Development of a simulation for measuring neutron electric dipole moment

Ryo KATAYAMA[1], Kenji MISHIMA[2], Satoru YAMASHITA[2], Dai SAKURAI[3], Masaaki KITAGUCHI[4], Tamaki YOSHIOKA[5], Yoshichika SEKI[6]

[1] Department of Physics, The University of Tokyo, [2] International Center for Elementary Particle Physics , Department of physics, Tokyo University of Science, Department of Physics, Nagoya University, Research Center for Advanced Particle Physics , [6]RIKEN

Introduction

- The neutron electric dipole moment (nEDM) is sensitive to new physics beyond the standard model because a lot of them expect new CP violation.
- For example, the highest precise nEDM measurement is 2.9×10^{-26} e•cm, while the super symmetry model (SUSY) predicts from 10^{-27} to 10^{-28} e•cm.
-Improving the precision 1 to 2 order of magnitude, we could achieve the region SUSY predicts (see Fig1).
- The signal is the spin precession nEDM produces in an electric fields.
- The ultra cold neutron (UCN), cooled down to about 300 neV, is able to be confined inside a material container and measured accurately its nEDM.
-Turning on electric fields parallel/anti-parallel to magnetic fields and by subtraction of one another, we are able to extract the nEDM (see Fig2).

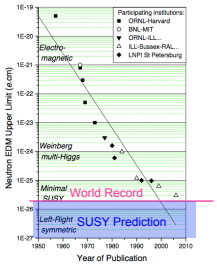


Fig.1 Sensitivity of nEDM experiments over time (P.G. Harris, arXiv:0709.3100)

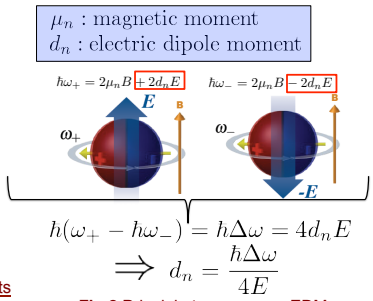
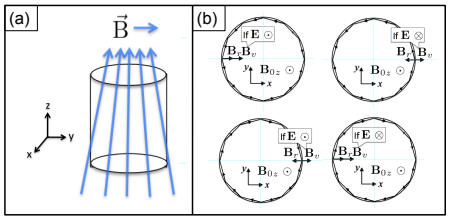


Fig.2 Principle to measure nEDM

Systemetic uncertainties for nEDM experiments

-If there are any process, except nEDM, which does not compensate after the measurement procedure, it becomes a systematic uncertainty.
-The systematic uncertainties, generally, could occur owing to the motion of UCN, the geometry of systems, and the distortion in the magnetic fields.
-Thus, it is essential to qualitatively understand these effects.
-We focus on the uncertainty depending on the situation as follows:
  -There is cylindrical symmetric distorted magnetic fields in a cylindrical container, and UCNs rotate collectively for 100 second (See Fig3).
- For example, when UCN rotates clockwise (or anti-clockwise) with 6cm and 3m/sec for 100 sec in field whose strength are 1 uT and 10 KV/cm and distorted magnetic fields is 1 nT/m, false-EDM is about 3(or 6)$\times10^{-27}$ e cm.



If UCN rotates as left figure, the relativistic magnetic fields, Bv, and the distorted fields, Br, also rotate, namely, UCN feel as though there are the steady and a perturbative rotated fields. In this situation, the spin precession is as follows:
-The case with the perturbation is faster than the other.
-The case in left-rotation is faster precession than the other.
-The case that Bv parallel to Br is faster than the other.
Hence, by the subtraction of one another, systematic uncertainties occur.

Fig.3 (a) Schematic diagram of a distorted magnetic fields (b) Schematic diagram of the distorted magnetic fields (Br) and relativistic one (Bv)

Development of a simulation for nEDM experiments

- We newly develop a simulation by reorganizing Geant4-UCN based on Geant4 ver4.9.2.
- Geant4-UCN, developed by PSI [1], can simulates the motion of UCN taking into account geometry and the gravity fields properly.
- We add essential function to Geant4-UCN as follows:
  1. The reflection law according to micro-roughness model (MR model) is incorporated to Geant4 UCN, because the traditional law known as Lambert's cosine law is entirely difference from actual measurement [2].
  2. We incorporate the equation of motion according to the relativistic spin precession, BMT equation, into Geant4-UCN.
- In spite of great efforts as above, we found the fact that time variable has rounding error corresponding to 10^{-27} e cm false EDM [3].
-To avoid the problem, extracting the set of coding relevant to the essential function we organize an alternative to Geant4-UCN, and It can simulate properly with errors corresponding to 10^{-29} e cm [3].

Reference
[1] http://ucn.web.psi.ch/mc/geant4ucn
[2] EPJA10, Diffuse reflection of ultracold neutron from low-roughness surfaces, F.Atchison et,al.
[3] Ryo KATAYAMA,NOP 2013, to be published

Systematic uncertainty dependency on roughness

- The diffuse scattering from the surface of a material container can be effective in suppressing systematic uncertainties because they depend on specific motions.
-MR model prediction of the diffuse scattering is determined by surface roughness, b and w parameter, and its nuclei force, fermi potential: V_F.
  -The b parameter indicates roughness perpendicular to the surface plane, while the w parameter parallel to it.
- We simulate diffusion effects choosing conditions as follows:
  - Distortion source: a dipole moment whose strength is 1 nT at the center and gradient is 0.9 nT/m between up and down sides.
  - Container: made of crystal, whose V_F is 94 neV.
  - Roughness are selected as nine matrix:
    - The b parameter are chosen to 1/10, 2/10, and 3/10 out of its theoretical limitation,7.4 nm.
    - We have no information of w parameter, so that it is chosen as three division of Ni (22 nm) and DLC (45 nm) one, well known.

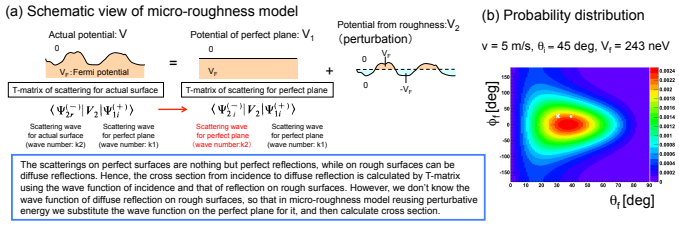


Fig.4 Micro-roughness model, A. Steyerl, Z.Physik 254, 169 (1972), PRC 81, 055505 (2010)

Simulation results

-We acquire data sets by using procedure as follows:
  1. Make UCN throwing in ±x-direction at (0, 5.99 cm, 0) with an electric fields parallel/anti-parallel to magnetic fields and roughness fixed.
  2. Subtract the measured data after 100 second from one another.
  3. Repeat 1 – 2 above 168 times to estimate expected uncertainty.
-The result obtained from the combination of various roughness shows in Fig5 as 3D plot false-EDM, b and w, sorted as clock/anti-clockwise.
-Statistic uncertainty: about 3 $\times10^{-29}$ e cm.
-It proves that
  -The uncertainty for anti-clockwise is suppressed to about 7.3×10^{-28} e cm, while for clockwise to about 6.7×10^{-28} e cm.
  -The maximum difference for anti-clockwise among roughness is about 0.8×10^{-28}, while for clockwise about 1.4×10^{-28}.

Anti-clockwise false-EDM (e cm)

b\w	22	33	45
0.7	7.7E-28	7.5E-28	7.4E-28
1.4	7.1E-28	7.1E-28	7.9E-28
2.1	7.1E-28	7.1E-28	7.1E-28

Clockwise false-EDM (e cm)

b\w	22	33	45
0.7	6.5E-28	6.9E-28	6.3E-28
1.4	6.6E-28	6.2E-28	6.5E-28
2.1	7.6E-28	7.2E-28	6.7E-28

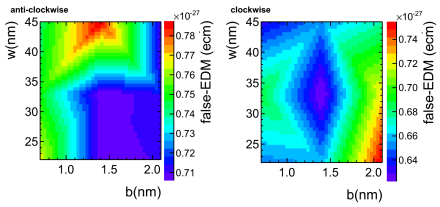


Fig.5 (a) The b and w 9 parameter matrix (b) The 3D plot fasle-EDM, b and w parameter

Summary

Assuming
  -MR model, whose b are 0.7, 1.4, 2.1 nm and w are 22, 33, 45 nm.
  -UCNs at first rotating with 3m/sec
  -the 6 cm radius and 10 cm height cylinder made of crystal
  -A steady 10KV/cm electric fields and 1uT magnetic one and cylindrical symmetric 0.9 nT/m dipole magnetic fields
then the false-EDM is suppressed from 6×10^{-27} to 7×10^{-28} e cm for anti-clockwise by randomization, while from 3×10^{-27} to 7×10^{-28} e cm for clockwise. The false-EDM difference between maximum and minimum is about 1 $\times10^{-28}$ e cm.
-Future plan:
  -Do simulation changing geometry.
  -Measure actual roughness and incorporate them to MR model.