JUN 22 1969

OAK RIDGE NATIONAL LABORATORY

operated by

UNION CARBIDE CORPORATION
NUCLEAR DIVISION

for the

U.S. ATOMIC ENERGY COMMISSION

MASTER

ORNL - TM - 1875

COPY NO. - 283

DATE - June 9, 1967

Neutron Physics Division

DISTORTED-WAVE ANALYSIS OF INELASTIC SCATTERING
OF 61.7-MeV PROTONS FROM $^{60}\text{Ni}^*$

F. E. Bertrand, ** J. K. Dickens, and T. A. Love

Differential cross sections for the scattering of 61.7-MeV protons from the first excited level ($E_x = 1.33$ MeV) of ^{60}Ni have been measured between 15 and 40 deg with an experimental resolution of 0.3%. The data are reproduced well by a distorted-wave calculation using the vibrational model with $\beta = 0.20$.

NOTE:

This Work Partially Supported by
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Under Order R-104(1)

*To be published in Physics Letters.

**Oak Ridge Graduate Fellow from Louisiana State University under appointment from the Oak Ridge Associated Universities, Inc.

NOTICE This document contains information of a preliminary nature and was prepared primarily for internal use at the Oak Ridge National Laboratory. It is subject to revision or correction and therefore does not represent a final report.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

- A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or
- B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

PAGES 1 to 2
WERE INTENTIONALLY
LEFT BLANK

During the past few years a large amount of data have been accumulated on the inelastic scattering of nucleons from various nuclei for bombarding energies up to ~ 15 MeV. These data have been amenable to interpretation by using the distorted-wave method¹ as a basis for computation with one of several nuclear models to describe the interaction between the bombarding nucleon and the particular target nucleus. For nuclei in the Ni-Zn mass region, the vibrational model has been successfully applied to describe inelastic scattering from the strongly excited first-excited states. For ^{60}Ni , calculations using this model have reproduced experimental angular distributions obtained for inelastically scattered neutrons,² protons,³ deuterons,⁴ and alphas,⁵ and the results give consistent values for the nuclear deformation parameter β between 0.19 and 0.21, in good agreement with $\beta = 0.19$ obtained from Coulomb excitation.⁶

Since it is of interest to study the transition from calculations using this phenomenological model, valid at low bombarding energies, to the impulse approximation calculation,⁷ valid in the hundred-MeV region, recent efforts have involved extending inelastic-scattering measurements to higher bombarding energies. The first reports of measurements in the 30- to 50-MeV region yielded an unexpected result, namely that the distorted-wave calculations did not reproduce the inelastic data for small scattering angles. The calculations underestimated the experimental data by factors of two or more.^{8,9} The question arose, then, whether it was the experimental method or the theory that required investigation. A close examination of the experimental results indicated that determination of

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

809

inelastic cross sections at small scattering angles is hampered by the predominant elastic scattering. That is, even though the detector resolution is adequate to resolve the several groups of scattered nucleons when the cross sections are comparable, at small angles where the elastic-scattering cross section is much greater than the inelastic-scattering cross section, peak stripping methods have to be employed to extract the inelastic data. This suggests that before an extensive study of the theory is undertaken, an attempt should be made to obtain inelastic differential cross sections at small angles with a detector having greatly improved resolution, thus markedly reducing the uncertainties inherent in peak-stripping methods.

The results reported here were obtained with a three-counter detection system (for mass discrimination) which had as the final counter a lithium-drifted germanium, total-absorption detector.¹⁰ The total resolution for this experiment was ~ 200 keV (FWHM). Protons of energy ~ 61.7 MeV were extracted from the Oak Ridge Isochronous Cyclotron (ORIC) and bent through 153° by a beam analyzing magnet whose entrance and exit slits were set to give ~ 60 keV beam spread. The protons struck a 4-mg/cm^2 -thick target of ^{60}Ni , isotopically enriched to $>99\%$ in the isotope. Pulses from the counter array, produced by charged particles scattered from the target, were processed by an on-line PDP-8 computer and stored on magnetic tape. The final processing and data reduction were accomplished by utilizing the ORNL IBM-360 computer.

Data were obtained in 5-deg intervals between laboratory angles of 15° and 40° . In addition, the detector system response to 61.7-MeV protons was measured by allowing a very weak direct beam to strike the detector system.

The relevant part of the spectrum at 15 deg is shown in Fig. 1. The cross-hatched area indicates the uncertainty in subtraction introduced by the "tail" of the very much larger peak associated with the elastic scattering at this angle. This uncertainty is $\approx 20\%$ of the area extracted for the inelastic scattering peak, and is a definite improvement over earlier work.

The angular distributions obtained from the experimental data are shown in Fig. 2, along with the theoretical results from distorted-wave analysis. The optical-model parameters for the distorted waves were taken from the recent report of Fulmer *et al.*,¹¹ and the distorted-wave analysis used the vibrational model for ^{60}Ni and complex coupling for the interaction. We did not search for "best-fit" parameters; a slight increase of the real well depth V would improve the fit to the elastic data and slightly change the shape of the distorted-wave calculation without affecting the normalization of the latter. The deformation parameter for this calculation was chosen to be 0.20; the resulting theoretical angular distribution agrees very well with the inelastic data as indicated in Fig. 2. At least for this case, the theoretical method is valid at small angles.

- - - - -

We express our appreciation to R. W. Peelle, W. R. Burrus, and N. W. Hill for their efforts in the design and development of the experimental system. Thanks are also extended to Y. Cassagnou and F. G. Perey for their encouragement and assistance during the experimental phase, and to the ORIC Cyclotron crew for efficient machine operation.

Fig. 1. Spectrum of Protons Obtained from Interaction of 61.7-MeV Protons with ^{60}Ni . The laboratory scattering angle is 15 deg. The detector response to 61.7-MeV protons is indicated by the dashed curve. The appropriate subtraction from the inelastic peak of events due to elastic scattering is ~ 20 per cent of the total yield between E_{lab} of 60.0 and 60.5 MeV; the cross-hatched area represents the uncertainty associated with the determination of the subtraction. The solid curve represents the inelastic scattering of protons from the first excited state.

ORNL-DWG 67-3722

Fig. 2. Angular Distributions for 61.7-MeV Protons Elastically and Inelastically Scattered from ^{60}Ni . The errors shown include uncertainty in overall normalization, and for the inelastic data they include the uncertainty associated with the subtraction. The solid curves represent results of theoretical calculations using optical-model and distorted-wave methods.

REFERENCES

1. G. R. Satchler, Nucl. Phys. 55 (1964) 1.
2. P. H. Stelson, R. L. Robinson, H. J. Kim, J. Rapaport, G. R. Satchler, Nucl. Phys. 68 (1965) 97.
3. M. P. Fricke and G. R. Satchler, Phys. Rev. 139 (1965) B567.
4. J. K. Dickens, F. G. Perey, and G. R. Satchler, Nucl. Phys. 73 (1965) 529.
5. H. W. Broek, J. L. Yntema, B. Buck, and G. R. Satchler, Nucl. Phys. 64 (1965) 259.
6. P. H. Stelson and F. K. McGowan, Phys. Rev. 121 (1961) 209.
7. A. K. Kerman, H. McManus, and R. M. Thaler, Ann. Phys. (N. Y.) 8 (1959) 551.
8. B. Buck, Phys. Rev. 130 (1963) 712.
9. M. P. Fricke and G. R. Satchler, Phys. Rev. 139 (1965) B567.
10. F. E. Bertrand, R. W. Peelle, T. A. Love, R. J. Fox, N. W. Hill, and H. A. Todd, "A Total-Absorption Detector for 60-MeV Protons Using Lithium-Drifted Germanium," IEEE Trans. Nucl. Sci., Vol. NS-13, No. 3 (June 1966) 279.
11. C. B. Fulmer, J. B. Ball, A. Scott, and M. L. Whitten (submitted to Physics Letters).

Internal Distribution

ORNL TM-1875

1-3. L. S. Abbott	36. F. C. Maienschein
4. F. S. Alsmiller	37. F. K. McGowan
5. R. G. Alsmiller, Jr.	38. R. W. Peelle
6. T. W. Armstrong	39. F. G. Perey
7. J. B. Ball	40. R. T. Santoro
8. H. W. Bertini	41. G. R. Satchler
9-14. F. E. Bertrand	42. P. H. Stelson
15. W. R. Burrus	43. Taro Tamura
16. C. E. Clifford	44. D. K. Trubey
17-21. J. K. Dickens	45. J. W. Wachter
22. R. M. Drisko	46. W. Zobel
23. J. L. C. Ford	47. G. Dessauer (consultant)
24. C. B. Fulmer	48. B. C. Diven (consultant)
25. W. A. Gibson	49. M. H. Kalos (consultant)
26. E. E. Gross	50. L. V. Spencer (consultant)
27. M. P. Guthrie	51-52. Central Research Library
28. R. M. Haybron	53. Document Reference Section
29. N. W. Hill	54-283. Laboratory Records Department
30. D. C. Irving	284. Laboratory Records ORNL RC
31-35. T. A. Love	285. ORNL Patent Office

External Distribution

286. P. B. Hemmig, Division of Reactor Development and Technology, U. S. Atomic Energy Commission, Washington, D. C. 20545
287. I. F. Zartman, Division of Reactor Development, U. S. Atomic Energy Commission, Washington, D. C. 20545
288. Y. Cassagnou, CEN, Saclay, France
289. C. N. Waddell, University of Southern California, Los Angeles, California
290. R. H. Bessel, Brookhaven National Laboratory, Upton, New York
291. D. C. Ralph, Chairman, Department of Physics, Louisiana State University, Baton Rouge, La.
292. J. Marshall, Department of Physics, Louisiana State University, Baton Rouge, La.
- 293-307. Division of Technical Information Extension (DTIE)
308. Division of Research and Development (ORO)