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ELASTIC AND INELASTIC SCATTERING OF PROTONS FROM ^{120}Sn FOR E_p = 20.6, 25.2, 30.6, AND 36.2 MeV: TABULATED DIFFERENTIAL CROSS SECTIONS

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MAY 1968

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ELASTIC AND INELASTIC SCATTERING OF PROTONS FROM ^{120}Sn FOR E_p = 20.6, 25.2, 30.6, AND 36.2 MeV: TABULATED DIFFERENTIAL CROSS SECTIONS[1]

F. E. Bertrand, T. A. Love, N. Baron,[2]
F. G. Perey, and J. K. Dickens

ABSTRACT

Numerical values of differential cross sections for elastic and inelastic scattering of protons from ^{120}Sn for bombarding proton energies of 20.6, 25.2, 30.6, and 36.2 MeV are reported in tabular form. Inelastic-scattering data are reported for the 1.17-MeV (2^+) state at all incident energies, and for the 2.35-MeV (3^-) state at 20.6-, 25.2-, and 36.2-MeV incident energies. Cross sections were obtained at $\sim 5^\circ$ intervals between laboratory angles of 15° and 110°.

As part of a continuing program[3] to obtain differential cross sections for selected reactions to compare with predictions of nuclear reaction theories we have measured elastic scattering of protons from ^{120}Sn for E_p = 20.6, 25.2, 30.6, and 36.2 MeV. In addition, inelastic scattering cross sections were obtained for proton excitation of the first excited state in ^{120}Sn ($J^\pi = 2^+$) at E_x = 1.17 MeV at all four

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[1]We express our appreciation to A. Marusak for assistance during the run, and to the ORIC Cyclotron crew for efficient machine operation.

[2]National Aeronautics and Space Administration, Lewis Research Center, Cleveland, Ohio.

[3]See, for example, ORNL-3637, which covers 5- to 13.5-MeV deuterons from ^{60}Ni; ORNL-3727, which covers 8- to 15-MeV deuterons from ^{114}Cd; ORNL-3850, which covers 12.0- and 14.0-MeV deuterons from ^{90}Zr and the reaction ^{90}Zr(d,p)^{91}Zr; ORNL-3851, which covers 12.0-MeV protons from ^{62}Ni, ^{63}Cu, and ^{64}Zn; ORNL-3934, which covers 12.7-MeV protons from ^{90}Zr, ^{92}Zr, and ^{94}Zr; and ORNL-4182, which covers 11.0-MeV protons from ^{48}Ti, ^{51}V, ^{52}Cr, ^{54}Fe, ^{56}Fe, ^{59}Co, ^{60}Ni, ^{62}Ni, ^{64}Ni, ^{63}Cu, ^{65}Cu, ^{64}Zn, ^{66}Zn, and ^{68}Zn.

incident energies, and for excitation of the strongly excited $J^{\pi} = 3^-$ state at $E_x = 2.35$ MeV for $E_p = 20.6$, 25.2, and 36.2 MeV. Numerical values of the elastic differential cross sections are given in Table I, the data for the excitation of the 2^+ state in Table II, and the data for excitation of the 3^- state in Table III.

Incident protons were accelerated by the Oak Ridge Isochronous Cyclotron, magnetically bent through a 153° analyzing magnet and focussed in a ¼-in. diameter spot at the scattering chamber center. The incident beam intensity was monitored using a Faraday cup and the accumulated charge was measured with a high stability ORNL solid state integrator, which was calibrated with a precision current source. Protons scattered from the ^{120}Sn target (the target was enriched to >99% in the isotope) were detected using a cooled Ge(Li) planer detector mounted so that the protons entered the side of the detector and were stopped in the depleted region.[4] The total energy resolution (FWHM) was ~0.1% for each incident energy used. Pulses from the detector were amplified, converted to digital form, transferred to memory of a PDP-8 computer,[5] and the resulting spectra were stored on magnetic tape. Peak areas were extracted using a peak-stripping routine written for a PDP-7 computer.[6]

The column headings of the tables are defined as follows:

$\theta_{c.m.}$ = center-of-mass angle, deg,

$d\sigma/d\omega$ = center-of-mass differential cross section, mb/steradian,

$\Delta\sigma$ = relative error associated with $d\sigma/d\omega$, mb/steradian,

σ/σ_C = ratio of the elastic cross section to the Rutherford cross section.

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[4] F. E. Bertrand et al., "A Total-Absorption Detector for 60-MeV Protons Using Lithium-Drifted Germanium," IEEE Trans. Nucl. Sci., vol. NS-13, No. 3, 279 (June 1966).

[5] B. W. Rust and W. R. Burrus, Flexi-Kludge – A Multi-Parameter Nuclear Spectrum Summing System for the PDP-8, ORNL-TM-1879 (August 1967).

[6] J. A. Biggerstaff et al., ORNL-4134 (unpublished).

The relative error, $\Delta\sigma$, primarily affects the shapes of the angular distributions. For elastic scattering the errors due to counting statistics were small, and the major contribution to $\Delta\sigma$ was the estimate of uncertainties associated with our knowledge of the variation of the target thickness in the region struck by the beam. The ^{120}Sn target was nominally 4.5 mg/cm^2; deviations from a uniform target thickness were determined by measuring the energy lost by 5.15-MeV alpha particles. In the region struck by the beam, the variation in target thickness amounted to 3 ± 1%. For inelastic scattering, in addition to the target nonuniformity, the major contributions to $\Delta\sigma$ include counting statistics and the estimation of the error associated with subtraction of the background. An additional uncertainty for the E_x = 2.35-MeV data was associated with the unknown contributions of partially resolved proton groups corresponding to excitation of levels in ^{120}Sn with E_x between 2.3 and 2.4 MeV. We assumed that the reaction of interest dominated the resulting peak seen in the pulse-height spectrum. Analysis of the data using this assumption indicated that the contribution from the unresolved levels was ≤30%. The largest uncertainties occur at the minima of the angular distributions.

The absolute normalization assigned to the measured cross sections depended on the measured target thickness, the detector solid-angle measurement, and the beam integration measurements, and was estimated to be accurate to within 10%. The run at E_p = 30.6 MeV was taken principally to compare with the reported angular distribution at E_p = 30.3 MeV,[7] and the absolute values for the two angular distributions agree to within 5%. Angle settings were measured with a precision of 0.1° with respect to the geometrical zero line of the chamber. The geometrical zero line was determined to be the physical zero line to within 0.5°. The beam energy was determined by measuring the magnetic field in the 153° bending magnet. We estimate the beam energy uncertainty at <100 keV.

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[7]B. W. Ridley and J. F. Turner, Nucl. Phys. 58, 497 (1964).

TABLE I. DIFFERENTIAL CROSS SECTIONS FOR PROTONS ELASTICALLY SCATTERED FROM 120-SN

$\theta_{c.m.}$ (DEG)	$d\sigma/d\omega$ (MB/STERADIAN)	$\Delta\sigma$ (MB/STERADIAN)	σ/σ_C
	ELAB = 20.6 MEV		
15.1	22086	2686	0.858
20.2	6841	370	0.832
25.2	2916	150	0.855
30.2	1189	62	0.712
35.3	433	22	0.472
40.3	161.7	8.3	0.295
45.3	94.2	4.8	0.269
50.4	79.4	4.0	0.337
55.4	70.8	3.6	0.427
60.4	58.5	3.0	0.485
65.4	40.9	2.1	0.451
70.5	23.8	1.2	0.341
75.5	10.21	0.55	0.185
80.5	5.11	0.28	0.115
85.5	4.91	0.27	0.135
90.5	7.49	0.39	0.246
95.5	8.28	0.44	0.321
100.5	7.46	0.40	0.336
110.5	2.94	0.17	0.172
	ELAB = 25.2 MEV		
15.1	12598	868	0.736
20.2	4075	244	0.745
25.2	1593	94	0.702
30.2	621	31	0.559
35.3	255	13	0.419
40.3	108.5	5.5	0.298
45.3	46.7	2.4	0.200
50.4	34.3	1.8	0.219
55.4	41.0	2.1	0.372
60.4	41.9	2.1	0.522
65.4	27.0	1.4	0.448
70.5	10.89	0.56	0.234

(CONTINUED NEXT PAGE)

$\theta_{c.m.}$ (DEG)	$d\sigma/d\omega$ (MB/STERADIAN)	$\Delta\sigma$ (MB/STERADIAN)	σ/σ_C
75,5	2.94	0,17	0,080
80,5	3.37	0,20	0,114
85,5	6.89	0,36	0,284
90,5	8.00	0,41	0,395
95,5	5.92	0,32	0,345
100,5	3.12	0,17	0,211
105,5	1.138	0,078	0,089
110,5	0.730	0,046	0,064
ELAB = 30,6 MEV			
15,1	7407	398	0,638
25,2	723	36	0,470
30,2	384	19	0,511
35,3	218	11	0,528
40,3	73.0	3,7	0,295
45,3	13.80	0,71	0,087
50,4	27.1	1,4	0,255
60,4	35.5	1,8	0,652
65,4	13.64	0,69	0,334
75,5	4.25	0,22	0,171
82,5	8.93	0,46	0,483
90,5	4.76	0,25	0,347
105,5	1.417	0,080	0,163
110,5	2.10	0,11	0,273
ELAB = 36,2 MEV			
15,1	6511	353	0,785
20,2	1258	64	0,475
25,2	407	21	0,371
30,2	371	19	0,690
35,3	220	11	0,745
39,3	71.7	3,6	0,369
42,3	16.53	0,88	0,113
45,3	8.93	0,47	0,079
47,4	19.9	1,0	0,208
50,4	39.8	2,0	0,524

(CONTINUED NEXT PAGE)

$\theta_{c.m.}$ (DEG)	$d\sigma/d\omega$ (MB/STERADIAN)	$\Delta\sigma$ (MB/STERADIAN)	σ/σ_C
55,4	46.1	2,4	0,864
60,4	22.5	1,2	0,579
65,4	4.94	0,27	0,169
67,9	3.24	0,19	0,127
70,5	4.70	0,25	0,209
75,5	8.86	0,46	0,499
80,5	7.80	0,41	0,545
85,5	4.00	0,21	0,340
90,5	1.586	0,088	0,162
95,5	1.372	0,076	0,165
100,5	1.794	0,099	0,251
105,5	1.708	0,096	0,274
110,5	1.133	0,065	0,207

TABLE 2. DIFFERENTIAL CROSS SECTIONS FOR PROTONS INELASTICALLY SCATTERED FROM 120-SN (Q=-1.17 MEV)

$\theta_{c.m.}$ (DEG)	$d\sigma/d\omega$ (MB/STERADIAN)	$\Delta\sigma$ (MB/STERADIAN)
	ELAB = 20.6 MEV	
20.2	4.78	0.69
25.2	5.22	0.52
30.2	5.01	0.50
35.3	3.07	0.30
40.3	1.92	0.19
45.4	1.01	0.10
50.4	1.21	0.12
55.4	1.23	0.12
60.4	1.53	0.15
65.4	1.41	0.14
70.5	0.932	0.093
75.5	0.599	0.059
80.5	0.392	0.039
85.5	0.311	0.033
90.5	0.371	0.037
95.5	0.370	0.039
100.5	0.312	0.034
110.5	0.300	0.032
	ELAB = 25.2 MEV	
20.2	5.86	0.82
25.2	6.50	0.82
30.2	5.38	0.40
35.3	2.70	0.20
40.3	1.50	0.11
45.3	1.046	0.078
50.4	1.319	0.098
55.4	1.48	0.11
60.4	1.125	0.084
65.4	0.804	0.064
70.5	0.687	0.051
75.5	0.555	0.050
80.5	0.405	0.043

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$\theta_{c.m.}$ (DEG)	$d\sigma/d\omega$ (MB/STERADIAN)	$\Delta\sigma$ (MB/STERADIAN)
85,5	0.345	0,036
90,5	0.311	0,024
95,5	0.288	0,030
100,5	0.293	0,030
105,5	0.336	0,034
110,5	0.304	0,023

ELAB = 30,6 MEV

15,1	5.54	0,55
25,2	6.67	0,66
30,2	4.31	0,43
35,3	2.44	0,24
40,3	1.59	0,15
45,3	1.60	0,15
50,4	1.47	0,14
60,4	0.708	0,070
65,4	0.840	0,083
75,5	0.576	0,057
82,5	0.276	0,027
90,5	0.336	0,033
105,5	0.193	0,019
110,5	0.148	0,014

ELAB = 36,2 MEV

15,1	5.50	0,52
20,2	6.97	0,52
25,2	6.72	0,50
30,2	3.44	0,25
35,3	2.04	0,15
39,3	2.37	0,17
42,3	2.36	0,17
45,3	1.97	0,14
47,4	1.70	0,12
50,4	1.101	0,082
55,4	0.701	0,058
60,4	0.776	0,072

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$\theta_{c.m.}$ (DEG)	$d\sigma/d\omega$ (MB/STERADIAN)	$\Delta\sigma$ (MB/STERADIAN)
65.4	0.956	0.071
68.0	0.897	0.070
70.5	0.690	0.051
75.5	0.365	0.030
80.5	0.269	0.030
85.5	0.299	0.024
90.5	0.390	0.029
95.5	0.263	0.019
100.5	0.155	0.014
105.5	0.104	0.012
110.5	0.105	0.011

TABLE 3. DIFFERENTIAL CROSS SECTIONS FOR PROTONS INELASTICALLY SCATTERED FROM 120-SN (Q=-2.35 MEV)

$\theta_{c.m.}$ (DEG)	$d\sigma/d\omega$ (MB/STERADIAN)	$\Delta\sigma$ (MB/STERADIAN)
	ELAB = 20.6 MEV	
20.2	1.62	0.29
25.2	1.63	0.24
30.3	2.56	0.38
35.3	3.11	0.46
40.3	2.82	0.42
45.4	2.20	0.32
50.4	1.62	0.24
55.4	1.10	0.16
60.4	0.92	0.13
65.5	1.12	0.16
70.5	1.19	0.17
75.5	1.37	0.20
80.5	1.02	0.15
85.5	0.89	0.13
90.5	0.68	0.10
95.5	0.418	0.062
100.5	0.327	0.049
110.5	0.325	0.048
	ELAB = 25.2 MEV	
30.3	2.96	0.44
35.3	3.25	0.48
40.3	3.05	0.45
45.4	2.13	0.31
50.4	1.58	0.23
55.4	1.05	0.15
60.4	0.91	0.13
65.5	1.04	0.15
70.5	1.10	0.16
75.5	0.99	0.14
80.5	0.70	0.10
85.5	0.528	0.079
90.5	0.396	0.059

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$\theta_{c.m.}$ (DEG)	$d\sigma/d\omega$ (MB/STERADIAN)	$\Delta\sigma$ (MB/STERADIAN)
95,5	0,339	0,050
100,5	0.293	0,043
105,5	0,300	0,045
110,5	0,270	0,040

ELAB = 36,2 MEV

15,1	5.37	0,80
20.2	5.76	0,86
25,2	6,06	0,90
30,2	5.83	0,87
35,3	5.08	0,76
39,3	3.89	0,58
42,3	3.26	0,48
45,4	2.89	0,43
47,4	2.57	0,38
50,4	2,51	0,37
55,4	2.00	0,30
60,4	1.24	0,18
65,5	1.20	0,18
68,0	1.12	0,16
70,5	1.17	0,17
75,5	0.72	0,10
80,5	0.560	0,083
85,5	0.381	0,057
90,5	0.395	0,059
95,5	0.319	0,047
100,5	0,293	0,043
105,5	0.199	0,029
110,5	0.167	0,025

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