Cross Sections and Analyzing Powers in Deuteron Elastic Scattering

los alamos
scientific laboratory
of the University of California
LOS ALAMOS, NEW MEXICO 87544

UNITED STATES
ATOMIC ENERGY COMMISSION
CONTRACT W-7405-ENG. 36

Printed in the United States of America. Available from
National Technical Information Service
U. S. Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22151
Price: Printed Copy $3.00; Microfiche $0.95

LA-5051
UC-34
ISSUED: October 1972

los alamos
scientific laboratory
of the University of California
LOS ALAMOS, NEW MEXICO 87544

Cross Sections and Analyzing Powers in Deuteron Elastic Scattering

by

R. A. Hardekopf
D. D. Armstrong
L. L. Catlin
P. W. Keaton, Jr.
G. P. Lawrence

CROSS SECTIONS AND ANALYZING POWERS IN DEUTERON ELASTIC SCATTERING

by

R. A. Hardekopf, D. D. Armstrong, L. L. Catlin,

P. W. Keaton, Jr., and G. P. Lawrence

ABSTRACT

All tensor analyzing powers have been measured for 15-MeV deuterons elastically scattered from ^{4}He, ^{52}Cr, ^{56}Fe, ^{60}Ni, ^{90}Zr, ^{122}Sn, and ^{197}Au. The results are presented in tabular and graphical form along with relative cross sections obtained for all but ^{4}He.

INTRODUCTION

The data presented here were obtained as part of an investigation of the deuteron optical-model potential.[1,2] A complete and consistent set of deuteron-scattering data on several nuclei at one energy were required for comparison with optical-model calculations.[3] Although an optical-model fit to the deuteron differential cross section and analyzing tensors could be credible only if it spanned several energies as well as several atomic numbers, to date no one has obtained a fit to these five observables at a single energy for any target nucleus.

The data acquisition was made possible by the development at the Los Alamos Scientific Laboratory (LASL) of a high-intensity, Lamb-shift polarized ion source,[4] a rotating scattering chamber, and rapid methods for reliable determination of all four analyzing powers in deuteron-induced reactions.[3,5]

Except for helium, all targets were isotopically enriched metallic foils ~ 0.1 to 0.5 mg/cm^2 thick. The helium was contained at 1.0 atm in a gas-scattering cell made of 0.0025-mm-thick HAVAR* foil.

*HAVAR is the trade name of a high-tensile-strength alloy manufactured by the Hamilton Watch Co.

Four detector telescopes at azimuthal positions corresponding to left, right, up, and down were used. The LASL tandem on-line computer controlled the reaction-chamber rotation sequence, the deuteron-beam nuclear magnetic substate, m_I, and measurement of the beam polarization.[5] Beam polarizations[6] of typically 80% m_I = +1 or 0, were used for the measurements. The notation and coordinate systems used are consistent with the Madison Convention.[7]

The data are presented both in tabular form and graphically. We assign an absolute uncertainty of ±0.02 to all of the analyzing-power data. Statistical uncertainties for these data were generally less than ±0.01. Only relative differential cross sections were measured, and these data are assigned a relative uncertainty of 5%. This estimate includes contributions from counting statistics as well as beam integration and dead-time correction. The cross-section angular distributions have been normalized to optical-model predictions.[3]

REFERENCES

1. P. W. Keaton, Jr., E. Aufdembrink, and L. R. Veeser, Los Alamos Scientific Laboratory report LA-4379-MS (1970).

2. P. W. Keaton, Jr., and D. D. Armstrong, to be published.

3. D. D. Armstrong, R. A. Hardekopf, and P. W. Keaton, Bull. Am. Phys. Soc. 17, 686 (1972); and to be published.

4. J. L. McKibben, G. P. Lawrence, and G. G. Ohlsen, Third Symposium Polarization Phenomena in Nuclear Reactions (Univ. of Wisc. Press, Madison, 1971) p. 828; G. P. Lawrence, G. G. Ohlsen, and J. L. McKibben, Phys. Letters 28B, 594 (1969).

5. G. P. Lawrence, G. G. Ohlsen, J. L. McKibben, P. W. Keaton, Jr., and D. D. Armstrong, Third Symposium Polarization Phenomena in Nuclear Reactions (Univ. of Wisc. Press, Madison, 1971) p. 855.

6. G. G. Ohlsen, G. P. Lawrence, P. W. Keaton, Jr., J. L. McKibben, and D. D. Armstrong, ibid., p. 842.

7. Madison Convention, ibid.

DEUTERON ELASTIC SCATTERING ON HELIUM-4 AT 15 MEV

THETA(CM)	A(Y)	A(ZZ)	A(XZ)	.5A(XX-YY)
29.91	-.014	-.007	.068	-.080
37.28	-.054	-.068	.070	-.138
44.57	-.227	-.104	.040	-.240
48.16	-.429	-.197	.006	-.292
51.78	-.689	-.318	-.113	-.353
55.32	-.744	-.404	-.131	-.257
58.87	-.575	-.264	-.072	-.099
62.38	-.339	-.131	.011	.061
65.84	-.142	.014	.047	.130
72.67	.051	.102	.203	.243
79.34	.099	.168	.273	.315
85.63	.063	.200	.263	.413
92.13	-.008	.196	.252	.459
98.22	-.096	.207	.251	.510
104.08	-.194	.246	.231	.529
109.71	-.292	.253	.211	.529
115.08	-.374	.235	.189	.480
120.21	-.393	.249	.147	.414
125.08	-.347	.217	.138	.261
129.71	-.177	.214	.128	.060
134.08	.086	.166	.086	-.171
138.22	.375	.157	.077	-.317
142.13	.578	.112	.059	-.442
145.83	.685	.100	.049	-.458
149.34	.692	.117	.116	-.392
152.67	.648	.124	.082	-.313
155.84	.605	.071	.099	-.252
161.78	.432	.079	.074	-.124
167.28	.314	.093	.042	-.072

DEUTERON ELASTIC SCATTERING ON CHROMIUM-52 AT 15 MEV

THETA(CM)	(MB/SR)	A(Y)	A(ZZ)	A(XZ)	.5A(XX-YY)
10.39	40670.000				
12.46	18063.000				
15.58	7794.000				
20.76	2232.000				
25.94	532.800				
31.11	164.900				
36.27	125.200				
41.43	98.960	.027	-.009	.006	-.017
46.57	53.500	-.003	-.004	-.007	-.014
51.70	27.710	-.078	.015	.044	-.060
56.82	14.450	-.198	.022	.095	-.044
61.92	6.621	-.224	.003	.047	-.026
67.01	5.882	-.046	-.016	.039	-.092
72.09	3.375	.244	.028	.007	-.080
77.15	2.484	.298	.040	-.006	-.025
82.19	2.918	.043	.027	-.054	.015
87.21	3.005	-.191	-.039	-.005	-.023
92.22	2.480	-.366	-.123	.004	-.107
97.21	1.441	-.445	-.173	.049	-.192
102.19	.603	-.338	-.276	.137	-.291
107.15	.372	.383	.060	-.001	-.105
112.09	.513	.494	.172	-.074	-.022
117.01	.757	.176	.139	-.055	.020
121.92	.859	-.098	-.001	-.036	-.017
126.82	.818	-.333	-.085	-.063	-.052
131.70	.555	-.521	-.237	-.058	-.125
136.57	.356	-.640	-.371	-.063	-.248
141.43	.206	-.502	-.345	-.106	-.274
146.27	.148	.102	.032	.025	.011
151.11	.169	.401	.417	.207	.309
155.94	.223	.389	.286	.146	.277

DEUTERON ELASTIC SCATTERING ON IRON-54 AT 15 MEV

THETA(CM)	(MB/SR)	A(Y)	A(ZZ)	A(XZ)	.5A(XX-YY)
10.36	48670.000				
12.43	22620.000				
15.53	9747.000				
20.71	2719.000				
25.87	669.900				
31.03	236.600				
36.18	172.400				
41.33	120.100	-.003	-.022	.007	-.025
46.46	60.370	-.011	-.006	.002	-.042
51.58	27.240	-.065	.020	.041	-.040
56.69	14.480	-.134	.024	.075	-.042
61.79	10.450	-.077	.027	.043	-.048
66.87	7.694	.076	.003	.041	-.038
71.94	5.276	.190	.015	.010	-.059
76.99	4.115	.106	-.001	-.000	-.015
82.03	3.688	-.115	-.024	-.024	.041
87.06	2.892	-.269	-.047	.014	-.056
92.06	2.116	-.339	-.125	.072	-.095
97.06	1.044	-.244	0.000	.070	-.158
102.03	.554	.205	0.000	.036	-.036
106.99		.400	0.000	-.058	.132
111.94	.816	.178	0.000	-.041	.035
116.87		-.042	0.000	-.004	-.052
121.79	.837	-.248	0.000	.000	-.157
126.69		-.393	0.000	.023	-.194
131.58	.405	-.435	0.000	-.009	-.256
136.46		-.277	0.000	.029	-.195
141.33	.171	.152	0.000	-.001	-.032
146.18		.336	0.000	.039	.270
151.03	.244	.168	0.000	.018	.305

DEUTERON ELASTIC SCATTERING ON NICKEL-60 AT 15 MEV

THETA(CM)	(MB/SR)	A(Y)	A(ZZ)	A(XZ)	.5A(XX-YY)
41.25	143.994	-.026	-.018	.005	-.022
46.37	70.449	-.044	-.002	.012	-.042
51.49	29.992	-.075	.056	.046	-.042
56.59	17.050	-.052	.011	.063	-.027
61.68	14.377	.027	.010	.044	.013
66.76	11.801	.065	.034	.019	-.011
71.82	8.672	.041	0.000	.007	-.021
76.87	6.196	-.042	-.015	.010	-.037
81.92	4.597	-.237	-.048	.036	-.064
86.93	3.133	-.307	-.085	.079	-.106
91.94	1.920	-.180	-.052	.093	-.106
96.93	1.209	.144	.043	.054	.030
101.91	1.014	.322	.162	-.024	.101
106.87	1.148	.158	.112	-.014	.080
111.82	1.206	-.080	.007	-.004	-.014
116.76	1.063	-.272	-.150	-.004	-.146
121.68	.815	-.398	-.266	.017	-.216
126.59	.505	-.403	-.341	.029	-.329
131.49	.316	-.097	-.238	.103	-.326
136.37	.261	.316	.136	.041	-.015
141.25	.306	.398	.322	.030	.146
146.11	.385	.202	.309	-.027	.155
150.97	.437	-.074	.202	-.058	.145
155.82	.411	-.310	.036	-.088	.108

DEUTERON ELASTIC SCATTERING ON ZIRCONIUM-90 AT 15 MEV

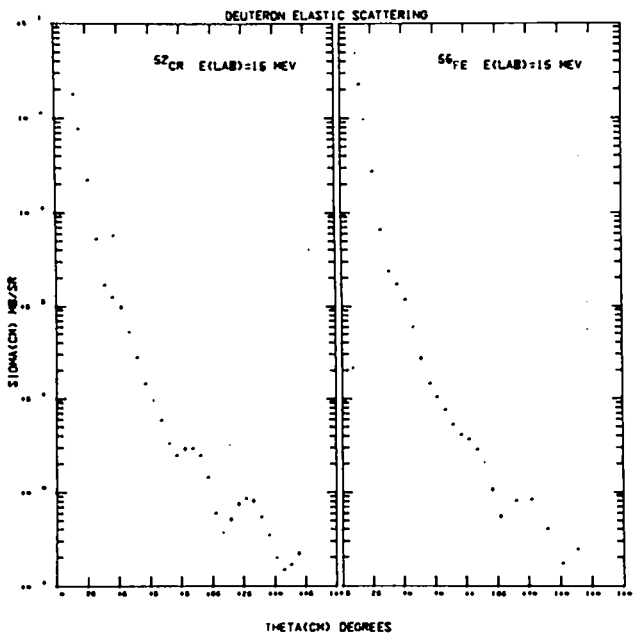
THETA(CM)	I**2/SB)	A(Y)	A(ZZ)	A(XZ)	.5A(XX-YY)
10.22	155700.000				
12.27	88110.000				
15.33	26540.000				
20.44	7814.000				
25.54	2497.000				
30.64	857.800				
35.74	417.100				
40.83	139.200	-.017	.005	.047	-.047
45.91	106.300	.051	-.008	.021	-.035
50.93	58.860	.034	.005	-.008	-.004
56.05	56.570	-.054	.005	.001	.009
61.11	19.160	-.155	-.022	.061	-.054
66.16	19.030	-.201	-.014	.094	-.053
71.21	8.075	-.034	.006	.034	-.116
76.24	6.197	.194	.026	-.005	-.023
81.26	7.428	.102	.030	-.046	.061
86.28	7.893	-.058	.012	-.046	.052
91.28	6.055	-.217	-.069	.005	-.056
96.28	3.663	-.354	-.118	.051	-.108
101.26	1.751	-.308	-.160	.099	-.181
106.24	1.087	.142	.002	.071	-.125
111.21	1.136	.353	.187	-.012	.098
116.16	1.523	.154	.109	-.037	.040
121.11	1.521	-.040	.007	.052	-.032
126.05	1.361	-.312	-.127	-.020	-.108
130.98	.976	-.443	-.277	-.043	-.268
135.91	.635	-.389	-.336	.068	-.278
140.83	.416	-.014	-.130	.033	-.153
145.74	.334	.319	.247	.024	.194
150.64	.373	.236	.415	.043	.296
155.54	.453	-.109	.255	-.066	.289

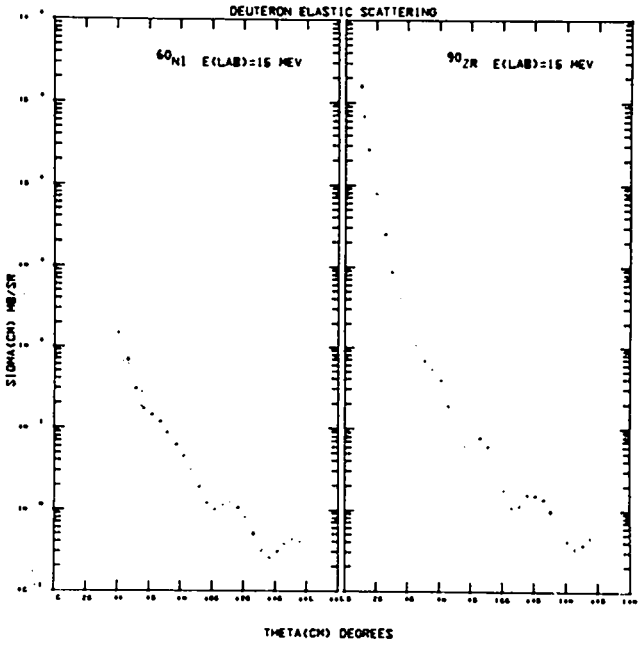
DEUTERON ELASTIC SCATTERING ON TIN-122 AT 15 MEV

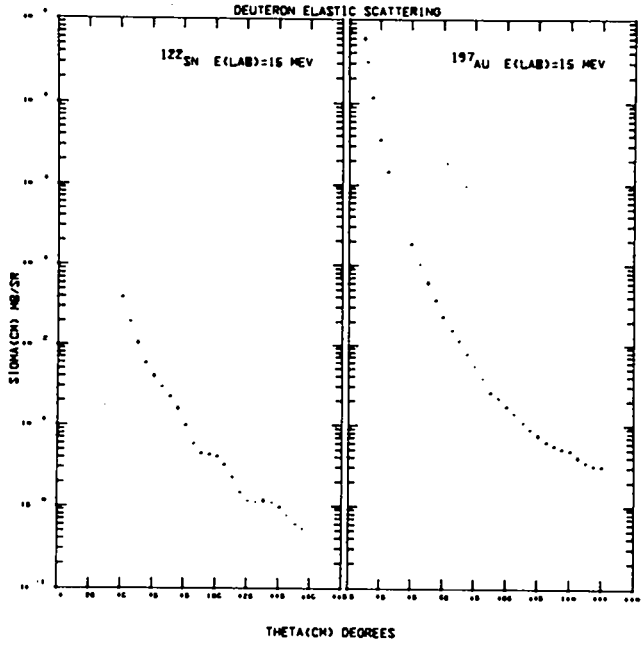
THETA(CM)	I**2/SB)	A(Y)	A(ZZ)	A(XZ)	.5A(XX-YY)
40.61	17%.669	-.024	-.014	.027	-.004
45.67	105.033	-.041	.020	.033	-.016
50.71	103.158	-.049	.014	.028	-.020
55.79	50.165	.002	.014	.039	-.018
60.83	39.763	.046	.003	.026	-.025
65.86	29.822	.046	-.006	.015	-.011
70.90	22.323	-.021	-.003	-.006	-.008
75.92	14.176	-.078	-.006	.024	-.025
80.94	9.854	-.092	.003	.041	-.026
85.95	5.884	.006	.018	.060	-.006
90.95	%.%36	.151	.028	.056	-.011
95.95	%.363	.077	.008	.009	.009
100.94	4.116	-.029	-.011	.007	-.013
105.92	3.183	-.138	-.044	.020	-.020
110.90	2.250	-.137	-.044	.072	-.037
115.86	1.687	.004	-.055	.100	-.062
120.83	1.160	.189	-.008	.078	.009
125.78	1.129	.177	.036	.031	.015
130.73	1.160	.062	.010	.006	.011
135.67	1.112	-.090	-.024	-.003	-.024
140.61	.986	-.169	-.047	.011	-.036
145.55	.773	-.125	-.020	.049	-.058
150.48	.606	-.018	-.056	.031	-.029
155.40	.532	.132	-.041	.049	.049

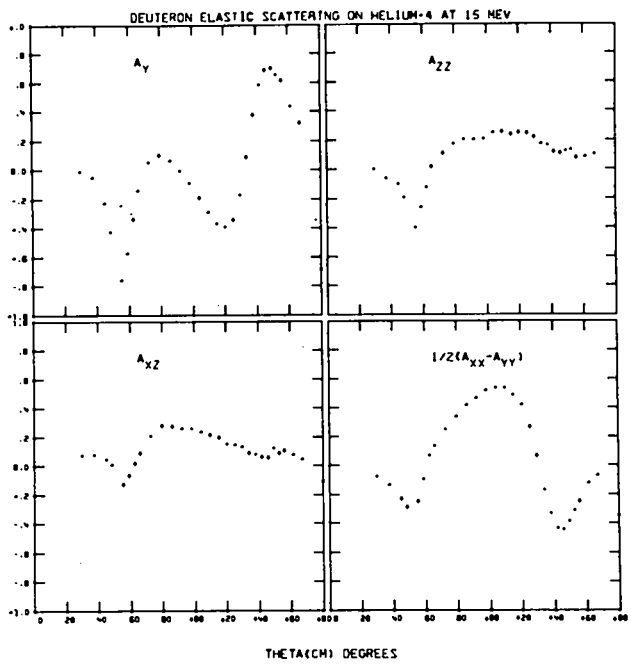
DEUTERON ELASTIC SCATTERING ON GOLD-197 AT 15 MEV

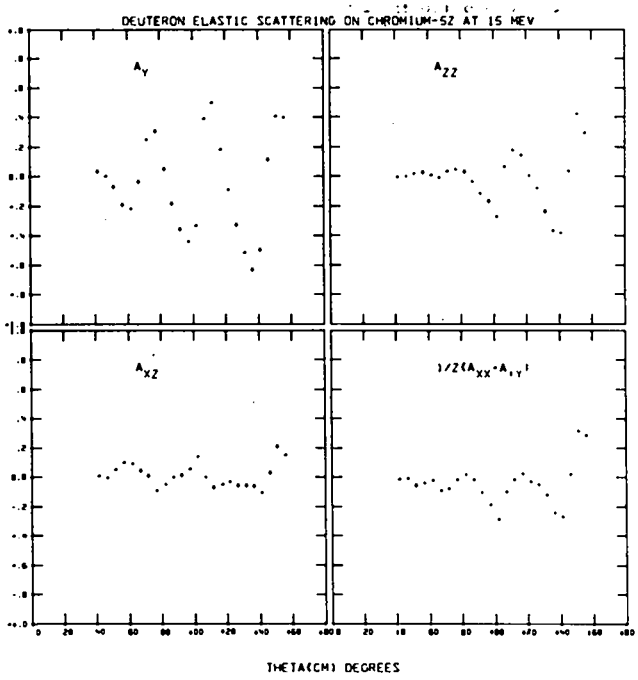
THETA(CM)	I**2/SB)	A(Y)	A(ZZ)	A(XZ)	.5A(XX-YY)
10.10	584700.000				
12.12	307490.000				
15.15	114000.000				
20.20	35580.000				
25.25	14450.000				
30.29	7011.000				
40.38	1839.000	-.009	.008	.009	-.012
45.41	1065.000	-.008	-.005	-.005	-.008
50.45	607.600	-.004	.005	-.007	-.024
55.48	371.200	-.007	-.002	0.000	-.011
60.50	232.600	-.010	.007	.018	-.017
65.53	156.200	-.012	-.014	.008	-.025
70.55	113.600	-.009	-.002	-.012	-.014
75.57	77.446	-.013	-.003	.008	-.012
80.58	54.000	-.019	-.004	-.010	-.011
85.58	38.280	-.019	-.001	.012	.014
90.59	25.310	.008	-.003	.025	.003
95.58	21.550	.063	.006	.024	.009
100.58	17.200	-.011	.012	.032	-.023
105.57	14.160	.010	-.003	.004	-.020
110.55	10.080	-.021	-.004	.024	-.015
115.53	8.884	-.010	-.014	.007	.010
120.51	7.411	-.061	-.011	.011	.028
125.48	6.237	.020	-.026	.019	.027
130.45	5.534	.003	-.005	.018	-.022
135.41	5.122	-.004	-.040	.022	.007
140.37	%.914	-.014	-.024	.020	.002
145.34	3.957	-.014	-.018	-.001	.000
150.29	3.662	-.006	-.055	.018	.020
155.25	3.125	.002	-.010	.017	.014
160.20	3.063	.007	-.018	.018	-.010

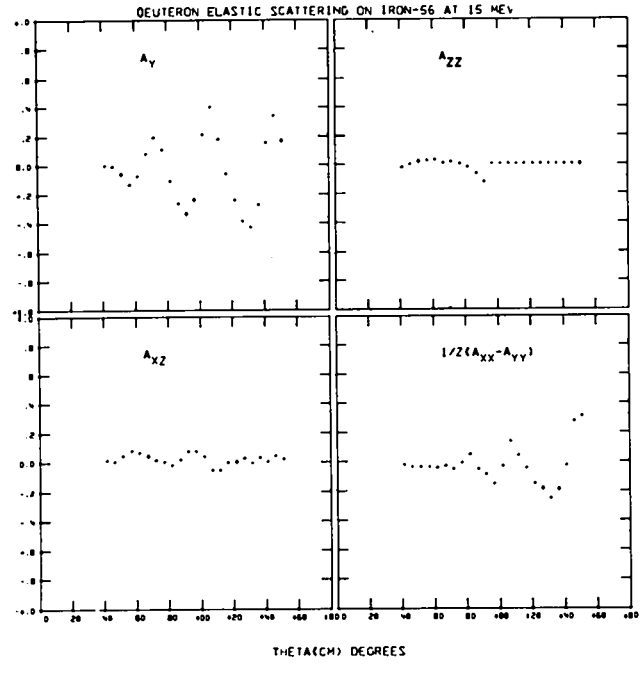

DEUTERON ELASTIC SCATTERING
^{52}CR E(LAB)=16 MEV
^{56}FE E(LAB)=15 MEV
SIGMA(CM) MB/SR
THETA(CM) DEGREES

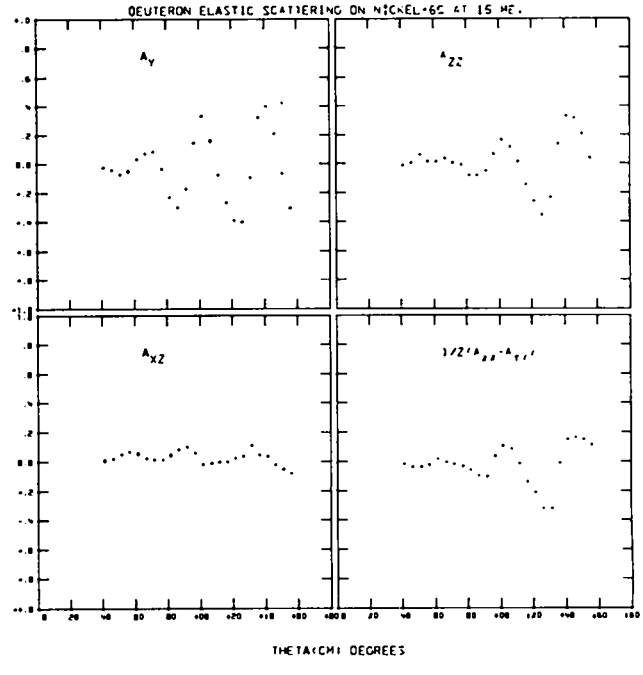

DEUTERON ELASTIC SCATTERING
^{60}NI E(LAB)=16 MEV
^{90}ZR E(LAB)=16 MEV
SIGMA(CM) MB/SR
THETA(CM) DEGREES

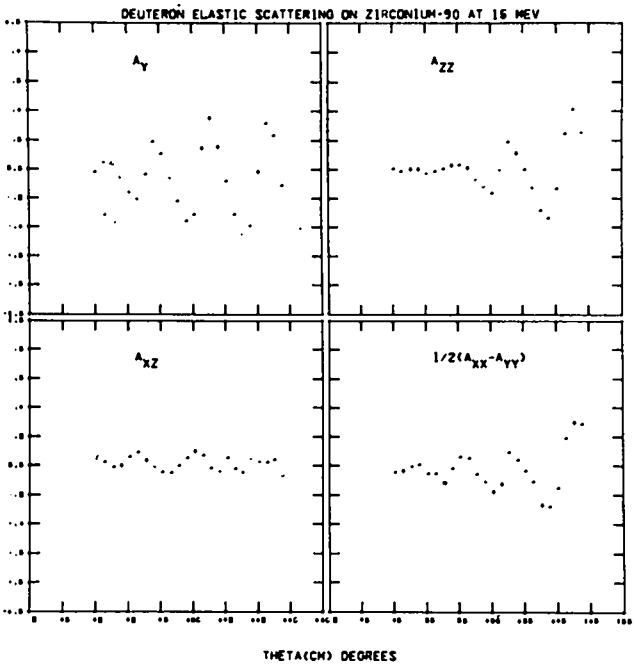

DEUTERON ELASTIC SCATTERING
^{122}SN E(LAB)=16 MEV
^{197}AU E(LAB)=15 MEV
SIGMA(CM) MB/SR
THETA(CM) DEGREES

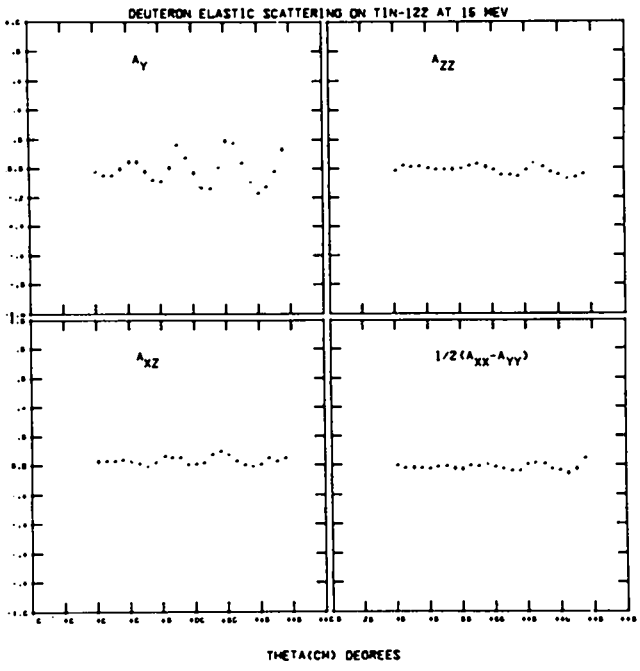

DEUTERON ELASTIC SCATTERING ON HELIUM-4 AT 15 MEV
A_y
A_{zz}
A_{xz}
$1/2(A_{xx}-A_{yy})$
THETA(CM) DEGREES

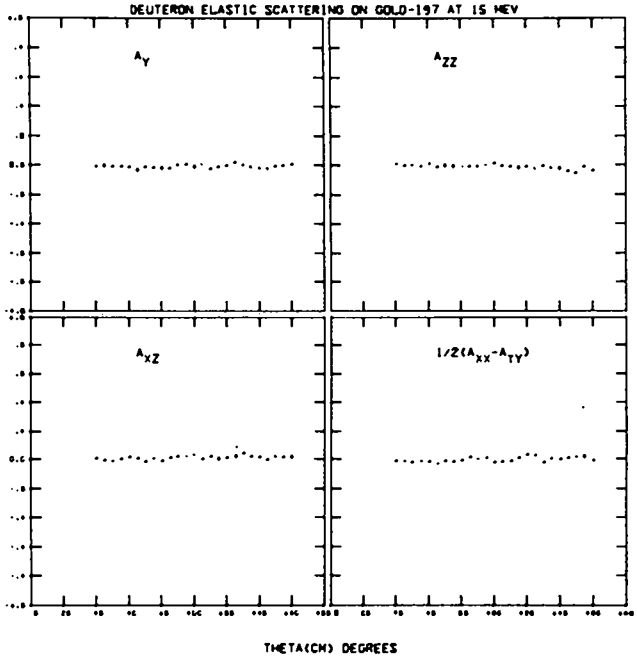

DEUTERON ELASTIC SCATTERING ON CHROMIUM-52 AT 15 MEV
A_y
A_{zz}
A_{xz}
$1/2(A_{xx}-A_{yy})$
THETA(CM) DEGREES


DEUTERON ELASTIC SCATTERING ON IRON-56 AT 15 MEV
A_y
A_{zz}
A_{xz}
$1/2(A_{xx}-A_{yy})$
THETA(CM) DEGREES


DEUTERON ELASTIC SCATTERING ON NICKEL-60 AT 15 MEV
A_y
A_{zz}
A_{xz}
THETA(CM) DEGREES


DEUTERON ELASTIC SCATTERING ON ZIRCONIUM-90 AT 16 MEV
A_Y
A_{ZZ}
A_{XZ}
$1/2(A_{XX}-A_{YY})$
THETA(CM) DEGREES


DEUTERON ELASTIC SCATTERING ON TIN-122 AT 16 MEV
A_Y
A_{ZZ}
A_{XZ}
$1/2(A_{XX}-A_{YY})$
THETA(CM) DEGREES


DEUTERON ELASTIC SCATTERING ON GOLD-197 AT 15 MEV
A_Y
A_{ZZ}
A_{XZ}
$1/2(A_{XX}-A_{TY})$
THETA(CM) DEGREES

KT: 480 (204)