MEASUREMENT OF THE NITROGEN TOTAL CROSS SECTION FROM 0.5 eV to 50 MeV, AND ANALYSIS OF THE 433-keV RESONANCE

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Abstract: High-resolution neutron transmission measurements have been made on several thicknesses of nitrogen gas samples from 0.5 eV to 50 MeV at the Oak Ridge Electron Linear Accelerator (ORELA). A preliminary R-matrix analysis has been done for resonances up to 800 keV. An R-matrix analysis of previous data was done by LANL for ENDF/B-VI, including the lowest energy resonance in ^{14}N at 433 keV. They found a spin of $3/2$ (with $\ell = 1$) and a peak cross section of 7.0 b. Analysis of the present data yield a spin of $7/2$ (requiring $\ell \geq 2$) and a peak cross section of 11.5 b for this resonance. These results are important for transport calculations of neutrons through air. Scattering measurements are planned to determine the parity of this resonance.

(^{14}N high-resolution transmission measurements, resonance parameters, R-matrix analysis)

Introduction

The recent (1990) ENDF/B-VI evaluation of the cross sections for nitrogen by Young, Hale and Chadwick [1] again emphasized the lack of reliable total cross-section data in the low energy region. Nitrogen total cross-section data are needed for investigating problems involving the transport of neutrons through air. The most recent measurement is thirteen years old, and the most recent measurement below 500 keV was in 1961. We have made a series of high-resolution neutron transmission measurements on nitrogen gas samples using several different detectors and flight path lengths at ORELA to provide accurate data from 0.5 eV to 50 MeV.

Experimental Measurements

High Resolution Measurements from 0.1 to 20 MeV

For the high-resolution measurements from 0.1 to 20 MeV we used unmoderated neutrons directly from the ORELA tantalum target produced by 5-nsec wide, 150-MeV electron pulses at a repetition rate of 800 pps. The detector was a 9-by-9 cm NE-110 scintillator, one-cm thick, epoxy-coupled to two 12.5-cm diameter RCA 8854 photomultipliers located 201.568 meters from the tantalum target. This bare (non-coated) scintillator is mounted in a 0.025-mm thick, 17.8-cm-diam mylar reflecting cylinder. A 0.30-gm/cm^2 ^{10}B filter was used to eliminate overlap neutrons and a filter of 3.9 cm uranium plus 1.3 cm thorium was used to reduce the background due to gamma rays from the tantalum target. The phototube bases were gated off for 2 microsec to eliminate the gamma flash.

The nitrogen gas (99.995% purity) was contained in stainless steel cylinders [2] with approximately spherical end windows, an inside diameter of 16.14 cm, an inside length of 220.9 cm and a volume of $44,261\text{ cm}^3$. An identical cylinder was used for the open beam measurement to cancel out the effects of the resonances due to the components of stainless steel. Careful inspection of the sample-in/sample-out ratio showed no sign of large resonances in iron, indicating acceptable compensation of the cylinder windows. Gas pressure gauges on each cylinder were calibrated to an accuracy of 1 psi.

Two transmission measurements were made with nitrogen in one cylinder with pressures of 488 and 490 psi and a vacuum in the second cylinder for the open beam spectrum. The two cylinders were cycled about 100 times. Three measurements were made with nitrogen in the second cylinder with pressures from 480 to 487 psi and a vacuum in the first cylinder. After the transmission measurements on each cylinder were completed the weight of nitrogen and the pressure were measured for

each cylinder. The ratio of the weight of nitrogen to the pressure gauge reading for the first cylinder agreed with the similar quantity for the second cylinder to 0.34%. The total cross sections for the five runs were calculated as described below. Since the results were in good agreement, the five runs were added, resulting in a single data set with a weighted-average pressure of 487 psi, a weight of 1759 grams and a sample thickness of 0.3743 atoms/barn with an estimated uncertainty of 0.5%.

^6Li Measurements from 0.5 eV to 200 keV

For the transmission measurements in this energy region the collimation was changed so that only moderated neutrons from the water moderator of the ORELA target could reach the neutron detector, located at a flight path length of 80.117 meters. The detector was a ^6Li glass scintillator, 12.5 mm thick and 11.1 cm in diameter, mounted in a 0.025-mm-thick, 15-cm-diameter mylar reflecting cylinder between two RCA 8854 photomultiplier tubes. The accelerator was operated with burst widths of 30 nsec and a repetition rate of 80 pps. A 1.6-mm-thick cadmium filter was used to eliminate overlap neutrons and a 0.64-cm Pb filter to reduce the background due to gamma rays from the water moderator of the target.

Two transmission measurements were made, one with 993 gms of nitrogen gas in one cylinder with a sample thickness of 0.2113 atoms/barn and a vacuum in the other cylinder as the compensator, and the second one with 979 gms of nitrogen in the second cylinder with a sample thickness of 0.2092 atoms/barn and a vacuum in the first cylinder. Since the cross sections computed for these two runs agreed, the two data sets were averaged.

Measurements with the Be Block Target to 50 MeV

For measurements at high energies the ORELA Be block target was used and a thick NE-110 scintillation detector was located at a flight path length of 79.660 meters. The scintillator was 10.2 cm in diameter and 7.6 cm thick, and was mounted on a selected RCA 8854 photomultiplier. The ORELA was operated at a repetition rate of 800 pps with a pulse width of 24 ns. The flight path from 10 to 80 meters was filled with nitrogen gas to a pressure of one atmosphere for this high energy run.

Processing of the Transmission Data

The data for all three detectors have been corrected for the dead time (1104 ns) of the time digitizer, and several backgrounds which total less than 3% over most of the region for the ^6Li data and less than 1% and as small as 0.02% for the high resolution NE-110 data. The

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Fig. 1. Total cross-section data from the present measurements, compared with the ENDF/B-VI evaluation for ^{14}N .

backgrounds for the ${}^6\text{Li}$ data consist of a constant beam-independent background, a 17.6- μsec gamma-ray background from the capture of neutrons in the water moderator, overlap neutrons from the previous burst, and a time-dependent background arising from neutrons scattered from the ${}^6\text{Li}$ glass scintillator. For the high-resolution data, the backgrounds consist of only a constant and a very small 17.6- μsec gamma-ray background. Additional details on these backgrounds are discussed in a published paper and reports [3,4,5].

Total Cross-Section Results

The total cross sections for several energy regions are shown in Fig. 1, compared to the total cross section from the ${}^{14}\text{N}$ evaluation from ENDF/B-VI [1]. The upper plot is data from the ${}^6\text{Li}$ scintillation detector and the remainder are high-resolution 200-m data. The present results generally agree with the R-matrix analysis for ENDF/B-VI up to 2.5 MeV. In particular, our data confirm the evaluation in the region from 400 eV to 10 keV, where there was essentially no data. The primary difference is the 433-keV resonance.

R-Matrix Analysis Below 800 keV

As part of the ${}^{14}\text{N}$ evaluation [1] for ENDF/B-VI, the available total cross section data was included in an R-matrix analysis of the resonance region. For the resonance at 433 keV, $J = 3/2$ provided an acceptable fit to the total cross section data, with a peak cross section of 7.0 b. Except for $\ell = 0$ (which produces an interference minimum), the fits were insensitive to the ℓ -value; $\ell = 1$ was assumed.

A preliminary R-matrix analysis on our new data has been done below 800 keV using the computer code SAMMY. In this paper we present results for the two resonances below 500 keV, where the previous data base was poorest. The lowest energy resonance observed in ${}^{14}\text{N}$ is at 433 keV where we find the only acceptable fit to the data is with $J = 7/2$ which requires $\ell = 2$ or 3 (or up to 5). The parameters for this resonance are $E = 433.35 \pm 0.03$ keV, $\Gamma_n = 2.46 \pm 0.04$ keV, $\Gamma_\gamma = 40 \pm 70$ eV. Γ_p was held fixed at 0.0 since there is no evidence of the (n,p) reaction near this resonance. The large uncertainties on the capture width reflects the fact that the transmission data for this resonance are not sensitive to this parameter since it is so small compared to Γ_n . The fit for this resonance is shown in Fig. 2.

Attempts to fit this resonance with J less than 5/2 were not successful since the peak cross section of 11.5 barns could never be reached. For $J = 9/2$ a fit could be obtained which required the sum of Γ_γ and Γ_p to be approximately 500 eV. Since the Γ_p width must be very small, as noted above, this would require an unreasonable value for Γ_γ ; hence J cannot be 9/2.

The other resonance below 500 keV is at 491.2 ± 0.1 keV which was assigned [6] as $J = 1/2$, $\ell = 1$ with a relatively large proton width. Our analysis for a fixed value of Γ_γ of 4.0 eV gives $\Gamma_n = 1.9 \pm 0.1$ keV and $\Gamma_p = 5.2 \pm 0.3$ keV which is in agreement with values listed in reference 6, namely $\Gamma_p = 6 \pm 2$ keV and a total width of 7.8 ± 0.5 keV.

The preliminary R-matrix analysis has been extended to 800 keV.

Conclusions

Accurate high-resolution transmission data have been obtained from 0.5 eV to 50 MeV using both unmoderated and moderated neutrons from the ORELA tantalum target and high-energy neutrons from the Be block target. The previous data below 500 keV, reported in 1961, had inadequate resolution to define the peak cross section

Fig. 2. Data for the 433-keV resonance, compared with our SAMMY fit (solid line). The dashed line is the ENDF/B-VI evaluation.

of the resonance at 433 keV. The present results significantly improve the data base below 500 keV, as well as provide the highest resolution data available above 500 keV. Using our new high resolution data, we have presented results for the two resonances below 500 keV, as analyzed with the R-matrix code SAMMY. The lowest lying resonance, at 433 keV, was found to have a much larger peak cross section (11.5 b rather than 7.0 b), and $\ell \geq 2$. These results will affect neutron transport calculations through air. Differential elastic-scattering measurements are planned for the resonance region to determine the ℓ values of the resonances.

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References

1. P. Young, G. Hale and M. Chadwick, ENDF/B-VI evaluation for ${}^{14}\text{N}$, MAT 725 (June 1990).
2. R. R. Winters, R. F. Carlton, C. H. Johnson, N. W. Hill and M. R. Lacerna, *Phys. Rev. C* **43**, 492 (February 1991).
3. M. S. Pandey, J. B. Garg and J. A. Harvey, *Phys. Rev. C* **15**, 600 (1977).
4. D. C. Larson, C. H. Johnson, J. A. Harvey and N. W. Hill, *Measurement of the Neutron Total Cross Section of Fluorine from 5 eV to 20 MeV*, ORNL/TM-5612 (October 1976).
5. D. C. Larson, N. M. Larson, J. A. Harvey, N. W. Hill and C. H. Johnson, *Application of New Techniques to ORELA Neutron Transmission Measurements and Their Uncertainty Analysis: The Case of Natural Nickel from 2 keV to 20 MeV*, ORNL/TM-8203 (October 1983).
6. S. F. Mughabghab, M. Divadeenam and N. E. Holden, *Neutron Cross Sections*, Vol. 1, Part-A, Academic Press, New York (1981).