Electron EDM Experiment using Francium at TRIUMF

Robert Collister

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Outline

• EDM searches
• Atomic fountain experiment
• Finer experimental details
Electric Dipole Moment Searches
EDM?

- Intrinsic separation of charge
- Violates P-symmetry

- Violates T-symmetry
  - Equivalent to CP-violation
CP violation in Standard Model

• CP violation observed in electroweak interaction
  • None in QCD, not large enough to explain baryon asymmetry

• In Standard Model: $d_e < 10^{-38}$ e cm $d_n < 10^{-32}$ e cm

• eEDM limits:
  - $d_e \leq 1.3 \times 10^{-28}$ e cm HfF+ 2017
  - $d_e \leq 1.3 \times 10^{-29}$ e cm ThO 2014
  - $d_e \leq 1.3 \times 10^{-27}$ e cm Ti-205 2002

• Experiments search for EDMs as any observation is new source of CP violation → new physics!
  • Results complementary to high energy colliders
eEDM in francium

- eEDM search in alkali atoms look for energy difference in valence electron aligned v. anti-aligned with applied E-field
  - Or as a phase difference between superposition of states

- Alkali atoms: simple atomic physics

- Relativistic enhancement:  Rb: 25  Cs: 118.5  Fr: 903

- Apparatus first built using Cs at LBNL, to learn better control of systematics

- Relocation to TRIUMF for Fr: goal: $d_e \leq 8 \times 10^{-30} \text{ e cm}$
Atomic Fountain Experiment
Francium atomic fountain

- Two magneto-optical traps
  - Collection of Fr from beam
  - Launch MOT

- Launch atoms: measurement in freefall, free space

- Magnetic shielding, electric field plates

- Optical state preparation, analysis, and detection

- Proof-of-principle  PRA 75, 063416 (2007)
Why a fountain?

• Atoms precess in E,B fields

• EDM signal: odd in reversal of E

• Motional magnetic field effect \((v \times E)\)
  • Odd in reversal of E, mimics EDM

• Fountain: Velocity reverses under gravity
  • Suppress motional systematic
  • Atoms slow: \(E\) quantization

• Systematics are the limiting error in EDM experiments
eEDM Experimental Details
Atom transport

- Launch by detuning vertical beams
  2.44 m  $\rightarrow$  6.8 m/s

- Magnetic sextupoles BF/BD
  - Focus/defocus to counter expansion

- Shaped field plates
  - Counter strong-field seeking atoms

- ~75% return to be re-trapped
  - Great for limited Fr
Atom transport

BD/BF: magnetic sextupoles
D1/F2/D3: Shaped field plates
X/Y: Parallel/Perpendicular to field plates
Magnetic shielding

- Need magnetic shielding factor $10^7$
  - 4 nested shells
- Lots of tricky aspects
- See poster
eEDM Research Collaboration

LBNL

Robert Collister, Ben Feinberg, Harvey Gould, Yan Li, Charles Munger Jr., Hiroshi Nishimura, Chris Timossi

TRIUMF

John Behr, Matthew Pearson

Missouri S&T

Ulrich Jentschura

… and you?
Bonus content
Proof-of-principle Cs fountain

- Demonstrated:
  - Launching Cs
  - State preparation and detection
  - E quantization
eEDM limits over time

60 years of measuring zero

Credit: Ben Sauer