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PARITY VIOLATING NEUTRON SPIN ROTATION

I. Introduction. Neutron spin rotation expected from quark-quark weak interactions in the standard Model, which induce weak interactions between nucleons that violate parity. Because the range for W and Z exchange between quarks is small compared to the nucleon size, NN weak interaction amplitudes are one of the few observables which are first-order sensitive to quark-quark correlations in the nucleon. NN weak interactions also induce parity-odd effects in atomic structure, where they are the microscopic source for nuclear anapole moments [1-3].

Parity-odd spin rotation has been measured in heavy nuclei [4-7], but the dynamics are too complicated to use this information to learn about the NN weak interaction amplitudes. To do this one must measure parity-odd neutron spin rotation and other parity-odd observables in light nuclei such as H, D, ^{3}He and ^{4}He. Because strong interaction effects are now calculable in few body nuclei and weak amplitudes can be added as a perturbation, several ne calculations of parity odd effects in these systems have appeared recently [8] to complement earlier works [9]. The effected size of the parity-odd rotation angle in such few body systems is about $10^{-6}\ rad\backslash m$ to $10^{-7}\ rad\backslash m$ [9].

Of the five independent weak transition amplitudes present in NN elastic scattering at law energy, only the $^1S_0 - ^3P_0$ proton-proton amplitude is fixed from experiment [10]; the result are unknown. The existing calculation of *dφ/dz* in n-^{4}He ($d\varphi/dz = -0{,}97 f_\pi - 0{,}22 h^0_\omega + 0{,}22 h^1_\omega - 0{,}32 h^0_p + 0{,}11 h^1_p$) [27] was conducted within the meson exchange picture developed by Desplanques, Donoghue and Holstein (DDH) which uses π and ρ and ω exchange parametrized by weak couplings at the NN vertex labeled by superscripts which indicate the isospin change. Within the DDH approach *dφ/dz* in n-^{4}He spans a range of $\pm 1.5 \cdot 10^{-6}\ rad\backslash m$: this broad range of possibilities is dominated by the uncertainties in the weak couplings and reflects in part our poor understanding of quark-quark correlation physics in QCD. *dφ/dz* in n-^{4}He has been related to existing measurements of nuclear parity violation in a model which subsumes many poorly-understood short range NN effects by expressing parity odd amplitudes in terms of isoscalar $(X_n + X_p)$ and isovector $(X_n - X_p)$ one-body potentials. n-^{4}He spin rotation is interesting within the context of this model since it determines X_n. Within this model measurements in odd-proton systems such as p-^{4}He and ^{19}F constrain X_p. The prediction in this model for n-^{4}He spin rotation is $d\varphi/dz = (-6{,}5 +/-2{,}2) \bullet 10^{-7} rad\backslash m$.

II. Neutron spin rotation and experimental technique. The phenomenon of neutron spin rotation can be un derstood in terms of neutron optics. The parity-violating (PV) weak interaction between the neutrons and the medium causes the amplitudes of the positive and negative neutron helicity states of polarized neutrons to accumulate different phases. The difference φPV between the phase shifts of the helicity states leads to a rotation of the neutron polarization vector about its momentum, which manifestly violates parity [32]. The rotation angle per unit length of a neutron of wave vector k in a medium of density ρ is $d\varphi/dz = 4\pi\rho_{PV}/k$, where f_{PV} is the forward limit of the parity-odd pwave scattering amplitude. Because f_{PV} is proportional to the parity-odd correlation $\vec{\sigma}_n \cdot \vec{k}_n$ with $\vec{\sigma}_n$ the neutron spin vector and ~ kn the neutron momentum, $d\varphi/dz$ is constant as $k \to 0$ in the absence of resonances [33].

The experimental technique has been presented in detail [34, 35]. The apparatus shown in Fig. 1 must distinguish small PV rotations from rotations that arise from magnetic fields. φ_{PV} is isolated by alternately moving the medium in front of and behind a neutron spin precession coil and measuring the change in the spin rotation angle using the neutron equivalent of a crossed polarizer/analyzer pair familiar from light optics. Neutrons polarized along $\hat{y}$ enter a central precession coil with an internal magnetic field along $\hat{y}(\pi - coil)$ which precesses a spin component along $+\hat{x}$ to $-\hat{x}$. The contribution to the total rotation angle coming from parity violation in the liquid changes sign as the liquid is moved. To further suppress systematic uncertainties and noise, the beam and apparatus are split into right and left halves, and the targets are filled so that the liquid occupies the chamber downstream of the π–coil on one side and the chamber upstream of the π–coil on the other side. The PV components of the neutron spin rotation angle have opposite signs on each side, and the difference of the two rotation angles is insensitive to both static residual magnetic fields and any common-mode time-dependent magnetic field integrals along the neutron trajectories.

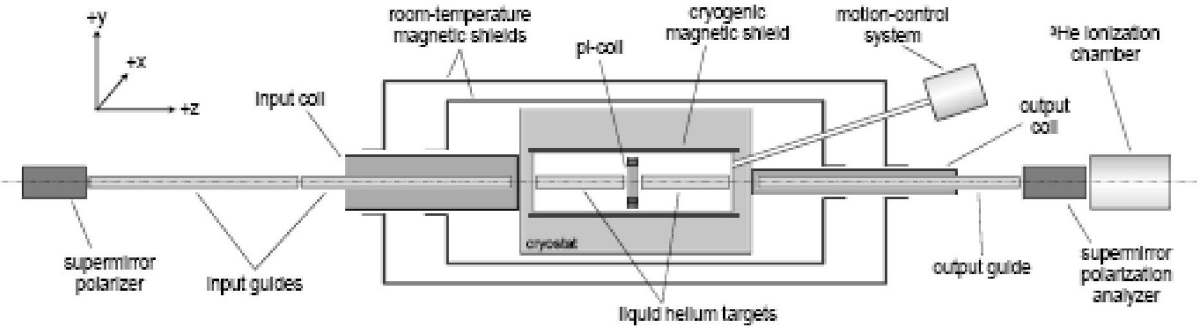

Figure 1 – Overview of an apparatus to measure parity-odd neutron spin rotation in liquid helium

The first phase of the measurement of neutron spin rotation in 4He was performed at the *NG*-6 slow neutron beamline at the National Institute of Standards and Technology (NIST) Center for Neutron Research [36]. The neutrons were polarized vertically by a polarizing supermirror [37] and enter the magnetic shield/target region using a glass neutron guide and a magnetic field from an input coil to transport and preserve the neutron polarization[38]. The target vessel was mounted inside a magnetic shield centered in a nonmagnetic liquid helium cryostat and supported in turn inside two more layers of magnetic shielding. The liquid is moved between the four separate target chambers using a centrifugal pump immersed in a 4K liquid helium bath outside the target with flexible tubes pulled by strings to determine which pair of target chambers fill or drain [34]. Internal fluxgate magnetometers indicate a typical internal axial magnetic field of 10nT. After the target region an output coil and another float glass neutron guide conducts the transmitted neutrons to the polarization analyzer. The output coil adiabatically rotates the x-component of the neutron polarization by ±π/2 in the x − y plane through modulation of the current direction in one of two orthogonal solenoids. This rotated spin component points along ±y? at the analyzer position to produce an asymmetry in the flux transmitted through the polarization analyzer given by $\frac{N_+ - N_-}{N_+ + N_-} = \langle PA\ sin\varphi \rangle$, where PA is the product of the neutron polarization from the polarizer and the analyzing power of the analyzer, φ is the neutron spin rotation angle, and N_+ and $N_-$are the count rates for + and − states of the output coil. The average is taken over the neutron velocity spectrum of the beam. The ion chamber operates in current mode using the $n + {}^3\mathrm{He} \to {}^3\mathrm{H} + p$ reaction and possesses four charge-sensitive collection plates along the beam direction with each plate subdivided into four quadrants[39]. The parity-odd spin rotation angle is constructed from the angles measured in the left and right target chambers and in the + and − π-coil states. A rotation angle is constructed from the angles measured with no current in the π-coil; this asymmetry must give zero in the absence of systematic errors. Possible false effects from slow drifts in the polarimetry were suppressed by analyzing the time sequence of asymmetries with an algorithm which cancels linear and quadratic time-dependent effects [40]. The left-right beam and target segmentation was essential to suppress common-mode no statistical noise from reactor power fluctuations in the 1 Hz frequency band- width of the rotation angle measurements: the noise was reduced by a factor of 8 [34]. The statistical un- certainty from the distribution of asymmetries is ≈ 15% larger than would be expected from neutron counting statistics; about 8% of this extra noise comes from magnetic field fluctuations not removed by the filtering algorithm and a few percent comes from the current-mode operation of the ion chamber. The measured π-coil off angle of $\left(-1.2 \pm 10.0(stat.)\right) \times \frac{10^{-7} rad}{m}$ which is interleaved between the π-coil on measurements places an upper bound on the sum of all systematic effects. It is about a factor of 4 more sensitive than the π-on data to any systematic effects coupled to a constant longitudinal magnetic field but is not sufficiently precise to reduce the systematic uncertainty to the required level. This was done in separate measurements and calculations [41]. Our result for the neutron spin rotation angle per unit length in 4He in the first phase of the measurement, $\frac{d\varphi}{dz} = \left(+1.7 \pm 9.1(stat.) \pm 1.4(sys.)\right) \times 10^{-7} \frac{rad}{m}$ [42], is consistent with zero and with a previous unpublished result. [43]

III. Future measurements of neutron spin rotation in helium and hydrogen. The small size of the systematic uncertainty and the good prospects for stronger suppression of the internal magnetic fields encourage a next attempt in liquid 4He on a more intense slow neutron beam. The new NG-C slow neutron beam under construction at NIST[44] coupled with a new supermirror polarizer is projected to provide a neutron fluence of 7×10^{10} n/s, a factor of 60 greater than that used in the previous experiment. We plan to improve the apparatus by using better-optimized magnetic shielding and control of external field fluctuations, an improved liquid helium pump and a helium liquifier to reduce deadtime from liquid motion and cryogen transfers, a neutron polarizer and analyzer of improved phase space uniformity, and supermirror input and output guides. We expect to reduce the statistical uncertainty on dφ/dz to 2×10^{-7} rad/m with smaller systematic uncertainties. This precision would place a tight constraint on a linear combination of NN weak amplitudes. More theoretical work promises to impact the interpretation of this measurement. A calculation of $d\varphi/dz$ in n-4He using Greens Function Monte Carlo techniques now in progress [45] should greatly improve the precision of the relative weighting with which the different weak amplitudes contribute. Theoretical approaches based on effective field theory [11, 13, 14] are under construction which incorporate the chiral symmetry of QCD. In particular, a new calculation of neutron spin rotation in hydrogen and deuterium in pionless effective field theory has recently appeared [46]. Liquid hydrogen in the para molecular state (which has $J = L = S = 0$) does not depolarize a slow neutron beam, whose kinetic energies are well below the 15 meV threshold for the excitation of the para to ortho molecular transition, and the slow neutron scattering cross section in parahydrogen is small enough that a target length of about 20 cm can be used. Both the successful operation of the liquid parahydrogen target for the NPDGamma experiment at LANSCE [47] and the successful use of slow neutron transmission to measure its (very small) ortho- hydrogen content [48] bode well for the development of a liquid parahydrogen target that could be used to measure parity-odd neutron spin rotation in liquid parahydrogen.

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