The Quest for the Electric Dipole Moment of the Neutron

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Symmetries play a central role in the understanding of fundamental interactions, particularly the discrete symmetries P (parity), C (charge conjugation), and T (time reversal). Establishing that the weak interaction violates all three of these symmetries has been instrumental in constructing the Standard Model. The pattern of symmetry violation is subtle and interesting. While the violation of P has major observable consequences in nuclear beta decays, the violation of T is only significant for processes involving heavy quarks and has not been observed with nuclei. This feature is explained by the structure of the Standard Model of weak interactions, which allows for T violation (or CP violation) only if the model contains at least three generations of quarks. In nuclei, the virtual effects associated with the second and third generations of quarks are extremely small, and therefore T violation is also expected to be very small.

This lecture will focus on a precision test of T symmetry with neutrons, pursued in order to challenge the Standard Model of weak interactions. Specifically, we will discuss electric dipole moment (EDM) of the neutron, which is defined as the coupling between the neutron spin and an applied electric field, in the same way that the magnetic dipole moment represents the coupling between the spin and the magnetic field.

We will cover the following topics in a two-hour lecture:

- The EDM of a spin 1/2 particle is a T-violating observable. The neutron EDM is a sensitive probe of new physics beyond the Standard Model of weak interaction.

- The high precision of experiments is made possible by the use of ultracold neutrons. These extremely low-energy neutrons can be stored in material bottles and exposed to an applied electric field for long durations, comparable to the beta decay lifetime of the neutron, which is 15 minutes. We will give an introductory course on ultracold neutrons, explaining the central concept of the neutron optical potential, also called the Fermi potential.

- We will explain the basic experimental concepts of neutron spin manipulation: polarizer, analyzer, resonance methods to measure the Larmor precession frequency. In particular we will describe Ramsey's method of separated oscillating fields.

- To finish we will present and discuss concrete experiments.

Precision measurements of neutron beta decay

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Free neutrons decay into proton, electron and electron antineutrino. Neutron decay is the prototype for nuclear beta decay, with nuclear structure effects absent. Accurate neutron decay data are needed in calculations of many processes involving semileptonic weak interaction, such as primordial or stellar nucleosynthesis or the detection of reactor antineutrinos by inverse beta decay. On the other hand, neutron decay can be used to search for new physics beyond the Standard Model of particle physics: in the standard model, neutron decay is described by only two parameters, while a good dozen of observables, such as the neutron lifetime and correlations in neutron decay, are available to over-constrain the model and to search for deviations.

One lecture will be devoted to the measurement of neutron lifetime. It will discuss neutron sources, storage experiments as measurement of the total and beam experiments as measurement of a partial neutron lifetime, and the so-called neutron lifetime puzzle. In the other lecture, the geometry and symmetry properties of correlations in neutron decay will be related to concept of measurements and associated systematic effects. Experimental concepts and recent examples will be discussed. A particular focus of both lectures is the connection between the design of an experiment and its systematic effects.