Status of the ThO eEDM search experiment

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ACME Collaboration

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Overview

- Limit from Tl atomic beam: $d_e \leq 1.6 \times 10^{-27} \text{e cm}^1$
- Projection for ThO beam: $\delta d_e \simeq 10^{-30} \text{e cm} \sqrt{\text{day}} \text{ (stat)}$

- Why do we think this is possible?

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1B C Regan et al, PRL 88, 071805 (2002)
Cartoon version of an eEDM search

\[ \Delta \omega = 2 \ d_e \mathcal{E}_{\text{eff}} \]

- Look for “extra” spin precession that is correlated with the electric field, \( \mathcal{E}_{\text{eff}} \)
Why ThO molecules?

**Sensitivity limit**

- \( \delta \omega \geq \frac{1/\tau}{\sqrt{N_{tot}}} \)
- \( \Rightarrow \delta d_e \gtrsim \frac{1/\tau}{2E_{eff}\sqrt{\dot{N}T_{tot}}} \)

**Statistical sensitivity with ThO**

- Large effective electric field, \( E_{eff} \sim 10^{11} \text{ V/cm} \)
- Large coherence time, \( \tau \geq 1.7 \text{ ms} \) (measured)
- Large count rate, \( \dot{N} \sim 5 \times 10^7 / \text{s} \) (projected)

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(Simplified) level structure of the ThO molecule

- eEDM enhancement is in the paramagnetic $H$ state

- Number of ideal properties for an eEDM experiment in a beam
Measurement of molecular beam flux $\rightarrow \dot{N}$

$\dot{N} = N_{\text{beam}} \approx 10^{13} / \text{sr/pulse}$
Lifetime of the $H$ state $\longrightarrow$ coherence time, $\tau$

- Radiative lifetime, $\tau \geq 1.7 \text{ ms}$
Advantages of ThO

Statistical sensitivity

- Large eEDM enhancement factor ($\sim 4 \times \text{YbF, PbO}$)
- Long-lived metastable state ($\tau \sim 2 \text{ ms}$)
- Demonstrated production of cold molecules into a beam

Systematic error rejection

- Small magnetic moment ($^3\Delta_1$) ⇒ magnetic noise insensitive
- Large tensor Stark shifts ($\sim$ other eEDM molecules)
- $\Omega$-doublets to reject many systematics (geometric phase !)

Experimentally well-behaved

- ThO spectroscopy is well-known, all relevant transitions only involve diode lasers !
- Blue-shifted fluorescence, compared to backgrounds
Summary: eEDM search with ThO molecules

Based on measured quantities, the projected sensitivity is
\[ \delta d_e \simeq 10^{-30} \text{e cm } \sqrt{\text{day}} \text{ (stat)} \]

ThO has a number of features to suppress/reject known systematic effects to below this level.

Current status

- Construction of molecular beam source & lasers + electronics
- Design of interaction region
A more detailed schematic of the experiment
Cryogenic source: intense beam of cold ThO molecules

- Cryogenic ThO beam
- Supersonic YbF beam

<table>
<thead>
<tr>
<th></th>
<th>Cryogenic ThO beam</th>
<th>Supersonic YbF beam</th>
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<tbody>
<tr>
<td>Molecules, $N_{ground}$</td>
<td>$2 \times 10^{12}$/sr/pulse</td>
<td>$1.4 \times 10^{9}$/sr/pulse</td>
</tr>
<tr>
<td>Velocity, $v_{∥}$</td>
<td>150 m/s</td>
<td>300 m/s</td>
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\[ \frac{1}{\tau \sqrt{N}} \] is smaller by a factor of $\sim 100$ for a cold ThO beam

Distinguishing geometric phases from an EDM