OAK RIDGE NATIONAL LABORATORY
operated by
UNION CARBIDE CORPORATION
NUCLEAR DIVISION
for the
U.S. ATOMIC ENERGY COMMISSION

ORNL-TM-1991
COPY NO. - 89
DATE - September 1967

Some Recent Nuclear Cross Section Measurements at ORNL

April 1, 1967 - September 30, 1967

P. H. Stelson

ABSTRACT

This memo reviews some of the recent nuclear cross section activities at ORNL for the period April 1, 1967 through September 30, 1967.

OAK RIDGE NATIONAL LABORATORY

1. The $^{14}N(n,n'\gamma)$ Reaction for $6.0 \leq E_n \leq 8.4$ MeV (J. K. Dickens, E. Eichler, F. G. Perey, P. H. Stelson, John Ashe,* and D. O. Nellis*)

We have obtained gamma-ray spectra for the reactions $^{14}N(n,n'\gamma)^{14}N$ and $^{14}N(n,\alpha\gamma)^{11}B$ for incident neutron energies E_n = 6.0, 6.5, 7.0, 7.6, 8.0, and 8.4 MeV. The gamma rays were detected using a coaxial Ge(Li) detector of 30 cc active volume. The detector was placed at 55° with respect to the incident beam line, and was 75 cm from the sample. The sample was 100 gm of Be_3N_2 in the form of a right circular cylinder. Data were also obtained using a 75 gm Be sample to provide an estimate of the background. The incident neutron beam was produced by bombarding a deuterium-filled gas cell with the appropriate energy pulsed deuteron beam from the ORNL 6-MV Van de Graaff. The resulting neutron beam was monitored using a scintillation counter; a time-of-flight spectrum from this detector was recorded simultaneously with the gamma-ray data.

Figure 1 shows the spectrum obtained at E_n = 8 MeV for gamma-ray data associated with prompt gamma-ray production; time-of-flight was used with the gamma-ray detector to discriminate against other gamma rays. Preliminary identification of gamma-ray peaks is indicated in the figure. Energies of unidentified gamma rays are indicated by using smaller lettering. We intend to obtain absolute cross sections for production of gamma rays from ^{14}N for the incident neutron energies quoted above. Future plans include extending these measurements to higher neutron energies.

2. Neutron Elastic and Inelastic Cross Sections for ^{56}Fe from 4.60 to 7.55 MeV (W. E. Kinney, J. A. Biggerstaff, J. K. Dickens, M. V. Harlow,** J. W. McConnell, F. G. Perey, and P. H. Stelson)

Neutron elastic and inelastic cross sections have been measured by the time-of-flight method for ^{56}Fe in the energy range from 4.60 to 7.55 MeV. Total cross sections are given in Table 1 and shown in Fig. 2. Hauser-Feshbach calculations were in agreement with the data from 4.60 to 5.56 MeV but predicted increasingly higher cross sections with increasing energy and decreasing Q above this energy range for the levels with $Q < -0.846$ MeV.

*Texas Nuclear Corporation.

**Los Alamos Scientific Laboratory.

Table 1

Total Neutron Electric and Inelastic Cross Sections for ^{56}Fe

-Q, MeV / E_n, MeV	0	0.846	2.084	2.645	[2.939, 2.957]	[3.119, 3.122]	[3.368, 3.388, 3.445, 3.450]	[3.600, 3.601, 3.605]	[3.829, 3.856]	[4.046, 4.099, 4.116]	4.296 – 4.728
4.60 ± 0.05	2200 ± 300	268 ± 23	106 ± 12	122 ± 14	140 ± 15	140 ± 16	-	-	-	-	-
5.00 ± 0.04	1960 ± 100	195 ± 11	-	-	-	-	-	-	-	-	-
5.04 ± 0.04	2070 ± 100	230 ± 14	81 ± 10	105 ± 12	108 ± 12	123 ± 16	195 ± 23	133 ± 16	103 ± 12	-	-
5.56 ± 0.04	1960 ± 110	214 ± 18	65 ± 8	78 ± 10	87 ± 10	97 ± 12	175 ± 23	116 ± 14	98 ± 12	125 ± 18	-
6.12 ± 0.04	1970 ± 110	163 ± 14	47 ± 5	44 ± 6	53 ± 6	70 ± 7	110 ± 13	69 ± 9	55 ± 7	70 ± 12	-
6.53 ± 0.03	1960 ± 50	158 ± 13	40 ± 3	42 ± 4	53 ± 8	50 ± 7	94 ± 18	64 ± 19	45 ± 10	67 ± 12	-
7.55 ± 0.04	1910 ± 30	121 ± 7	28 ± 3	25 ± 3	13 ± 2	30 ± 3	45 ± 5	20 ± 3	20 ± 2	30 ± 3	120 ± 12

DWBA and Hauser-Feshbach calculations were in good agreement with both the total and differential cross sections at all energies for the - 0.845 MeV level. A nearly constant direct interaction contribution of ~ 80 mb was found over the energy range.

To achieve even partial agreement with the - (3.600 + 3.605) MeV levels either the - 3.600 MeV level had to be assigned a spin greater than 0 or a third level with spin greater than 0 had to be included.

Optical model parameters given in Table 2 were used and the real and imaginary well depths were varied to achieve a χ^2 best fit to the elastic differential cross section data. The average real well depth in the range of 4 to 7.6 MeV incident neutron energies is 46.5 MeV and the imaginary well depth is 12 MeV.

Table 2

Fixed Optical Model Parameters

Real Radius	1.25 f
Real Diffuseness	0.65 f
Imaginary Radius	1.25 f
Imaginary Diffuseness	0.47 f
Spin-Orbit Radius	1.25 f
Spin-Orbit Diffuseness	0.65 f
Spin-Orbit Well Depth	7.2 MeV

3. <u>Measurements of 7.6 MeV Neutron Inelastic Scattering</u> (F. G. Perey, J. A. Biggerstaff, J. K. Dickens, W. E. Kinney, J. W. McConnell, and P. H. Stelson)

In October 1966 a PDP-7 computer system was installed and adapted to do the "walk correction" on line. Inelastic scattering data, using the computer on line, were obtained in November 1966. The measurements were performed with the 5.5 MV Van de Graaff at $E_n = 7.6$ MeV on C, Mg, Al, Si, S, Fe, Co, and Y.

Computer programs were written to reduce the data using the light pen facility of the system. All of the data have now been converted to cross sections and corrected for multiple scattering. Final results of the 7.6 MeV elastic scattering data are shown in Fig. 3 and the results for some of the inelastic cross sections are shown in Fig. 4.

4. Elastic Scattering from Doubly-Closed Shell Nuclei (C. H. Johnson, J. L. Fowler, and F. X. Haas*)

Since the interaction of neutrons with doubly-closed shell nuclei such as ^{16}O, ^{40}Ca, and ^{208}Pb is expected to show simple structures, we are measuring and analyzing the total and differential elastic scattering of neutrons from these nuclei in order to assign J values, parities, and reduced widths for the resonance states. A few of these states with large reduced widths appear to be essentially single-particle shell model states. Much more often, however, they seem to have intermediate structure involving simple core excitations. At least two theoretical approaches to the explanation of these intermediate states have been offered; one the particle-hole approach based on shell model states,[1-3] and the other based on the cluster model.[4] Earlier detailed predictions of the particle-hole model for ^{208}Pb resonances were not verified by experiment.[5]

In the case of neutron scattering from ^{16}O, various coupling schemes (for example see ref. 6) suggest there should be a $d_{5/2}$ resonance below the broad $d_{3/2}$ resonance at 3.35 MeV neutron energy.[7] We have recently measured the total cross section of ^{16}O with 2 keV energy resolution in the vicinity of the 1.83 MeV resonance which had been

---

*Student guest from Monsanto Research Corporation (graduate student, University of Cincinnati).

[1] C. Shakin, Ann. Phys. 22, 373 (1963).

[2] G. E. Brown and A. M. Green, Nucl. Phys. 75, 401 (1965).

[3] B. Margolis and N. de Takacsy, Can. J. Phys. 44, 1431 (1966).

[4] S. Matthies, V. G. Neudachin, and Yu. F. Smirnov, Nucl. Phys. 38, 63 (1962).

[5] J. L. Fowler, Phys. Rev. 147, 870 (1966).

[6] J. T. Reynolds and N. C. Francis, Bull. Am. Phys. Soc. 12, No. 4, 516 (1967).

[7] C. H. Johnson and J. L. Fowler, to be published in Phys. Rev. Oct. 20, 1967.

assigned a J value of ≥ 3/2.[1] We confirm that the resonance at 1.65 MeV has J = 7/2 as given in the literature[2] and find it has a width of 4 keV. We find the 1.83 MeV resonance has J = 3/2 and a width of 6.5 keV. Its interference with the background phase shifts[3] suggests it is a $d_{3/2}$ resonance. We also confirm that the resonance at 1.90 MeV has J = 1/2.

We have extended our ^{40}Ca measurements[4] down to 0.82 MeV. The present work done with 3 keV resolution from 0.82 to 1.2 MeV shows about 20 peaks. With this resolution none of the observed peak heights correspond to resonances with J value greater than 1/2.

---

[1]F. Ajzenberg-Selove and T. Lauritsen, Nucl. Phys. 11, 1 (1959).

[2]R. O. Lane, A. S. Langsdorf, J. E. Monahan, and A. J. Elwyn, Ann. Phys. 12, 135 (1961).

[3]C. H. Johnson and J. L. Fowler, to be published in Phys. Rev. Oct. 20, 1967.

[4]C. H. Johnson, J. L. Fowler, R. L. Kernell, and F. D. Martin, Bull. Am. Phys. Soc. 12, 106 (1967).

APPENDIX

Listed below is the title of a published paper.

Spin Parity Assignments via Neutron Decay of Analogue Resonance, H. J. Kim, R. L. Robinson, R. L. Kernell, and C. H. Johnson, Phys. Rev. Letters 19, 325 (1967).

Listed below are titles of papers to be published.

1. Fluctuations in Angular Distributions of $^{12}C(^{16}O,\alpha)^{24}Mg$, M. L. Halbert, F. E. Durham, C. D. Moak, and A. Zucker, Phys. Rev.

2. Excitation of Low-Lying States of ^{89}Zr by the (p,n) Reaction on ^{89}Y, H. J. Kim and R. L. Robinson, Phys. Rev.

3. A Study of Proton Particle-Hole States in ^{40}Ca by the $^{39}K(^{3}He,d)^{40}Ca$ Reaction, K. K. Seth, J. A. Biggerstaff, P. D. Miller, and G. R. Satchler, Phys. Rev.

4. The $^{89}Y(p,n)^{89}Zr$ Cross Section Near the First Two Analogue Resonances, C. H. Johnson, R. L. Kernell, and S. Ramavataram, Nucl. Phys.

5. The $^{63,65}Cu(^{3}He,d)^{64,66}Zn$ Reactions, J. L. C. Ford, Jr., K. L. Warsh, R. L. Robinson, and C. D. Moak, Nucl. Phys.

6. Limit to the Electric Dipole Moment of the Neutron, P. D. Miller, W. B. Dress, J. K. Baird, and N. F. Ramsey, Phys. Rev. Letters.

7. Proton Particle-Hole States in ^{116}Sn, J. A. Biggerstaff, C. Bingham, P. D. Miller, J. Solomon, and K. K. Seth, Phys. Letters.

8. Coulomb Excitation of ^{75}As, R. L. Robinson, F. K. McGowan, P. H. Stelson, and W. T. Milner, Nucl. Phys.

9. Recent Neutron Capture Data at Stellar Temperatures, R. L. Macklin and J. H. Gibbons, Ap. J. "Notes" Section.

10. A Study of $^{10}B(n,\alpha)^{7}Li$, $^{7}Li^{*}$ for $30 < E_n$ (keV) < 500, R. L. Macklin and J. H. Gibbons, Phys. Rev.

11. (p,n) and (d,n) Time-of-Flight Experiments, P. H. Stelson, Proc. Symposium on Nuclear Physics Research with Low-Energy Accelerators, University of Maryland, College Park, Maryland, June 19-24, 1967.

12. Nuclear Cross Sections for Charged-Particle-Induced Reactions N and O, H. J. Kim, W. T. Milner, and F. K. McGowan, Nuclear Data (in press).

Listed below is the title of an Oak Ridge National Laboratory Report, ORNL-TM-1804, to be published.

Simultaneous Measurements of the Neutron Fission and Capture Cross Sections for ^{235}U for Neutron Incident Energies from 0.4 eV to 3 keV, G. deSaussure, R. Gwin, L. W. Weston, R. W. Ingle, R. W. Hockenbury, and R. R. Fullwood.

Listed below is the title of a paper presented at the American Nuclear Society Meeting, San Diego, June 30, 1967.

Simultaneous Measurements of the ^{233}U Fission and Capture Cross Sections, L. W. Weston, R. Gwin, G. deSaussure, R. W. Ingle, R. R. Fullwood, and R. W. Hockenbury, ANS Transactions 10, 220 (1967).

Listed below are titles of papers presented at the American Physical Society Meeting, Toronto, Canada, June 21-23, 1967.

1. Search for Neutron Electric Dipole Moment, W. B. Dress, P. D. Miller, J. K. Baird, and N. F. Ramsey.

2. Polarization of Neutrons from the $^{9}Be(d,n)^{10}B$ Reaction, T. G. Miller and J. A. Biggerstaff.

Listed below are titles of papers presented at the International Conference on Nuclear Structure, Tokyo, September 7-13, 1967.

1. Proton Single Particle States in ^{40}Ca, K. K. Seth, J. A. Biggerstaff, P. D. Miller, and G. R. Satchler.

2. Proton States in ^{116}Sn, J. A. Biggerstaff, C. Bingham, P. D. Miller, and K. K. Seth.

Listed below are titles of papers to be presented at the Division of Nuclear Physics, American Physical Society Meeting, Madison, Wisconsin, October 23-25, 1967.

1. Clues from Neutron Capture to the Origins of Heavy Elements, J. H. Gibbons.

2. Coulomb Excitation of States in Even-A Tungsten, Osmium, and Platinum Nuclei with Protons, ^{4}He and ^{16}O Ions, W. T. Milner, F. K. McGowan, R. L. Robinson, P. H. Stelson, and R. O. Sayer.

Listed below is the title of a paper to be presented at the Meeting of the American Physical Society, New York, November 16-18, 1967.

Improved Sensitivity to a Neutron Electric Dipole Moment, J. K. Baird, P. D. Miller, W. B. Dress, and N. F. Ramsey.

FIGURE CAPTIONS

1. Gamma-ray spectrum from the reaction of 8-MeV neutrons with ^{14}N for gamma rays detected at 55°.

2. Integral cross sections for ^{56}Fe as a function of energy. Numbers with each curve are -Q for the levels

3. Elastic scattering of 7.6-MeV neutrons. The dots indicate the data points and the solid line the microscopic cross section which will reproduce the data points with contributions from multiple scattering in the scatterer.

4. Inelastic scattering of 7.6-MeV neutrons from some of the low-lying levels of the studied element.

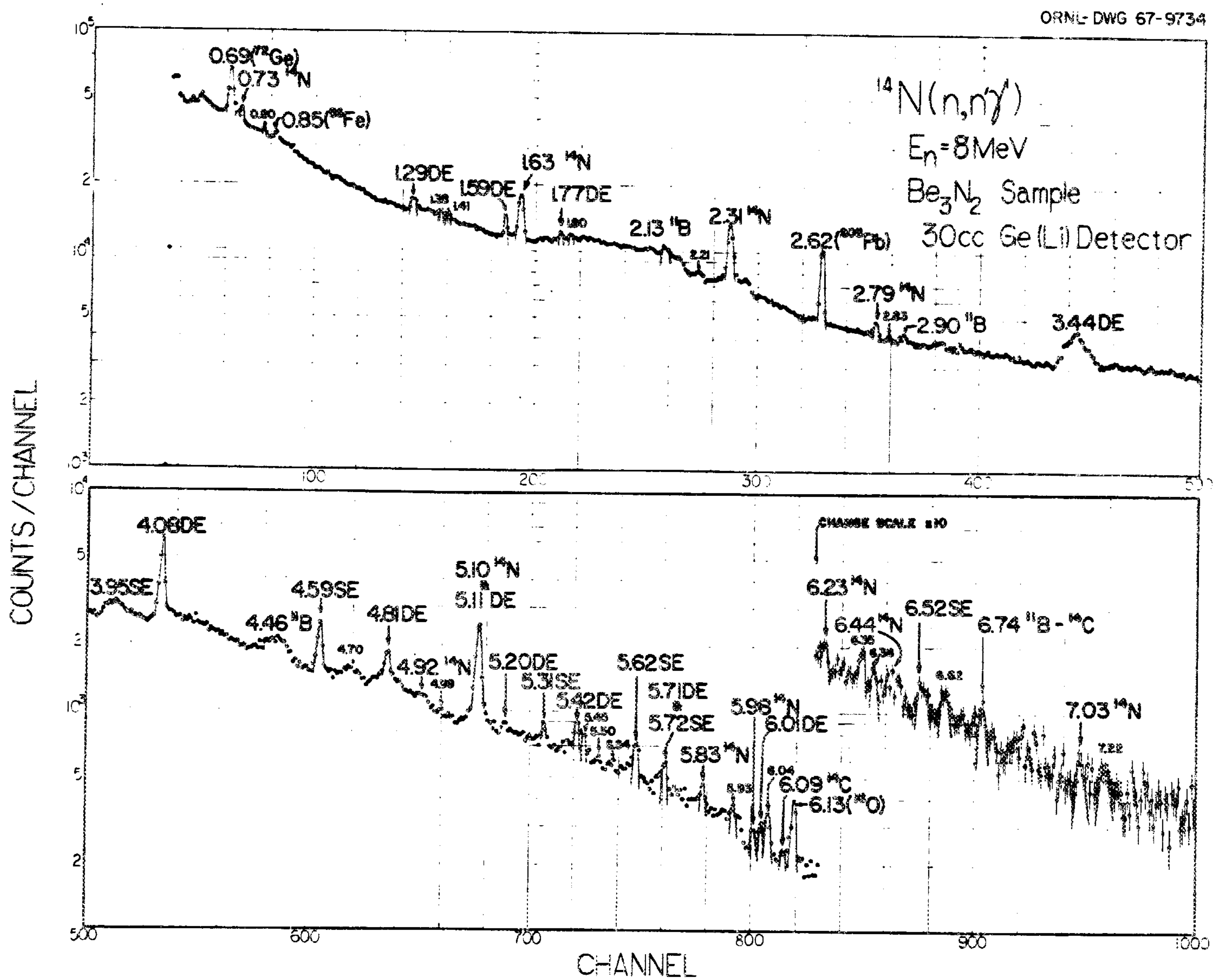
ORNL-DWG 67-9734
14N(n,n'γ)
En=8MeV
Be3N2 Sample
30cc Ge(Li) Detector
COUNTS / CHANNEL
CHANNEL
0.69(72Ge)
0.73 14N
0.85(56Fe)
1.29DE
1.59DE
1.63 14N
1.77DE
2.13 11B
2.31 14N
2.62(208Pb)
2.79 14N
2.90 11B
3.44DE
3.95SE
4.08DE
4.46 11B
4.59SE
4.81DE
4.92 14N
5.10 14N
5.11 DE
5.20DE
5.31SE
5.42DE
5.62SE
5.71DE
5.72SE
5.83 14N
5.98 14N
6.01DE
6.09 14C
6.13(16O)
CHANGE SCALE x10
6.23 14N
6.44 14N
6.52SE
6.74 11B - 14C
7.03 14N

Fig. 1

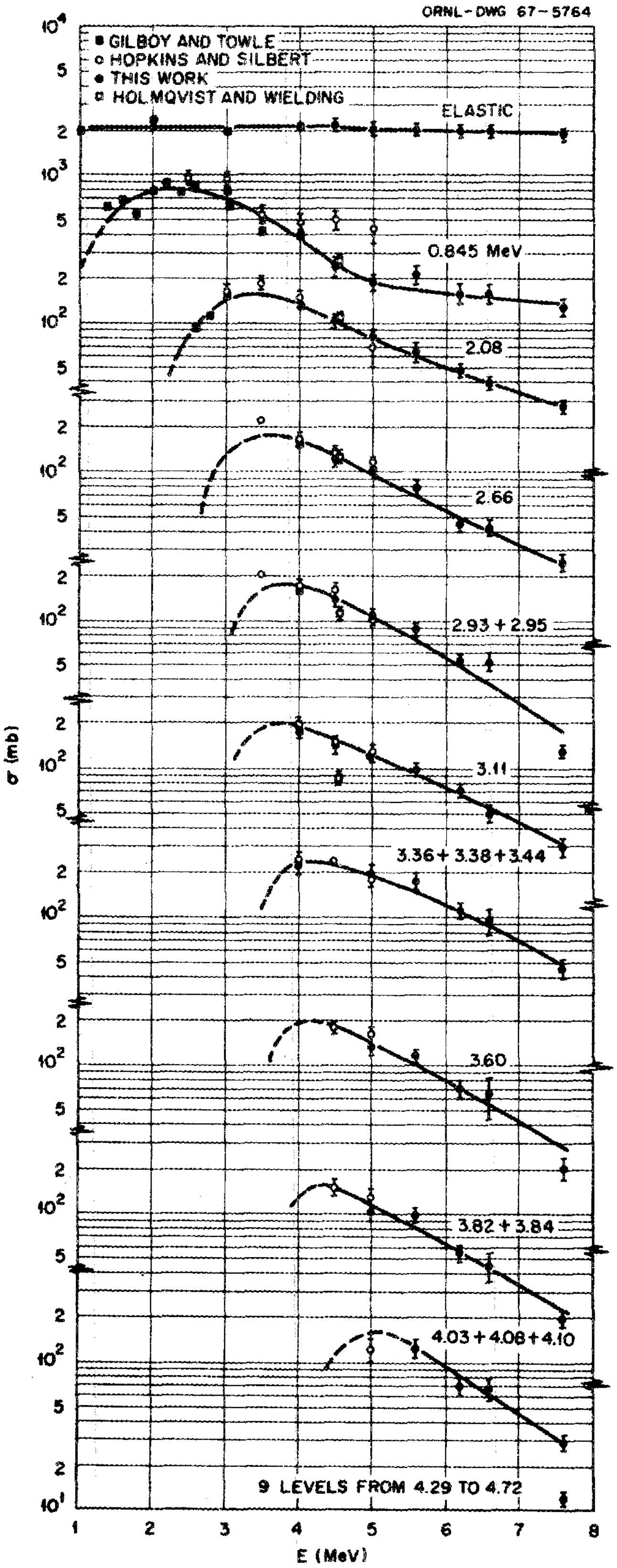
ORNL-DWG 67-5764
GILBOY AND TOWLE
HOPKINS AND SILBERT
THIS WORK
HOLMQVIST AND WIELDING
ELASTIC
0.845 MeV
2.08
2.66
2.93 + 2.95
3.11
3.36 + 3.38 + 3.44
3.60
3.82 + 3.84
4.03 + 4.08 + 4.10
9 LEVELS FROM 4.29 TO 4.72
σ (mb)
E (MeV)

Fig. 2

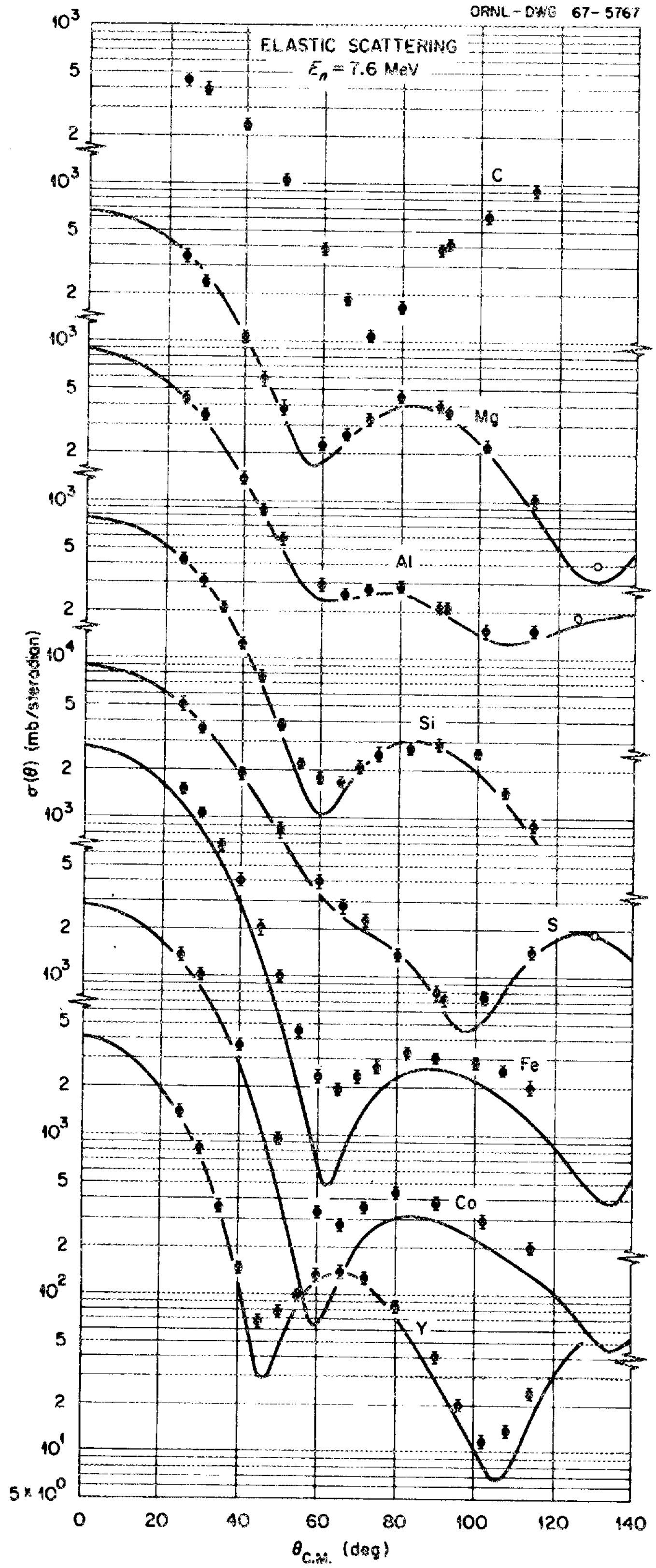
ORNL-DWG 67-5767
ELASTIC SCATTERING
E_n = 7.6 MeV
C
Mg
Al
Si
S
Fe
Co
Y
σ(θ) (mb/steradian)
θ_C.M. (deg)
0
20
40
60
80
100
120
140

Fig. 3

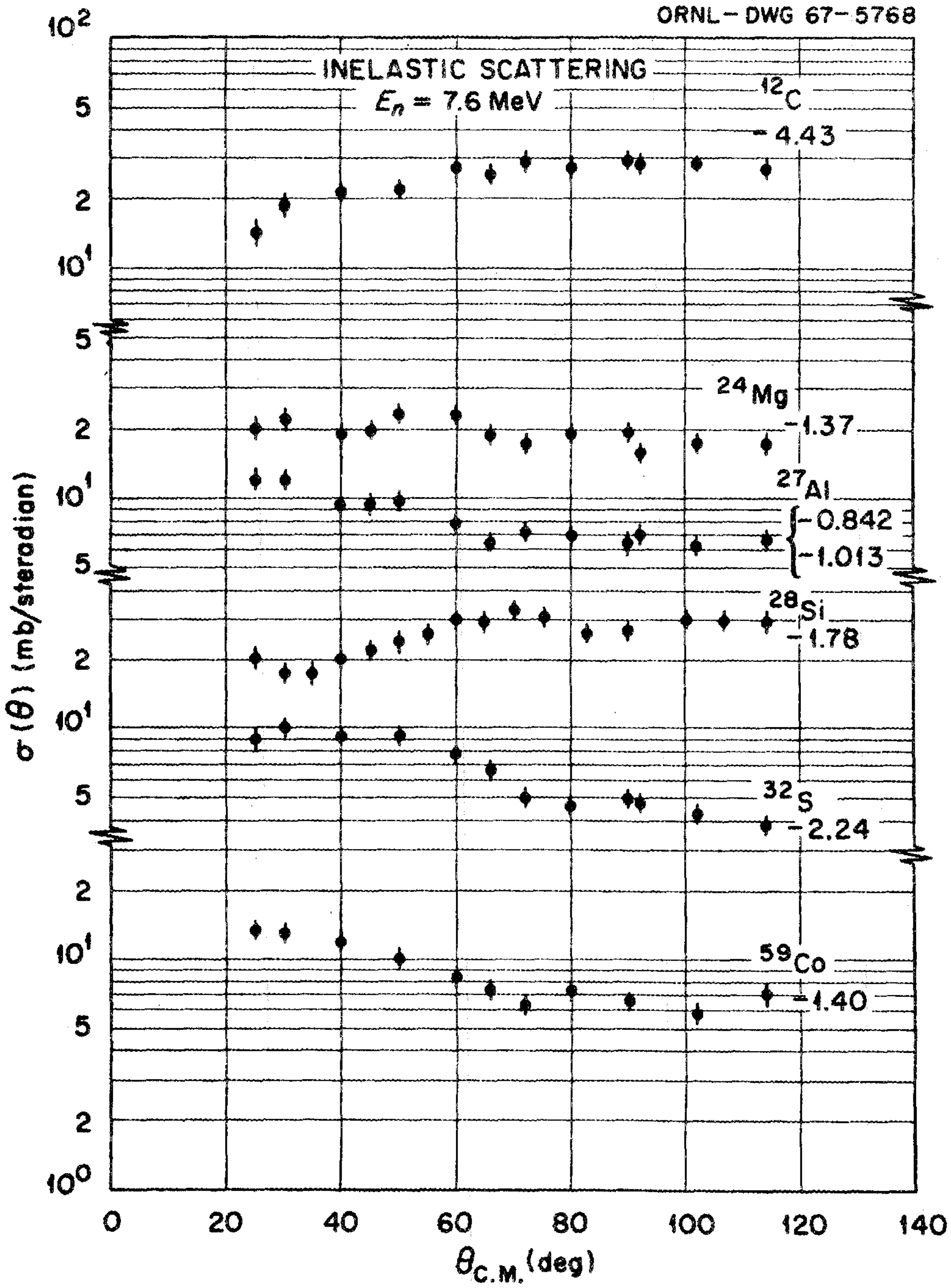
ORNL-DWG 67-5768
INELASTIC SCATTERING
E_n = 7.6 MeV
^{12}C
-4.43
^{24}Mg
-1.37
^{27}Al
-0.842
-1.013
^{28}Si
-1.78
^{32}S
-2.24
^{59}Co
-1.40
σ (θ) (mb/steradian)
$\theta_{C.M.}$ (deg)
0
20
40
60
80
100
120
140
10^2
5
2
10^1
5
2
10^1
5
2
10^1
5
2
10^1
5
2
10^0

Fig. 4

DISTRIBUTION

1. H. T. Motz, LASL
2. M. S. Moore, Idaho Nucl. Corp.
3. Harry Alter, Atomics Int.
4. Robert Beyster, GA
5. R. C. Block, RPI
6. R. S. Caswell, NBS
7. L. F. Chase, Lockheed
8. R. E. Chrien, BNL
9. J. M. Ferguson, U.S. Naval Rad. Def. Lab
10. S. C. Fultz, LRL
11. H. Goldstein, Columbia
12. C. M. Gottschalk, USAEC
13. E. Haddad, USAEC
14. W. W. Havens, Columbia
15. H. E. Jackson, ANL
16. G. A. Kolstad, USAEC
17. I. L. Morgan, Texas Nuclear
18. H. W. Newson, Duke
19. G. C. Phillips, Rice
20. E. F. Shrader, Case Western Reserve
21. H. L. Schultz, Yale
22. A. B. Smith, ANL
23. R. F. Taschek, LASL
24. W. R. Van Antwerp, NDL
25. N. F. Wikner, Defense Atomic Support Agency
26. I. F. Zartman, USAEC
27-39. P. H. Stelson, ORNL
40. J. K. Bair, ORNL
41. J. A. Biggerstaff, ORNL
42. Gerard deSaussure, ORNL
43. J. K. Dickens, ORNL
44. J. L. C. Ford, ORNL
45. J. L. Fowler, ORNL
46. J. H. Gibbons, ORNL
47-48. J. A. Harvey, ORNL
49. C. H. Johnson, ORNL
50. C. M. Jones, ORNL
51. H. J. Kim, ORNL
52. W. E. Kinney, ORNL
53. F. K. McGowan, ORNL
54. R. L. Macklin, ORNL
55. F. C. Maienschein, ORNL
56. P. D. Miller, ORNL
57. C. D. Moak, ORNL

58. R. W. Peelle, ORNL
59. F. G. J. Perey, ORNL
60. Frances Pleasonton, ORNL
61. R. L. Robinson, ORNL
62. H. W. Schmitt, ORNL
63. M. J. Skinner, ORNL
64. G. G. Slaughter, ORNL
65. A. H. Snell, ORNL
66. V. V. Verbinski, ORNL
67. K. Way, ORNL
68. A. M. Weinberg, ORNL
69. L. W. Weston, ORNL
70-71. LRD-ORNL
72. ORNL-RC
73-87. DTIE
88-89. Central Research Library
90. Document Reference Section
91. Laboratory and University Div.. ORO