New approach to test a neutron electroneutrality by spin interferometry technique

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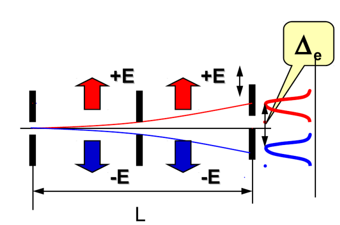
Motivation

Electroneutrality of the free neutron is commonly accepted.

- The zero neutron electric charge is not a request of Standard Model.
- Zero neutron electric charge is the test of physics beyond the Standard Model.
    - Overall, only a few hints exist for physics beyond the Standard Model, and the neutrality of neutrons and atoms is such a hint.
    - Some models beyond the SM violates boson - lepton (B- L) symmetry could accommodate a nonzero neutron charge $q_n = \varepsilon(B - L) \neq 0$, but the charge of the hydrogen atom (which has $B = L$) would remain zero.
    - Some variants of theories with additional extra dimensions give the possibility to have non-zero neutron electric charge.

Neutron electric charge experiment[1]



Parameters of the setup

$L = 9\text{m},\ \lambda = 17.5\text{Å},$

$E = 60\ \text{kV/cm}.$

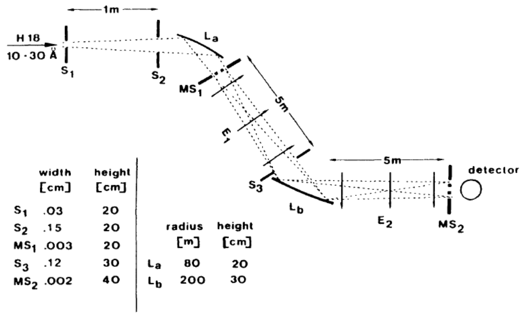


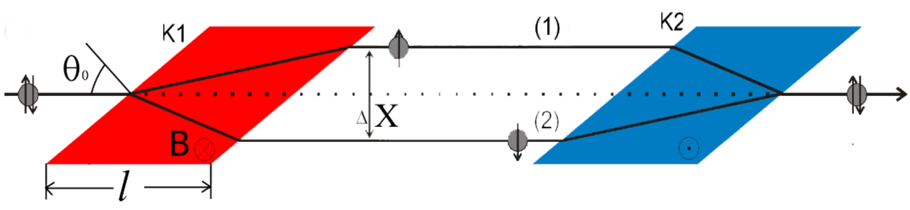
FIG. 1. The design of the deflection apparatus. MS_1 and MS_2 is a multislit system with 31 slits, 30 μm wide, separated by 30-μm-wide absorbing zones. For clarity the dimensions and angles of deflection are not to scale.

Reached accuracy

$$q_n = (-0.4 \pm 1.1)10^{-21} \cdot e$$

[1] J.Baumann, R.Gahler, J.Kalus, W.Mampe, PR D37, 3107 (1988)

SESANS method

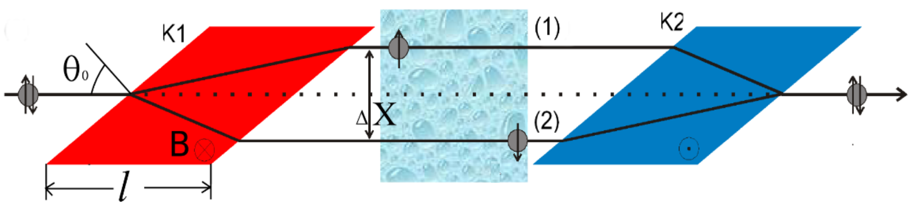


Neutron beam polarization **P** is directed perpendicularly to guiding magnetic field B. Neutron wave function can be written in form

$$\psi_{in} = \frac{1}{\sqrt{2}} \begin{pmatrix} e^{-\frac{i\varphi_0}{2}} \\ e^{+\frac{i\varphi_0}{2}} \end{pmatrix},$$

here φ_0 - neutron spin direction in azimuthally plane. Let's consider **P** parallel to X-axis ($\varphi_0 = 0$) $\Rightarrow$ $\boxed{\mathbf{P} = (1, 0, 0)}$

SESANS method - II



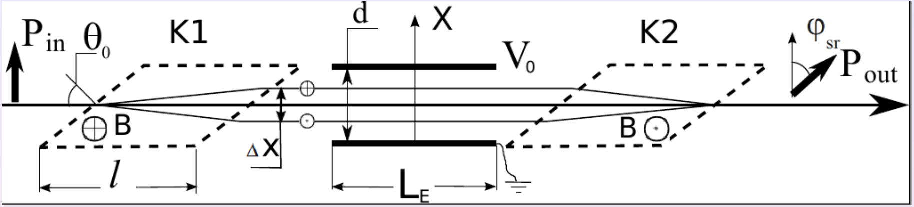
Let's apply $V_{sr}(x)$. The phase difference between these two eigenstates will be

$$\varphi_{sr} = (V_{sr}(x_0) - V_{sr}(x_0 + \Delta x))/\hbar \cdot \tau,$$

The neutron wave function on the exit of coil K2 will be

$$\psi_{out} = \frac{1}{\sqrt{2}} \begin{pmatrix} e^{-\frac{i\varphi_{sr}}{2}} \\ e^{+\frac{i\varphi_{sr}}{2}} \end{pmatrix} \Rightarrow \boxed{\mathbf{P} = (\cos\varphi_{sr}, \sin\varphi_{sr}, 0)}$$

Electric field



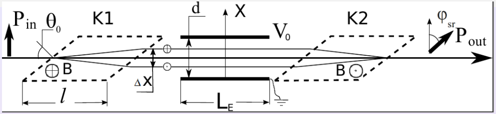
Electric field is applied $V_E(x) = E_0 \cdot x$.
The spin rotation angle will be:

$$\phi_e = \frac{E_0 q_n \Delta x}{\hbar} \cdot \tau$$

The value of spatial splitting Δx is

$$\Delta x = \frac{\mu B}{E} \cdot l \cdot \tan\theta_0$$

Numerical estimations



Neutron beam splitting

$$\Delta x = \frac{\boxed{\lambda_n^2} lB \tan(\theta_0) \gamma m_n}{4\pi^2 \hbar}$$

Phase shift due to neutron electric charge

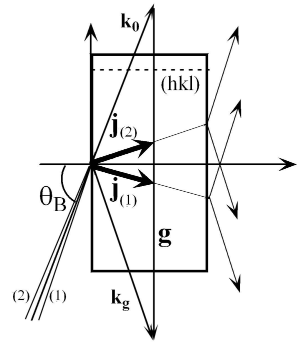
$$\boxed{\phi_e = E_0 q_n l L_E B \tan\theta_0 \gamma \frac{\boxed{\lambda_n^3} m_n^2}{8\pi^3 \hbar^3},}$$

Numerical estimations show, that under the conditions ($B = 0.1$T, $L_E = 1$m, $l = 1$m, $E_0 = 100$ kV/cm, $\tan\theta_0 = 10$, $\lambda_n = 10$Å)

$$\phi_e = 2.6 \cdot 10^{15} \cdot e_n.$$

where $e_n = q_n/e$. The accuracy of $\Delta\phi_e \simeq 10^{-5}$ corresponds to the neutron electric charge $\boxed{\sigma(e_n) \simeq 4 \cdot 10^{-21}}$ part from electron charge.

Laue diffraction in perfect crystal



Symmetrical Laue diffraction.

$\mathbf{j}_{(1)}$ and $\mathbf{j}_{(2)}$ are the neutron fluxes for two direction of incident beam.

Effect of diffraction enhancement

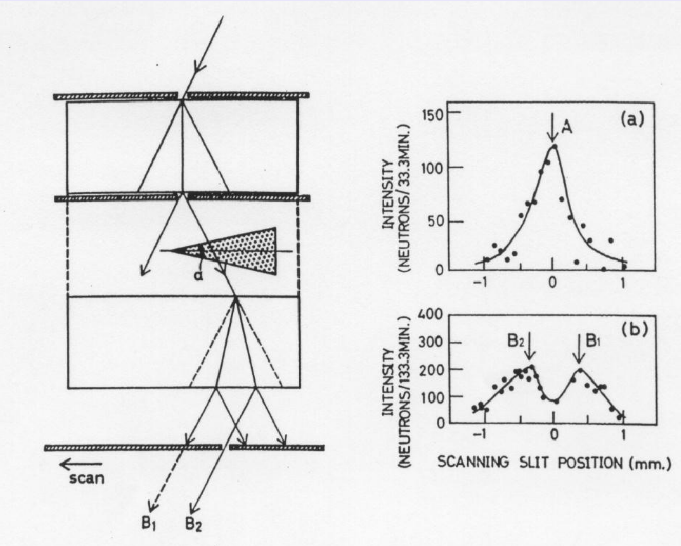
The neutron in the crystal changes the momentum direction by the angle of Ω (by several tens degrees) while the incident neutron beam deflects by the Bragg width (within a few arc seconds)

$$\Omega = \Delta\theta \cdot \frac{E}{2v_g} \Rightarrow \Delta\theta \cdot 10^5$$

The same phenomenon occurs then not direction but neutron energy is changed according to the

$$\Delta\theta = \frac{\Delta E}{2E} \tan\theta_B$$

Measurement the neutron prism refraction[2]

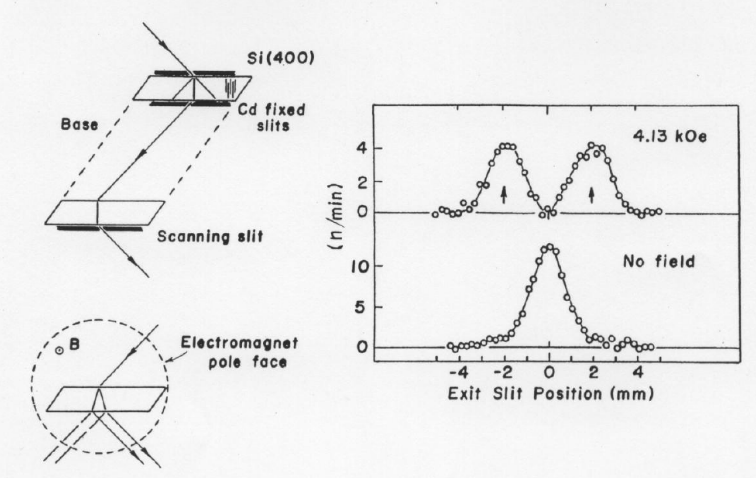


$\Leftarrow$ no refracting prism

$\Leftarrow 0.032$ arc sec $=$
$= 1.5 \cdot 10^{-7}$ rad
refracting prism

[2] S.Kikuta et al., J. Phys. Soc. Japan, **39** (1975) 471

Change neuron length wave in magnetic field[3]

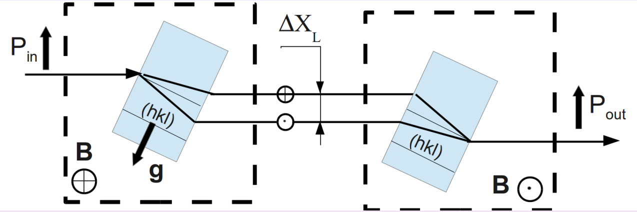


⇚ 4.13 kOe magnetic field

⇚ no magnetic field

[3] A.Zeilinger, C.G.Shull, Phys.Rev.B **19** (1979) 3957

SESANS + Laue diffraction



The values of neutron splitting

Laue diffr.+SESANS | Standard SESANS

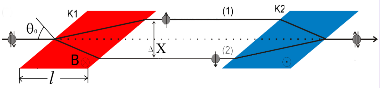
$$\Delta X_L = \frac{\mu B}{2v_g} L \sin\theta_B \iff \Delta X = \frac{\mu B}{E} \cdot l \cdot \tan\theta_0$$

About $K_g = \frac{E}{2v_g} \Rightarrow 10^5$ **times more.**

ΔX_L for (220) plane of silicon and (100) plane of quartz crystals, $L = 10$ cm and $\theta_B = 65^0$ can be $\sim 10\mu$m and $\sim 25\mu$m correspondingly for the $B = 1$ G.

Measurement a neutron refraction by SESANS[4]

SESANS at WWR-M reactor (PNPI, Gatchina)



Neutron length wave - 2.3 Å,

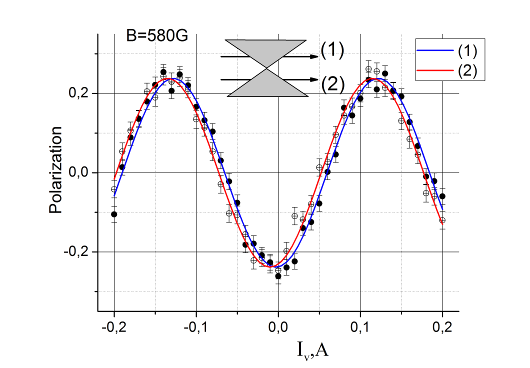
$B = (40 \div 800)$Oe

$\theta_0 = 45^0$

$l = 50$cm

Δx reached about 200 nm.

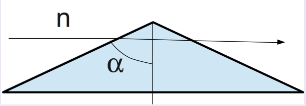
Example of experimental curves



We use the quartz crystal prism with the vertex angle about 156^0 for neutron beam refraction.

[4] Thanks to Axelrod L.A. and Zabenkin V.N.

Neutron refraction in quartz prism



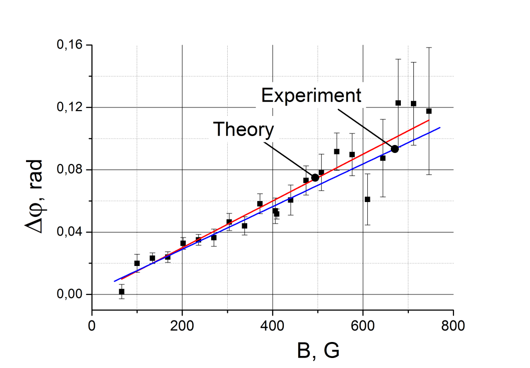
Value of phase shift due to refraction in prism

$$\Delta\varphi_r = \frac{V_0}{E}\frac{2\pi}{\lambda}\Delta x \tan\alpha$$

The used quartz prism

$V_0 \simeq 10^{-7}$ eV, $\alpha = 78^0$

The phase shift dependence on a value of magnetic field in main coils.



Summary

New approach to test a neutron electroneutrality is proposed.

- It is based on using spin interferometer technique realised in the SESANS apparatuses
- The sensitivity of the proposed technique can be a few 10^{-21} e, that is about the best current accuracy
- There is a possibility to improve the method accuracy on a few orders based on a neutron Laue diffraction in a perfect crystal
- The demonstration experiment to test the possibility to measure phase shift caused by neutron refraction in media was done. The results fully coincide with the theoretical expectation.