Searches for the Neutron EDM

Tests of BtSM Physics

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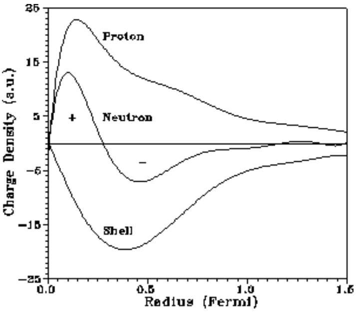
Outline

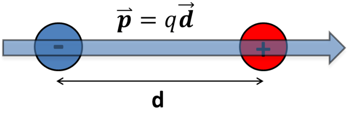
1. What is the neutron EDM?
2. Why do we care?
3. How do we measure it?
4. Who is measuring it?
5. When will we have answers?

Electric Dipole Moments

The electric dipole moment (EDM) is the second moment in the multipole expansion of the electric charge distribution.

It reflects the net seperation between positive and negative charges in a system.





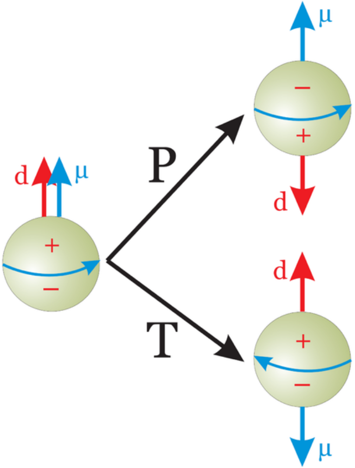
Naïvely, we can look at the neutron charge distribution and see this kind of seperation.

CP Violation

An Intrinsic electric dipole moment of a fundamental particle violates Time Reversal (T) symmetry.

T-violation $\rightarrow$ CP-violation

CP-violation is known to occur in the weak interaction, but further sources of CP-violation are not known.



[1] (Incorrect) Figure created by A. Knecht

Sources of CP Violation

Weak Decays of K and B Mesons

Massive Neutrinos

Supersymmetric Models

Complex Phases in CKM Matrix

Chromo "EDMs"

EDMs of Fundamental Particles

Decay of the Higgs Boson into Gauge Bosons

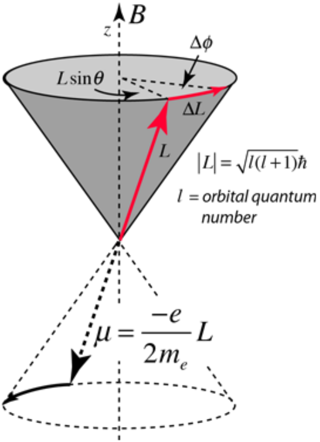
Experimental Techniques

The basic method of measuring an EDM is to measure the precession of the neutron spin in parallel and anti-parallel magnetic and electric fields.

$$h\nu = 2\mu_n B \pm 2d_n E \qquad (1)$$

This is called the Larmor Precession. By taking the difference, one can extract d_n

$$d_n = \frac{h}{4E}\delta\nu \qquad (2)$$



[2] Hyperphysics – Larmor Precession

Experimental Techniques

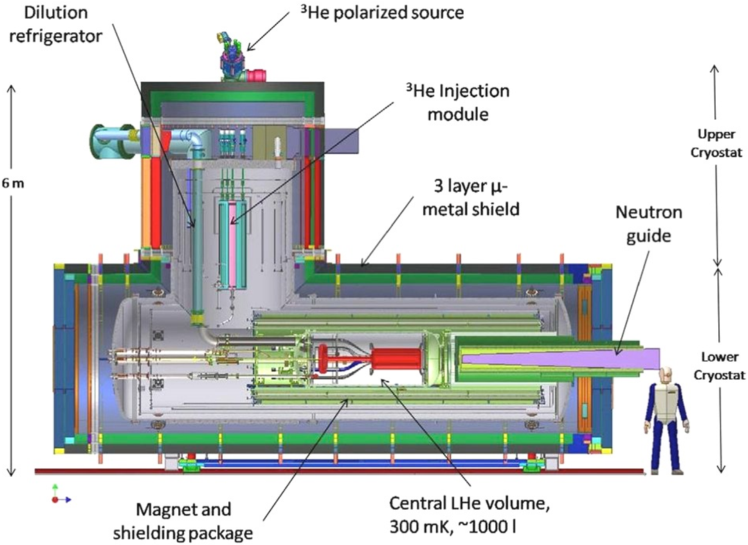
The magnetic moment of the neutron is well known:

$$\mu_n = -1.9130427(5)\mu_N \tag{3}$$

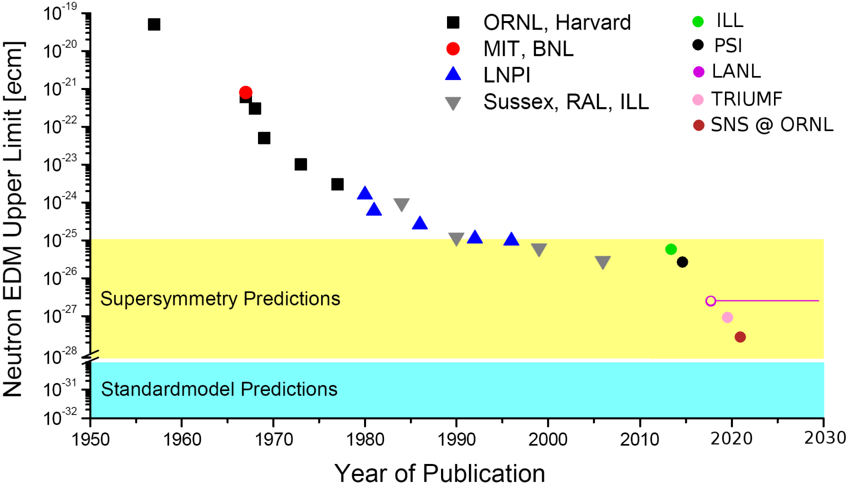
So the difficulty in the experiment is having a steady, well-known magnetic field.

Further Needs:

- Drift of the neutrons in the EM fields
- Precise determination of spin direction
- Shielding from external magnetic fields
- Use ^{3}He for cooling and as a co-magnetometer
- Use Ultracold neutrons to minimize excitations



[2] https://www.phy.ornl.gov/nedm/



[3] Original figure created by A. Knecht

Thanks for your attention!

References

[1] "Neutron Electric Dipole Moment", Wikipedia, `https://en.wikipedia.org/wiki/Neutron_electric_dipole_moment`

[2] A. Moyotl "New Sources of CP Violation", *J. Phys. Conf. Ser.* **912** (2017)

[3] T. M. Ito, "Plans for a Neutron EDM Experiment at SNS", *J. Phys. Conf. Ser.* **69** 012037 (2007) [arXiv:nucl-ex/0702024]

The Strong CP problem

In the early 1970's, several problems were being worked out with QCD and the strong interaction. One of these was the $U(1)_A$ anomaly, proposed by Weinberg (1975).

The solution of this problem came from adding a CP violating term to the QCD Lagrangian:

$$\mathcal{L} = \mathcal{L}_{QCD} + \theta \frac{g^2}{32\pi^2} F_a^{\mu\nu} \tilde{F}_{a\mu\nu} \tag{4}$$

where this θ parameter is the QCD phase angle.

Limits on the neutron electric dipole moment require $\theta < 10^{-10}$. The fact that θ must be so small is known as the **Strong CP Problem**.

Physics beyond the Standard Model

There are several extensions to the Standard Model that provide predictions for the size of the nEDM.

Examples:

- Unparticles: H. Georgi, Phys. Rev. Lett. 98, 221601. (2007)
- Chromo EDMs
- Trilinear Gauge Boson Couplings
- Higgs Boson decay to gauge bosons
- Supersymmetric Models: R. Arnowitt et. al., Phys. Rev. D 43, 3085. (1991)

Overview of experimental collaborations

Several experiments are currently running or being planned:

- CryoEDM: Sussex, RAL, Oxford, ILL, Kure (UK)
- Gatchina-EDM: PNPI, ILL, PTI (Russia)
- nEDM: PSI (Switzerland)
- nEDM: KEK (Japan)
- nEDM @ SNS: ORNL (USA)
- nEDM: LANL (USA)
- nEDM: TRIUMF (Canada)