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Supervisory Control and Data Acquisition system of the n2EDM experiment

Master's Thesis

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Abstract

Just as nowadays no serious experiment can be built and conducted by a single person, the experiment itself cannot consist of a single tool. The n2EDM experiment aims to achieve an ambitious goal: to measure the electric dipole moment of neutron with a new level of precision. Such challenging project demands the need for the complex and well-connected system. This thesis intends to describe the development of new and improvement of existing components, such as:

- **COM handler** — an adapter translating the POSIX pipes to the TCP/IP connections. Every node in the system is connected with others through it.
- **Sequencer** — a software node orchestrating other nodes. It follows the user-generated script allowing one to describe the reproducible behaviour of the whole DAQ system with a human-readable set of commands.
- **Proxy for the remote magnetometers** — a smart bridge between the pool of the remote magnetometers and a standard TCP/IP interface of the COM handler.
- **Surrounding field compensation system** — a system for active stabilisation of the magnetic field. It uses the data collected by the remote magnetometers and a set of controlled coils to minimise the fluctuations of the magnetic field in the area of the experiment. Better description when I start working on it.

These pieces are essential for the n2EDM experiment to function, so the aim was to make them error-resistant, extendable and easy to support for the future developers.

Contents

Chapter 1

Introduction

Out of S. Okubo's effect
At high temperature
A fur coat is sewed for the Universe
Shaped for its crooked figure

A. D. Sakharov [6]

We interact with matter every day. Even you, the reader, are probably made out of matter! However, antimatter is so rare that it is considered to cost a few hundred millions Swiss francs per gram [1], making it the most expensive substance in the universe. Why does such a stunning difference in the abundance exist?

First step to solving this problem is to define what are the required conditions that would allow the disbalance to evolve. Those conditions [2] were described [6] by Andrei Sakharov in 1967:

- Violation of baryon number conservation
- C- and CP-symmetry violation
- Processes take place far from thermal equilibrium

Let's take a look at the CP-symmetry and prove that a non-zero electric dipole moment of an elementary particle would indeed break it. We would select neutron as a particle of choice.

The neutron in the ground state has spin of $I = 1/2$ and can be characterised completely by a single quantum number of a spin projection $m_I = \pm 1/2$. We can write down a Hamiltonian [3] of this neutron in external electric and magnetic fields $\vec{E}$ and $\vec{B}$:

$$\mathcal{H} = -\frac{d_n \vec{I} \cdot \vec{E} + \mu_n \vec{I} \cdot \vec{B}}{I} \tag{1.1}$$

with d_n and μ_n being the electric and magnetic moments of the neutron [4].

It does not make sense to discuss the potential violation of the symmetries before we define them. Fundamental symmetries are blended into the fabric of our Universe by providing sufficient conditions [5] for the conservation laws. In our analysis we would consider three symmetries of the Standard Model: C, P and T.

- (C)harge —- replaces every particle with its antiparticle: $q \to -q$
- (P)arity — inverts the physical space: $\vec{r} \to -\vec{r}$
- (T)ime — turns the time back: $t \to -t$

How would the P and T inversions affect [2] the Hamiltonian from Eq. 1.1?

Parity transformation only act on a polar vector of the electric field: $\vec{E} \to -\vec{E}$, both $\vec{B}$ and $\vec{I}$ are conserved. This brings us to

$$P\mathcal{H} = -\frac{d_n \vec{I} \cdot \left(-\vec{E}\right) + \mu_n \vec{I} \cdot \vec{B}}{I} \neq \mathcal{H} \tag{1.2}$$

Time reversal would affect only axial vectors $\vec{B}$ and $\vec{I}$: $\vec{B} \to -\vec{B}$, $\vec{I} \to -\vec{I}$, the field $\vec{E}$ is left as is:

$$T\mathcal{H} = -\frac{d_n \left(-\vec{I}\right) \cdot \vec{E} + \mu_n \left(-\vec{I}\right) \cdot \left(-\vec{B}\right)}{I} \neq \mathcal{H} \tag{1.3}$$

Assuming that the CPT invariance [7] is conserved, we derive the violation of a CP-symmetry.

We have defined our motivation for determining the value of the neutron electric dipole moment. But how can we do it?

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