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6.9 Search for Charge Symmetry Breaking in n-p Scattering

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An ongoing experiment[1] at IUCF is aimed at measuring polarization observables sensitive to charge symmetry breaking (CSB) in n-p scattering at E_n = 189 MeV. We will measure left-right asymmetries in the scattering of polarized neutrons from polarized protons to a statistical precision of $\sim\pm5\times10^{-4}$ in each of six angle bins spanning the range $60° \leq \theta_{cm}(n) \leq 120°$. From these results we can extract information on the CSB difference[1-4] $[\Delta A(\theta) \equiv A_n(\theta)-A_p(\theta)]$ between the analyzing powers one would measure with polarized n beam on an unpolarized p target $[A_n(\theta)]$ and with unpolarized beam on polarized target $[A_p(\theta)]$. Without accurate knowledge of either polarization we can determine the absolute value $\Delta A(\theta_0)$ at the angle where $A(\theta) \equiv [A_n(\theta)+A_p(\theta)]/2$ crosses zero ($\theta_0^{cm} \simeq 90°$ at our energy) and the angular dependence of $\Delta A(\theta)/A(\theta)$ at other angles. The experiment will be sensitive to $|\Delta A| \sim .001$, at which level CSB effects are expected theoretically from quark mass differences[5] and indirect electromagnetic contributions (simultaneous exchange of hadrons and photons) to the nuclear force.[3,4]

The polarized neutron facility, detectors, electronics, front-end microprocessor, and acquisition software for the experiment are complete and have been used in a number of test runs. The $\vec{n}$ beam, produced via the $^2H(\vec{p},\vec{n})$ reaction at θ_{lab}=10° with 50 nA of polarized protons incident on a 20-cm long liquid deuterium (LD_2) target, has a typical polarization P_b = 0.6 and an intensity $\sim 1.6\times10^6$ n/sec on a 5 × 7 cm secondary target. Scattered neutrons and recoil protons are detected in coincidence by left-right symmetric detector arms, each spanning the range $25° \leq \theta_{lab} \leq 61°$ and sensitive to both n and p. Each arm comprises a wedge-shaped plastic scintillator, two planes of x-y multiwire proportional chambers, and a position-sensitive liquid scintillator detector subdivided into 96 optically isolated cells. The system is used without modification for various calibration, diagnostic, and null measurements of p-p and p-d scattering, with a secondary proton beam also obtained from the LD_2 production target.

The polarized proton target (PPT) is of a "spin refrigerator" design,[6] exploiting the strongly anisotropic g-factor of Yb ions doped into yttrium ethyl sulfate (YES). Advantages of this design are modest requirements in cryogenics (temperature ~ 0.6K), polarizing field strength (~1.1 T) and uniformity, the latter allowing an open coil geometry useful for broad-angle measurements. The desired target polarization $P_t \approx 0.6$ has been achieved to date only with small YES crystals; production runs await modifications currently in progress to improve P_t for the large-area crystals needed in the experiment. Typical spin relaxation times are $\gtrsim$ 50 hours in a 0.1 T holding field. Target polarization can be flipped both with and without accompanying reversal of the holding field, allowing cancellation of certain instrumental asymmetries.

The detection system permits measurement of the opening angle (θ_{open}) and coplanarity (ϕ_{open}) of n-p pairs with FWHM resolutions ~3.0° and 5.0°, respectively. Adequate discrimination of free n-p scattering from quasifree scattering events is obtained via software cuts on θ_{open}, ϕ_{open}, the event origin, n and p timing, and p energy loss information, supplemented by subtraction of quasifree background measured with a hydrogen-free "dummy" target. The success of the discrimination is shown in fig. 1, where background accounts for $\lesssim$ 0.1% of the free-scattering θ_{open} peak area.

Spin-dependent observables of interest are extracted from angle-dependent yields, surviving all free-scattering cuts and the dummy-target subtraction, for eight "spin states" corresponding to the different combinations of proton detector arm (L or R) and $\vec{n}$ beam and $\vec{p}$ target spin projections. In particular, we can extract (in a few ways, with differing sensitivities to certain systematic errors) the variable

$$X(\theta) \equiv \frac{P_bA_n(\theta) - P_tA_p(\theta)}{P_bA_n(\theta) + P_tA_p(\theta)} \simeq \frac{1}{2}\left[\frac{\Delta P}{P} + \frac{\Delta A(\theta)}{A(\theta)}\right],$$

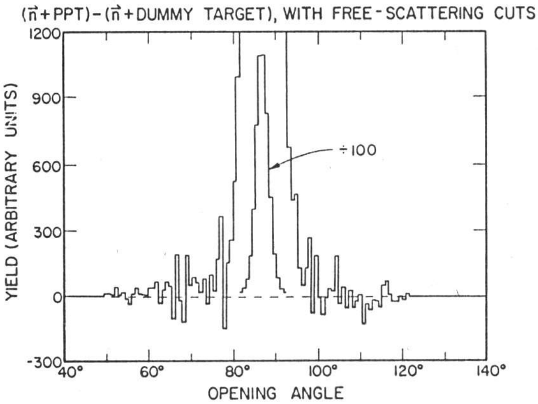

Fig. 1. Typical θ_{open} spectrum, for n-p events over all angles and spin states, after application of all free-scattering cuts and subtraction of quasifree background measured with a dummy target.

where $\Delta P = P_b - P_t$ and $P = (P_b + P_t)/2$. For example, X may be related to the measured yields (L_{++}, etc., with the first subscript indicating beam spin) and integrated relative neutron fluxes (I_{++}, etc.) by

$$X = \left[\frac{I_{++}I_{--}}{I_{+-}I_{-+}}\right]^{1/2}\left[\frac{L_{+-}L_{-+}R_{+-}R_{-+}}{L_{++}L_{--}R_{++}R_{--}}\right]^{1/4} \times$$

$$\left[\frac{\sqrt{L_{+-}/R_{+-}} - \sqrt{R_{+-}/L_{+-}} + \sqrt{R_{-+}/L_{-+}} - \sqrt{L_{-+}/R_{-+}}}{\sqrt{L_{++}/R_{++}} - \sqrt{R_{++}/L_{++}} + \sqrt{R_{--}/L_{--}} - \sqrt{L_{--}/R_{--}}}\right].$$

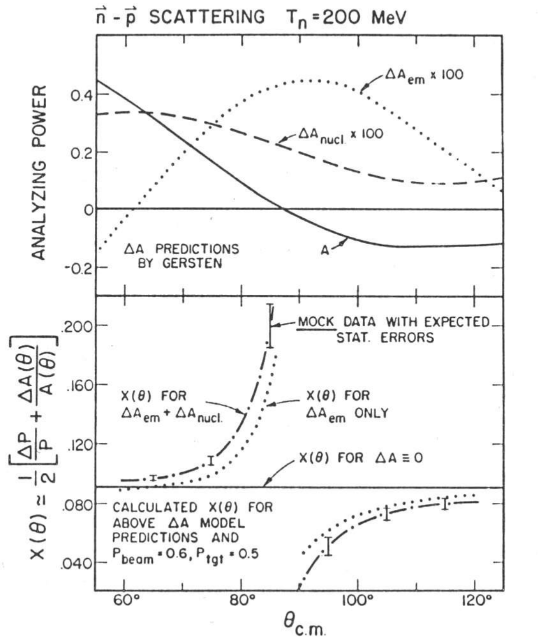

Fig. 2. Theoretical calculations of $A(\theta)$, $\Delta A(\theta)$, and the CSB variable $X(\theta)$ over the angle range covered in the experiment. The isospin-mixing parameters[4] include several strong-interaction contributions which partially cancel to give ΔA_{nucl} shown.

The angular dependence of $X(\theta)$, which provides a signature of CSB, does not rely on accurate knowledge of P_b, P_t, or I_{++}, etc. Figure 2 shows calculations of $\Delta A(\theta)$ and $X(\theta)$ arising from both electromagnetic (spin-orbit) and strong interaction sources, according to first-order Born approximation predictions of Gersten.[4] Also indicated in fig. 2 are projected statistical uncertainties for $X(\theta)$ that should be provided by the IUCF experiment (corresponding to a total of 4×10^7 detected free n-p scattering events summed over all angles and spin states).

The most troublesome sources of systematic error in the experiment are instrumental L-R asymmetries directly simulating the CSB effect, in that they change sign with a flip of one, but not the other, of the beam and target spins. We will measure sensitivity to such effects in a set of auxiliary experiments, using various combinations of polarized and unpolarized secondary n and p beams, polarized and unpolarized YES target, and different holding fields. For example, we will use $\vec{p}$-$\vec{p}$ scattering of a secondary $\vec{p}$ beam with large sideways polarization to measure to high precision and cancel (by adjusting correction coils) horizontal components in the PPT polarization. Otherwise, these horizontal components could combine with horizontal components in $\vec{P}_b$ (which arise from the polarization in the $^2H(p,\vec{n})$ production reaction and do not reverse direction when the primary proton beam spin is flipped) to produce a spurious CSB effect via the spin correlation parameters C_{SL} and C_{LS} for $\vec{n}$-$\vec{p}$ scattering.

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