Letter of intent

Experimental search for neutron – mirror neutron oscillations at DUSEL

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Theoretical motivation

As suggested long ago there might exist a parallel sector of "mirror particles" in form of a hidden duplicate of the observable particle sector [1]. In this picture, ordinary and mirror sectors should have identical particle contents and identical microphysics, in particular the same spectra of masses and coupling constants. Each ordinary particle, i.e. electron, nucleon etc. is supposed to have its mirror twin exactly degenerate in mass but being sterile with respect to the ordinary gauge interactions. The gravitational interactions are supposed to be universal between the two sectors. Nowadays this hypothesis becomes increasingly popular for its intriguing implications in particle physics and cosmology (for recent reviews, see [2]). Mirror matter could be a viable dark matter candidate, with a variety of interesting applications for key cosmological issues [3].

Besides gravity, the two sectors could communicate also by other means. In particular, any neutral ordinary particle, elementary or composite, could have a mixing with its mirror partner. The "ordinary-mirror" oscillation phenomenon thus possibly would render the search for mirror matter amenable to terrestrial experiments. For instance, the kinetic mixing between the ordinary and mirror photons [4] can be investigated searching for a transition of positronium to mirror positronium [5]. The mass mixing between the ordinary and mirror neutrinos could be revealed in the active-sterile neutrino oscillations [6]. Also ordinary pions and Kaons could have a mass mixing with their mirror partners which can be induced e.g. by some extra gauge forces between the elementary particles of the two sectors [7].

From the phenomenological viewpoint, the small mass mixing between the ordinary neutron n and its mirror partner n' leads to the most intriguing possibility. As it was shown in ref. [8], the existing experimental limits on n-n' oscillations are very weak, allowing the oscillation time $\tau_{\rm osc} = 1/\delta m$ to be smaller than the neutron decay time $\tau_{\rm n} \sim 10^3$ s. This could have direct astrophysical consequences, in particular, for the propagation of ultra-high energy cosmic rays at cosmological distances [8] or of the neutrons from the solar flares [9]. The experimental possibilities to test the n-n' oscillation were discussed in detail in ref. [10].

Since mirror neutrons are invisible, the n-n' oscillation can manifest experimentally only as a neutron disappearance. However, as shown in ref. [8], the neutron cannot disappear from a stable nucleus and thus does not induce nuclear instabilities, which is in a drastic difference to the case of neutron-antineutron oscillations [11]. On the other hand, the n-n' oscillation in vacuum, similar to neutron-antineutron oscillation, is very sensitive to external conditions: it is suppressed by matter effects and, remarkably, by the magnetic field of the Earth. Clearly, the possibility of a fast oscillation process which violates baryon number conservation looks rather intriguing (for comparison, the direct experimental limit on the neutron - antineutron oscillation time is 8.6×10^7 s [12] while the limit obtained from nuclear stability is about the same, 1.3×10^8 s [13]).

1. Methods to search for n-n' transitions

The probability of transition from the initial neutron state at time 0 to a mirror neutron state at time t_f of free neutron flight is given by

$$P_{nn'}(t_f) = \frac{\delta m^2}{\delta m^2 + \omega^2} \cdot \sin^2\left(t_f \sqrt{\delta m^2 + \omega^2}\right), \quad (1)$$

where $\omega = \mu_n H/2$ (here and in the following natural units are used, $c = \hbar = 1$) and $\delta m^{-1} = \tau_{osc}$ — time of oscillation.

Experiments are restricted to short times $t_f << \tau_{osc}$, which strongly reduces the requirement on the weakness of the magnetic field H. As long as $\omega t_f << 1$ the transition probability is not suppressed, and one derives from eq. (1) the relation

$$P_{nn'}(t_f) = \left(t_f / \tau_{osc}\right)^2 . \quad (2)$$

Considering t_f = 0.1 s, the transition probability is not significantly affected by a magnetic field in the order 20 nT ($\omega t_f \approx 0.1$).

In the opposite case, $\omega t_f >> 1$, the average of the oscillating term in eq. (1) is $1/2$ thus leading to

$$P_{nn'}(t_f) = \frac{1}{2\left(\omega\tau_{osc}\right)^2} . \quad (3)$$

A suppression factor $2\left(\omega t_f\right)^2 = 10$ is already obtained with a magnetic field of 0.5 μT.

There are two ways search for n-n′ oscillations: experiment with storage of ultracold neutrons (UCN) in trap and neutron beam experiment. The main idea of the experiment with UCN is to measure the difference of storage times of UCN in a trap with magnetic field switched on and off. If oscillations take place mirror neutrons will pass through the trap wall without interaction. As a result the storage time will be reduced.

For the beam experiment it is necessary to measure the difference of neutron flux at the end of flight path when the magnetic field along flight path is switched on and switched off.

2. Present status n-n′ experiment

Experiments with storage of UCN have been carried out using the well-known UCN facility PF2 of the ILL reactor [14, 15]. The best result was reached by PNPI-ILL collaboration [15]. As a result of measurements carried out in this work a new lower limit for the time of neutron mirror neutron oscillations was established:

$$\tau_{\text{osc}}\left(90\%\ \text{C.L.}\right) \geq 414\ \text{s}\ .$$

This limit is already not too far from the neutron lifetime but might still be too low to provide restriction of the mechanism of appearance of high-energy protons above the GZK-cutoff in cosmic radiation due to n-n' oscillations.

We argue here that UCN storage is indeed a very effective experimental method to search for the n-n' transitions, but it has some restriction for future improvement. An improvement by a factor 2 may be reached due to increasing the storage volume to a trap diameter of 1 m. Another factor of 3 may occur in the future when a UCN density of 10^3 cm^{-3} will be available from new powerful UCN sources. Therefore the limit for UCN method is about 10^3 s.

3. Proposal for experimental search for neutron – mirror neutron oscillations at DUSEL

More substantial improvement in the search for n-n' transitions might be realized in a new-proposed neutron-antineutron transition search proposed in ref. [16] for the DUSEL laboratory. This project assumes a vertical path (1 km) with time of flight of cold neutrons about 1s, with beam intensity ~10^{12} s^{-1}. The same installation with small modifications can be used for the n-n' experiment. Employing a precise monitoring system and an integral method to detect the neutron intensity it might be possible to reach a sensitivity up to $10^4 – 10^5$ s for the n-n' oscillation time.

Fig.1 shows the scheme of $n-\bar{n}$ experiment [16] with modifications for n-n' experiment. In principle both experiments can be realized simultaneously. Detector for n-n' experiment can be installed on the place of neutron beam damp. Monitor detector can be installed at the entrance of the flight path. Monitor detector will be prepared in form of a ring that will not interfere with $n-\bar{n}$ experiment. The monitor detector will allow to suppress fluctuations of reactor power, it is very important element of n-n' experiment. The main detector of n-n' experiment (as well as monitor detector) will consist from 100 neutron detectors (lithium glass scintillator with photodiode). The main task is to suppress reactor fluctuations down to the level of statistical fluctuations which is rather low since the counting rate of the main n-n' detector is expected on the level 10^{11}-10^{12} s^{-1}. Fortunately, positive experience in such type of task exists, for example, in experimental search for circular polarization in $n + p \rightarrow d + \gamma$ reaction [17]. (This experiment has been carried out also with inter reactor target.)

Our preliminary estimation shows that it will be possible to suppress the reactor fluctuations (as well as the noise of detector channel) down to the level of statistical fluctuations of neutron counts. It can be achieved due to detector monitoring system and multi-channel system of neutron detectors. The electronic scheme of n-n' experiment is shown in Fig.2.

In conclusion we would like to say that according to our estimates it will be possible to reach a sensitivity up to 10^4- 10^5 s for n-n' oscillation time. This would represent an important progress in the effort of finding mirror dark matter under laboratory condition.

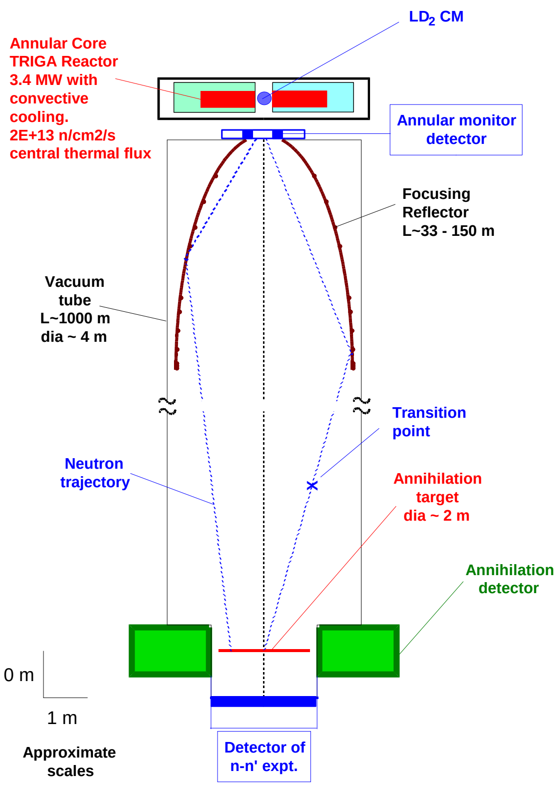

Fig.1. Scheme of $n - \bar{n}$ experiment with modification for n-n' experiment.

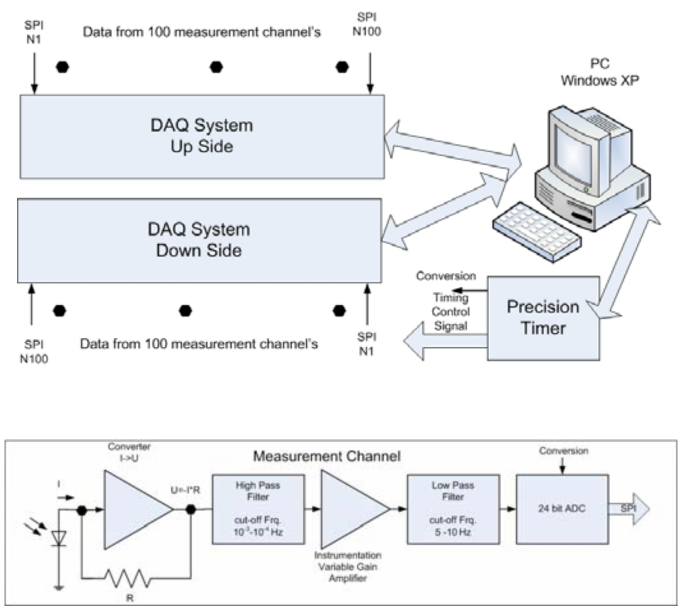

Fig.2. The electronic scheme of n-n' experiment.

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