Improved measurements of the electric dipole moment of radium

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I. Motivation / physics case and the technique proposed

Atomic radium is a unique system that can provide unprecedented sensitivity to CP-violation owing to a myriad of advantageous properties. Octupole deformed ("pear-shaped") nuclei in radium isotopes are believed to enhance sensitivity to nuclear CP-violation by several orders of magnitude [1-3]. Moreover, the rigid deformation in radium is easier to interpret and complimentary to many other experiments [3-5]. Radium can be laser cooled and trapped using standard techniques in atomic, molecular, and optical physics [6,7]. Several mCi of both long-lived odd isotopes, ^{223}Ra ($\tau_{1/2}$ = 11.43d, **I** = 3/2) and ^{225}Ra ($\tau_{1/2}$ = 14.7d, **I** = 1/2), can be loaded into off-line experiments using standard radioactive material handling procedures. The radium electric dipole moment (EDM) apparatus at Argonne National Laboratory cools radium atoms into a tightly confined optical dipole trap, which is less sensitive to geometric phase effects, relaxes requirements for magnetic field uniformity, and allows for the application of a higher electric fields. Figure 1 shows a diagram of the experimental apparatus with major sections labeled. Recent results using ytterbium atoms [8](which are much less sensitive to CP-violation) have demonstrated that the experimental techniques demonstrated with radium can limit the radium EDM to 10^{-26} e cm or below, provided statistical precision can be improved.

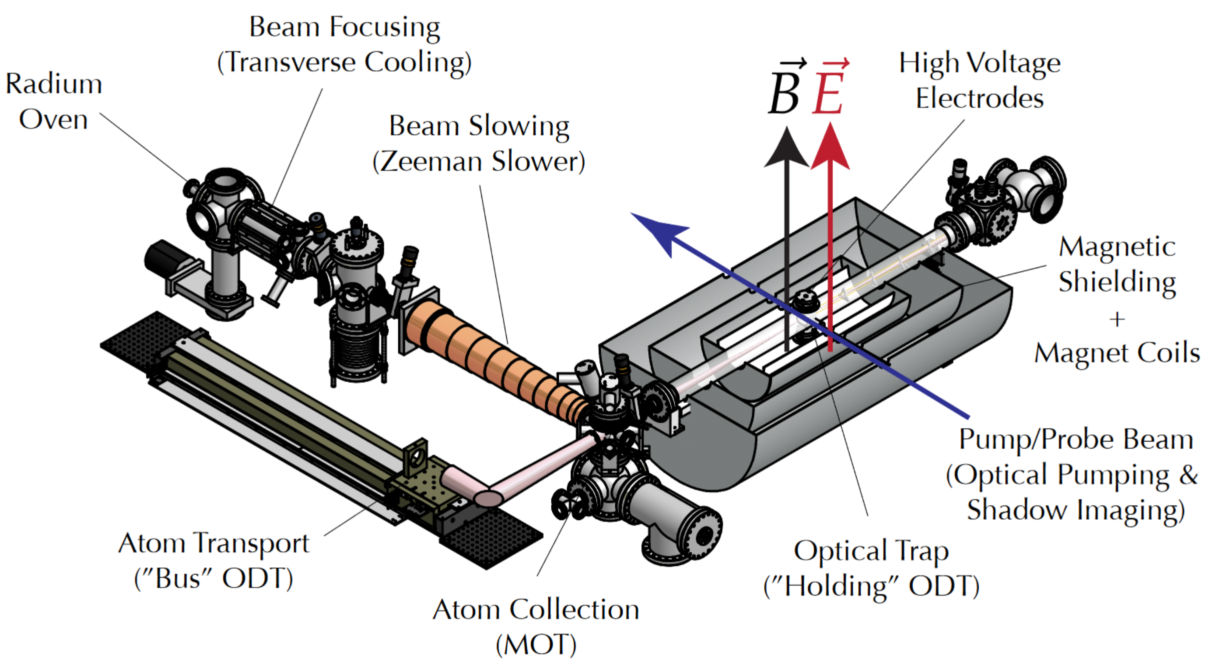

Figure 1: A schematic diagram of the radium EDM apparatus at Argonne National Laboratory. The overall length is approximately 2 m.

II. Progress and future prospects

The first limit on the EDM of ^{225}Ra [9] was based on measurements performed between October and December of 2014 using one 3 mCi and one 6 mCi sample of ^{225}Ra atoms obtained from Oak Ridge National Laboratory via the US National Isotope Development Center. After implementing a vacuum system upgrade, a second measurement was performed in June of 2015 using a single 9 mCi sample which improved upon the previous limit by over an order of magnitude to $|d(^{225}\mathrm{Ra})| < 1.4 \times 10^{-23}$ e cm (95% CL) [10]. Following these measurements, we pursued and demonstrated experimental upgrades that will enable greatly enhanced sensitivity in future measurements. New niobium electrodes have been developed, tested, and installed in the radium EDM apparatus which can apply an electric field of 300kV/cm [11]. Additionally, we demonstrated an improved detection technique based on coherent atom transfer to a metastable electronic state. This approach can improve the signal to noise in spin precession detection by over an order of magnitude [12]. Finally, we confirmed via spectroscopy that a suitable re-pumping scheme exists to use the stronger (but leaky) $^1S_0$ to $^1P_1$ transition at 483 nm for cooling and trapping radium [13]. We have purchased all major equipment for a new experimental front-end which uses this transition to capture radium atoms more efficiently and are in the processes of demonstrating magneto-optical trapping of radium using the 483 nm transition.

III. Timeline

The availability of ^{225}Ra continues to prevent an imminent EDM measurement with sensitivity at the 10^{-25} e cm level. Current sources of ^{225}Ra are greatly oversubscribed in fulfilling ^{225}Ac (the decay daughter of ^{225}Ra) requests for cancer research. Thus, current experimental efforts prioritize two parallel tasks. First, we are developing a new front-end for our apparatus which uses the stronger $^1S_0$ to $^1P_1$ transition at 483 nm for cooling and trapping. Second, we are using the current radium EDM apparatus to demonstrate the viability of EDM measurements in ^{223}Ra. We expect both efforts to conclude at the end of FY24, at which time we will combine the new front-end with the rest of the current EDM apparatus to perform a ^{223}Ra EDM measurement with 10^{-26} e cm sensitivity.

IV. Resources required

We require continued support over the next several years for materials and supplies to maintain the experimental apparatus (including the cost of radium isotopes) along with support for the effort necessary to complete: development of the 483 nm experimental front-end; demonstration of cooling, trapping, and spin precession detection of ^{223}Ra; and further development of electrodes and HV systems capable of increasing lab-applied fields to 500kV/cm and precise field reversal. Additionally, continued support for efforts to harvest isotopes from the Facility for Rare Isotope Beams (FRIB) at Michigan State University [14], including efforts to optimize the formation of atomic beams using harvested isotopes will greatly benefit future radium EDM measurement efforts by providing increased quantities of both ^{223}Ra and ^{225}Ra.

V. Who is involved

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VI. References

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