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AUTHOR(S): E.I. Sharapov, S.A. Wender, H.Postma, S.J. Seestrom
C.R. Gould, O.A. Wasson, Yu. P. Popov, and C.D. Bowman

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THE MEASUREMENTS OF PARITY VIOLATION IN RESONANT NEUTRON-CAPTURE REACTIONS

E.I. Sharapov[1], S. A. Wender[2], H. Postma[3], S. J. Seestrom[2], C.R. Gould[4],
A. Wasson[5], Yu. P. Popov[1], and C. D. Bowman[2]

[1] *Joint Institute for Nuclear Research, Dubna, USSR*
[2] *Los Alamos National Laboratory, Los Alamos, NM USA 87545*
[3] *University of Technology, Delft, The Netherlands*
[4] *North Carolina State University, Raleigh, NC USA 27695*
[5] *National Institute of Science and Technology, Washington, DC*

ABSTRACT

The study of parity violation in total (n,γ) cross sections on ^{139}La and ^{117}Sn targets was performed at the LANSCE pulsed neutron source using longitudinally polarized neutrons and a BaF_2 detector. The effect of parity nonconservation in the ^{139}La(n,γ) reaction for the resonance at E_n=0.73 eV was confirmed. New results for p-wave resonances in the ^{117}Sn(n,γ) reaction were obtained. A comparison between the capture and transmission techniques is presented.

INTRODUCTION

Parity nonconservation (PNC) in neutron p-wave resonances has been studied by using the transmission technique for several years[1-4]. Definite cases of parity violation have been found for compound states in ^{81}Br, ^{111}Cd, ^{117}Sn, ^{139}La and ^{238}U. The transmission method measures the total cross section and seems to be well established. In this method the neutron detector is located directly in the beam and the count rate for each helicity is measured as a function of incident neutron energy. The p-wave resonance appears as a weak dip on the high counting rate level which plays the role of a background. Large target masses of approximately 1 kg are necessary. Only the capture part of the cross section is responsible for the PNC effect; the potential scattering does not contribute and leads only to the loss of neutron intensity.

The measurement of the helicity dependence of neutron capture cross sections promises to be a more direct way to observe PNC effects in p-wave resonances. This method is not sensitive to potential scattering and smaller targets may be used. This is especially important when enriched isotopes are required. The γ-ray detectors are located outside the neutron beam and should have greater than 50% efficiency. The background from scattered neutrons must also be minimized.

The (n,γ) technique was successfully used by Masuda et al.[5] to measure parity violation in the ^{139}La resonance at $E_n = 0.73eV$. An unpublished communication from IAE Moscow[6] treats the case of the ^{111}Cd p-wave resonances by the (n,γ) method. The present report discusses the first measurements to investigate the possibility of using polarized (n,γ) reactions to study parity violation at the Los Alamos Neutron Scattering Center (LANSCE) pulsed neutron source.

EXPERIMENTAL APPARATUS

Measurements were made using the time-of-flight technique. The 800 MeV, 125 nsec wide, beam from the proton storage ring (PSR) at the Los Alamos Meson Physics Facility (LAMPF) produced neutrons by spallation reactions in a tungsten target. Beam spills occurred at a rate of 20 hz. The water-moderated neutron flux is described by the expression[7]:

$$F(E_n) = \frac{2 \times 10^8}{E_n(eV)L^2(m)}(cm^2 * eV * sec)^{-1}$$

This equation assumes an average proton current of 100 μamps and a sample viewing 100 cm^2 of the moderator. The validity of this expression has been confirmed in experiments by Koehler[8].

Neutrons are polarized by transmission through a polarized proton filter. We use an LMN polarizer and a spin-flipper that have been described in detail in Ref. 9. The polarization of the neutron beam was rather low in this experiment, $f_n = 17\%$ instead of the normal value of 40%; we believe this is due to deterioration of the LMN crystals. Positive and negative neutron helicity states were alternated every 10 seconds using the spin flipper. Data were also obtained reversing the spin direction by changing the microwave pumping frequency. The asymmetries quoted in this paper are the weighted average of the results for the two microwave frequencies.

Polarized neutrons reached the metallic samples of ^{139}La (6.8×10^{22} and 3.1×10^{22} atoms/cm^2) and of ^{117}Sn (92% enrichment, 2.9×10^{22} atoms/cm^2) located approximately 22.5 m from the water moderator. The beam was collimated to a spot 5 cm in diameter at the sample location using collimators made from boron-loaded polyethylene. A longitudinal magnetic guide field ($B = 16G$) was provided by a solenoid that extended from the spin-flipper to the sample position.

The γ-ray detector consisted of two 15x15 cm^2, 15 cm thick cubic BaF_2 crystals located 10 cm from the center of the beam on either side of the flight path. ^{6}Li-metal disks (2.5 cm thick, 15 cm in diameter) were placed between each detector and the solenoid section outside the sample. The detector was shielded with 10 cm thick lead and borated polyethylene plates. The solid angle for the two detectors was approximately 25% of 4π. The background of high-energy neutrons and γ- rays paralyzed the detector for 150 μsec after the initial beam burst.

The anode outputs of the photomultiplier tubes (PMT) were connected to two fast discriminators. One discriminator determined the lower γ-ray energy level; the other discriminator determined the upper γ-ray energy level. The logical sums of these discriminators for each detector were summed and connected to a multiscaler. The width of the discriminator output pulses was 20 nsec. The lower level discrimination was set to approximately 1 MeV. The upper level was set to 5 MeV for ^{139}La and 9 MeV for ^{117}Sn.

The data acquisition system, which was developed for the TRIPLE transmission measurements[4], used the XSYS language on a DEC μVAXII workstation. Typical time-of-flight spectra are shown in Fig. 1 for 0.8 cm thick ^{139}La (the channel width is 1 μsec) and in Fig. 2 for 0.8 cm thick ^{117}Sn (the channel width is 0.5 μsec). The continuum spectra outside the peaks are due to s-wave capture and to background. The high-energy strong s-wave resonances were distorted because of the large instantaneous current in the photomultipliers.

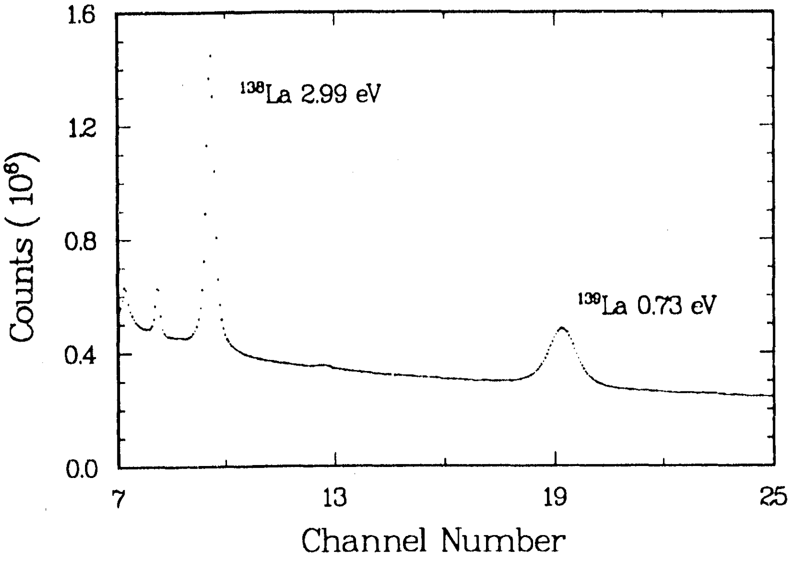

Fig. 1 Time of flight spectrum for La.

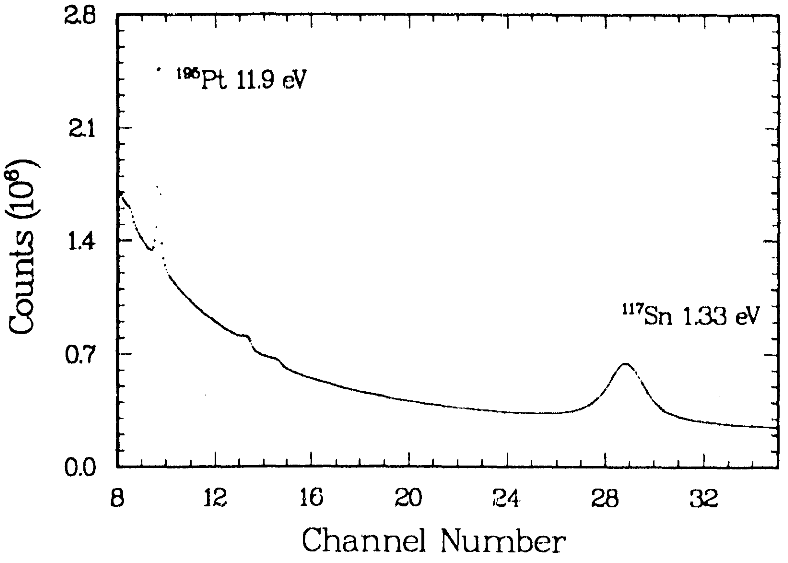

Fig. 2 Time of flight spectrum for ^{117}Sn.

RESULTS

The data were analyzed to obtain the longitudinal asymmetry ϵ_γ for the p-wave resonance peaks. ϵ_γ is defined as: $\epsilon_\gamma = (1/f_n)(N_+ - N_-)/(N_+ + N_-)$ where f_n is the polarization of the neutron beam and N is the number of counts for each spin state. The number of counts $N_+ + N_-$ was obtained by fitting a Lorenztian peak shape to the summed spectrum. The energy and width determined in this way were used to fit the difference spectrum to determine $N_+ - N_-$. Plots of the difference spectra and fits for ^{139}La and ^{117}Sn are shown in Fig. 3 and Fig. 4.

The γ-ray counts N are not linearly proportional to capture cross sections σ_{CAP} for thick samples. The effects of self-attenuation and the capture of scattered neutrons in the target should be taken into account. We therefore measured ^{139}La data for two different sample thicknesses that are shown in Fig. 5 together with the data of Ref. 5. The relative beam polarization was obtained by NMR measurements; the absolute beam polarization was obtained by normalizing our two La measurements to the curve defined by the data of Ref. 5. For the thin La sample this corresponds to a beam polarization of $f_n = (16.5 \pm 1)\%$. The results of this preliminary analysis are shown in Table I.

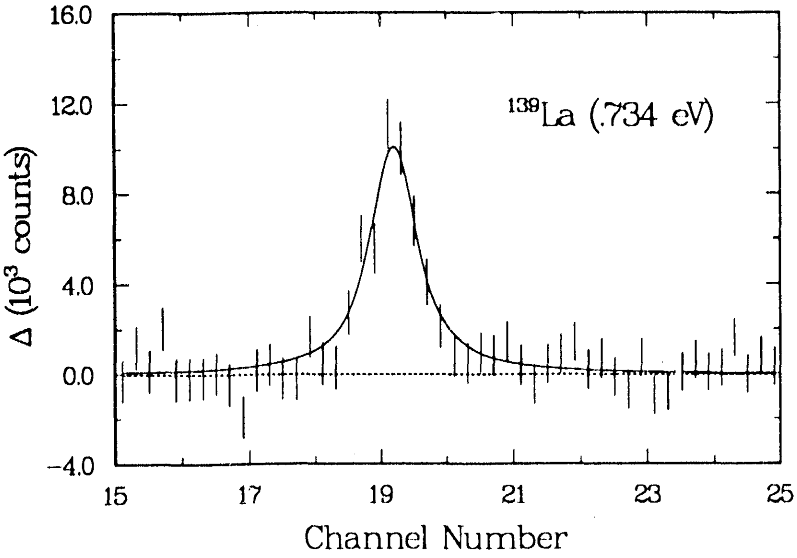

Fig. 3 Difference spectrum in region of .734 eV resonance in ^{139}La.

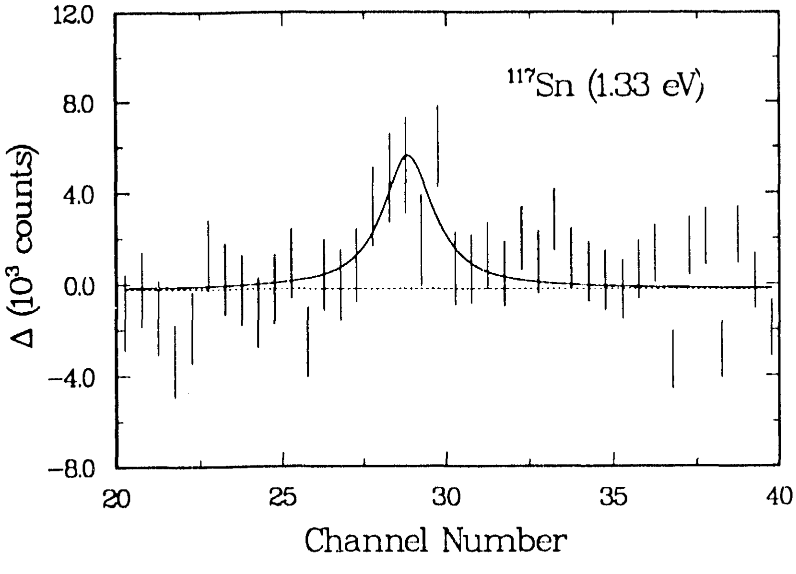

Fig. 4 Difference spectrum in region of 1.33 eV resonance in ^{117}Sn.

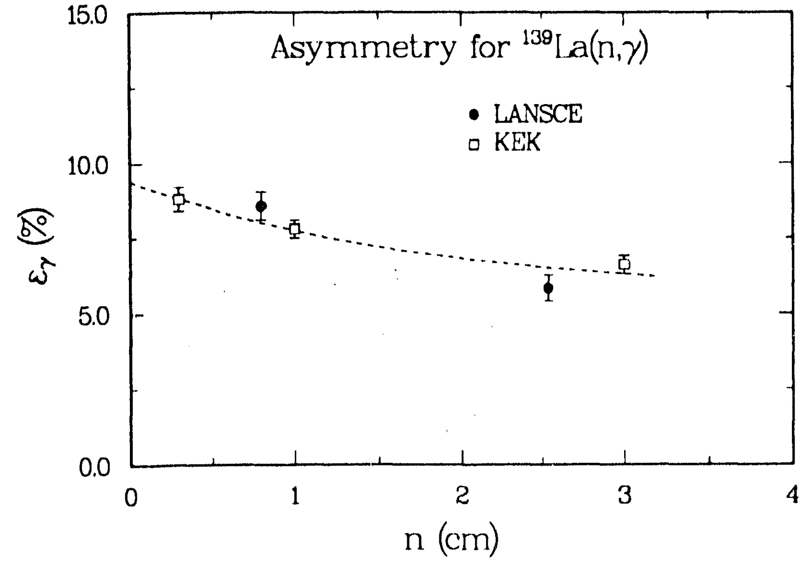

Fig. 5 Comparison of ϵ_γ from KEK and LANSCE.

We made no correction for sample thickness effects for the 1.33 eV ^{117}Sn resonance. It will certainly be less than in the case of ^{139}La because of the two times better ratio of $\sigma_{CAP}/\sigma_{POT}$ for ^{117}Sn. The ^{117}Sn result is two times larger than the value from transmission measurements in Ref. 1 but not in disagreement with the result of Ref. 2. A weak neutron resonance was found at $E_n = 26.4eV$ in addition to the known resonance[10] at $E_n = 34.0eV$ in ^{117}Sn. Upper limits of the longitudinal asymmetry for these resonances are shown in Table I.

Table I: Parity-Violating Asymmetries Measured in Neutron Capture

Sample	n (10^{22} atom/cm^2)	E_n (eV)	ϵ_γ (%)
La	3.1	0.73	8.6 ± 0.5
La	6.8		5.8 ± 0.4
^{117}Sn	2.9	1.33	1.1 ± 0.2
^{117}Sn	2.9	26.4	-1.3 ± 1.6
^{117}Sn	2.9	34.0	0.45 ± 0.49

COMPARISON OF CAPTURE AND TRANSMISSION

Capture experiments were the first to show parity-violating effects in slow neutron reactions but are in general more difficult to analyze than transmission experiments because of the need for additional spectroscopic information relating to the decay channels[11]. An important exception arises for 4π gamma ray detection where the two methods are equivalent. The p-wave neutron width is negligible compared to the gamma ray width and both experiments are essentially measuring the helicity dependence of the total resonance cross section. Capture measurements can have a sensitivity advantage because there is no contribution from potential scattering.

Both experiments measure a parity-violating cross section σ_{PV} as defined, for example, in the appendix of Ref. 12. The capture asymmetry $\epsilon_\gamma = \sigma_{PV}/\sigma_{CAP}$ will nearly always be larger than the transmission asymmetry $\epsilon_n = -n\sigma_{PV} \equiv 2\sigma_{PV}/\sigma_{TOT}$ for an $n = 2$ mfp target (the optimum thickness for transmission). This ratio particularly favors capture if the p wave is weak ($\sigma_{CAP} \sim \sigma_p << \sigma_{TOT}$). Capture is also favored for thin targets; in capture the error in σ_{PV} scales as $1/\sqrt{n}$ compared to $1/n$ for transmission. Large quantities of isotopic material will usually be impossible to obtain. The actual errors will depend of course on the relative efficiencies of the detectors, the neutron flux striking the samples, and on the backgrounds in each experiment.

Transmission experiments overcome these limitations by working with thick samples close to the neutron source and by placing a large detector at a long flight path. This resolves neutron resonances up to high energies, which is important in surveys of parity-violating asymmetries. This is a problem for capture experiments in which small samples are usually placed close in to the neutron source with detectors at the same location. Capture experiments also must analyze multiple scattering effects which dilute the asymmetry[5]. Most of these effects are due to neutrons scattered by s-wave amplitudes which do not flip the spin, so the corrections can be reliably made. But it is a complication that is not present in the transmission work.

CONCLUSION

An experiment was performed at the LANSCE pulsed neutron source to measure the PNC effect in neutron capture. Although the experiment was not optimized, the capture γ-ray method has proved to be a viable and promising technique for parity violation study at LANSCE/LAMPF. It is particularly advantageous for weak resonances and in cases of enriched isotopes in small quantities and is complementary to the transmission method. This technique may prove to be a very useful tool for future time-reversal experiments.

There are many improvements that should be made before the next set of experiments are performed. The background from fast neutrons must be reduced with additional shielding. The effect of detector paralysis at short flight times could be reduced by segmenting the detector which would in addition allow multiplicity and angular distribution measurements to be performed.

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