Probing the electric neutrality of neutrons

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Introduction

We propose to test the electric neutrality of neutrons by using Ramsey's method of separated oscillating fields applied to quantum states in the gravity potential of the earth.

In the presence of an electric field E, the energy of the quantum states changes due to an additional electrostatic potential if a neutron carries a nonvanishing charge. The energy shift differs from state to state due to the properties of the wave function in a linear potential. The energy difference between two quantum states with and without applying an electric field is measured.

In the long run our new method has the potential to improve the current limit for q_n by 2 orders of magnitude.

Goals

- probe neutron's neutrality
- Ramsey's method applied to neutron's quantum states in the gravity potential of the earth (exp. setup: see proposal by H. Abele)
- electric field E shifts energy of quantum states if $q_n \neq 0$ nonzero charge (nonlinear effect)
- sensitivity in energy:

$$\Delta E = \frac{\Delta\phi\,\hbar}{t} = 4.8 \times 10^{-21}\ \text{eV}$$

for N = 430.000 neutrons (50 days beam time) and t = 130 s interrogation time

- sensitivity to charge:

$$q_n = 10^{-23}\ q_e$$

with an electric field of E = 10^6 V/m

Work plan

1. Modifications of the already existing setup:
   separation of region 1 and 2
   length of region 2 is 15 cm
   installation at PF2 at ILL in 2010
2. Observation of transitions between quantum states in resonance:
   measurement of Rabi floppings with higher statistics
3. Installation of region 3 to 5:
   flight path in region 3 is 60 to 80 cm
   measurement of first Ramsey signal in 2011
4. Search for phase shifts induced by a hypothetical charge of a neutron in 2012

State of the art

direct measurements of neutron charge q_n:
deflection y of a neutron beam in a homogeneous electric field E_0 of length L

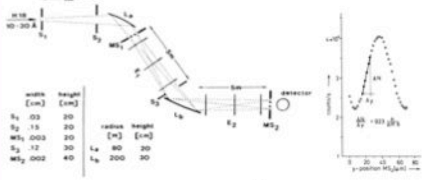
$$y = \frac{q_n E_0 L^2}{2 m_n v^2}$$

uncertainty in the measurement

$$\sigma_y = \frac{\Delta}{\sqrt{N}}$$

where 2Δ is the full width at half maximum of the beam profile, and *N* is the total number of counts

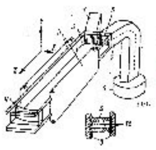
- ***Baumann et al.*** *(1988)*:
  multislit-system, cold neutrons



sensitivity: $\Theta = \frac{y}{L} = 10^{-11}$

result: $q_n = (-0.4 \pm 1.1) \times 10^{-21} q_e$

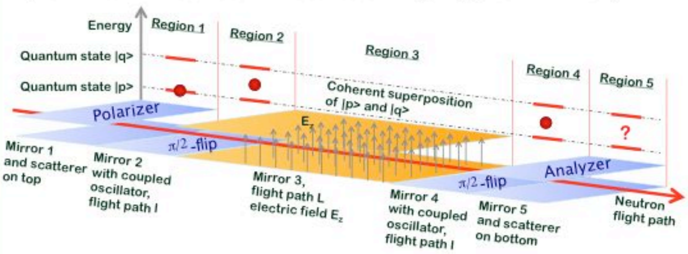
- ***Borisov et al.*** *(1988)*:
  UCN experiment



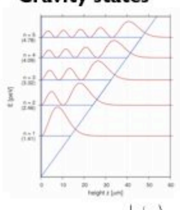
result:
$q_n = (-4.3 \pm 7.1) \times 10^{-20} q_e$

Experimental setup

- Ramsey's method of separated oscillating fields applied to neutron's quantum states in the gravity potential of the earth
- resonance transition frequency ω_{13} = 2902 Hz for (E_3 - E_1) = 1.91 peV
  $\pi/2$ flip: oscillating magnetic field gradients or modulation of mirror potential (vibrations)
- flight path with electric field: E_z = 6 × 10^6 V/m
  improve: decrease distance of electrodes to 100 µm (E_z = 30 × 10^6 V/m)

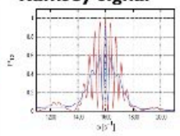


Gravity states



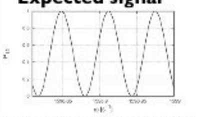
- Airy functions $|\psi_n\rangle$

Ramsey signal



- narrow resonance lines
- slope of central peak indep. of velocity spectrum

Expected signal



- for storage time of 100s

Optimisation of parameters:

- Neutron wavelength and statistical sensitivity
- Electric field optimization
- Mirror flatness and stability of oscillator
- Deviations, proportional to the electric field E_z

Method

- electrostatic potential

$$\Delta V = q_n E_z z$$

leads to an energy shift

$$\Delta E_n = \langle \psi_n \mid \Delta V \mid \psi_n \rangle$$

nonlinear effect due to gravity potential

- difference of energy shifts probed by Ramsey's method

$$\Delta E = \Delta E_m - \Delta E_n$$

- normalised energy shift is independent of the quantum states m, n but depends on q_n

$$\frac{\Delta E}{E} = q_n E_z \frac{\langle\psi_m|z|\psi_m\rangle - \langle\psi_n|z|\psi_n\rangle}{E_m - E_n}$$

for transitions from 1 → 3 we get:

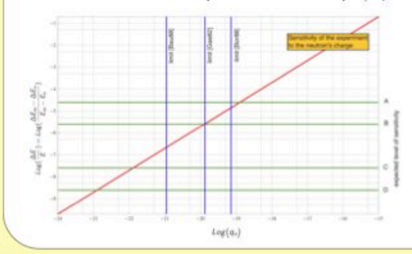
$$\frac{\Delta E[eV]}{E[eV]} = q_n[e] E_z[V/m] \times 6.51 \times 10^6 [m/eV]$$

- for ΔE = 4.8 × 10^{-21} eV,
  E = 1.91 peV,
  E_z = 30 × 10^6 V/m

we get $q_n < 1.3 \times 10^{-23}\ q_e$

Sensitivity

- beam experiment at PF2 at ILL:
  N = 430.000 neutrons (50 days beam time), t = 130 ms interrogation time
  ΔE = 4.8 × 10^{-17} eV; q_n = 1.3 × 10^{-19} q_e (A)
- beam experiment with new source:
  N = 43.000.000 neutrons (50 days beam time), t = 130 ms interrogation time
  ΔE = 4.8 × 10^{-18} eV; q_n = 1.3 × 10^{-20} q_e (B)
- storage experiment at PF2 at ILL:
  N = 430.000 neutrons (50 days beam time), t = 130 s interrogation time
  ΔE = 4.8 × 10^{-20} eV; q_n = 1.3 × 10^{-22} q_e (C)
- storage experiment with new source:
  N = 43.000.000 neutrons (50 days beam time), t = 130 s interrogation time
  ΔE = 4.8 × 10^{-21} eV; q_n = 1.3 × 10^{-23} q_e (D)



Funds requested

- staff:

1 Ph.D. position for 30 months	€ 82.000,00
1 student researcher for 6 months	€ 9.388,20
Sum	**€ 91.388,20**

- scientific instrumentation:

Year 2010 - 2012	**€ 116.669,86**

*) 2 micrometer positioning tables, € 35.701,90
*) Glasplates as neutron mirrors, € 8.080,00
*) triple-beam miniature interferometer, € 44.000,00
*) Surface Roughness tester, € 1.195,00
*) Turbomolecular pump, € 9.065,00

- consumables:

Years 2010 - 2013	**€ 47.500,00**

Typical consumabels:
positioning devices (supports, fixings, precision translation-rotation elements, micrometer-screws, calibration wires); detergents and other agents, dust-free equipment, cleaning tissue; neutron absorption and shielding materials; other special materials (Macor, Kronglass, unmagnetic steels, erosion wires, plexiglass, plastic-scintillators, special cements and glues); high-purity detector gases for low-background neutron detectors; metal coating for neutron reflectors and mirrors, electrodes; vacuum materials (Cu- and Au joints, welding flanges, tubing, feedthroughs); electronics (active and passive components, printed boards, memories, ASICs, FPGAs, cables); sputtering targets for CR39 detectors

- travel:

Year 2010 - 2013	**€ 9.850,00**

References

(1) J. Baumann, R. Gähler, J. Kalus, and W. Mampe: Experimental limit for the charge of the free neutron, Phys. Rev. D **37**, 3107 (1988)
(2) Y.V. Borisov, N.V. Borovikava, A.V. Vasil'ev, L.A. Grigor'eva, S. N. Ivanov, N.T. Kashukeev, V.V. Nesvizhevskii, A. P. Serebrov, and P. S. Yaidzhiev, On the feasibility of using ultracold neutrons to measure the electric charge of the neutron, Sov. Phys. Tech. Phys. **33**, 574 (1988)
(3) R. Gähler, J. Kalus, and W. Mampe: Experimental limit for the charge of the free neutron, Phys. Rev. D **25**, 2887 (1982)
(4) H. Abele, T. Jenke, H. Leeb, and J. Schmiedmayer: Ramsey's method of separated oscillating fields and its application to gravitationally induced quantum phaseshifts, arXiv:0907.5447