A Permanent-magnet Storage Device for Neutron Lifetime Measurements

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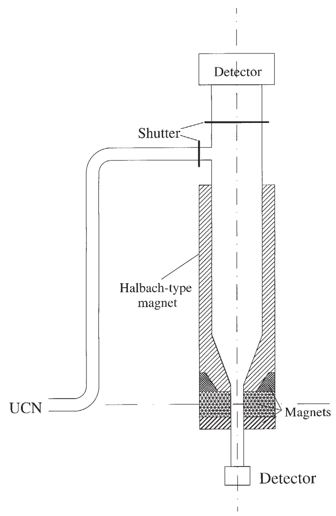
The principal goal of all experiments on the neutron decay $n \rightarrow p + e^{-} + \overline{\nu}$ is the determination of the absolute value and the phase of the weak-interaction coupling constants, especially of g_A and g_V. This may, e.g., be achieved by measuring the asymmetry parameter A for the direction of the decay electron relative to the direction of the neutron spin, and the neutron lifetime.

The most troublesome systematic error in storage experiments on the neutron lifetime stems from collisions with the container walls. In order to avoid such collisions one may trap the neutrons in magnetic bottles or let them run through magnetic storage rings [1]. These devices use the interaction of the neutron magnetic moment $\vec{\mu}$ with the magnetic field $\vec{B}$. The force $\vec{F} = \nabla(\vec{\mu} \cdot \vec{B})$ repels neutrons of one spin direction from regions of high field. Spin-flip and subsequent loss of the neutron from the trap is avoided if the change $|\mathrm{d}\vec{B}/\mathrm{d}t|$ of the magnetic field the neutron feels is small compared to the frequency $\nu_{\mathrm{Larmor}} = \gamma \cdot B/2\pi$ of its Larmor precession (here $\gamma = 183\,\mathrm{MHz/T}$ is the gyromagnetic ratio of the particle). It is clear that low-field regions are especially dangerous in this respect.

Nowadays the main problem of the method is the strong magnetic field necessary to contain a sufficient number of neutrons: to trap a neutron of kinetic energy $T = 1\,\mu\mathrm{eV}$ in a magnetic bottle a field of more than 15 T would be necessary. With the advent of FRMII and the construction of the source Mini-D_2 [2] for ultra-cold neutrons (UCN) the scenario will change drastically: The number of neutrons with energies below 50-100 neV will be sufficient to perform successful storage experiments even with permanent-magnet traps. With such traps the necessary magnetic fields of around 1 T are reachable without problems. Furthermore the low velocity of UCN helps in avoiding neutron spin-flip.

A permanent-magnet trap for neutron-lifetime experiments is developed at the moment. The configuration presently favored is a cylinder of about 60 – 80 cm length and around 16 cm inner diameter, with its axis in vertical direction. The experimental configuration is sketched in Fig. 1a. Radial confinement of the neutrons will be achieved with a Halbach-type [3] octupole or decapole configuration. In the special octupole configuration chosen the magnetization points outward in radial direction in every eighth sector and changes its direction by 56.25° from sector to sector. The magnetic-field in the Halbach section is shown in Fig. 1b. The permanent-magnet material used in the simulation had a maximum energy density of $(H \cdot B)_{\max} = 40\,\mathrm{MGOe}$ and a remanence of 1.3 T. The UCN are prevented from escaping through the bottom part by a special permanent-magnet configuration and through the top simply by gravity. Special care was taken to avoid very-low-field regions inside the trap; as pointed out above, neutrons passing these regions could suffer spin flip. More than 10^5 UCN with energies below 60 neV may be confined in the trap, when operated at the UCN source of FRM II.

At the start of the measurement the trap will be closed at the top by a shutter and afterwards rotated around the horizontal axis indicated in Fig. 1a) into horizontal position. Then it is filled from the side through a neutron guide with a controlled number of neutrons. At the end of the filling procedure the access through this neutron guide is closed and the trap rotated back into vertical position. The shutter at the top is opened to remove the last material wall in the trap accessible to the neutrons. During the storage time the detector at the bottom serves as a neutron-loss monitor. Another detector may count the rate of electrons from neutron decay. After several times the lifetime of the neutron the trap is again rotated, this time by 180°, the top shutter opened and the neutrons counted by the UCN detector behind it. This procedure may be repeated many times. From the mean number of neutrons present at the start and at the end of the measurement cycles the n lifetime can be extracted.



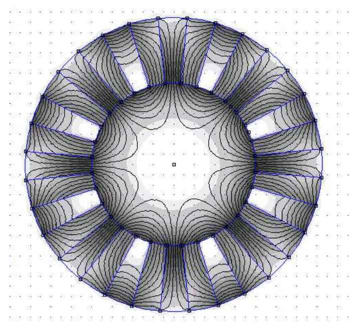


Fig. 1: a) Sketch of a possible permanent-magnet trap; b) Presentation of the magnetic-field map in the straight section of the magnet (one grey-scale step corresponds to 0.15 T).

References

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