Discovering or Ruling Out an Electron Electric Dipole Moment Using Francium

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The proposed Joint Nuclear Facility at Project X will have proton beam currents about two orders of magnitude larger than TRIUMF and ISOLDE and, may produce $5 \times 10^{19}$ Fr/s - sufficient to lower the electron EDM upper limit by a factor of 10.$^3$

Lowering the upper limit to the electron electric dipole moment (EDM) by two or three orders of magnitude will result either in the discovery of an electron EDM or in more stringent constraints on Supersymmetric (SUSY) models. It is already becoming difficult to have SUSY and not have EDMs, especially when constraints from the electron EDM limit are combined with constraints from the neutron EDM and atomic EDM limits. Present electron EDM results$^{[1, 2]}$ are a factor of 100 below some SUSY models$^{[3–9]}$ with super-partner masses of 100 GeV and CP-violating phases of unity and are not in complete agreement for models with one-TeV masses$^{[10]}$.

Discovering an electron EDM proves that there is a new source of CP violation, proves that there is TeV-scale physics, and provides compelling motivation to construct the International Linear Collider - perhaps even in the absence of discoveries at the Large Hadron Collider. And if SUSY particles are discovered, the EDM may still be needed to inform us of their behavior under CP.

To claim discovery of an EDM, an experiment must be demonstrably uncontaminated by systematic effects, and to challenge SUSY the sensitivity of the experiment must be unambiguous. A francium electron EDM experiment can achieve both of these goals. There being no experimentally observable standard model electron EDM, there is no effect that needs to be subtracted out. There is no QCD effect, there are no hadronic effects: the electron is a fundamental particle. The relation between an EDM of an alkali atom and of an electron is the simplest and most reliably calculated EDM effect in any multi-electron system. The calculations have been performed using different techniques and by different authors with numerical differences typically below twenty percent. And the calculations are similar to those used for calculating parity violating effects in atoms and so have indirectly been validated by experiment.

With francium comes a higher sensitivity to an electron EDM than any atom previously used and the high nuclear spin and magnetic dipole moment of $^{211}$Fr, when combined with laser cooling, brings the most complete systematic rejection of any electron EDM experiment yet attempted. Systematic effects arise in electron (and neutron) EDM experiments because the electric and magnetic dipole moments are both proportional to the electron's (neutron's) spin. Magnetic fields that change synchronously with the electric field can mimic an EDM. Even in experiments where there is no net motion, the Lorentz transform due to the atom's motion through the electric field gives rise to a motional magnetic field $B_{mot} = \frac{v \times E}{c^2}$ that can lead to first-order systematic effects.

These effects can be removed in first order if the atom is quantized in the electric field, no external magnetic fields are applied, and motional and remnant magnetic fields are made small. The remaining systematic effects scale as inverse powers of the electric field allowing one to quickly distinguish between a true EDM (linear in $E$) and the systematic effect (proportional to $1/E^3$). The ratio of systematic effect sensitivity to electron EDM sensitivity in $^{211}$Fr is two orders of magnitude smaller than in any other alkali atom.

What is presently lacking is a source of francium intense enough to make measurements sensitive enough to lower the electron EDM limit by three orders of magnitude and to test for systematics, both false positives and false negatives. The proposed Joint Nuclear Facility at Project X will have proton beam currents to produce sufficient $^{211}$Fr.