Invited talk

Searches for new CP-violating physics using cold and ultracold molecules

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From cosmological observations of the asymmetry between matter and antimatter, it is known that new physics that violates CP symmetry must appear at some high energy scale. In many theories of physics beyond the Standard Model that account for this fact, the new physics leads to electric dipole moments (EDMs) or related asymmetric charge distributions along the spins of quantized particles such as electrons, protons, and nuclei. These EDMs arise from virtual excitations of new quantum fields that carry CP-violating interactions, much like the electron's anomalous magnetic moment arises from virtual excitations of the electromagnetic field.

The CP violation in the Standard Model gives rise to nonzero but extremely small EDMs, some 6 orders of magnitude smaller than current experimental sensitivities. By contrast, in typical extensions to the Standard Model, EDMs can be much larger even if the mass of particles associated with the new quantum fields is extremely large. Recent EDM experiments already probe mass scales well above TeV range in many models, significantly beyond the direct reach of the Large Hadron Collider. Because the observed value of the Higgs boson mass is naturally associated with new physics in the 1-1000 TeV range, probing such high mass scales is at the forefront of modern particle physics.

This talk will describe three ongoing experiments aiming to detect EDMs with unprecedented sensitivity. All are based on the $\sim 10^4$-fold enhancement of energy shifts due to EDMs in polar molecules, relative to atoms. First, we will provide an update on the ongoing third generation of the ACME experiment, [1] which aims to detect the electron's EDM (eEDM) using metastable ThO molecules. The ACME III apparatus is fully assembled and operating routinely, with statistical uncertainty sufficient to surpass the current best limit on the eEDM by an order of magnitude. We will describe ongoing work to uncover and quantify possible systematic errors in ACME III. Next, we will discuss the CeNTREX experiment, which aims to detect the proton EDM (pEDM) using ground-state TlF molecules.[2] Like ACME, CeNTREX uses a high flux of molecules in a cryogenic beam to achieve good statistics. We will describe the status of CeNTREX, which is nearing the end of its construction phase.

Finally, we will discuss a new, long-term effort to search for the EDM-like nuclear Schiff moment, with potentially orders of magnitude higher sensitivity than current experiments. Here, we aim to employ two major new features. First, we will use octupole-deformed nuclei that enhance the Schiff moment by $\sim 10^3$-fold relative to ordinary spherical nuclei. Second, we will embed these nuclei in ultracold polar molecules, where much longer spin coherence times (and hence better energy resolution) in possible relative to beam experiments. In particular, we aim to measure the Schiff moment of ^{223}Fr nuclei, in ultracold FrAg molecules, which have been calculated to have near-ideal sensitivity to the nuclear Schiff moment.[3] Both Fr and Ag atoms have been laser cooled, and calculations indicate that ultracold FrAg molecules should be amenable to assembly using the same methods used to produce quantum gases of bi-alkali molecules.[4] We will describe progress towards this goal.

[1] ACME Collaboration, *Nature* **562**, 355 (2018).
[2] O. Grasdijk *et al., Quant. Sci. Technol.* **6**, 044007 (2021).
[3] A. Marc, M. Hubert, and T. Fleig, *Phys. Rev. A* **108**, 062815 (2023).
[4] J. Kłos, H. Li, E. Tiesinga, and S. Kotochigova, *New J. Phys.* **24** 025005 (2022).