



Eidgenössische Technische Hochschule Zürich  
Swiss Federal Institute of Technology Zurich

# **Supervisory Control and Data Acquisition system of the n2EDM experiment**

Master's Thesis

Konstantin Nesterov

Saturday 16<sup>th</sup> November, 2019

Advisors: Prof. Dr. K. S. Kirch, Dr. Jochen Krempel

Department of Physics, ETH Zürich

---

## 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

---

<b>Contents</b>	<b>ii</b>
<b>1 Introduction</b>	<b>1</b>
<b>Bibliography</b>	<b>4</b>

## 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 [7]

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 [7] 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  $\vec{B}$ :

---


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

with  $d_n$  and  $\mu_n$  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 [6] 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:  $q \rightarrow -q$
- (P)arity — inverts the physical space:  $\vec{r} \rightarrow -\vec{r}$
- (T)ime — turns the time back:  $t \rightarrow -t$

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:  $\vec{E} \rightarrow -\vec{E}$ , both  $\vec{B}$  and  $\vec{I}$  are conserved. This brings us to

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

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

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

Assuming that the  $CPT$  invariance [8] is conserved, we derive the violation of a  $CP$ -symmetry, which provides us motivation to measure the EDM of the neutron.

*"Wait a minute,"* could have said an attentive reader at this point. *"Does not Standard Model predict a non-zero EDM of the neutron already? I am still not convinced why would you want to conduct this experiment."*

And an attentive reader would have had a completely fair point! Indeed, Standard Model predicts [5] the following:

$$d_n \approx 2 \cdot 10^{-32} \text{ e} \cdot \text{cm} \quad (1.4)$$

However, we would still like to measure  $d_n$  for the reasons listed below:

- The only way to prove the theory is to check it experimentally. So far no one has measured  $d_n$  with a precision close to the predicted value

- The result that can be achieved by using Standard Model is too weak to explain the baryogenesis [2], yet baryogenesis has clearly happened
- If we go beyond Standard Model to find a mechanism, through which the Universe as we know it could have been formed, we need to cut off theories that do not agree with experimental data. This is something that this experiment does perfectly: on the Fig. 11 one can see all theoretical models that the measurement of the neutron EDM has ruled out, allowing the scientists to focus on more prominent theories.



Figure 11: Measurement history of the neutron EDM [3]

Hopefully these reasons would convince even the most demanding reader in the need to conduct the  $n2EDM$  experiment. But what is  $n2EDM$  exactly? We will try to explain that in the next chapter.

---

## Bibliography

---

- [1] Alvaro de Rújula and Rolf Landua. Antimatter Questions & Answers, 2001. URL: <https://archive.ph/20080421220420/http://livefromcern.web.cern.ch/livefromcern/antimatter/FAQ1.html>.
- [2] Dirk Dubbers and Michael G. Schmidt. The neutron and its role in cosmology and particle physics. *Reviews of Modern Physics*, 83(4), 2011. doi:10.1103/RevModPhys.83.1111.
- [3] R. Golub and Steve K. Lamoreaux. Neutron electric-dipole moment, ultracold neutrons and polarized  $^3\text{He}$ . *Physics Reports*, 237(1):1–62, 1994. doi:10.1016/0370-1573(94)90084-1.
- [4] R. Golub and J. M. Pendlebury. The electric dipole moment of the neutron. *Contemporary Physics*, 13(6):519–558, nov 1972. URL: <http://www.tandfonline.com/doi/abs/10.1080/00107517208228016>, doi:10.1080/00107517208228016.
- [5] I. B. Khriplovich and A. R. Zhitnitsky. What is the value of the neutron electric dipole moment in the Kobayashi-Maskawa model? *Physics Letters B*, 109(6):490–492, 1982. doi:10.1016/0370-2693(82)91121-2.
- [6] E. Noether. Invariante Variationsprobleme. *Nachrichten von der Gesellschaft der Wissenschaften zu Göttingen, Mathematisch-Physikalische Klasse*, 1918:235–257, 1918. URL: <http://eudml.org/doc/59024>.
- [7] D. Sakharov. Violation of CP invariance, C asymmetry, and baryon asymmetry of the universe. *Soviet Physics - Uspekhi*, 34(5):392–393, 1991. doi:10.1070/PU1991v034n05ABEH002497.
- [8] Julian Schwinger. The Theory of Quantized Fields. I. *Physical Review*, 82(6):914–927, jun 1951. URL: <https://link.aps.org/doi/10.1103/PhysRev.82.914>, doi:10.1103/PhysRev.82.914.



Eidgenössische Technische Hochschule Zürich  
Swiss Federal Institute of Technology Zurich

## Declaration of originality

The signed declaration of originality is a component of every semester paper, Bachelor's thesis, Master's thesis and any other degree paper undertaken during the course of studies, including the respective electronic versions.

Lecturers may also require a declaration of originality for other written papers compiled for their courses.

---

I hereby confirm that I am the sole author of the written work here enclosed and that I have compiled it in my own words. Parts excepted are corrections of form and content by the supervisor.

**Title of work** (in block letters):

**Authored by** (in block letters):

*For papers written by groups the names of all authors are required.*

**Name(s):**

**First name(s):**


With my signature I confirm that

- I have committed none of the forms of plagiarism described in the '[Citation etiquette](#)' information sheet.
- I have documented all methods, data and processes truthfully.
- I have not manipulated any data.
- I have mentioned all persons who were significant facilitators of the work.

I am aware that the work may be screened electronically for plagiarism.

**Place, date**

**Signature(s)**


*For papers written by groups the names of all authors are required. Their signatures collectively guarantee the entire content of the written paper.*