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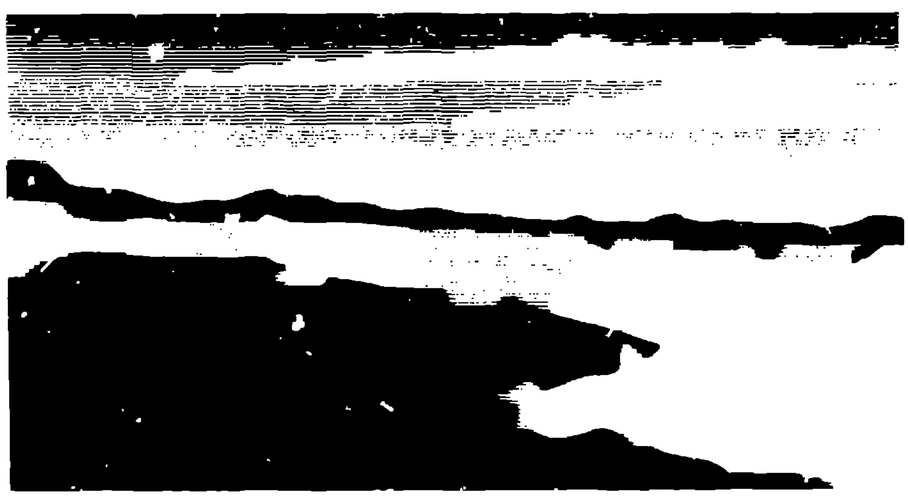

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A Neutron Beam Polarizer for Study of Parity Violation in Neutron-Nucleus Interactions

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Abstract. A dynamically-polarized proton target operating at 5 Tesla and 1 K has been built to polarize an epithermal neutron beam for studies of parity violation in compound-nuclear resonances. Nearly 0.9 proton polarization was obtained in an electron-beam irradiated ammonia target. This was used to produce a neutron beam polarization of 0.7 at epithermal energies. The combination of the polarized proton target and the LANSCE spallation neutron source produces the most intense pulsed polarized epithermal neutron beam in the world. The neutron-beam polarizer is described and methods to determine neutron beam polarization are presented.

INTRODUCTION

Development of neutron spallation sources has created a new capability to study fundamental symmetries such as parity and time-reversal violation, in compound-nuclear resonances. These experiments require a high-intensity, polarized low-energy neutron beam with a relatively short pulse length. In this paper we describe the polarized neutron-beam facility at the Los Alamos Neutron Scattering Center (LANSCE) built by the TRIPLE collaboration for parity-violation (PV) studies in neutron-nucleus interactions.

The large spin dependence of the n-p scattering cross section has been used to polarize low-energy neutron beams by transmitting neutrons through material containing polarized protons. This method was first used at the Joint Institute for Nuclear Research, Dubna, in the 1960's (1). Since, significant progress has been made in building targets for spin experiments in nuclear and high-energy physics (2). Recently, almost 100% proton polarization was reported using the dynamic nuclear polarization method at 1 K and 5 Tesla with electron beam irradiated NH_3 material (3). The energy independence of the spin-spin n-p cross section makes a cryogenic polarized proton filter a useful neutron beam polarizer in the energy interval from 0.1 eV up to 50 keV.

The TRIPLE cryogenic neutron-spin filter produces longitudinally polarized epithermal neutrons for PV experiments. The experiment and preliminary results are discussed by Yen *et al.* (4) in these Proceedings. The requirements for the neutron-spin filter include high proton polarization, resistance to radiation damage from γ-rays, small beam attenuation, and operational simplicity and reliability.

Polarized ^{3}He can be also used to polarize low-energy neutrons. Recent developments in optically polarized ^{3}He targets, especially the availability of low-cost and high-power GaAlAs diode laser arrays, have made the polarized ^{3}He cells an alternative for producing polarized low-energy neutron beams. At present, 70% polarization has been achieved with ^{3}He gas in pressures up to 10 atmospheres. Use of optically polarized ^{3}He has been discussed in a number of papers in the Conference (5). The total absorption cross section, almost the same as the capture cross section, for the n-^{3}He reaction is about 980 b at 0.7 eV. The absorption cross section results from a strong subthreshold *s*-wave resonance and falls off inversely with the neutron velocity (6). This energy dependence of the cross section limits a practical neutron-spin filter below 10 eV. In our PV experiments the energy range of interest is from 0.1 eV to 1 keV.

The polarization of a neutron beam transmitted through a longitudinally polarized proton target with polarization of f_H is given by

$$f_n = \tanh(f_H n \sigma_P t), \tag{1}$$

where n is the number density of the protons per cm^3 in the target, σ_P is the polarization cross section, and t is the thickness of the filtering material. The polarization cross section is $\sigma_P = (\sigma_{\rightleftarrows} - \sigma_{\rightrightarrows})/2$, where the arrows indicate the direction of the neutron spin with respect to the direction of the proton polarization. In the energy region of 1 eV to several keV, these cross sections are nearly constant, $\sigma_{\rightleftarrows}$ is 37.2 b and $\sigma_{\rightrightarrows}$ is 3.7 b, giving σ_P = 16.7 b (7,8). Neutrons with spin direction opposite to the polarization of the filter will be scattered. Neutrons with parallel spin direction will be attenuated by part of the triplet n-p cross section and scattering from the other background nuclei present in the material. The transmission of the beam is given by

$$T = T_o \cosh(f_H n \sigma_P t), \tag{2}$$

where

$$T_o = \exp\left(-\sum_i n_i \sigma_0 t\right). \qquad (3)$$

The sum is over all the types of nuclei present in the material. The unpolarized total cross section for the n-p reaction is σ_0 = 20.5 b and is σ_0 ~ 10 b for n-^{14}N scattering (6). Figure 1 presents the neutron beam polarization and transmission as a function of proton polarization in NH_3 for three different thicknesses of the polarizing material. The transmissions do not include contributions from liquid ^{4}He or other cryostat materials in the path of the neutron beam.

PV effects are proportional to f_n and the measurement time required to obtain a given statistical accuracy is inversely proportional to the figure-of-merit (FOM) of the filter, If_n^2, where I represents the beam intensity and f_n depends on the proton polarization. The FOM is optimized using the thickness of the polarizing material and the cross-sectional area of the filter.

THE POLARIZED PROTON FILTER

A layout of the TRIPLE apparatus for PV experiments is schematically shown in Fig. 2 and is described in detail in Ref. (9). Intense epithermal neutron pulses are produced by impinging 800-MeV proton pulses with a FWHM of 125 ns at the

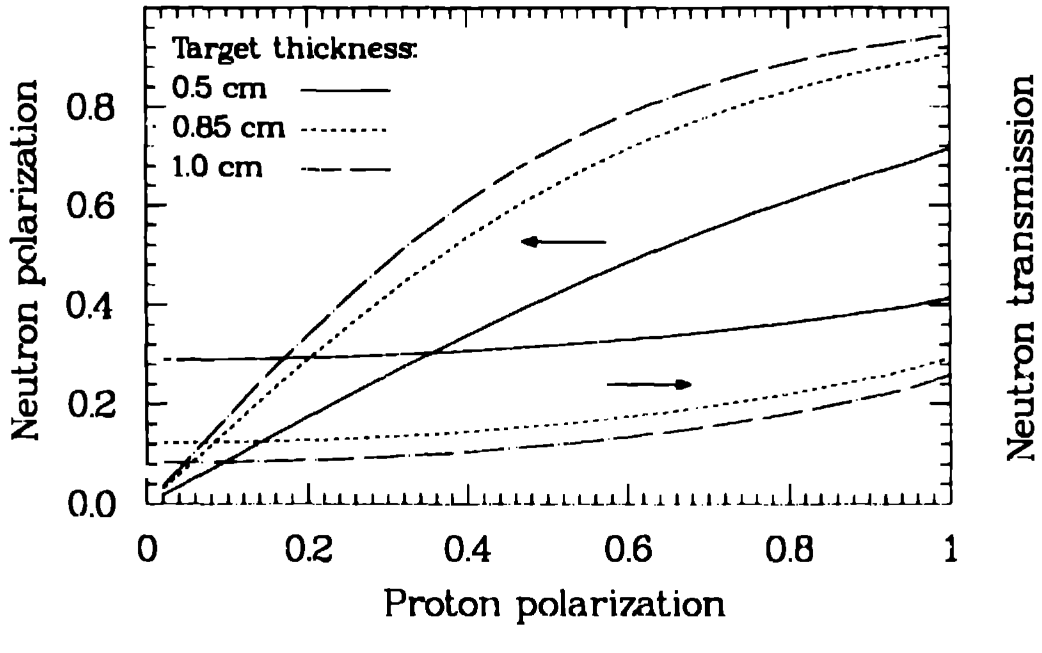

FIGURE 1. Neutron beam polarization and transmission as a function of proton polarization in NH_3 for the effective polarizing thicknesses of 0.5, 0.85, and 1.0 cm.

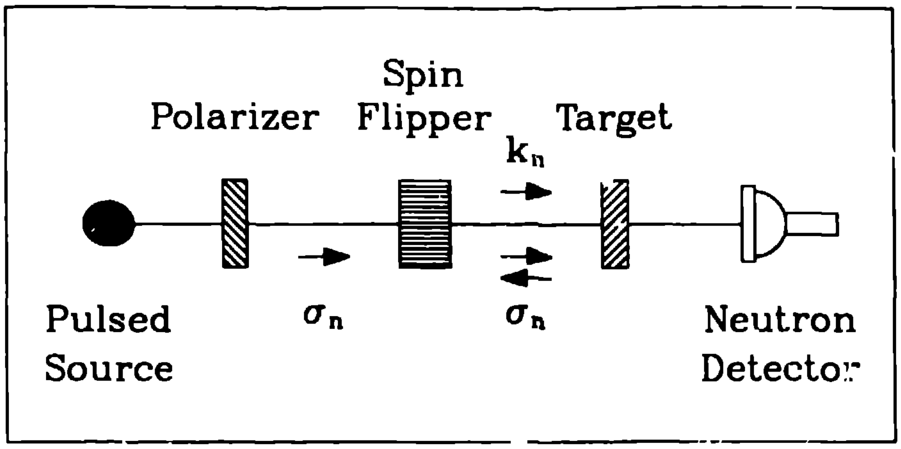

FIGURE 2. TRIPLE apparatus for PV measurements.

rate of 20 Hz on a tungsten target. A water moderator is used to decrease the neutron energy to the epithermal range. After a collimation, the beam is polarized by the spin filter and then the neutron helicity state is controlled by the spin flipper (9,10). The flipper consists of a system of longitudinal and transverse magnetic fields and is effective over a neutron energy range of $E_{max}/E_{min} \sim 1000$. The systematic errors of the experiment were reduced by changing the neutron helicity state every 10 seconds and the direction of the proton polarization every few days.

In the neutron-spin filter, which is a polarized proton target, protons are polarized dynamically by microwave pumping at 1 K and 5 Tesla. Figure 3 shows schematically the proton filter. The system consists of a 5-Tesla split-coil superconducting magnet. The field homogeneity, as measured in the LANSCE target room in the presence of iron shielding, was $1.3 \cdot 10^{-4}$ over a volume of 8 cm in diameter and 2 cm in length. The magnet was manufactured with an undistorted homogeneity of 1 part in 10^5 (11).

The polarizing material is NH_3 in the form of 1–2-mm grains. Paramagnetic polarizing centers were produced by irradiating the material with 30-MeV electrons with the dose of $2\text{–}4 \cdot 10^{16}$ e^-/cm^2 and rate of 0.5–1 $\mu A/cm^2$. The NH_3 filter is a cylindrical disk 80 mm in diameter and 13 mm in length cooled to 1 K in a pumped ^4He bath. A cooling power capacity of 2 W at 1.05 K is obtained with a pumping speed of 8200 m^3/h for ^4He gas. This cooling capacity is needed to remove heat caused by the microwave pumping, which with NH_3 was 20 mW/cm^3. We have also tested 1-Butanol material doped with EHBA (12) to a level of $3 \cdot 10^{19}$ $spins/cm^3$. With this sample, a microwave power of 45 mW/cm^3 was required.

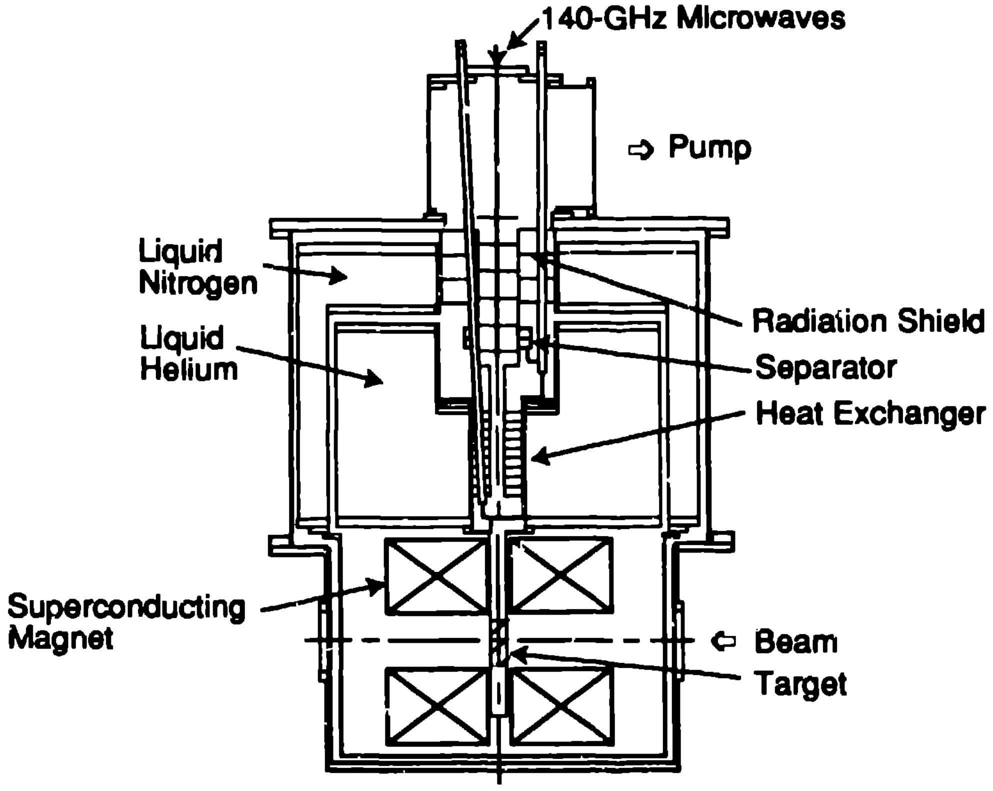

FIGURE 3. Schematic of the TRIPLE longitudinally-polarized proton filter.

PERFORMANCE OF THE POLARIZER

Proton polarization was measured with NMR using the Liverpool-type detector system (13). Typical proton polarizations with NH_3 during the experiments were +0.85 and −0.90. The neutron beam polarizations were +0.73 and −0.67, respectively. The neutron beam polarization measurement is described below. From Fig. 1, one can estimate that the effective thickness of the NH_3 was less than 0.3 cm, which was the design value. Also, the comparison of the proton polarization values measured with NMR and the beam polarization values indicate that there was a linearity problem with NMR (13). The time constant for the build-up of the proton polarization is about 30 min.

A sample composed of 1-Butanol beads was also polarized in the same cryostat. The density of polarizing centers was $6 \cdot 10^{19}$ spins/cm^3. Proton polarization of ±0.60 was achieved in a sample of 8 cm^3. In a sample of 65 cm^3, polarizations were +0.24/ −0.34. The electron spin density in this sample was $3 \cdot 10^{19}$ spins/cm^3.

POLARIZATION MEASUREMENT OF THE NEUTRON BEAM

Three different techniques were used to determine the neutron beam polarization.

(a) The proton polarization of the polarizer was measured with NMR and then the neutron polarization was calculated from Eq. (1) by using the known thickness of the filter, t. The thickness of the filter material was determined with the attenuation of 0.662-MeV gamma rays from a ^{137}Cs source. As a result, the filling factor was obtained to be 0.63. NMR is not sensitive to inhomogeneities in the polarization or in the thickness of the material, which can lead to an inhomogeneous beam polarization. However, an NMR measurement is accurate, it does not disturb the neutron beam and a NMR measurement takes less than 30 seconds. Therefore, NMR was used in the experiment as a continuous neutron-beam polarization monitor.

(b) Neutron beam polarization could be determined from the absolute value of the transmission of the neutron beam by using Eq. (2), where the factor $f_H n \sigma_p t$ was extracted and then substituted in Eq. (1) (7,14). A better way to measure the beam polarization is to determine the transmission ratio of the polarized and unpolarized filter. According to Eq. (2),

$$f_n = \sqrt{1 - \frac{T_0^2}{T_{pol}^2}}, \tag{4}$$

where T_0 (T_{pol}) is the transmission through the unpolarized (polarized) filter. With this method, one does not need to know the thickness of the material, proton polarization, or cross sections. In an hour we can obtain a beam polarization with the accuracy of 2%.

(c) The parity-violating (PV) longitudinal asymmetry P of the 0.734-eV p-wave resonance in ^{139}La has been determined to the accuracy of $P = (9.55 \pm 0.35)\%$ (14). To measure the neutron polarization produced by the spin filter at 0.734 eV, a measurement of the PV longitudinal asymmetry was performed using the method described in Ref. (14). The measured neutron asymmetry of the 0.734-eV p-wave resonance is proportional to $f_n P$, thus allowing f_n to be determined. The upper panel of Fig. 4 shows a TOF spectrum of ^{139}La around 0.7 eV. The lower panel shows the PV asymmetry of the 0.734-eV resonance after a 20-min run (32000 proton pulses). A 5% neutron polarization measurement can be achieved in two hours. A problem of this method is that the beam polarization is measured only at one energy, at the lower part of our energy region of interest. Therefore, the energy dependence of the n-p cross section has to be known, as well as the effect of the spin flipper on the beam polarization as a function of the neutron energy (9,10).

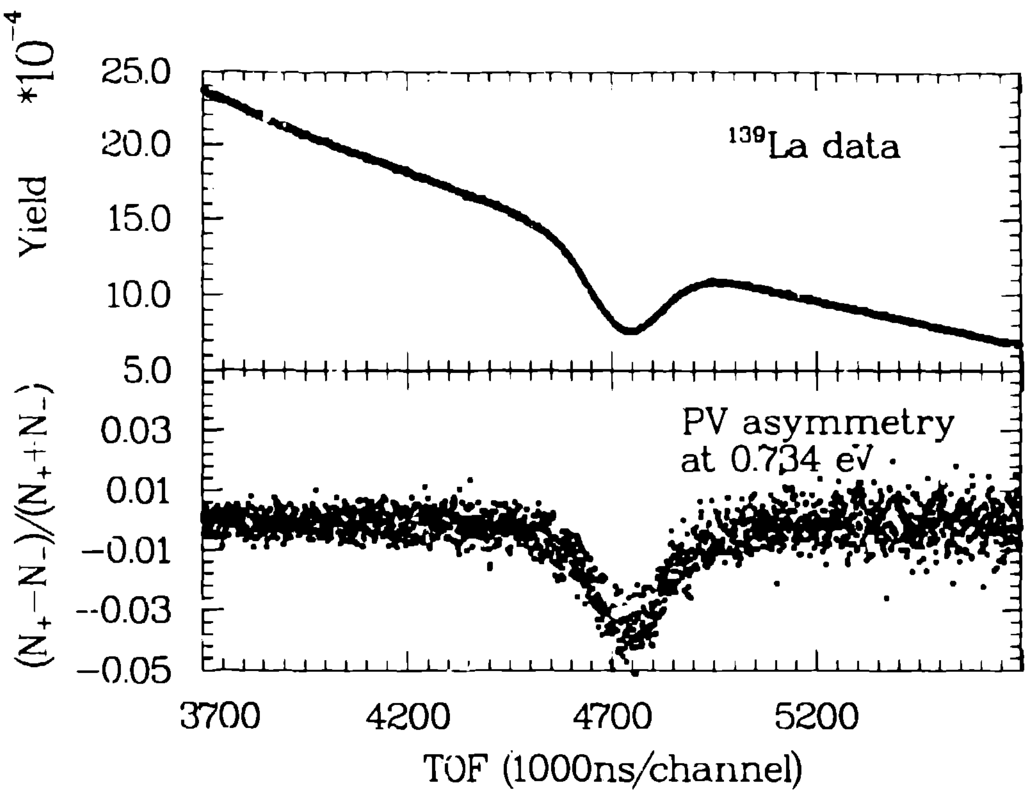

FIGURE 4. Top: The ^{139}La TOF spectrum in the vicinity of 0.7 eV. Bottom: The parity-violating asymmetry of 0.734-eV *p*-wave resonance in ^{139}La.

ACKNOWLEDGMENTS

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REFERENCES

1. Draghicescu, D., Lushchikov, V. I., Nikolenko, V. G., Taran, Yu. V., and Shapiro, F. L., *Phys. Lett.* 12, 334 (1964).
2. Jeffries, C. D., "History of the Development of Polarized Targets," in *Proceedings of the 9th International Symposium on High Energy Spin Physics*, eds. Althoff, K.-H. and Meyer, W., Springer-Verlag, 1991, Vol. 1, pp. 3–19.
3. Crabb, D. G., "Polarization Studies with Radiation Doped Ammonia at 5 T and 1 K," in *Proceedings of the 9th International Symposium on High Energy Spin Physics*, eds. Althoff, K.-H. and Meyer, W., Springer-Verlag, 1991, Vol. 2, pp. 289–300.
4. Yen, Yi-Fen *et al.*, "Study of Parity and Time-Reversal Violation in Neutron-Nucleus Interactions," in these Proceedings.

5. Cummings, W. *et al.*, "Application of High-Power GaAlAs Diode Laser Arrays for Optically Pumped Spin Exchanged Polarized ^{3}He Targets," in these Proceedings; Coulter, K. P. *et al.*, "Advances in Alkali Spin-Exchange Pumped ^{3}He Targets," in these Proceedings; Thompson, A. K. *et al.*, "A Polarized ^{3}He Based Neutron Spin Filter at NIST," in these Proceedings.
6. ENDF/B-IV Data File for ^{1}H, ^{3}He, and ^{14}N (National Nuclear Data Center, Brookhaven National Laboratory, Upton, New York, April 1989), evaluated by Hale, G. and Young, P.
7. Lushchikov, V. I., Taran, Yu. V., and Shapiro, F. L., *Yad. Fiz.* **10**, 1178 (1969).
8. Hoshizaki, N. and Masaike, A., *Japanese J. Appl. Phys.* **25**, L244 (1986).
9. Roberson, N. R. *et al.*, *Nucl. Instrum. Methods A* **326**, 549 (1993).
10. Bowman, J. D. *et al.*, "A Spin-Reversal System for Epithermal Neutrons," to be published in *Nucl. Instrum. Methods*.
11. Magnet and refrigerator were fabricated by Oxford Instruments Ltd., England.
12. Krumpolc, M. and Rôcek, J., *J. Am. Chem. Soc.* **101**, 3206 (1979).
13. Court, G., "Review of Non-linear Corrections in CW Q-meter Target Polarization Measurements," in these Proceedings.
14. Yuan, V. W. *et al.*, *Phys. Rev. C* **44**, 2187 (1991).