1 of 1

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Engineering Physics and Mathematics Division

MEASUREMENT AND ANALYSIS OF THE NITROGEN TOTAL AND DIFFERENTIAL SCATTERING CROSS SECTIONS IN THE RESONANCE REGION

Cloyd O. Beasley, Jr.*
Nancy M. Larson*
J. A. Harvey*
Duane C. Larson*
Gerald M. Hale**

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*Oak Ridge National Laboratory
Oak Ridge, Tennessee

**Theoretical Division
Los Alamos National Laboratory
Los Alamos, New Mexico

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MASTER

Cloyd O. Beasley, Jr.,¹ Nancy M. Larson,² John A. Harvey,³
Duane C. Larson,⁴ and Gerald M. Hale⁵

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Society for Testing and Materials, Philadelphia, 1994.

ABSTRACT: High-resolution neutron transmission and
differential elastic scattering measurements have been made
on samples of nitrogen from 0.5 eV to 10 MeV at the Oak
Ridge Electron Linear Accelerator (ORELA). For the
transmission measurement several different detectors were
used at various flight path lengths, with high-purity
nitrogen gas samples. The data have been corrected for the
dead time of the time digitizer and for several small
backgrounds. For the scattering measurements six detectors
were placed at various angles inside an evacuated scattering

¹Operations Manager, Oak Ridge National Laboratory,
Engineering Physics and Mathematics Division, MS-6361, P. O.
Box 2008, Oak Ridge, TN 37831.

²Ibid., Research Staff, Computing Applications Division,
MS-6356.

³Ibid., Director, Oak Ridge Electron Linear Accelerator
(ORELA), Engineering Physics and Mathematics Division, MS-
6356.

⁴Ibid., Section Leader, Nuclear Data Measurement and
Evaluation, Engineering Physics and Mathematics Division, MS-
6354.

⁵Theoretical Division, Los Alamos National Laboratory,
Los Alamos, NM 87545.

chamber at 200 meters from the neutron producing target. The sample was silicon nitride held in a thin graphite container. Scattering from carbon and silicon samples was also measured to correct for these materials and calibrate the relative efficiencies of the scattering detectors. The data have been corrected for dead time and for a constant background. A preliminary analysis has been completed to obtain parameters of the resonances up to 4.8 MeV.

KEYWORDS: ^{14}N high-resolution transmission and scattering measurements, R-matrix analysis, resonance parameters.

INTRODUCTION

Efforts to reproduce the measured activity induced by low energy neutrons in Cobalt-60, Chlorine-36, and Europium-152,154 as a function of distance from ground zero at 500 to 2000 meters resulting from the Hiroshima nuclear explosion have been unsuccessful. Improved neutron cross sections of nitrogen (N) and oxygen (O) for neutrons from low energies up to the energy of the source are needed to calculate the neutron transport in air at these large distances. A recent neutron cross section evaluation for nitrogen (ENDF/B-VI Mod 0) by Young, Hale and Chadwick [1] was completed in 1990. Some experimental data below 500 keV neutron energy were over 30 years old. This evaluation work resulted in a request for new neutron cross section measurements for nitrogen covering a wide energy range. This paper describes the high-resolution neutron total and differential elastic scattering measurements from 0.5 eV to 10 MeV which were made at the ORELA to satisfy the request. Using this new total cross section data, Hale [2] did a new R-Matrix analysis of the nitrogen resonance region and found a better fit if spins and parities of some resonances were changed from those used in ENDF/B-VI Mod 0. These results were used in an update [1] of the nitrogen evaluation (Mod 1) issued in June, 1992. Since differential scattering data are more sensitive to parities of resonances, the present paper reports an analysis of the new ORELA scattering data to verify the spins and parities found by Hale in his analysis for Mod 1.

Details of the transmission measurement have been reported previously and are only briefly reviewed here. In the present work, total and differential elastic data were analyzed with the R-matrix code SAMMY [3] to obtain resonance parameters consistent with both types of data.

EXPERIMENTAL TRANSMISSION MEASUREMENTS

High-Resolution Measurements from 0.1 to 20 MeV

For the high-resolution transmission measurements in this energy region, unmoderated neutrons directly from the ORELA tantalum target were produced by 5-nsec wide 150-MeV electron pulses at a repetition rate of 800 pps. Details of this measurement are reported in an earlier paper. [4]

Measurements from 0.5 eV to 200 keV

For the transmission measurements in this energy region the collimation was changed so that only neutrons from the water moderator of the ORELA target could reach the neutron detector. The burst width was 30 nsec with a repetition rate of 80 pps. Additional details are reported in the earlier paper. [4]

EXPERIMENTAL DIFFERENTIAL ELASTIC SCATTERING MEASUREMENTS

High-resolution scattering measurements were done at the 200-m flight-path station. A collimator allowed both moderated and unmoderated neutrons to reach the sample.

Providing a nitrogen sample in a form suitable for scattering measurements is a difficult problem; we finally settled on silicon nitride. The sample consisted of 57.80 g of silicon nitride (Si_3N_4) powder contained in a 8.4 g hollow graphite cylinder with a 0.05 cm bottom (7.0 cm high, 3.81 cm outside diameter, and 3.70 cm inside diameter). The cylinder was suspended at the center of a 183-cm-diam scattering chamber, which was evacuated and isolated from the flight-path beam tube by means of a 0.025-cm Mylar entrance window. Measurements were also made with a silicon (Si) sample 6.17 cm diameter and 0.58 cm thick mounted at a $63\frac{1}{2}^\circ$ angle from the direction of the neutron beam.

The scattering data were obtained using a 0.3-g/cm^2 ^{10}B filter to eliminate low-energy neutrons associated with the previous burst and with two filters of Uranium-238 to reduce the intensity of the gamma flash from the target. One filter (0.73 cm thick) covered the whole collimator; the other (2.5 cm thick) shadowed only the tantalum part of the target. The measurements covered the energy region from approximately 10 keV to 10 MeV. The electron beam burst width was 9 nsec.

Six neutron detectors were located 19.1 cm from the center of the chamber at laboratory angles of 36.1° , 51.8° , 86.0° , 116.5° , 137.2° , and 158.5° from the direction of the incident neutron beam. Each neutron detector consisted of a 7.62-cm-long by 4.32-cm-diam cylinder of NE-110, which was viewed at each end by RCA 8850 photomultiplier tubes. Additional details of the experimental arrangement for these

scattering measurements can be found in Ref. [5]; information on the calculated efficiencies for the two-phototube detectors is given in Ref. [6].

Data were also taken with one of the detectors placed in the incident beam to measure the product of the flux and detector efficiency as a function of neutron energy. Scattering measurements using a graphite sample were also made to determine the relative efficiencies of the other five detectors.

All spectra were normalized by means of a neutron monitor detector. After correcting for dead time and constant room background, the scattering spectra were divided by the spectrum from the in-beam detector to remove effects of the energy dependence of the incident flux and detector efficiency. The data were not corrected for multiple scattering in the sample (this was done as part of the R-matrix analysis), and have an uncertainty of $\approx 10\%$ for the relative differential scattering cross section.

R-MATRIX ANALYSES OF THE CROSS-SECTIONS

Values of resonance parameters (resonance energy and widths) and assignment of quantum numbers (spin J , and orbital angular momentum ℓ and corresponding parity π) may be determined or confirmed through combined analyses of the total cross-section and differential elastic scattering cross-section data. The differential scattering data are particularly useful in determining values for ℓ (and π). The analysis is complicated, however, because of a number of experimental impediments:

(a) The target used was Si_3N_4 . But silicon itself has many resonances, and accurate determination of the silicon resonances is necessary to properly analyze the nitrogen resonances. Even so, existence of a silicon resonance at an inauspicious energy can result in masking of the desired nitrogen scattering behavior.

(b) At higher energies, not only do the peak cross-sections of resonances decrease, but the differential scattering becomes less sensitive to differences in quantum numbers, ℓ in particular.

(c) The target must be a finite size in order to obtain sufficient scattering counts; but the finite size presents resolution problems, as well as absorption of scattered particles. This phenomenon is best seen in forward scattering, where the experimental peak height is often lower than predicted, although acceptable energy dependence for a given set of quantum numbers can be obtained at other angles.

Our work to provide the best possible parametric assignments for all nitrogen resonances is on-going; preliminary results are reported here. The current "best

fit" to the total cross section data is shown in Figure 1, for energies between the lowest resonance (at 433 keV) and 4.8 MeV.

Fig. 1--Total cross section from the high-resolution ORELA transmission measurement. The solid curve shows our preliminary R-matrix fit.

We now consider the spin/parity assignments for the individual resonances from 433 keV to 2.5 MeV.

Prior to ENDF/B-VI Mod 1, the spin assignment for the 433-keV resonance had been taken to be $3/2$. After that time, analysis of our high-resolution measurements [3] of the total cross section determined that J must be $7/2$, and that value was used in the modified ENDF/B-VI (Mod 1) analysis by Hale [1]. The differential scattering data provide confirmation of this assignment, and clearly indicate $\ell = 2$ (rather than $\ell = 3$) is the correct assignment, as shown in Fig. 2.

Fig. 2--Differential elastic scattering cross section for the 433-keV resonance of ^{14}N , at laboratory angles of 36.6, 86.0, and 158.5 degrees respectively. The solid curve represents the $\ell = 2$ assignment, and the dashed $\ell = 3$.

[Note: An approximation was used in determining the experimental energies of the scattered neutrons from the time-of-flight information; the approximation appears to break down at backward angles. Thus the structure in the calculation appears to be at higher energy than the corresponding structure in the data. Since this and other

difficulties with the differential elastic scattering data have yet to be fully considered, thus far these data are used only to determine the quantum numbers and not for precise fitting of resonance parameters.]

The 491-keV resonance is too small to obtain a clear spin assignment from the differential scattering data. The data, however, are not inconsistent with the previous assignment of $1/2^-$ for J^π .

The 639-keV and 997-keV resonances are both definite s-waves ($\ell = 0$), the first with $J = 1/2$ and the second $J = 3/2$.

The resonance at 1.116 MeV had been assigned $J^\pi = 5/2^-$ [2]. Figure 3 shows the differential elastic data for this resonance, compared with both positive and negative parity theoretical curves, confirming that the negative-parity assignment is reasonable.

Fig. 3--Differential elastic scattering cross section for the 1.116-MeV resonance, at laboratory angles 36.6, 86.0, and 158.5 degrees. The dashed curve represents the positive-parity assignment, and the solid the negative-parity.

The previous assignment for the 1.185-MeV resonance was $J = 5/2$. Comparison of theoretical calculations with the differential elastic scattering data is shown in Fig. 4. Based on these calculations we tentatively assign negative parity to this resonance.

Fig. 4--Differential elastic scattering cross section for the 1.185-MeV resonance, at laboratory angles 36.6, 86.0, and 158.5 degrees. The dashed curve represents the positive-parity assignment, and the solid the negative-parity.

The 1.21 MeV resonance was assigned $J^\pi = 1/2^-$. The differential elastic data provide no definitive information about this resonance, primarily because of the presence of nearby silicon resonances.

A broad $\ell = 0$ state underlies this region; Hale [2] determined this state to be $J^\pi = 3/2^+$ at energy 1.255 MeV.

The 1.35-MeV and 1.41-MeV resonances have been assigned $J^\pi = 5/2^+$ and $3/2^-$ respectively. Our analysis of the differential elastic data confirms these assignments.

Resonances at 1.60 and 1.78 MeV were previously assigned $J^\pi = 5/2^-$ and $5/2^+$ respectively. The differential scattering data are inconclusive on the parities.

The resonance at 2.220 MeV had been assigned $J^\pi = 3/2^-$. Calculations of the differential elastic scattering cross section for this resonance show almost no distinction between the positive and negative parity options; neither is inconsistent with the data. Data from other reactions had been used to determine that the parity is negative [2].

CONCLUSION

Total and differential elastic scattering data for nitrogen have been obtained at ORELA and analyzed with the R-matrix formalism. The scattering data have provided essential information to aid in determining the orbital angular momentum ℓ values for resonances. The data have confirmed some earlier results and provided new ℓ values for other resonances. The large resonance at 433 keV has been shown to have $\ell = 2$.

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