Contents

1 Thomas-BMT equation

The Thomas-BMT equation describes the dynamics of spin vector $\boldsymbol{s}$ in magnetic field $\boldsymbol{B}$ and electrostatic field $\boldsymbol{E}$. Generalized to account for the EDM effects, it can be written (in the rest frame) as follows: [1, p. 6]

$$\frac{\mathrm{d}\boldsymbol{s}}{\mathrm{d}t} = \boldsymbol{s} \times (\boldsymbol{\Omega}_{MDM} + \boldsymbol{\Omega}_{EDM}), \tag{1}$$

where the MDM and EDM angular frequencies $\boldsymbol{\Omega}_{MDM}$ and $\boldsymbol{\Omega}_{EDM}$ are

$$\boldsymbol{\Omega}_{MDM} = \frac{q}{m}\left[G\boldsymbol{B} - \left(G - \frac{1}{\gamma^2 - 1}\right)\frac{\boldsymbol{E}\times\boldsymbol{\beta}}{c}\right], \tag{2}$$

$$\boldsymbol{\Omega}_{EDM} = \frac{q}{m}\frac{\eta}{2}\left[\frac{\boldsymbol{E}}{c} + \boldsymbol{\beta}\times\boldsymbol{B}\right]. \tag{3}$$

In the equations above, m, q, G are the particle mass, electric charge, and anomalous MDM respectively; $\beta = {}^{v_0}/_{c}$, is the ratio of the particle velocity to the speed of light; γ is the Lorentz factor. The EDM factor η is defined by $d = \eta\frac{q}{2mc}s$, where d is the particle EDM and s is its spin.

2 Spin tune

In the standard spinor formalism, the spin transfer matrix per turn in a ring R equals [p. 4][2]

$$\boldsymbol{t}_R = \exp(-i\pi\nu_s\boldsymbol{\sigma}\cdot\boldsymbol{c}) = \cos\pi\nu_s - i(\boldsymbol{\sigma}\cdot\boldsymbol{c})\sin\pi\nu_s, \tag{4}$$

where $\boldsymbol{\sigma}$ is the Pauli matrix vector, $\boldsymbol{c}$ is a unit vector, pointing along the local spin precession axis. The spin precession angular velocity can be written as

$$\boldsymbol{\Omega}_s = 2\pi f_s\boldsymbol{c} = 2\pi f_R\nu_s\boldsymbol{c},$$

where f_R is the beam revolution frequency, and ν_s is the *spin tune*, i.e. the number of spin revolutions per turn.

3 The Frozen Spin concept

It can be observed in eq (2) that, in the absence of an EDM, the spin of a beam particle can be frozen along its momentum direction: $\boldsymbol{\Omega}_{MDM} = \boldsymbol{0}$, i.e., the so-called Frozen Spin (FS) condition can be realized.

EXPLAIN HOW FS IS A RESONANCE. [4]

EDM experiment methodologies can now be classified into two subgroups: 1) Resonance, and 2) Non-resonance.

3.1 Storage rings for EDM search experiments

Storage rings can be classified into three groups:

1. purely magnetic (like COSY, NICA, etc),
2. purely electrostatic (Brookhaven AGS Analog Ring),
3. combined rings.

In view of eq (2), the FS condition cannot be realized in a purely magnetic ring. For a number of particles, such as the proton, whose $G > 0$, a purely electrostatic ring can be used in a resonance-type EDM experiment methodology. For particles with $G < 0$ (such as the deuteron), this is not an option, and a combined ring must be used.

For the realization of the FS condition in a combined ring, a radial E-field $E_r = \frac{GBc\beta\gamma^2}{1-G\beta^2\gamma^2}$ is introduced. [3]

Reasons why a purely electrostatic ring can be used in a resonance-type methodology in the proton case. Reasons why a combined ring is required for the deuteron case in order to realize a resonance-type methodology.

4 Non-resonance methods

4.1 COSY Spin Tune Mapping + RF Wien Filter Method

5 Resonance methods

5.1 BNL Frozen Spin Method

5.2 Koop's Spin Wheel Modification

5.3 Frequency Domain Method

References

[1] Eremey Valetov. FIELD MODELING, SYMPLECTIC TRACKING, AND SPIN DECOHERENCE FOR EDM AND MUON G-2 LATTICES [Internet]. [Michigan, USA]: Michigan State University; Available from: http://collaborations.fz-juelich.de/ikp/jedi/public_files/theses/valetovphd.pdf

[2] Saleev A, Nikolaev NN, Rathmann F, Augustyniak W, Bagdasarian Z, Bai M, et al. Spin tune mapping as a novel tool to probe the spin dynamics in storage rings. Physical Review Accelerators and Beams [Internet]. 2017 Jul 7 [cited 2018 Oct 8];20(7). Available from: http://arxiv.org/abs/1703.01295

[3] D. Anastassopoulos, V. Anastassopoulos, D. Babusci. AGS Proposal: Search for a permanent electric dipole moment of the deuteron nucleus at the 10 29 e cm level. [Internet]. BNL; 2008 [cited 2016 Nov 25]. Available from: https://www.bnl.gov/edm/files/pdf/deuteron_proposal_080423_final.pdf

[4] Stockhorst H. Polarized Proton and Deuteron Beams at COSY. arXiv:physics/0411148 [Internet]. 2004 Nov 16 [cited 2018 Oct 22]; Available from: http://arxiv.org/abs/physics/0411148