SEARCH FOR CHARGE SYMMETRY VIOLATION IN n-p SCATTERING

S.E. Vigdor, L.D. Knutson,* A.D. Bacher, W.W. Jacobs, J.T. Meek, H.-O. Meyer, P.A. Quin,* and P. Schwandt

The concept of charge symmetry of nuclear forces (i.e., invariance under reflection through the 1-2 plane in isospin space) has implications beyond the usually specified requirement of equal n-n and p-p nuclear potentials. Specifically, it also prohibits isospin-mixing in the n-p system. Henley and Miller[1)] correspondingly distinguish two classes of possible charge-symmetry breaking (CSB) forces, namely, those which affect only the n-n and p-p systems (Class III, with isospin parts symmetric under interchange of the two nucleons), and those which affect only n-p (Class IV, with anti-symmetric isospin and spin dependence). Although there is presently no direct evidence of CSB in nuclear forces, small CSB terms of both classes are expected from various meson-exchange contributions to the nucleon-nucleon potential,[1-3)] and may be partly responsible for the well-established anomalies in Coulomb energy differences between pairs of mirror nuclei.

We are planning to carry out a sensitive experimental test of charge symmetry in intermediate-energy ($E_{lab} \approx 200$ MeV) n-p scattering. The great advantage over a comparison of n-n and p-p results is the absence of a Coulomb interaction whose overwhelming contribution to apparent CSB effects must be very carefully subtracted. The electromagnetic spin-orbit coupling of the two nucleons is still present in the n-p system, but does not present a fundamental problem, since its contribution to CSB effects is precisely calculable[2)] and turns out to be comparable in magnitude to the expected meson-exchange effects for $E_n \sim 200$ MeV. The implications of charge symmetry (plus rotational invariance) for polarization observables in n-p scattering are indicated schematically in fig. 1:

(i) for unpolarized beam and unpolarized target, the polarization of neutrons scattered at c.m. angle $\theta$ must be equal to that of the protons recoiling at the supplementary angle,

$$P_n(\theta) = P_p(\pi-\theta);$$

(ii) for polarized beam on unpolarized target and unpolarized beam on polarized target, there is (by arguments analogous to fig. 1a) a similar equality for the analyzing powers,

$$A_n(\theta) = A_p(\pi-\theta);$$

(iii) for beam and target both 100% polarized normal to the scattering plane, the left-right asymmetry ($\varepsilon$) of the scattering at any angle must

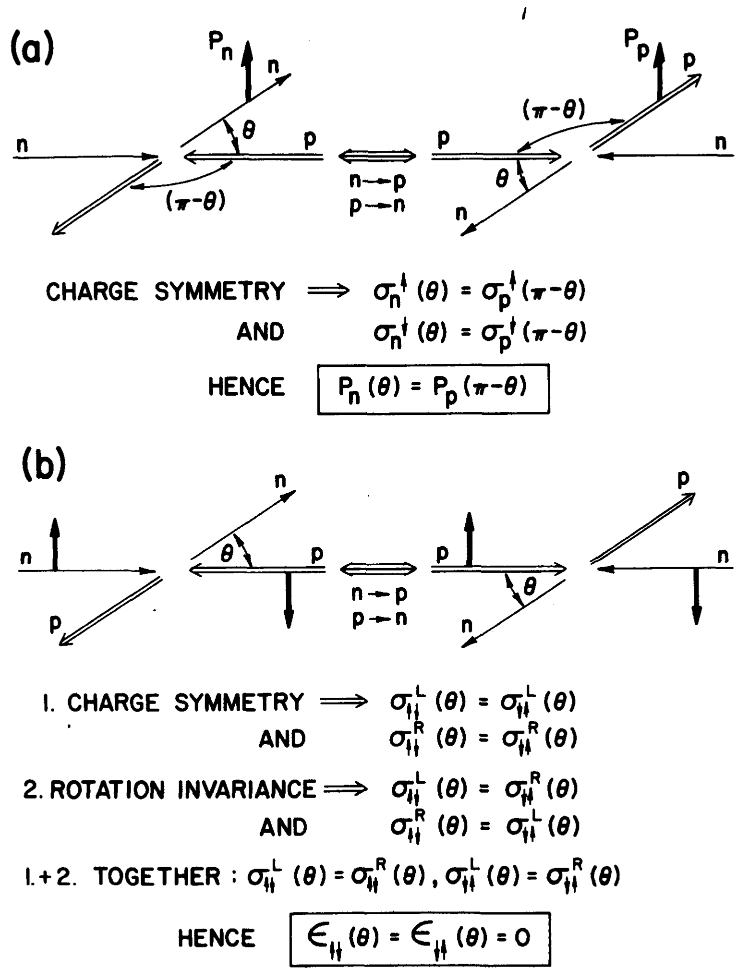


*Figure 1. Schematic illustration of the implications of charge symmetry (plus rotational invariance) for polarization observables in n-p scattering.*

vanish if the beam and target spins are oppositely directed,

$$\varepsilon_{\uparrow\downarrow}(\theta) = \varepsilon_{\downarrow\uparrow}(\theta) = 0.$$

An observed deviation from any of the above equalities, over and above the expected effect from the electromagnetic spin-orbit coupling, would constitute a clean signature of a Class IV CSB nuclear force. The three requirements above are closely related theoretically {e.g., $\varepsilon_{\uparrow\downarrow}(\theta) = \Delta A(\theta)/(1-C_{nn}(\theta))$, where $\Delta A(\theta) \equiv A_n(\theta) - A_p(\pi-\theta)$ and $C_{nn}(\theta)$ is a spin-correlation parameter}; but experimentally the proposed test of condition (iii) appears to allow the most effective minimization of systematic measurement errors. In the actual experiment, of course, the beam and target polarizations ($P_b$ and $P_t$) will be substantially smaller than 100%. Simultaneous measurements over a broad range of scattering angles, centered about the zero-crossing angle ($\theta_o$) of the average analyzing power $A(\theta) \equiv 1/2\{(A_n(\theta) + A_p(\pi-\theta)\}$, will allow high sensitivity to CSB without requiring accurate knowledge of $P_b$ and $P_t$.

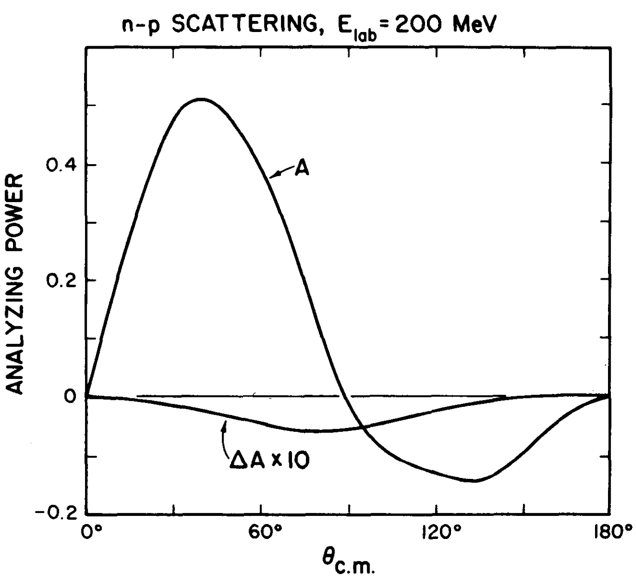


*Figure 2. Phase-shift calculations of the average $A(\theta)$ and of the difference $A(\theta)$ of neutron and proton analyzing powers for n-p scattering at $E_{lab}$ = 200 MeV. P-wave and d-wave isospin-mixing parameters are taken from ref. 3.*

In fig. 2 we show a phase-shift prediction of $A(\theta)$ and $\Delta A(\theta)$ for n-p scattering at $E_{lab}$ = 200 MeV. The singlet-triplet (isospin-) mixing parameters used for p- and d-waves in this calculation were taken from a prediction by Gersten[3)] of the effect of the n-p mass difference on single-pion exchange. The details of the CSB mechanism in Gersten's work are not clear, but the shape of the predicted $\Delta A(\theta)$ angular distribution in the vicinity of $\theta_0$($\simeq 90^o$ at this energy) is essentially model-independent. This shape is determined by the known (charge-symmetry conserving) n-p scattering amplitudes and by the p-wave dominance of the CSB amplitude at $E_n \sim 200$ MeV. The sign and magnitude of $\Delta A$, on the other hand, are model-dependent. The calculation in fig. 2 shows $\Delta A(\theta_0) \simeq -0.005$. Calculations based on other meson-exchange effects[2)] give maximum values of $|\Delta A| \simeq 0.001 - 0.002$. A number of diagrams known to contribute to CSB have not yet been quantitatively evaluated. The proposed experiment would be sensitive to values of $|\Delta A| \gtrsim 0.001$.

Although the maximum magnitude of $\Delta A$ is likely to increase with increasing bombarding energy above $E_n$ = 200 MeV, calculations suggest that the angular distribution of $\Delta A(\theta \simeq \theta_0)$ will become less favorable for measurements, and also more sensitive to d-wave contributions, which may be appreciable for some CSB forces but not for others. In addition, the occurrence of $\theta_0$ so close to $90^o$ at $E_n$ = 200 MeV allows a null experiment on $\vec{p} - \vec{p}$ scattering to be performed under the same conditions and using the same apparatus as will be used in the $\vec{n} - \vec{p}$ measurement. We thus expect the significance of a measurement to the proposed precision to be optimized at $E_n \simeq 200$ MeV.

At present, we have initiated purchases of materials needed for some of the major equipment items (the tentative experiment layout is shown in fig. 3). The polarized proton target, to be constructed by the University

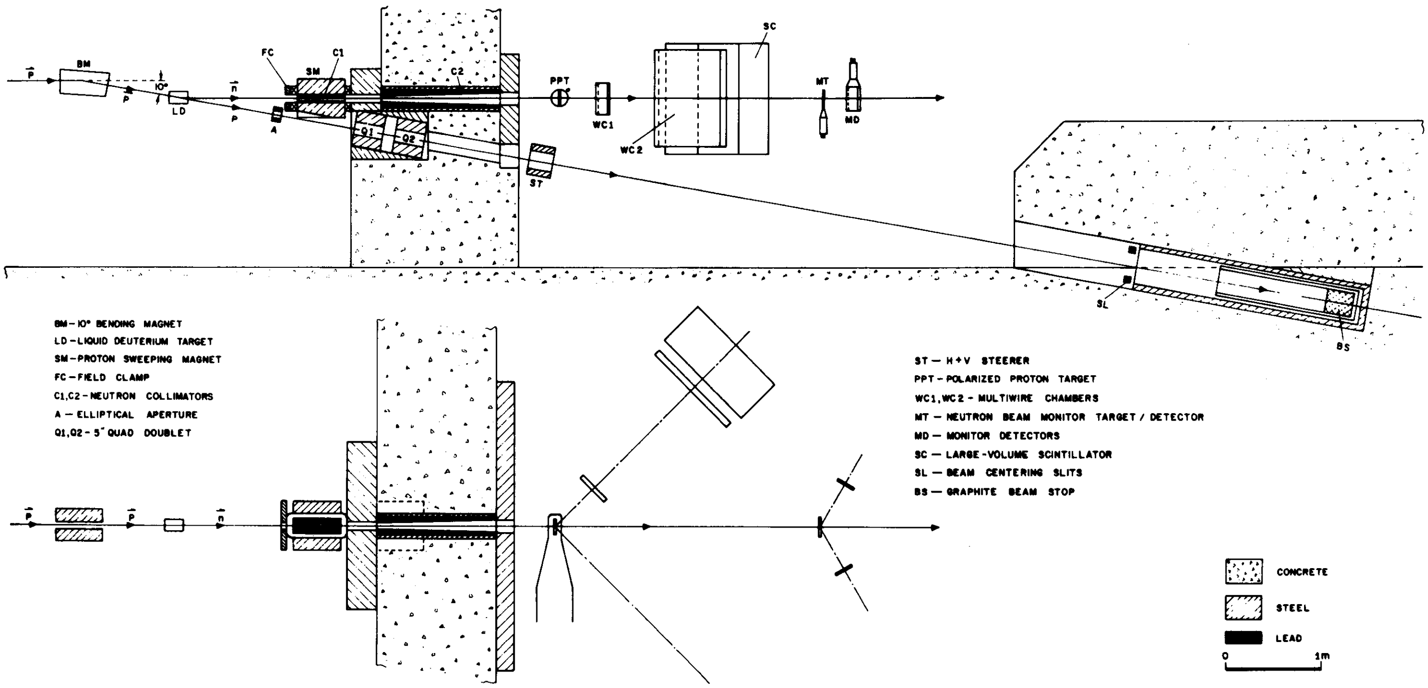


*Figure 3. Proposed layout of the polarized neutron beam line and apparatus for the charge symmetry test. A detection array identical to that shown will be placed symmetrically to the beam right.*

of Wisconsin contingent, will follow the "spin refrigerator" design reported in ref. 4. The neutrons and protons will be detected in coincidence in symmetrically placed large-area detector arrays, providing information on both opening angle and coplanarity in order to discriminate against events from quasi-free scattering off the heavier nuclei present in the target. It is expected that the actual measurements will be initiated sometime in 1981. Preliminary runs, prior to the availability of the polarized neutron beam or polarized target, will be used to test detectors and electronics, and to determine the level to which we can discriminate against the quasi-free scattering background. The initial run with the polarized beam and target will provide the first measurements of $\vec{n}$-$\vec{p}$ spin-correlation parameters in this energy region.

*University of Wisconsin, Madison, WI 53706.

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3) A. Gersten, Phys. Rev. C18, 2252 (1978).

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