A novel method to look for the electric dipole moment of the electron using a metastable state of PbO

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We have proposed and begun implementing an experiment to look for an electric dipole moment (EDM) of the electron using the metastable $a(1)(^3\Sigma^+)$ state of the PbO molecule. The discovery of an electron EDM (d_e) within the next few orders of magnitude beyond the current limit of $|d_e| < 4 \cdot 10^{-27} e \cdot cm$ [1] would be clear evidence for physics beyond the Standard Model (SM). A search in this regime is of particular interest since nearly all of the currently favored extensions to the SM (especially those based on supersymmetry) predict an EDM at this level [2]. Furthermore, if an EDM is discovered its magnitude could help to determine central features of the underlying theory, such as the gauge group structure [3] and the mechanism of symmetry breaking [4]. Based on estimated shot-noise limits, the first generation of our experiment is expected to be sensitive to $|d_e| \approx 10^{-29} e \cdot cm$, and a subsequent improved version is anticipated to reach $|d_e| \approx 10^{-31}\ e \cdot cm$. The high level of sensitivity is due mainly to the extreme polarizability of diatomic molecules and to the fact that the experiment can be carried out in a vapor cell. This allows us to achieve high counting rates and a very large *internal* electric field ($6 - 60 \cdot 10^9\ V/cm$) in the presence of a small external field ($\sim 10\ V/cm$). The large internal field leads to an enhancement of the linear Stark shift caused by an EDM in an applied electric field.

In the first version of the EDM experiment a pulsed dye laser will be used to directly populate the $a(1)$ state from the $X(0)$ ground state. The laser polarization will lead to an alignment of the molecular angular momentum. After excitation the molecules will be left to precess in applied collinear electric and magnetic fields, while fluorescence from decays back to the X state is monitored. The presence of an EDM would lead to a shift in the frequency of the resulting quantum beat signal when the relative orientation of the electric and magnetic fields is reversed.

Extensive materials testing has been done to find cell and electrode materials which will work at the high temperatures ($T \simeq 700\ °C$) required for the optimal vapor pressure of PbO ($P \simeq 10^{-2}\ Torr$). Vapor cells are currently being constructed from an alumina body with sapphire windows. We will use either Ir or Pt for the electrode material to limit chemical reaction with the PbO vapor. Concurrently, we have designed a heater with very low inductance to produce the desired temperature distribution across the cell. To avoid magnetic fields due to heater currents, solid state switches have been designed to switch off 10 A of current in 10 μs, with leakage currents $I_{leakage} < 1\ nA$ in the off state.

In order to allow for interpretation of our experiment in terms of d_e, a number of spectroscopic parameters for the $a(1)$ level must be known. This work is currently under way at both Yale and Amherst. Determination of hyperfine structure for the $a(1)$ state is near completion. Measurement of polarizability and g-factors will be carried out in the near future using the heater and vapor cell under construction at Yale.

Strong transitions between the $a(1)$ state and other excited electronic states of PbO would enable more efficient excitation and detection schemes in the second version of the experiment. To search for such transitions, we have measured total lifetimes and branching ratios for decays from most known higher excited states to $a(1)$ [5]. It is expected that additional unknown states exist, which couple more strongly to $a(1)$ than do any of the known levels. Work to look for such states will likely begin within the next year.

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