1.3 Time reversal in β decay - the emiT experiment

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The emiT experiment is a search for time-reversal (T) invariance violation in the beta decay of free neutrons. Both CP (charge conjugation - parity) and explicit T violation have been observed in the neutral K meson system. (Theoretically one expects that a combined CPT symmetry exist in all Lorentz-invariant field theories, thus CP and T symmetries must be intimately related.) However, some 35 years since the discovery of CP violation, neither CP nor T violation has been seen in any other system and possible origins are still not well understood. Although CP(T) violation can be accommodated within the standard model of nuclear and particle physics, it may also be an indication of physics beyond the standard model.

The standard model predicts T-violating observable in beta decay to be extremely small (Second order in the weak coupling constant) and hence beyond the reach of modern experiments.[1] However, potentially measurable T-violating effects are predicted to occur in some non-standard models such as those with left-right symmetry, exotic fermions, or lepto-quarks.[2,3] Thus a precision search for T-violation in neutron beta decay provides an excellent test of exotic physics.

The emiT experiment probes the T-odd P-even triple correlation between the neutron spin and the momenta of the neutrino and electron, $D\sigma_n \cdot P_e \times P_\nu$, in neutron beta decay. The coefficient of this correlation, D, is measured by detecting decay electrons in coincidence with recoil protons from a polarized neutron beam. This test is complementary to the more sensitive electric dipole moment (EDM) searches. EDMs violate both T and P and thus result from different physical processes.

emiT uses a beam of cold (2.7 meV), polarized neutrons from the Cold Neutron Research Facility at NIST in Gaithersburg, MD. The detector was installed on the NG-6 beamline at NIST from November of 1996 until September of 1997. A total of roughly 14 million coincidence events were recorded with a maximum sustained coincidence rate of ~ 7 Hz. Analysis of these data has been completed.[4] The result, $D = -0.1 \pm 1.3 \times 10^{-3}$, represents a small improvement over the current world average. It is limited by statistical uncertainty; however, systematic effects are not insignificant. The largest, $D_{ATP} = 4 \times 10^{-4}$, results from an asymmetric neutron beam combined with a slightly misaligned (Transverse) neutron polarization. The primary reason for the unexpectedly large magnitude of this effect was the lack of detector symmetry due to disabled channels in the proton detection segments (Normally the highly symmetric detector is fairly insensitive to such effects). The root cause of this problem was excessive energy loss in the proton detectors and the associated dead time, noise, and electronic failures due to high voltage sparks. Work on an upgrade to the apparatus (see Sec. 1.4) which will solve the problems experienced during the first run is currently in progress at the NPL. A new measurement is planned at NIST in 2001.

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[4] L.J. Lising *et al.*, Phys. Rev. C, to be submitted.

1.4 Upgrades to the emiT detector

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Past experiments searching for T violation in the β decay of polarized neutrons have reached a sensitivity to D of 1.4×10^{-3}. Technological advances in neutron polarization and an optimized detector geometry should allow emiT to attain a sensitivity to D of 3×10^{-4}, given the current capture flux available at the NG-6 beamline at NIST (1.4×10^{9} n/cm^{2}s). This level of sensitivity represents a factor of five improvement over previous neutron T tests, and may permit restrictions to be placed on several extensions to the Standard Model that allow values of D near 10^{-3}.

The emiT detector consists of four electron detectors (plastic scintillators) and four proton detectors (large-area PIN diode arrays) arranged in an alternating octagonal array concentric with the neutron beam. The average angle between any given proton detector and it's opposing electron detector is 135°. This configuration was chosen to take advantage of the electron–proton angular distribution which is strongly peaked around 160° due to the disparate masses of the decay products. When compared to the 90° geometry used in previous experiments, this choice results in an increased signal rate equivalent to roughly a factor of three increase in neutron bean flux.[1]

The protons produced in the decay of free neutrons have a relatively low energy. (The Q-value for the decay is 782 keV, producing protons with energies $\leq$ 751 keV.) While this allows for a delayed coincidence trigger between the proton and electron (eliminating much of the background due to cosmic rays) it makes detection difficult. The PIN diode array and associated electronics are therefore held at a nominal voltage of -30 kV which accelerates the protons to detectable energies and focuses them onto the PIN diode detectors.

During the first run, high voltage related problems stemming from higher than expected energy loss in the PIN diodes led to damaged electronic components and a non-symmetric detector. Systematic effects were less effectively canceled due to the lack of full detector symmetry and a more complex data analysis scheme was required.[2]

To assure that the second run is not affected by these problems, a number of detector upgrades are currently in progress at NPL. Sensitive electronics have been isolated through the use of analog fiber-optic links. The DAQ electronics have been extensively reworked. Lower power consumption will decrease the cooling requirements, and sharper ADC thresholds will allow better background rejection. This should allow operation at lower voltages thus increasing the stability of the detector. The fiber-optic links and new ADC cards have been constructed and are performing extremely well.

In addition, upgrades to the DAQ software will allow closer monitoring of the detector status and will improve the capability for real time data analysis. A tentative decision to replace the PIN diodes with Surface Barrier detectors has been made based on comparative studies of PIPS, PIN and Surface Barrier detectors. Investigations into the source of the observed high voltage instability are continuing. Finally, an upgrade to the NIST reactor will result in a factor of approximately two higher cold neutron flux. It is expected that emiT will resume collecting data in the fall of 2000, likely reaching the design goal of D $< 3 \times 10^{-4}$ early in 2001.

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