A Storage Device with Superconducting Magnets for the Measurement of the Neutron Lifetime

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The value for the neutron lifetime, $\tau_n = 885.7 \pm 0.8\,\mathrm{s}$, adopted by the Particle Data Group [1] is mainly determined by one measurement with ultra-cold neutrons (UCN), stored in a bottle with fomblin coated walls [2]. The main source of systematic errors in such measurements are neutron losses during collisions with the trap walls. In order to avoid such losses one may use a magnetic field to contain "low-field seeking" UCN, i.e. those neutrons that are repelled from regions of high flux density. This method, complementary to most of those used up to now, should allow to decrease the systematic errors and at the same time constitutes a highly welcome check of previous measurements.

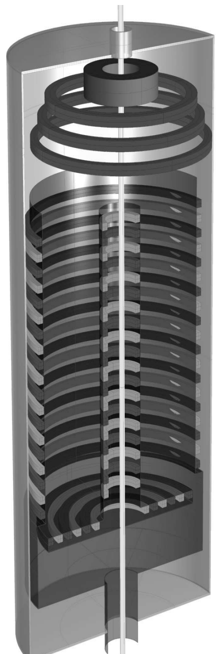

Fig. 1: Schematic view of the magnetic storage device for UCN. The superconducting coils are shown in light and dark grey. Three coils at the top serve to focus the accelerated decay protons on the detector (indicated as hollow cylinder). Further explanations may be found in the text.

A schematic view of the planned trap with superconducting magnets is shown in Fig. 1. A double cylinder with 10 cm inner and about 50 cm outer radius and with a height of around 1.2 m is composed of sandwiches of superconducting ring coils (cross-section about $3 \cdot 3\ \mathrm{cm}^2$, current density $400\ \mathrm{A/mm}^2$) with vacuum in between. The direction of the current is reversed from coil to coil. With this set-up a field of 2 T is generated at a distance of about 1 cm from the surface of the coils. The bottom of the trap is composed in a similar way of concentric rings. The axis of the arrangement is vertical and the top may stay open, as gravity keeps the UCN in the trap. A current rod on the axis serves to avoid zero-field regions with their enhanced danger of neutron spin flip (see below). One or two ring-shaped slits in the lower edges allow to fill the trap and to detect depolarized neutrons, the main source of possible systematic errors: as they are no longer repelled by regions of high flux density they in priciple could leave the trap. At a volume of about $700\,\mathrm{dm}^3$ and a UCN density of well above $10^3/\mathrm{cm}^3$ at FRM II we may expect to store more than 10^8 UCN in one filling. This large number of trapped UCN, together with the possibility to vary the magnetic flux density by changing the current in the superconducting coils, allows to scrutinize possible systematic effects. In this way we hope to decrease the total error for τ_n to about 0.1 s.

The device is filled with UCN at zero magnetic field. Afterwards the field is ramped up within about 60 s to its nominal value. To avoid losses during this period the inner walls of the trap will be coated with a UCN reflecting material [e.g. Be, Ni or DLC (diamond-like carbon)]. After trapping the neutrons, we can measure their lifetime. One well-known method is to determine the number of neutrons left after different waiting times. A more elegant way would be to count the protons from neutron decay continuously with a scintillation counter arrangement above the trap. To this end the protons have to be accelerated from their original energy of less than 750 eV by an electric field that at the same time serves to extract them to the top. About -10 kV between storage volume bottom and top is sufficient to reach an extraction efficiency of about 90%. After further acceleration to about 30 keV and some focusing these protons hit a large-area CsI(pure) scintillator which has a good detection efficiency at the low temperatures necessary to operate the superconductors. The wave-length shifted scintillation light is registered by either photomultipliers, hybrid or avalanche photodiodes that are insensitive to the high magnetic field at the trap top. There are two important sources of systematic errors in the experimental value of τ_n, i) the presence of neutrons of wrong polarization (high-field seekers) at measurement start and ii) neutron spin flip during the measuring cycle. As the inner walls of the trap are coated with neutron reflecting material these neutrons are kept and finally guided through the filling slits to a UCN detector at the bottom of the arrangement.

As already indicated, covering the trap walls has another advantage: if energetic UCN penetrate through the magnetic wall, they are reflected with very small losses and stay in the storage volume. As events of this kind are expected to be rare, such losses may be kept negligible.

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References

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[2] S.S. Arzumanov *et al.*, Nucl. Instr. Methods A **440** (2000) 511