

ELASTIC AND INELASTIC SCATTERING OF FAST NEUTRONS
FROM HEAVY WEIGHT NUCLEI

by

Clinton Edward Hollandsworth, Jr.

Department of Physics
Duke University

Date: May 20, 1963

Approved:

H. W. Lewis

Harold W. Lewis, Supervisor

Henry W. Kessen

Hertha Spover

Mark Hines

David A. Smith

A dissertation submitted in partial fulfillment of the
requirements for the degree of Doctor of Philosophy
in the Department of Physics in the Graduate
School of Arts and Sciences
of Duke University

1963

ABSTRACT

(Physics)

ELASTIC AND INELASTIC SCATTERING
OF FAST NEUTRONS FROM HEAVY
WEIGHT NUCLEI

by

Clinton Edward Hollandsworth, Jr.

Department of Physics
Duke University

Date: _____

Approved:

H. W. Lewis, Supervisor

An abstract of a dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the Department of Physics in the Graduate School of Arts and Sciences of Duke University

ABSTRACT

ELASTIC AND INELASTIC SCATTERING OF FAST NEUTRONS
FROM HEAVY WEIGHT NUCLEI

by

Clinton Edward Hollandsworth, Jr.

The energy spectra of neutrons scattered inelastically from Ta, W, Pt, Au, Hg, Tl, Rb, Bi, Th, and U have been measured using time-of-flight techniques. The measurements were made for incident neutron energies of 4.00, 5.00, 6.00, and 6.50 Mev. Nuclear temperatures and Fermi gas level density coefficients have been determined at each value of incident energy and compared with theoretical predictions. The results indicate that the Fermi gas model provides a good description of the variation of average nuclear level densities with excitation energy for all nuclei studied, except those near closed shells where the constant temperature approximation seems valid.

Angular distributions of 5.00 Mev neutrons elastically scattered from Ta, Au, Tl, Rb, Th, and U have been measured and compared with optical model predictions based on a local potential with variable parameters and the non-local potential of Perey and Buck. The results indicate that the data are described reasonably well by either potential.

ACKNOWLEDGEMENTS

I wish to express my sincere appreciation to my research director, Dr. Harold W. Lewis, for his encouragement and support during the course of this investigation. I would like to thank my co-worker Dr. S. G. Buccino for his cooperation and assistance. I am particularly indebted to Dr. Philip R. Bevington for his support, encouragement, and advice both during the experiment and in the analysis and interpretation of the data.

I would like to thank Messrs. G. A. Pettit and C. Kapadia for their assistance in taking the data. Appreciation is due Mr. S. Edwards and the entire nuclear physics group for their assistance with the accelerator.

I wish to thank Mrs. Nancy Watkins and the staff of the Duke University Computing Laboratory for their cooperation. Appreciation is due Miss Dorothy Brand for her aid in the data reduction. I wish to acknowledge the assistance given by Mr. Milt Whitfield and the staff of the instrument shop. Finally, I wish to thank Mr. W. D. Meier for preparing the illustrations presented in this dissertation.

This work was supported in part by the Atomic Energy Commission and the computations involved in this research were carried out in the Duke University Computing Laboratory which is supported in part by the National Science Foundation.

C. E. H.

CONTENTS

ABSTRACT	ii
ACKNOWLEDGEMENTS	iii
LIST OF FIGURES	vi
LIST OF TABLES	vii
I. INTRODUCTION	2
II. THEORY	4
A. Inelastic Scattering, 4	
1. Reaction Mechanisms for Inelastic Scattering, 4	
a. Direct Interactions, 5	
b. Intermediate Processes, 6	
c. Compound Nucleus Processes, 7	
2. Fundamental Relation between Energy Spectra and the Nuclear Level Density, 8	
3. The Inverse Cross Section, 11	
4. The Nuclear Level Density, 11	
5. The Evaporation Approximation, 13	
6. Nuclear Models, 16	
a. Simple Fermi Gas Model, 17	
b. Pairing Correlations, 18	
c. The Lang-LeCouteur Model, 19	
d. Shell Effects, 22	
B. Elastic Scattering, 24	
1. Introduction, 24	
2. Optical Model Potentials, 26	
3. Optical Model for Neutron Scattering, 31	
III. EXPERIMENTAL APPARATUS AND PROCEDURE	34
A. The Time-of-Flight System, 34	
1. Pulsed Beam, 34	
2. Neutron Source, 43	
3. The Detector, 45	
4. The Scattering Geometry, 49	
5. Time-of-Flight Spectra, 50	

B.	Experimental Procedures, 57	
1.	Time per Channel, 57	
2.	Detector Efficiency, 58	
C.	Choice of Experimental Parameters, 62	
1.	Inelastic Scattering, 62	
2.	Elastic Scattering, 66	
IV.	DATA REDUCTION AND ANALYSIS	68
A.	General, 68	
B.	Reduction of Inelastic Scattering Data, 68	
C.	Reduction of Elastic Scattering Data, 71	
1.	Reduction and Analysis of Time Spectra, 71	
2.	Optical Model Calculations of Angular Distri- butions, 72	
3.	Corrections to the Data, 13	
V.	RESULTS AND CONCLUSIONS	76
A.	Elastic Scattering Results, 76	
B.	Inelastic Scattering Results, 89	
	LIST OF REFERENCES	112

LIST OF FIGURES

1.	Block Diagram of Electronics	37
2.	Circuit Diagram of Power Amplifier	40
3.	Circuit Diagram of 5 Mc/sec Amplifier-Phase Shifter	42
4.	Block Diagram of Generating Voltmeter and Auxiliary Equipment	47
5.	Experimental Arrangement	52
6.	Time Spectrum of Tungsten at 90°	54
7.	Time Spectrum of Thallium at 20°	56
8.	Relative Detector Efficiency	61
9.	Proposed Tunnel Diode Circuit	64
10.	Angular Distributions of Elastic Scattering for Tantalum and Gold	78
11.	Angular Distributions of Elastic Scattering for Thallium and Radiolead	80
12.	Angular Distributions of Elastic Scattering for Thorium and Uranium	82
13.	Comparison of Theoretical and Experimental Values of q . Comparison of Theoretical Values of q_0 and Experimental Values of σ_r	88
14.	Time Spectrum of Bismuth at 90°	93
15.	Fermi Gas Level Density Coefficient a $3/2$ versus A	97
16.	Fermi Gas Level Density Coefficient a $5/4$ versus A	100
17.	Nuclear Temperature T_0 versus A	103
18.	Variation of Nuclear Temperature with Excitation Energy	107

LIST OF TABLES

I	Neutron Source Properties	44
II	Optical Model Parameters	84
III	Nuclear Temperatures and Fermi Gas Level Density Coefficients	94
IV	Nuclear Temperatures Obtained in Other Experiments	104

ELASTIC AND INELASTIC SCATTERING OF FAST NEUTRONS
FROM HEAVY WEIGHT NUCLEI