0.72	−	2.218	$(3^-, 4^+)$	2.224	3,4
2.51	0.029	0.49	+	2.478	6^+	2.486	6
2.58	0.032	0.31	+				
2.69	0.023	0.57	?				
2.83	0.091	0.30	+				

In Sn^{122}, there are data from beta decay[8] and from (*p*,*p'*) [10] to compare with. The uncertainty in the cross section for the collective 3^- state at 2.50 MeV is due to the unfortunate coincidence that the peak was at the end of a plate in the 60° data. In Sn^{124} there are also (*p*,*p'*) data,[10] and as in the case of Sn^{122}, the agreement is reasonably good. The 2.21-MeV state of Sn^{124} and the 2.34-MeV state of Sn^{122} are presumably two-phonon states.

TABLE XI. Results for Cd^{112}.

This work				Ref. 14b		Ref. 14a	
$E(d,d')$ (MeV)	$\frac{d\sigma}{d\Omega}(59°)$[a] (mb/sr)	$\frac{(d\sigma/d\Omega)(59°)}{(d\sigma/d\Omega)(40°)}$	Parity	$E(d,p)$ (MeV)	J^π	E (MeV)	J
0.62	0.94	0.37	+	0.61	2^+		
1.22	0.014	0.20		1.23	0^+	1.221	(0)
1.30	(0.11)			1.30	2^+	1.302	2
1.42	~0.080	0.94		1.43	0^+	1.410 1.428	4
1.47	0.057	0.96		1.47	2^+	1.463	2
				1.86	0^+		
2.01	0.42	1.16	−	2.05			
2.10	0.026	0.29	+				
				2.28	0^+		
2.42	0.045	0.75	−				
2.52	0.046	0.25	+				
				2.64			
2.76	0.033	0.53	?				
2.83	0.031	0.35	+	2.83	0^+		
2.91	0.049	0.70	−				

[a] Parentheses indicate $d\sigma/d\Omega$ at 40°.

---

[8] J. Kantele and M. Karras, Phys. Rev. **135**, B9 (1964).

[9] R. K. Jolly, Phys. Rev. **139**, B318 (1965).

[10] C. Nealy and R. Sheline, Phys. Rey. **135**, B325 (1964).

TABLE XII. Results for Cd^{116}.

This work (d,d')				Ref. 4		Ref. 14	
E^* (MeV)	$\frac{d\sigma}{d\Omega}(59°)$ (mb/sr)	$\frac{(d\sigma/d\Omega)(59°)}{(d\sigma/d\Omega)(40°)}$	Parity	E (MeV)	J^π	E (MeV)	J
0.52	1.29	0.40	+	0.517	2^+		
1.22	0.19	0.71		1.217	2^+	1.205	2,4
						1.371	[0]
1.64	0.02	0.50				1.637	
1.93	~0.42	~1.1	−				
2.27	0.034	0.74	−				
2.33	0.019	0.50	?				
2.41	0.094	0.73	−				
2.47	0.045	0.63	?				
2.64	0.033	0.42	+				

Odd Tin Isotopes

The results for Sn^{117} and Sn^{119} are listed in Tables VIII and IX and compared with results of (d,p) and (d,t) reactions. It is interesting to note that the 1.03-MeV state in Sn^{117} is at once the principal $d_{5/2}$ single-particle state, and the principal component of the 2^+ vibrational state. This was pointed out previously[11] and explained theoretically,[12] but still the view is often expressed that a single state cannot be both a phonon and a single-particle state.

It is tempting to presume that the positive parity states found below about 1.7 MeV are couplings of the one-phonon vibrational state to the ground state of the odd nucleus. On this presumption, the sum of the cross sections for exciting these states should be the same as for the 2^+ vibrational state in neighboring even nuclei. Applying this test to the cross section at 60°, we find 0.54 mb/sr in Sn^{117} and 0.53 to 0.56 mb/sr in Sn^{119}, depending on which states are counted (note that the numbers in parenthesis in the tables are cross sections at 40°, which should be about three times less than cross sections at 60°); these compare very well with 0.53 mb/sr in Sn^{116} and 0.54 mb/sr in Sn^{118}.

A similar comparison for the 3^- states is complicated by the need for a subjective judgment on what energy range to include. If one arbitrarily takes the negative parity states between 2.0 and 2.6 MeV, one gets summed cross sections of 0.66 and 0.39 mb/sr, respectively, for Sn^{117} and Sn^{119} as compared with 0.75 and 0.74 mb/sr, respectively, for the 3^- states in Sn^{116} and Sn^{118}.

It appears strange that so much of the 2^+ strengths are concentrated in single levels in the odd isotopes. From coupling the $\frac{1}{2}^+$ ground state to the 2^+ vibration, one expects states of $\frac{5}{2}^+$ and $\frac{3}{2}^+$, with the cross section proportional to $(2I+1)$, so that no one state should have more than $\frac{3}{5}$ of the cross section. This limit seems to be exceeded in both Sn^{117} and Sn^{119}. It has recently been found[13] that the 1.03-MeV state in Sn^{117} is actually a doublet; this solves the dilemma for Sn^{117}, so that perhaps the other half of the dilemma is due to the 0.90-MeV state in Sn^{119} being a $\frac{3}{2}^+$–$\frac{5}{2}^+$ doublet.

There is some indication that the 2^+ vibrational levels lie lower in the odd isotopes than in the neighboring even ones. In Sn^{117} and Sn^{119}, the "center of gravity" of the one-phonon levels is at 1.18 and 0.96 MeV, respectively, as compared with 1.28 MeV in Sn^{116}, 1.22 MeV in Sn^{118}, and 1.18 MeV in Sn^{120}.

Cadmium Isotopes

The results for Cd^{110}, Cd^{112}, and Cd^{116} are listed in Tables X, XI, and XII. The other Cd isotopes were studied in Ref. 2, so that no further studies were made here. In analogy with Cd^{112} and Cd^{114}, one might guess that the 1.18-MeV state in Cd^{110} is the 0^+ member of the two-phonon triplet. The comparisons are made with (p,p') results,[14] plus some (d,p) results for Cd^{112}.[14a]

TABLE XIII. Results for Te^{124}.

This work (d,d')				Ref. 16 (d,t)			Ref. 4		Ref. 14	
$E(d,d')$ (MeV)	$\frac{d\sigma}{d\Omega}(60°)$[a] (mb/sr)	$\frac{(d\sigma/d\Omega)(60°)}{(d\sigma/d\Omega)(38°)}$	Parity	$E(d,t)$ (MeV)	$\frac{d\sigma}{d\Omega}$ (mb/sr)	J^π	E_{known} (MeV)	J^π	E (MeV)	J
0.60	0.53	0.47	+	0.61	0.15	2^+	0.603	2^+		
1.23	0.040	0.30							1.247	(4)
1.31	0.017	0.16		1.32	0.06	$(2^+, 4^+)$	1.325	2^+	1.323	2
1.65	0.032	1.73							1.657	
2.01	(0.045)								1.746	
2.11	(0.054)									
2.19	(0.031)									
2.28	0.15	0.97	−	2.31	0.36	3^-	2.295	3^-		
				2.44	0.07					
2.49	0.046	0.81	−	2.53	0.49					
				2.59	0.15					
2.65	0.022	0.54	?							
2.71	0.012	0.50	?	2.78	0.18		2.745	$1^\pm$, $2^\pm$		

[a] Parentheses indicate $d\sigma/d\Omega$ at 40°.

---

[11] B. L. Cohen and R. E. Price, Phys. Rev. **123**, 283 (1961).

[12] S. Yoshida, Nucl. Phys. **38**, 380 (1962).

[13] P. Stelson (private communication).

[14] (a) J. A. Cookson and W. Darcey, Nucl. Phys. **62**, 326 (1965); (b) B. Rosner, Phys. Rev. **136**, B664 (1964).

TABLE XIV. Results for Te^{126}.

This work (d,d')				Ref. 15 (d,p)			Ref. 16 (p,p')	Ref. 4
$E(d,d')$ (MeV)	$\frac{d\sigma}{d\Omega}(60°)$[a] (mb/sr)	$\frac{(d\sigma/d\Omega)(60°)}{(d\sigma/d\Omega)(40°)}$	Parity	$E(d,p)$ (MeV)	$\frac{d\sigma}{d\Omega}(\theta_0)$ (mb/sr)	J^π	$E(p,p')$ (MeV)	J^π
0.67	1.34	0.30	+	0.69	0.081	(2^+)	0.670	2^+
1.35	0.094	0.51					1.360	4^+
1.42	~0.05	~0.22		1.43	0.61	(2^+)	1.417	2^+
1.58	(0.84)			1.53	0.042	$(2^+, 3^+)$		
1.68	0.031	0.93						
1.75	0.046	0.74					1.780	$5^\pm, 6^\pm$
							1.875	
							2.015	
							2.054	
2.18	0.11	0.87	−				2.190	
				2.21	0.27	$(1^+, 2^+)$		
							2.227	
2.28	0.074	1.08	−				2.320	
2.37	0.42	1.18	−				2.395	
					0.17	0^+		
				2.43	0.38	$1^+, 2^+$	2.431	
2.46	0.055	0.73	−					
				2.53	0.19	$1^+, 2^+$	2.505	
				2.60	0.32			
					0.15	(1^-)		
2.72	0.058	0.69	−	2.69				
					0.12	$1^+, 2^+$	2.742	
2.85	0.036	0.24	+	2.84	0.79		2.860	
2.96	0.95	0.51	?				2.975	

[a] Parentheses indicate $d\sigma/d\Omega$ at 40°.

Tellurium Isotopes

The results for the Te isotopes are listed in Tables XIII to XVII. In general these data are less clear than those for Sn and Cd; the level densities are higher, and the statistics are poorer. As a result, many levels have undoubtedly been missed. For three of the isotopes, there are stripping data[15] to compare with, and in Te^{126}, there are (p,p') data.[16]

The target thicknesses for the Te isotopes were somewhat uncertain, (by about 30%) and this uncertainty reflects in the accuracy of the results. The level density is especially high in Te^{125}; the levels listed in Table XVII should therefore be considered as only a sampling of the strongly excited transitions.

Molybdenum Isotopes

The spectra for the molybdenum isotopes were essentially spectra from copper (cf. Fig. 3) with the 2^+ and 3^- collective levels from Mo added on, and a few extra counts in the valleys between copper peaks. The amount of information obtained is therefore very limited and may represent only a small fraction of the Mo levels. The results are listed in Tables XVIII to XXII, where they are compared with results from beta decay[17,18] and from the Nuclear Data Sheets.[4] The pre-

TABLE XV. Results for Te^{128}.

This work (d,d')				Ref. 4		Ref. 14	
$E(d,d')$ (MeV)	$\frac{d\sigma}{d\Omega}(60°)$[a] (mb/sr)	$\frac{(d\sigma/d\Omega)(60°)}{(d\sigma/d\Omega)(40°)}$	Parity	E_{known} (MeV)	J^π	E (MeV)	J
0.76	1.21	0.48	+	0.75	2^+		
1.51	(0.24)					1.496	[4]
						1.522	[2]
						1.972	
2.04	(0.16)					2.031	
2.14	(0.12)					2.138	
2.36	0.075	0.74	−				
2.50	0.30	0.85	−				
2.75[b]	0.05	0.65	−				
2.93[b]	0.059	0.92	−				
3.08	0.091	0.59	?				
3.17	0.14	0.85	−				

[a] Parentheses indicate $d\sigma/d\Omega$ at 40°. [b] Multiple.

TABLE XVI. Results for Te^{130}.

This work (d,d')				Ref. 4		Ref. 14	
$E(d,d')$ (MeV)	$\frac{d\sigma}{d\Omega}(60°)$ (mb/sr)	$\frac{(d\sigma/d\Omega)(60°)}{(d\sigma/d\Omega)(40°)}$	Parity	E_{known} (MeV)	J^π	E (MeV)	J
0.85	1.50	0.53	+	0.85	2^+		
						1.588	[4]
						1.633	[2]
						1.765	2
						1.815	
1.90	0.084	0.30				1.885	
						1.982	
						2.100	
2.30	0.10	0.48	+				
2.48	0.069	0.34	+				
2.55	0.058	0.54	?				
2.77	0.36	0.74	−				
2.99	0.077	0.54	?				

---

[15] R. K. Jolly, Phys. Rev. **136**, B683 (1964).

[16] G. C. Pramila, R. Middleton, T. Tamura, and G. R. Satchler, Nucl. Phys. **61**, 448 (1965).

[17] R. Van Lieshout, S. Monaro, G. B. Virgiani, and H. Morinaga, Phys. Rev. Letters **9**, 164 (1964).

[18] G. H. Hamilton *et al.*, Physica **30**, 1802 (1964).

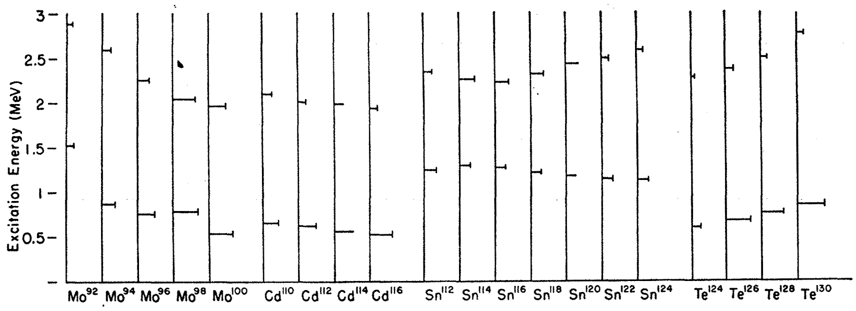

FIG. 4. Energies and cross sections (at 60°) for 2^+ and 3^- collective levels.

scription for determining parity used in the Sn region is not valid here as evidenced by the Zr results of Ref. 2. The tables therefore simply list cross sections at 60° and 45°. The 2^+ and 3^- collective states are nevertheless easily picked out from the tables by their large cross sections.

SYSTEMATICS OF COLLECTIVE STATES

The locations of the collective 2^+ and 3^- levels, and their cross sections for excitation in this experiment are plotted in Fig. 4. In general, these vary smoothly with A for a given element, but there are a few surprising exceptions. For example, the 3^- state is much more weakly excited in Sn^{122} and Sn^{124} than in the lighter Sn isotopes. It is also weaker in Te^{124} than in the heavier Te isotopes; however, this may be partly due to an error with target-thickness determination, since the cross section for exciting the 2^+ is also surprisingly small in this isotope. The Te targets have long since disintegrated so that there is no opportunity to recheck this thickness; however, the results of Ref. 15, obtained with this target, also suggest that the Te^{124} target thick-

TABLE XVII. Results for Te^{125}.

This work (d,d')				(d,p) Ref. 15 (d,t)						Ref. 4	
$E(d,d')$ (MeV)	$\frac{d\sigma}{d\Omega}(60°)$[a] (mb/sr)	$\frac{(d\sigma/d\Omega)(60°)}{(d\sigma/d\Omega)(40°)}$	Parity	$E(d,p)$ (MeV)	$\frac{d\sigma}{d\Omega}$ (mb/sr)	J^π	$E(d,t)$ (MeV)	$\frac{d\sigma}{d\Omega}$ (mb/sr)	J^π	E_{known} (MeV)	J^π
							0.03	1.19	$\frac{3}{2}^+$	0.0353	$\frac{3}{2}^+$
							0.14	0.38	$\frac{11}{2}^-$	0.145	$\frac{11}{2}^-$
0.32	0.051	~0.35	+							0.321	$\frac{9}{2}^-, \frac{11}{2}^-$
0.46	~0.32	?					0.46	0.13	$(\frac{5}{2}^+)$	0.462	$\frac{5}{2}^+$
										0.524	
0.67	0.23	?		0.64	0.45	$(\frac{5}{2}^+)$	0.67	0.78	$\frac{5}{2}^+$	0.633 0.640 0.652 0.668	
				0.70	0.18	$(\frac{5}{2}^+)$					
0.74	0.041	?			0.07	$(\frac{5}{2}^+)$			$\frac{5}{2}^+$		
				0.77	0.075	$(\frac{7}{2}^+)$	0.80	0.10	$\frac{7}{2}^+$		
1.04	0.032	?					1.06	0.42			
1.13	0.028	0.31	+				1.14	0.31			
1.26	0.024	0.33	+				1.28	0.25			
							1.46	0.18			
1.57	(0.035)						1.61	0.06			
1.68	0.033	0.79	−								
1.75	0.032	0.73	−								
				1.81	0.15	$(\frac{3}{2}^+)$					
				1.91	0.36	$(\frac{3}{2}^+)$					
2.00	(0.032)			1.98	0.12	$\frac{3}{2}^-$					
					0.11	$\frac{3}{2}^-$					
2.09	(0.036)			2.03	0.17	$\frac{3}{2}^-$					
					0.14	$\frac{3}{2}^+$					
				2.11	0.64	$\frac{3}{2}^-$					
2.28	0.055	0.88	−								
2.35	0.064	0.83	−								

[a] Parentheses indicate $d\sigma/d\Omega$ at 40°.

ness was overestimated so that cross sections should be increased.

The cross sections for exciting both the 2^+ and 3^- states in Mo^{92} are smaller than for the other isotopes. This is understandable for the 2^+ as this is a closed shell (50 neutron) nucleus, but it is not expected for the 3^- state. It does not occur in the analogous zirconium isotope, Zr^{90}.

There is a slight discontinuity in the energies of the 2^+ states at Mo^{98}. This may be understood as due to a "slightly closed shell" effect; in Zr^{96}, where the $d_{5/2}$ behaves very much more like a separate major shell, this effect is much larger.

TABLE XVIII. Results for Mo^{92}.

This work (d,d')			Ref. 17 (β^+)	
E^* (MeV)	$\frac{d\sigma}{d\Omega}(60°)$ (mb/sr)	$\frac{d\sigma}{d\Omega}(45°)$ (mb/sr)	E (MeV)	J^π
1.52	0.45	0.55	1.540	2^+
2.30	0.054	0.055	2.273	4^+
2.52	0.057	0.06	2.570	5^-
			2.660	6^+
			2.795	8^+
2.88	0.34	0.39		
3.12	0.095	0.11		

According to Ref. 3 (and many later references), the cross section for direct interaction inelastic scattering should be proportional to β^2 (where β is the vibrational deformation parameter) and to the nuclear radius to the third or fourth power. The $B(E2)$ value is related to β as

$$B(E2)=\text{constant}\times\beta^2Z^2R^4$$

(where Z is the atomic number), whence the cross section should be proportional to $B(E2)/Z^2$. This relationship is checked in Fig. 5 (which cites Ref. 19) where $B(E2)/Z^2$ is plotted versus the cross section for (d,d') at 60°. Data for Pd from Ref. 2 are also included here.

TABLE XIX. Results for Mo^{94}.

This work (d,d')			Ref. 18 (β^+)		
$E(d,d')$ (MeV)	$\frac{d\sigma}{d\Omega}(60°)$ (mb/sr)	$\frac{d\sigma}{d\Omega}(45°)$ (mb/sr)	$E(\beta^+)$ (293 min) (MeV)	$E(\beta^+)$ (52 min) (MeV)	J^π
0.87	0.78	3.2	0.8707	0.870	2^+
1.62	~0.26	~0.23	1.5729		4^+
2.46	0.11	0.17	2.4223	2.400	6^+
2.59	0.51	0.50			

One does not expect very perfect agreement in this test, since the angular distributions have an oscillatory behavior which is expected to vary with the size of the nucleus, but the correlation is fairly clear from the figure. The fact that $B(E2)$ for Te^{124} is not much different than for the other Te isotopes makes its small cross section for (d,d') even more suspicious. The same might be said of the large cross section for Te^{130}.

TABLE XX. Results for Mo^{96}.

This work (d,d')			Ref. 4	
$E(d,d')$ (MeV)	$\frac{d\sigma}{d\Omega}(60°)$ (mb/sr)	$\frac{d\sigma}{d\Omega}(45°)$ (mb/sr)	E_{known} (MeV)	J^π
0.76	1.00	2.58	0.770	2^+
1.50	0.15	0.23		
1.61	0.17	0.29	1.61	
1.81	0.04	0.09	1.85	
			1.96	
2.25	0.69	~0.57	2.25	
2.41	0.043	0.07	2.41	
2.48	0.062	0.13	2.57	
2.80	0.14	0.14	{2.73 2.79	
3.02	0.07	0.09		

One is tempted to use Fig. 5 to obtain estimates of $B(E2)$ for Zr^{90} where values are not available. However, in this case, the 60° to 45° cross-section ratio is abnormal, so that very different results would be obtained at the two angles. Moreover, the fact that angular distributions are different might indicate that the reaction mechanism is different, so that the cross section is not so simply related to $B(E2)$.

TABLE XXI. Results for Mo^{98}.

This work (d,d')			Ref. 4	
$E(d,d')$ (MeV)	$\frac{d\sigma}{d\Omega}(60°)$ (mb/sr)	$\frac{d\sigma}{d\Omega}(45°)$ (mb/sr)	E_{known} (MeV)	J^π
0.79	1.4	2.7	0.78	2^+
			1.50	
1.76	0.048	0.081		
1.93	0.18			
2.04	1.28	0.58		
2.18	0.049	0.16		
2.36	0.097	0.11		
			2.66	

TABLE XXII. Results for Mo^{100}.

This work (d,d')			Ref. 4	
E^* (MeV)	$\frac{d\sigma}{d\Omega}(60°)$ (mb/sr)	$\frac{d\sigma}{d\Omega}(45°)$ (mb/sr)	E_{known} (MeV)	J^π
0.54	1.31	4.3	0.53	2^+
1.96	0.93	0.57		
2.07	0.096	0.10		
2.48	0.085	0.10		
2.60	0.095	0.18		

---

[19] L. S. Kisslinger and R. A. Sorensen, Rev. Mod. Phys. **35**, 853 (1963).

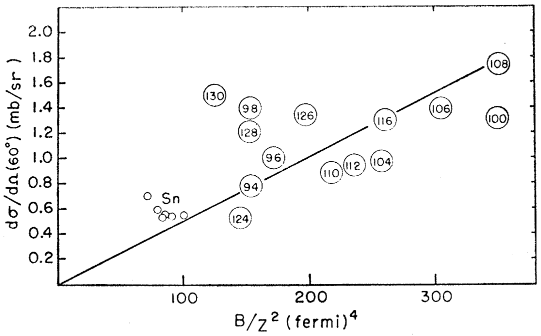

FIG. 5. Correlation between (d,d') differential cross section at 60° and $B(E2)/Z^2$ (Z is atomic number). Figures are mass numbers of targets. Points at lower left are from the various Sn isotopes. B values are from Ref. 19.

For the collective octupole state, $B(E3)$ or β_3 values are not known in many cases, so that it is interesting to derive estimates from the data reported here and in other work from this laboratory.[2,20]

The cross section should be approximately proportional[3] to β^2R^3, so that we assume it to be proportional to β^2A. In Table XXIII, values of β from the literature are listed for Ni^{60}, Cd^{110}, Cd^{112}, Cd^{116}, and Te^{126}. The first of these is used as a calibration for nuclei between Ni and Mo, and the average of the last four is used for nuclei between Mo and Te. The best angles from the standpoint of data availability were 45° for the first group, and 60° for the second. The excitation energies of the 3^- collective states and their cross sections at these angles are listed in Table XXIII. The latter are then used to calculate $\beta_3{}^2A$ using the appropriate calibration, and from $\beta_3{}^2A$, values of β_3 are derived in the last column.

In the Mo isotopes, where both calibrations are used, the agreement between the two calibrations is good in the lighter isotopes but poor in the heavier ones. Apparently the angular distributions are changing rapidly here.

The values of β_3 obtained in Table XXIII should be considered only as crude estimates. Judging from Fig. 5, this method might be reliable to perhaps 40% in obtaining $B(El)$ values, and since $B(El)$ is proportional to $\beta_l{}^2$, it should be reliable to about 20% in values of β_3. Since 60° is near a maximum in the angular distribution for $l=3$ transitions but not for $l=2$ transitions, determinations of β_3 might be somewhat better than this. On the other hand, any one value might be considerably more in error.

Recently, measurements of $B(E3)$ for the even tin isotopes have been reported[21]; those results, converted to β_3, are listed in column (9) of Table XXIII. There seems to be a qualitative disagreement with our results in that their values for the heaviest isotopes are somewhat larger than for the lighter isotopes of tin, whereas in our results, the opposite is the case. Their relatively large value for Sn^{116} is also not found here.

TABLE XXIII. Crude estimates of β for 3^- states. See discussion in text.

(1)	(2) β_3	(3) Ref.	(4) E (MeV)	(5) $d\sigma/d\Omega$ (mb/sr)	(6) θ	(7) $\beta_3{}^2A$	(8) β_3	(9) Ref. 21
Ni^{60}	0.18	a,d,e,g	4.05	0.55	46°	(1.95)		
Zn^{64}			3.02	1.38	45°	4.9	0.28	
Zn^{66}			2.81	1.43	45°	5.1	0.28	
Zn^{68}			2.74	1.02	45°	3.6	0.23	
Se^{76}			2.45	0.45	47°	1.60	0.15	
Se^{78}			2.55	1.00	47°	3.6	0.21	
Se^{80}			2.72	0.69	47°	2.45	0.17	
Se^{82}			2.96	0.61	47°	2.17	0.16	
Zr^{90}			2.76	0.54	47°	1.92	0.15	
Zr^{92}			2.35	0.53	45°	1.88	0.14	
Zr^{94}			2.06	0.71	47°	2.51	0.16	
Zr^{96}			1.87	0.94	47°	3.33	0.19	
Mo^{92}			2.87	0.34	60°	1.46	0.13	
				0.39	45°	1.39	0.12	
Mo^{94}			2.59	0.51	60°	2.19	0.15	
				0.50	45°	1.77	0.14	
Mo^{96}			2.25	0.69	60°	2.97	0.18	
				~0.57	45°	2.02	0.15	
Mo^{98}			2.04	1.27	60°	5.45	0.24	
				0.58	45°	2.06	0.15	
Mo^{100}			1.96	0.93	60°	3.98	0.20	
				0.57	45°	2.03	0.14	
Pd^{104}			2.20	0.57	59°	2.45	0.15	
Pd^{106}			2.09	0.62	59°	2.66	0.16	
Pd^{108}			2.03	0.54	59°	2.32	0.15	
Cd^{110}	0.14	b,c,d	2.09	0.55	59°	(2.16)		
Cd^{112}	0.14	b,c,d	2.01	0.42	59°	(2.20)		
Cd^{116}	0.12	b,c,d	1.93	0.42	59°	(1.67)		
Sn^{112}			2.36	0.51	60°	2.19	0.14	
Sn^{114}			2.27	0.89	60°	3.83	0.18	0.16
Sn^{116}			2.24	0.75	60°	3.22	0.17	0.20
Sn^{118}			2.33	0.74	60°	3.18	0.17	0.17
Sn^{122}			2.50	0.40	60°	1.72	0.12	0.19
Sn^{124}			2.59	0.30	60°	1.29	0.10	0.18
Te^{124}			2.28	0.15	60°	0.65	0.07(?)	
Te^{126}	0.12	f	2.37	0.42	60°	(1.81)		
Te^{128}			2.50	0.30	60°	1.29	0.10	
Te^{130}			2.77	0.36	60°	1.55	0.11	

[a] T. M. Stovall and N. M. Hintz, Phys. Rev. **135**, B330 (1964).
[b] F. K. McGowan, R. L. Robinson, P. H. Stelson, and I. L. C. Ford, Nucl. Phys. **66**, 97 (1965).
[c] P. H. Stelson, R. L. Robinson, H. J. Kim, J. Rapaport, and G. R. Satchler, Nucl. Phys. **68**, 97 (1965).
[d] G. R. Satchler, Nucl. Phys. (to be published).
[e] M. P. Fricke and G. R. Satchler, Phys. Rev. **139**, B567 (1965).
[f] G. C. Pramila, R. Middleton, T. Tamura, and G. R. Satchler, Nucl. Phys. **61**, 448 (1965).
[g] G. R. Satchler, R. H. Bassel, and R. M. Drisko, Phys. Letters **5**, 256 (1963).

ACKNOWLEDGMENTS

It is a pleasure to acknowledge help from R. H. Fulmer, E. K. Lin, R. K. Jolly, and A. L. McCarthy, and useful discussions with S. Hjorth and E. J. Schneid.

---

[20] E. K. Lin, Phys. Rev. **139**, B340 (1965).

[21] D. G. Alkhazov, Y. P. Gangrskii, I. K. Lemberg, and Y. I. Udralov, Izv. Akad. Nauk. SSSR, Ser. Fiz. **28**, 232 (1965).