Development of Sources for Ultra-Cold Neutrons at the FRM II

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Ultra-cold neutrons (UCN) are neutrons with energies below about 250 neV. They are reflected by special materials (e.g. Be) and by magnetic fields. Hence they may be stored for times up to hundreds of seconds. Storage experiments with the free neutron are essential in determining its fundamental properties. Presently the precision is mostly limited by the low UCN-densities achieved ($< 100/\mathrm{cm}^3$). Three alternatives for strong sources of UCN are investigated for the Forschungsreaktor München II (FRM II): (a) Cold neutrons are cooled in a small volume of solid deuterium and accumulated in an evacuated storage tube, (b) cold neutrons are cooled and stored in a vessel with superfluid helium, and (c) thermal neutrons are cooled in a big volume of solid deuterium and extracted steadily.

MINI-D, a small solid-deuterium source

This source [1] (cf. fig. 1) consists of an evacuated tube ($r = 3\,\mathrm{cm}, l = 6\,\mathrm{m}$, Be coated), which will be installed in the beam tube SR4, with one end facing the cold source and the other connected directly to the experiment. Inside this tube a small piece of solid deuterium ($180\,\mathrm{cm}^3$, 5 K) will be positioned near the cold source. In this so-called converter UCN will be produced by down-scattering of faster neutrons from the cold source. As the dimensions of the converter (length 6 cm) are small compared to the diffusion length (about 14 cm) most of the produced UCN will escape into the storage tube before they are absorbed or up-scattered. The losses in the storage tube due to absorption and up-scattering during wall collisions can be made small compared to those in the converter, if the wall temperature is below 30 K. Then within a few hundreds of seconds a UCN density builds up in the storage tube (and maybe in the experimental volume) which is comparable or even somewhat higher than that in the converter [1]. Calculations based on a realistic density of states in 5-K deuterium [2] give for an effective cold-neutron flux of $3 \cdot 10^{13}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ and a neutron temperature of 30 K a density which is as high as $5{\cdot}10^4\ \mathrm{UCN/cm}^3$. The low deuterium temperature is mandatory to avoid excessive up-scattering losses. Raising the temperature to 13 K would reduce the UCN density by about a factor of twenty.

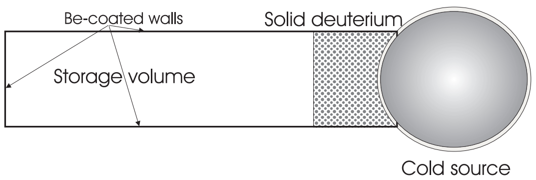

Fig. 1: Schematic view of the MINI-D source.

The source head is shown in fig.2. The storage tube has a double wall. Super-critical helium is pumped through the gap to keep the temperatures of deuterium and tube below 5 K and 20 K, respectively. At these low temperatures the up-scattering of UCN may be neglected. A cryostat with walls following the shape of the beam nose of SR4 houses the whole setup.

From Monte-Carlo calculations on the energy deposition by neutrons, γ rays and charged particles we expect a heat load of $\approx 150\,\mathrm{W}$ on the 5 K front part and of $\approx 350\,\mathrm{W}$ on the rear part. A flow of 75 g/s of super-critical helium should be sufficient to cool the arrangement. It is mandatory to have the deuterium as ortho-D_2 to keep the heat conduction inside the converter volume sufficiently high.

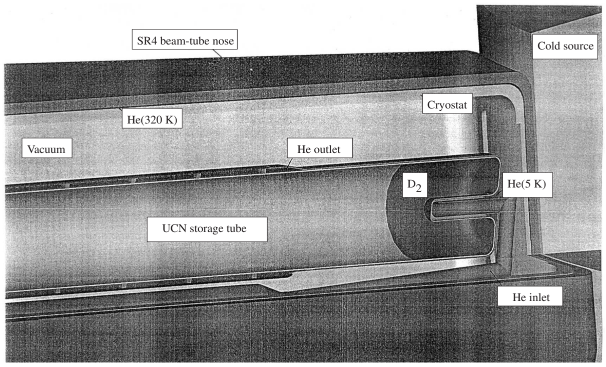

Fig. 2: View of the MINI-D source head.

Solidifying the deuterium from the liquid phase has the disadvantage that the volume decrease between freezing point and 5 K (about 3%) may probably result in cracks. Therefore we plan to spray gaseous deuterium into the cold tube nose through a thin (maybe removable) torus with eight to ten tiny nozzles or through a diffusor from sintered metal. The volume change poses another problem. During an (intentional or non-intentional) warm-up the deuterium expands and would break the tube if it could not escape. By giving the solid-deuterium volume the shape of a truncated cone such an escape will become possible.

The super-fluid-helium source

UCN sources on the basis of the second method have been built in Japan and at ILL. One of the arrangements from Japan [3] has been transferred to Garching. It shall be improved by reducing the losses at reflection from the vessel walls with the help of a Be coating and by detecting the UCN with solid-state detectors *in* the liquid. First experiments with such detectors were promising.

The big solid-deuterium source

A UCN source on the basis of the third method has been operated successfully at the Peterburg Nuclear Physics Institute (PNPI). A project study from PNPI for FRM II exists and shall be followed by a more detailed one. One could also think of operating the source with a mixture of solid and liquid deuterium or even with heavy-water ice (recent experiments at PNPI with a heavy-water-ice source were successful). The large volume makes the rapid realization of the concept unlikely. The idea may, however, serve as a basis for a second cold source for FRM II.

References

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[3] H. Yoshiki, K. Sakei, T. Kawai, and S. Goto'o, Cryogenics **34** (1994) 277