Limit on Parity Nonconservation in p-Nucleus Scattering at 6 GeV/c*

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We measure a limit on a parity-nonconserving asymmetry in the p-Be cross section at 6 GeV/c. The result is $(\sigma_+ - \sigma_-)/(\sigma_+ + \sigma_-) = (5 \pm 9) \times 10^{-6}$ where σ_+ (σ_-) is approximately the p-Be total cross section for positive (negative) beam helicity. Systematic errors are determined to be $< 5 \times 10^{-6}$.

A parity-nonconserving component in the force between nucleons is predicted in the current-current formulation of the weak interaction to be first order in the weak-coupling constant.[1] Small parity impurities in nuclear levels have been observed,[2] implying that the nuclear Hamiltonian connects states of unlike parity. The magnitude of these admixtures indicates that the weak force does enter in first order but quantitative comparison between theories of the nucleon-nucleon interaction and the sizes of the observed admixtures have been unsuccessful.[2] It is not clear whether the discrepancies are due to the treatment of nuclear-structure effects or the form assumed for the interaction.

The weak force between nucleons is of fundamental importance and in the absence of a complete theory, information about the energy dependence of parity-nonconserving effects is essential. Recently we obtained a result of $(1 \pm 4) \times 10^{-7}$ for the parity-nonconserving component in p-p scattering at 15 MeV.[3] Here we report on a transmission experiment to search for parity nonconservation in p-nucleus scattering at relativistic energies. The unique 6-GeV/c polarized-proton beam at the Argonne National Laboratory zero-gradient synchrotron was used to measure the dependence of the p-Be total-scattering cross section on the pseudoscalar quantity $\vec{s} \cdot \vec{p}$, where $\vec{s}$ is the spin of the incident proton and $\vec{p}$ is its momentum. If parity is conserved in the interaction between nucleons, the cross section is independent of $\vec{s} \cdot \vec{p}$. Effects are expected to be of the order 10^{-5}–10^{-7} and might increase with energy because of the short range of the weak force.[4] At such high energies nuclear structure will play a minor role in the interpretation of the results.

We measure the quantity $(\sigma_+ - \sigma_-)/(\sigma_+ + \sigma_-)$, where σ_+ (σ_-) is the cross section for p-Be scattering outside a small solid angle Ω (see below) with the proton spin aligned parallel (antiparallel) to its momentum. To detect small parity-nonconserving effects and to use high beam intensities effectively, integral counting techniques were used with two independent detector systems, one consisting of ionization chambers and the other photomultipliers coupled to scintillators. The target was 20 cm of Be metal, yielding an observed transmission (Z) of 0.573 ± 0.003 for the scintillator system and 0.586 ± 0.005 for the ion chambers. The polarized-proton beam intensity was approximately 5×10^7 protons per pulse with 2.6 sec between pulses. The beam polarization was vertical and was reversed at the ion source on alternate pulses to minimize the effects of electronic drifts. A polarimeter monitored the beam polarization; the average polarization was measured to be $|\vec{P}| = 0.67 \pm 0.04$. The polarization direction was aligned parallel or antiparallel to the proton momentum by bending the beam down 7.75°.

The scintillation detectors consisted of four arrays called P, I, T, and Y (Fig. 1). The P and Y detectors each had two pairs of split scintillators to measure up-down and left-right asymmetries. The P detector monitored beam motion and the Y detector monitored residual transverse

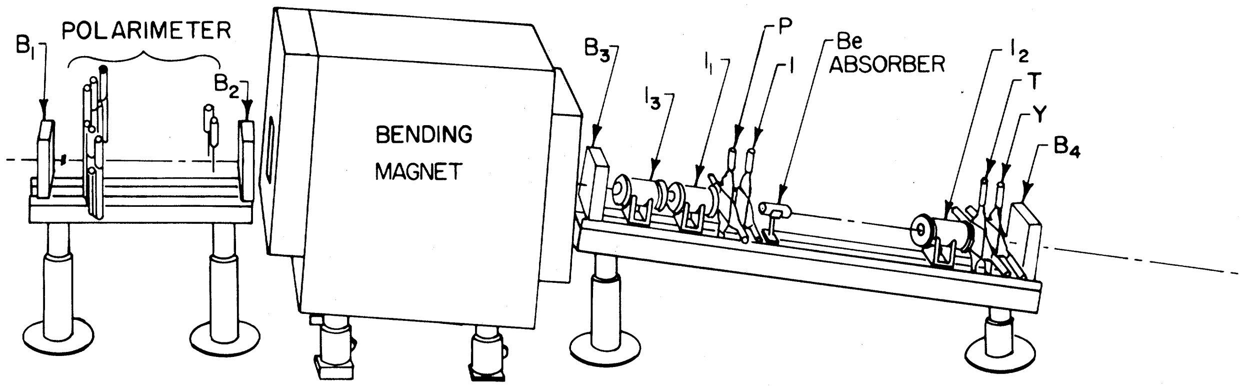

FIG. 1. Apparatus for parity-nonconservation measurement. The beam position monitors are B_1–B_4; the scintillation detectors are P, I, T, and Y; and the ion chambers are I_1–I_3.

polarization arising from imperfect alignment of the polarization vector with the momentum vector. The incident and transmitted beam intensities were measured by the I and T detectors, respectively. Each consisted of a square scintillator symmetrically viewed by four photomultipliers. The I detector intercepted all of the incident beam. The T detector, which defined the solid angle Ω, was a 76-mm square located 1.5 m downstream from the center of the Be target. This geometry was chosen to exclude most particles that suffered nuclear collisions but accept particles that underwent only multiple Coulomb collisions and to minimize the sensitivity to residual transverse polarization.

Each photomultiplier output current was converted to a voltage signal by an operational amplifier. The signals were integrated over a selected portion of the beam spill using voltage-to-frequency converters and scalers. The beam intensity fluctuated from pulse to pulse requiring very linear detectors and electronics to measure Z. The relative nonlinearity of the T and I detector systems was 0.5×10^{-4}. At the end of each spill the scaler data were accumulated by an on-line computer and written on magnetic tape for later detailed analysis. The period between spills was used for measurement of offset voltages and for gain calibration of the I and T detectors using pulsed light sources.

The difference between the incident and transmitted beam intensities was also measured using a balanced pair of ionization chambers (I_1 and I_2)[5] (Fig. 1). The pressure of the gas in the chambers was adjusted to balance one integrated current against the other. The difference charge was accumulated on a capacitor and measured after each pulse by a low-noise operational amplifier and a voltage-to-frequency converter. Such a null measuring system is relatively insensitive to amplifier drifts. A third chamber (I_3) monitored the beam intensity.

The chamber electrodes were constructed of 25-μm Al foils normal to the beam direction with 100-mm-diam sensitive area defined by guard rings. There were 41 electrodes spaced 5 mm apart. The gas was 90% methane at a pressure between 2 and 4 atm. A typical beam pulse produced a signal (V) of about 2 V from each chamber. The difference voltage (ΔV) had an rms deviation of about 2 mV, well above the noise level of the electronics. The ratio of ΔV to V was recorded for each beam pulse. The fractional change in transmission for a pair of pulses is given by $\Delta Z/Z = [(\Delta V/V)_+ - (\Delta V/V)_-]$, where $+(-)$ refers to positive (negative) beam helicity. Averaging the results of 127 runs of 50 pulses each we obtained $\Delta Z/Z = (9.9 \pm 18.7)\times 10^{-6}$.

The data from the scintillation detectors were obtained in four runs each approximately 3 h long. The effect on $Z = T/I$ of beam motion was determined by studying the correlations between fluctuations in Z and the up-down (V_P) and left-right (H_P) signals from the P detector. An improved estimator of transmission of the form $Z = T/I + \alpha V_P + \beta H_P$ was then constructed to be insensitive to beam motion. The effect of α and β was to reduce the fluctuations in Z by 10% and to reduce the sensitivities to V_P and H_P of Z by several orders of magnitude. It was not necessary to correct for fluctuations in beam intensity. The fractional change in Z with polarization reversal is then $\Delta Z/Z = (Z_+ - Z_-)/\frac{1}{2}(Z_+ + Z_-)$. The average value of $\Delta Z/Z$ for the scintillator system was

TABLE I. Summary of results and limits on systematic errors from scintillator data.

Variable	H_P	V_P	$\Delta I/I$	$\vec{P}_H$	$\vec{P}_V$
Change with polarization reversal	$2\pm 2\ \mu\mathrm{m}$	$0\pm 2\ \mu\mathrm{m}$	$(2\pm 1)\times 10^{-2}$	$<4\times 10^{-2}$	$<1\times 10^{-2}$
Sensitivity of $\Delta Z/Z$ to change in variable	$<10^{-7}\ \mu\mathrm{m}^{-1}$	$<10^{-7}\ \mu\mathrm{m}^{-1}$	10^{-4}	$<10^{-4}$	$<4\times 10^{-4}$
Limit on systematic error in the fractional change in cross section	3×10^{-7}	3×10^{-7}	3×10^{-6}	$<5\times 10^{-6}$	$<5\times 10^{-6}$

found to be $(-3.6\pm 6.8)\times 10^{-6}$.

Five possible sources of systematic error have been examined in detail. The results are given in Table I and are discussed below. In each case the limit on systematic error is the product of the limit on the change in a variable correlated with polarization reversal and the sensitivity of $\Delta Z/Z$ to that variable.

Changes in beam position (H_P, V_P) and intensity (I) correlated with polarization reversal were consistent with zero. The residual transverse polarization of the beam, $\vec{P}_H$ and $\vec{P}_V$ in the horizontal and vertical directions, respectively, was determined from the Y detector. By correcting for beam motion as observed with the P detector, the fluctuations in $\vec{P}_H$ and $\vec{P}_V$ were reduced by an order of magnitude.

The sensitivities of Z to H_P, V_P, and I were determined from the fluctuation in Z correlated with each of these three variables. The regression analysis which determined α and β essentially eliminated the sensitivity of $\Delta Z/Z$ to H_P and V_P. The sensitivity of $\Delta Z/Z$ to transverse polarization was studied with the bending magnet turned off and the detectors raised. The sensitivity to $\vec{P}_V$ was measured as a function of the centering of the beam on the T detector with the polarization vector fully vertical. The sensitivities to $\vec{P}_V$ and $\vec{P}_H$ during the data runs were estimated from beam-alignment data.

The fractional change in cross section with polarization direction is related to $\Delta Z/Z$ by

$$\frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-} = \frac{1}{2|\vec{P}|\ln Z}\left(\frac{\Delta Z}{Z}\right).$$

Taking values of $|\vec{P}|$ and Z given above, the fractional change in cross section is $(-1.4\pm 2.6)\times 10^{-5}$ from the ion chambers and $(5\pm 9)\times 10^{-6}$ from the scintillator system. The errors are the standard deviations and the upper limit on systematic error for the scintillator system is 5×10^{-6}. The errors quoted are about 3 times that expected from proton statistics alone. We hope to identify and eliminate the additional sources of noise in the near future. Our present result is consistent with current theories of parity nonconservation in the strong interaction.[4]

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