TID-27236

FINAL REPORT

AEC-ERDA Research Contract AT(11-1)2174

Columbia University's

Nevis Laboratories

"Research in Neutron Velocity Spectroscopy"

James Rainwater

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Part I

Introduction

Research in neutron spectroscopy, emphasizing resonances of neutron-nuclei interaction, was begun ~ 1941 by James Rainwater and W. W. Havens, Jr. using the small cyclotron in the basement of the Pupin Physics Laboratory. This work was under the direction of Dr. J. R. Dunning and at various times included others such as Dr. C. S. Wu, and Edward Melkonian. By the early 1950's, this facility was obsolete. The Nevis Synchrocyclotron, originally O.N.R. funded, was recognized from the start as a potentially superior source for pulsed, moderated, neutron resonance spectroscopy. First use of it for that purpose began ~ 1955 and is described in the article "Resonance Processes with Neutrons" by J. Rainwater in Vol. 40 of the Springer-Verlag "Handbuch der Physik" in 1957.

In the early 1960's, a 200 meter time-of-flight tunnel facility and detector station was funded by the A.E.C. and greatly improved operation began ~ 1963-4 using what was then an advanced 2000 channel analyzer system (electrostatic storage, fast storage-magnetic drum slow histogram storage). This led to a number of papers on ^{232}Th, ^{238}U, Ta, Au, Ag, As, Br, V, Nb, I, Cs, Mo, Sb, Te, and Pr, in addition to many of the detailed σ vs E plots of the total neutron cross section vs E for large numbers of elements which were published ~ 1966 in BNL-325.

The old analyzer was becoming unreliable and obsolete, however, so, support was obtained from the A.E.C. for obtaining an EMR 6130 on-line computer - with associated time-of-flight circuitry. A major "run" in 1968 used a substitute EMR 6050 computer, for an 8000 channel analyzer operation. In 1970, a 16,000 channel better system used the 6130 computer. These runs collected vast amounts of high quality data which has required the subsequent time for its (almost) complete analysis. It has led to nearly thirty published papers on the results, which usually increased the amount of information available on the neutron resonance parameters of the elements and isotopes studied by factors $\sim$ 10 or more.

In 1965, it was noted that the Nevis Synchrocyclotron (S.C.) was on the verge of obsolescence for its main research using pions and muons, in spite of the many historic research discoveries made using it since 1950.

A plan was made to convert the S.C. to a sector-focused S.C. which would (a) increase the proton energy from $\sim$ 380 MeV to $\sim$ 560 MeV, and increase the beam current by an order of magnitude, and (b) provide a long duty factor external proton beam for intermediate energy physics research. This program was supported by the N.S.F. as a national intermediate energy facility. Plans were included to continue the neutron time-of-flight spectroscopy program with greatly improved effectiveness. The modification program has occupied most of Professor Rainwater's time since 1965. The machine operation was stopped in late 1970 for the major modification. The completion of the modification has gone slower than expected, but is now in its final stages, with research expected in later 1976. The machine has been operated successfully in the external beam mode for exploratory experiments. In 1971 a decision was made to split up the A.E.C. Gen 72 contract which Professor Havens had administered. The Nevis neutron spectroscopy program under Professor Rainwater became A.E.C. Contract AT(11-1)2174. Progress reports on the results of the analysis of the 1968-70 data have been submitted for one year intervals from July 1, 1971 through June 1974. The various renewal proposals and progress reports also list the logic as to why the modified S.C. should be such an effective source for neutron resonance time-of-flight spectroscopy, and the new hardware systems prepared for such operation. The support of this research has now been taken over by the main N.S.F. grant for the S.C. program, and preparations are continuing for the use of the S.C. for such research, essentially as described in earlier A.E.C. contract proposals.

Because of the unexpectedly delayed time schedule for completion of the machine modifications and bringing the modified facility into full research operation, the net results of the contract AT(11-1)2174 efforts have been in the successful completion of almost all of the analysis to publication of the vast amounts of data from the 1968 and 1970 cyclotron "runs".

This section concludes with a summary paper which was given at the March 3-7, 1975 conference on "Nuclear Cross Sections and Technology", which describes the general aspects of the research and the sixteen papers published in Physical Review C beginning in 1972, all on the results of the 1968-70 data analysis. Since the last progress report in June 1974, Physical Review C papers have been published on our results for:

1. The isotopes of Cadmium. ^{110}Cd (79 resonances below 10 keV), ^{111}Cd (98 resonances to 2300 eV), ^{112}Cd (98 resonances to 11,500 eV), ^{113}Cd (37 resonances to 2250 eV, ^{114}Cd (55 resonances to 3030 eV), and ^{116}Cd (21 resonances to 10 keV).
2. The isotopes of Indium. ^{113}In (50 resonances below 2 keV), and ^{115}In (233 resonances to 2005 eV).
3. The isotopes of Gd. ^{154}Gd (48 resonances to 1 keV), ^{158}Gd (95 resonances to 10 keV) and ^{160}Gd (56 resonances to 10 keV).
4. Natural Chlorine, measured σ_t vs E to 400 keV with results for 35 resonances below 200 keV.
5. Natural Calcium, measured σ_t vs E to 550 eV (with a multi-level R-matrix fit for the 9 main strong s levels, and analysis for 22 weak (mainly R = 1) levels.

6. Natural Fluorine. R matrix fitting to the three resonances below 200 keV, for σ_t vs E.

7. Natural Magnesium. R matrix fitting of the measured σ vs E below 500 keV to 4 resonances.

8. The isotopes of Dy. ^{160}Dy (64 levels to 2 keV), ^{161}Dy (251 levels to 1 keV), ^{162}Dy (142 levels to 16 keV), ^{163}Dy (114 levels to 1 keV), and ^{164}Dy (116 levels to 21 keV).

9. Natural Argon. Measured σ_t vs E to 600 keV, R matrix fitting for 5 $\ell = 0$ levels below 300 keV, and level parameters for 18 $\ell = 1$ levels and 1 more $\ell = 0$ level to 600 keV.

10. Separated ^{175}Lu (446 levels to 3 keV).

11. Natural Aluminum. Measured σ_t vs E to 450 keV. R matrix fitting below 220 keV and parameters for 4 $\ell = 0$, and 3 $\ell = 1$ levels to 202 keV.

12. Separated ^{177}Hf. (176 levels to 700 eV).

13. The isotopes of Thallium. (σ_t vs E to 160 keV for natural Tℓ. 25 $\ell = 0$, 11 $\ell = 1$ levels in $^{203}T\ell$ and 5 $\ell = 0$ and 6 $\ell = 1$ levels in $^{205}T\ell$, plus $ag\Gamma_n$ and E for 44 $\ell = 1$ and $\Gamma \approx \Gamma_n$ values for 29 $\ell = 0$ levels above 20 keV for the element.

14. Natural Bismuth (^{209}Bi) (σ_t vs E to 75 keV with R matrix fitting to 9 $\ell = 0$ levels, and parameters for 18 $\ell = 1$ levels).

15. Natural Lanthanum (^{139}La) (σ_t vs E to 75 keV parameters for 150 levels to 26 keV).

16. We are now completing the analysis for over 300 resonances in Ta below 2 keV (1970 data). Later analysis of our 1964 data at SUNY-Albany by Professor Garg, with spurious levels deleted by Dr. Rahn based on some 1968 run Ta data, constitutes the resonance parameters from ~ 300 eV to 1400 eV in the latest BNL 325 compilation. The 1970 data was analyzed by an area method, partial shape analysis, and presently by a full shape fitting. The results will be submitted for publication when completed.

In conclusion, it is believed that this set of papers represents a major contribution to our knowledge of resonance neutron spectroscopy below 100 keV.

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