Theory Outlook

EDM Searches at Storage Rings

ECT∗, Trento, October 5, 2012 | Andreas Wirzba

Outline:

1. Observations and the physics case
2. Theory input
3. What to measure?
4. Reliable quantitative statements

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Come to the dark side of the force!

Naive estimate of the EDM scale of the nucleon

Khriplovich & Lamoreaux (1997); Kolya Nikolaev's talk

- CP & P conserving magnetic moment ~ nuclear magneton μ_N

$$\mu_N = \frac{e}{2m_\mathrm{p}} \sim 10^{-14}\,\mathrm{e\cdot cm}$$

- EDM $\neq 0$ requires parity P violation *:

  $\hookrightarrow$ pay the price $\sim 10^{-7}$.

- EDM $\neq 0$ requires CP violation †: the price is $\sim 10^{-3}$.

- In summary: $d_N \sim 10^{-7} \times 10^{-3} \times \mu_N \sim 10^{-24}\,\mathrm{e\cdot cm}$

- In SM (with $\bar\theta \equiv 0$) : extra P violation to undo flavor change:

$$\hookrightarrow \quad d_N^{\mathrm{SM}} \sim 10^{-7} \times 10^{-24}\,\mathrm{e\cdot cm} \sim 10^{-31}\,\mathrm{e\cdot cm}$$

More sophisticated calculations: Ramsey-Musolf's & Uraltsev's talks

* $G_F \cdot m_\pi^2 \sim 10^{-7}$ with $G_F \approx 1.166 \cdot 10^{-5}\,\mathrm{GeV}^{-2}$, $\quad ^\dagger$ $|\eta_{+-}| \equiv \frac{|A(K_L^0 \to \pi^+\pi^-)|}{|A(K_S^0 \to \pi^+\pi^-)|} = (2.232 \pm 0.011) \cdot 10^{-3}$

The physics case

The *N*-EDM range for testing or excluding theories beyond $\mathrm{SM}_{\bar{\theta}=0}$:

$$\therefore \quad 10^{-24}\,\mathrm{e}\cdot\mathrm{cm} < d_N < 10^{-31}\,\mathrm{e}\cdot\mathrm{cm}$$

Using current bound $d_\mathrm{n} < 2.9\cdot 10^{-26}\,\mathrm{e\,cm}$ & $d_\mathrm{p} < 7.9\cdot 10^{-25}\,\mathrm{e\,cm}$

Baker et al. (2006), Dimitriev & Sen'kov (2003) & Griffith et al. (2009) Hg atom

$\hookrightarrow$ the actual test range is rather

$$\therefore \quad 10^{-26}\,\mathrm{e}\cdot\mathrm{cm} < d_N < 10^{-31}\,\mathrm{e}\cdot\mathrm{cm}$$

Quoting Michael Ramsey-Musolf:

- *'n-EDM has killed more theories than any other single experiment'*
- *EDMs provide a powerful probe on EW baryogenesis*
- *Next generation of EDM searches* ($\sim 10^{-28}\,\mathrm{e}\cdot\mathrm{cm}$) *may conclusively test MSSM EW baryogensis.*

Bill Marciano: *$H\to\gamma\gamma$ beyond SM expectations (1.5 – 2σ) testable in 2-loop Higgs contributions to fermion EDMs rather than in diboson decays at LHC*

Input from many corners of theoretical physics:

(similarly to EDM measurements which use expertise/experts from many areas of experimental research, accelerator physics, non-linear dynamics)

- High energy (beyond-SM) physics, LHC results (Bill Marciano)
- EW Baryogenesis (Michael Ramsey-Musolf)
- Lattice QCD (Gerrit Schierholz and Taku Izubuchi)
- Chiral perturbation theory for nEDM (and pEDM) and relation (chiral & volume extensions) to Lattice QCD (Ulf Meißner)
- Low-energy effective field theory for deuteron, ^{3}He (and ^{3}H) EDMs (Bira van Kolck, Jan Bsaisou, Jordy de Vries)

What to measure (?)

in the case of quark- and/or gluon-type EDMs?

1. A positive measurement of the permanent EDM of any non-self-conjugating particle with spin (elementary or composed) is sufficient to establish the principle

2. To disentangle the mechanism, more measurements are needed: d_n, d_p, d_D, ... for quark- and gluon-type EDMs

3. The most distinctive mechanism is the dimension-four QCD θ-term. Measurements of the proton and neutron (and the deuteron) EDM might be sufficient to extract and test the $\bar{\theta} \leq 10^{-10}$ angle.

Reliable quantitative statements

Note: EDMs measurements are low-energy measurements

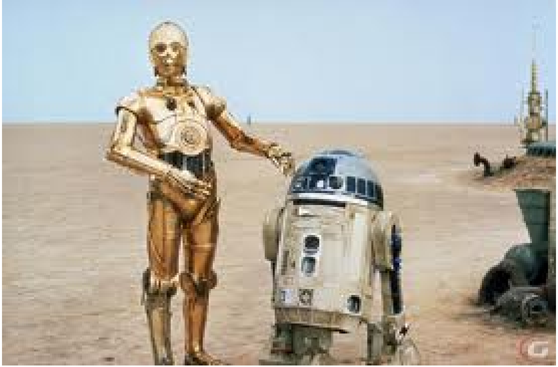
Thus, the pertinent theoretical treatment must be of low-energy and non-perturbative nature! We have two candidates:

1. lattice QCD
2. and low-energy effective field theories (extensions of chiral perturbation theory)

- In the long run lattice QCD will have the highest potential to predict proton and neutron EDMs:
- at least for the QCD θ-term induced EDMs.
- But applicability is an open question for
  - dimension-six operators beyond the SM (*e.g.* qEDM, qCEDM, gCEDM or four-quark EDMs)
  - and even more so for light nuclei (*e.g.* d, ^{3}He, t, or ^{7}Li)

The role of EFT

EDM-Translator from “quarkish” to “hadronic" language?



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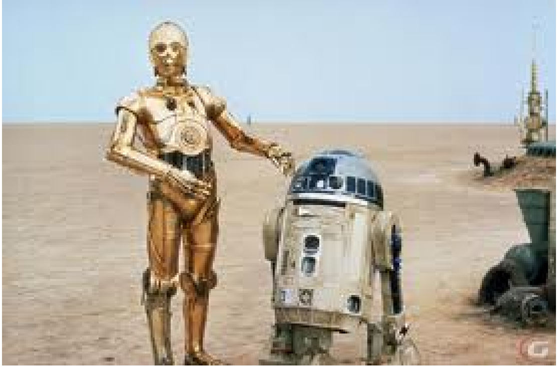

↪ Symmetries, esp. Chiral Symmetry and Goldstone Theorem
Low-Energy Effective Field Theory with External Sources

Outlook:

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- EDMs of light nuclei provide independent information to p and n
- EDMs of light nuclei may be larger & simpler than nucleon EDMs
- qEDM dominates if nuclear EDM is sum of nucleon EDMs
- Nuclear calculation possible up to accuracy of a few %
- Deuteron is a filter for the isospin-dependent qCEDM
- θEDM: $d_{^3\mathrm{He}} - 2d_\mathrm{p} - d_\mathrm{n} \quad \Leftrightarrow \quad \bar{\theta} \quad \Leftrightarrow$ p-,n-EDM

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Outlook: *May the force be with us!*

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From the theory point: a measurement of *p*, *n*, *d*, and ^{3}He EDM is necessary to disentangle the underlying physics