EDM^3: a new search for the electron EDM using molecules in a matrix

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EDM^3 Collaboration
Electric Dipole Moment Measurement using Molecules in a Matrix

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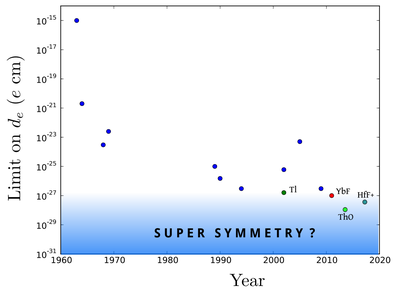
Electron electric dipole moment



- Electron EDM is a model-independent probe of new physics sources of T-violation
- EDM search experiments can probe physics at energies far beyond the reach of accelerators (PeV to EeV scales)
- Electron EDM sensitivity of an experiment:

$$\delta d_e = \frac{1/\tau}{2\mathcal{E}_{\rm eff}\sqrt{N}}$$

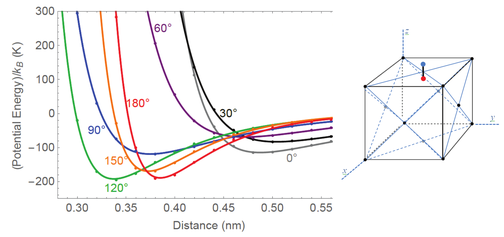
(τ: electron spin coherence time; $\mathcal{E}_{\rm eff}$: electric field seen by EDM in molecule; N: number of measured molecules)

- EDM^3 aims to improve on electron EDM sensitivity by using very large numbers of molecules

  Targeted EDM sensitivity: $\delta d_e < 10^{-34}$ cm

Molecules in rare gas matrices

- Clean single-crystal hosts can be grown using Ar at 4 K
- Molecules substitute for rare gas atom in fcc lattice site



Orientation-dependent potential energy curves for BaF ... Ar

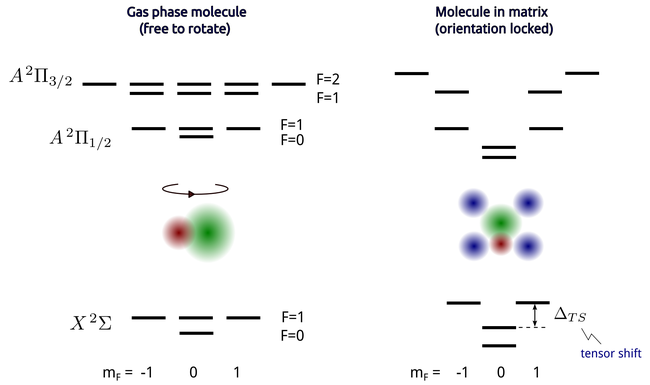
- 6 equivalent minimum energy configurations aligned with axes of crystal
- Tunneling between these configuration is highly suppressed, so molecules lock into orientations along the crystal axes (with librations around the equilibrium orientation)
- Advantages for EDM experiments:

• **Trapped molecules**, no motion-related systematics
• Locked orientations provide **perfect EDM comagnetometer**
• Locked orientation enables **EDM experiment in zero electric field** !

• Lots of molecules (> 10^{13}) can be trapped in the matrix
• Long spin coherence time (> 1 ms)
• Many new switches for systematic tests
(orientation reversal, crystal rotation, B-field coil rotation)

• Molecules trapped within small volume : easy to control fields, collect light
• Effect of substrate, crystal impurities can be easily varied and studied

Hyperfine structure of oriented BaF in matrix



- Oriented BaF molecules have **dark states & cycling transitions**, convenient for optical pumping and detection using lasers
- Molecules oriented by the matrix have large tensor shifts of hyperfine states. Tensor shift (in the presence of a lab E-field aligned with the crystal axes) is different for molecules oriented along/against the field

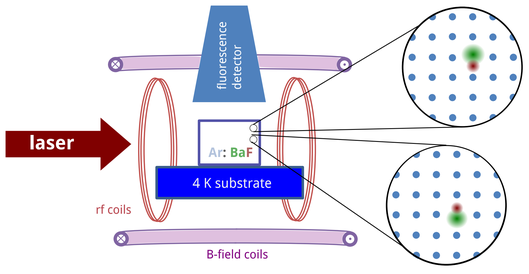
  Molecules with **opposite orientations can be separately addressed** using their different rf resonance frequencies in a lab E-field
- Tensor shift of hyperfine states offers a number of additional advantages:

  • strong suppression of systematics from transverse B-field components
  • convenient radio-frequency manipulation of hyperfine states
  for state preparation of EDM-sensitive superposition
  to start/stop precession of EDM-sensitive superposition
  to shelve population into bright states for detection
  to implement precise reversals during start/stop and shelving pulses

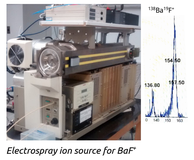
Control over systematics

- High statistical sensitivity allows for extensive studies of systematics
- Small size of sample: excellent shielding/uniformity of fields
- No applied electric field during precession: no leakage currents
- Simultaneous precession of oppositely oriented molecules: comagnetometers with identical g-factors
- Cryogenic experiment: control over magnetic fields, suppression of thermal voltages/currents
- Stationary molecules: no motional field systematics or geometric phases
- Control molecules: EDM-insensitive species (eg, CaF) can be used to check systematics
- Experiment can be repeated with new crystal (impurities, imperfections), different rare gas, different substrates, other polar molecules
- Many ways to reverse relative direction of electric and magnetic fields (coil rotation, crystal rotation, voltage/current reversal)
- Large dynamic range on parameters that can be varied (B-field, precession time, delay times between steps)
- Precession start/stop and reversals controlled with radio-frequency precision

Experiment schematic

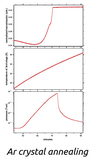


- BaF molecules produced by neutralization of mass-selected BaF$^+$ beam
- BaF deposited into Ar single crystal grown on cold substrate
- rf coils to drive hyperfine transitions
- Lasers for optical pumping and detection



Electrospray ion source for BaF$^+$

Vacuum system and cold head



Ar crystal annealing

Experiment sequence