

Neutron Group: Summary of Recent Accomplishments

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Penning-trap neutron lifetime measurement

A precision measurement of the neutron lifetime using a proton trap was recently completed [1]. The neutron fluence from a highly collimated beam of cold neutrons was continuously monitored while the decay protons were trapped and subsequently counted in a Penning trap [2]. The result of the experiment, $\tau_n = 886.8 \pm 3.4$ s, represents the most precise measurement of the neutron lifetime using an in-beam technique. It is in good agreement with the world average as compiled by the Particle Data Group, which is dominated by bottle-type measurements using ultracold neutrons. The agreement between these two experimental techniques, which possess completely different systematic uncertainties, brings to an end the notorious disagreements between different experiments that plagued neutron lifetime measurements for decades. The dominant uncertainty in the Penning-trap result comes from systematics related to the neutron counting, which can be reduced by improved absolute neutron fluence measurement techniques.

Absolute neutron fluence measurements

The ability to measure precisely ($\sim 0.1\%$) the fluence of thermal and cold neutron beams has a direct application in reducing the dominant uncertainties in the Penning-trap neutron lifetime experiment. The current uncertainty of 3.4 s could be reduced to approximately 2 s with a reliable calibration. The 2K neutron radiometer developed at IUCF measures neutron fluence by detecting the power produced by nuclear capture reactions in a target that totally absorbs an incident neutron beam. Recently, a measurement [3] was completed at the desired level of precision using a LiMg target made at IUCF [4]. In particular, we demonstrated that the device possesses a linear response to electrical power in the 50 nW to 500 nW range with better than 0.1% absolute accuracy for neutron rates above 10^5 s⁻¹. An important issue in realizing the highest accuracy from this device is the demonstration that all of the kinetic energy of the reaction products appears as heating of the target. Towards that end, the sensitivity of the radiometer is currently being improved even further so as to permit the use of a liquid ³He target. In preparation for this measurement the absolute wavelength of the calibration beam has been determined to 0.01%, making the NG-6M the most accurately-measured monochromatic neutron beam of its kind in the world [5]. The precise knowledge of the characteristics of this beam will make it useful for other experiments, such as tests of the absolute accuracy of ³He-based neutron polarizers and analyzers.

Precision measurement of the n-p, n-D, and n-³He coherent neutron scattering lengths

Recent advances in effective field theories and Monte Carlo calculation techniques for two-body and three-body interactions among nucleons now make it possible to calculate

neutron scattering lengths in low A nuclei from first principles starting from the measured N-N interaction. Results from measurements at NIST of the n-p ($b_{np} = -3.738 \pm 0.002$ fm) and n-D ($b_{nd} = 6.665 \pm 0.004$ fm) coherent scattering lengths [6,7] showed that essentially all existing calculations of the n-D coherent scattering length are in serious disagreement with experiment and that the accuracy of present measurements is sensitive to nuclear three-body forces. In addition, the precision of the measurement of the n- ^3He coherent scattering length, $b_{n-^3\text{He}} = 5.857 \pm 0.007$ fm, is an improvement over previous measurements of almost an order of magnitude and is also sensitive to 3N forces in the A=4 system. Since a recent precision measurement of the spin dependence of the n- ^3He scattering length has already been conducted, the two experiments together determine with high precision the scattering lengths in both spin channels.

Preparations for measurement of the parity-violating neutron spin rotation in helium

This experiment seeks to measure the parity non-conserving (PNC) rotation of the neutron spin as it passes through a liquid helium target. This angle of rotation is proportional to a linear combination the weak meson exchange amplitudes f_π and h_p^0 , which is orthogonal to the combination recently constrained by the measurement of the ^{133}Cs anapole moment. The initial run of this experiment was performed at NIST in 1996 and achieved a statistically limited null result of $\phi_{\text{PNC}} = (0.8 \pm 1.4) \times 10^{-6}$ rad/m [8]. We note that the statistical precision reached was not set by the NIST beam fluence; cryogenic problems were experienced during this run that substantially reduced the size of the data set. Measurements showed that the systematic uncertainty on ϕ_{PNC} was quite small, about 2×10^{-7} rad/m. A substantial effort centered at IUCF is underway to upgrade the apparatus in preparation for a second run with a goal on ϕ_{PNC} of 3×10^{-7} rad/m. This upgrade involves the complete reconstruction of the helium target to allow operation below 2K, where the helium enters the superfluid state.

^3He -based neutron spin filters

Neutron polarizers based on polarized ^3He gas are essential components in a number of proposed experiments in the fundamental neutron physics field. The neutron polarizer system for $np \rightarrow d\gamma$ [9], which will employ spin-exchange optical pumping of ^3He , is nearing completion at Michigan. A key component of this polarizer is the cell that contains the ^3He gas, which must have a very long relaxation time for the ^3He and allow transmission of neutrons. The development, construction, and testing of such cells has been done at NIST by Indiana University postdoctoral fellows and NIST staff. A double-chambered cell was employed for measurements at LANL of parity-violating gamma asymmetries in ^{35}Cl ($A_\gamma = -25.7 \pm 6.5 \times 10^{-6}$) and ^{139}La ($A_\gamma = -17.0 \pm 6.1 \times 10^{-6}$) that were measured in the course of developing the apparatus for a neutron-proton weak interaction experiment [10,11] (both results consistent with previous measurements). This ongoing program is also relevant to future measurements of decay correlation experiments that are being proposed for the SNS.

Precision measurement of the absolute n - ^3He total cross section

Final analysis of a $\sim 0.1\%$ measurement of the n - ^3He total cross section from ~ 30 meV to ~ 300 eV was completed [12]. The measurements demonstrate that the energy dependence of the cross section is $1/v$ to high accuracy. This information is needed to suppress certain systematic effects in future use of polarized ^3He polarizers and analyzers in polarized neutron beta decay.

Preparations for measurement of the parity-violating gamma asymmetry in polarized neutron capture on protons

This experiment will search for a small (~ 5 ppb) parity-odd asymmetry in polarized neutron capture on protons. The experiment and the new beamline where the experiment will be performed is under construction at LANSCE. IUCF is responsible for two major components of the apparatus: the current-mode CsI gamma detector array and the 20-l liquid parahydrogen target. The CsI array has been constructed and tested and is at LANL. It was supported by MRI funds from the NSF and is described in detail in the final report to the MRI program. The liquid parahydrogen target consists of a 20-l vessel with two mechanical refrigerators, a gas handling system, and a PLC control system for target operation and monitoring. The target has been designed, constructed, and successfully tested for cryogenic performance and for performance under accident scenarios at IUCF. The target is now on-site at LANL and preparations are underway to operate the target with hydrogen in a building external to the LANSCE facility. The current plan is to assemble the experimental apparatus immediately after the construction of the experimental cave, perform measurements to characterize systematic effects, and take data with liquid hydrogen in 2004.

Design and Construction of the LENS neutron source

The NSF Division of Materials Research has recently approved the construction of the LENS neutron source at IUCF. LENS will be a university-based pulsed cold neutron source for education, research, and instrumentation development [13]. Although most of the research associated with LENS will be in the area of materials science, work in nuclear/particle physics with neutrons will also be pursued. Possible areas of research include searches for better cold neutron moderators for ultracold neutron sources and testing of crucial components of apparatus and techniques for nuclear and particle physics experiments. Design work on the facility has been initiated for a review in October 2003.

Design of a cold neutron beam for the Spallation Neutron Source

After a recent NSAC review of the fundamental neutron physics field, the DOE has approved the start of a project to construct a nuclear/particle physics beamline at the Spallation Neutron Source at Oak Ridge. We have participated in the simulations for the design of this beamline in preparation for a review to be held in November 2003.

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