A permanent-magnet storage device for neutron lifetime measurements

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The lifetime τ_{n} of the neutron is one of the fundamental quantities in weak-interaction physics. Together with the parameters governing the correlations between the neutron decay products it allows to determine the weak coupling constants g_A and g_V.

The most precise measurements of τ_{n} employed ultra-cold neutrons (UCN), i.e. neutrons with energies below about 250 neV, captured in a vessel. The most serious systematic errors were those due to the uncertainty about spurious losses during the reflection of the neutrons at the coated vessel walls. The storage of UCN in a magnetic trap seems to be a good alternative to avoid these uncertainties. In such a trap the force $\vec{F} = \nabla(\vec{\mu} \cdot \vec{B})$ (where $\vec{B}$ denotes the magnetic flux density and $\vec{\mu}$, $\mu = 60\,\mathrm{neV/Tesla}$, the magnetic moment of the neutron) repels neutrons of one spin direction from regions of high field. Spin-flip and subsequent loss of the neutron from the trap are avoided if the change $\mathrm{d}|\vec{B}|/\mathrm{d}t$ in the reference frame of the neutron is small compared to the frequency $\nu_{\mathrm{Larmor}} = \gamma \cdot B/2\pi$ of its Larmor precession (here $\gamma = 183\,\mathrm{MHz/Tesla}$ is the gyromagnetic ratio of the particle).

The arrangement for magnetic storage favored by our group at the moment is a torus of rectangular cross-section without top (cf. Fig. 1). Side and bottom walls (about 5 cm thick) are made from sandwiches of permanent magnets (NdFeB) and permendur (FeCoV). Gravitation prevents UCN with energies below 60 neV from escaping through the top of the 60 cm high trap. At an inner radius of 10 cm and an outer radius of 30 cm the trap has the rather large volume of 150 dm^3. The magnetic flux density B at the walls will reach 1 Tesla. This allows to store neutrons of up to 60 neV energy. One may expect more than 10^7 neutrons to be stored per filling from the UCN source of FRM II; this, although only neutrons with one spin direction are trapped and only a fraction of the neutrons produced by the source are captured. In order to measure τ_{n}, the trap may be emptied at different times after filling and the number of neutrons that survived until then may be determined. A more promising way, however, seems to be the detection of the protons from neutron decay. As the bottle is open at the top, proton detectors may be installed there. In order to give a clear signal, the protons have to be accelerated towards these detectors, as their maximum recoil energy in neutron decay is only 750 eV. This acceleration is achieved by setting the detectors to a potential of -25 to -30 kV. Si PIN diodes may be a suitable choice. A small number should be sufficient to obtain good detection efficiency if one succeeds to produce an electric field which guides the protons towards the diodes.

The efficient detection of UCN losses by depolarization or up-scattering is mandatory. It is ensured by introducing slits in the outer edge of the magnet set-up (cf. Fig. 1). If these slits are small enough to let the magnetic field at the edge still be around 1 Tesla, only depolarized and up-scattered neutrons find their way through and are guided to dedicated neutron detectors. In order to detect as many of these "useless" neutrons as possible the magnet walls will be covered with a neutron reflecting surface which prevents depolarized and up-scattered neutrons from escaping undetected through the walls before they reach the slits.

Regions of small or zero B have to be avoided. Here the neutrons may be depolarized and will be lost soon after. To this end a small magnetic field will be super-imposed to the field from the permanent magnets by installing a straight rod at the torus axis. A current of a few hundreds of amperes through this rod is sufficient to produce an additional field in the mT region everywhere in the trap.

The storage device may be filled by moving the outer torus walls up. UCN may then flow through a region of small B into the trap. After filling the outer walls will be lowered again.

At the moment a cylindrical permanent-magnet trap is set up at Peterburg Nuclear Physics Institute with the collaboration of our group. It shall be brought to Institut Laue Langevin soon for first tests. As the diameter of this magnetic bottle is only 20 cm and the height does not exceed 50 cm, the volume is rather small (only about 16 dm^3). Nevertheless this arrangement will allow to study problems of neutron depolarization. At the same time we may test if the proton detection with Si PIN diodes is feasible.

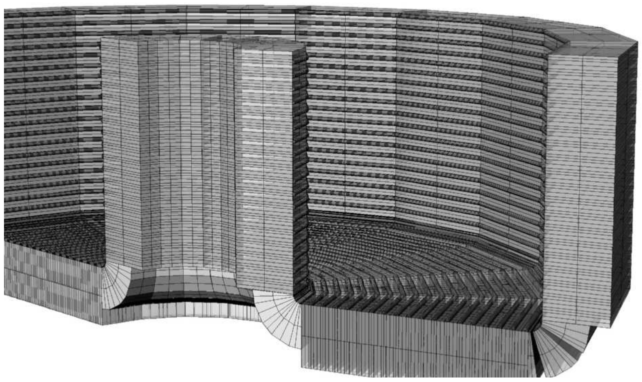

Fig. 1: Cut-away view of the neutron trap.The darker layers are from permendur, the lighter ones are the permanent magnets. The slits at the outer lower edge of the trap are clearly visible.