The Mini-D_2 Source for Ultra-Cold Neutrons

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In the beam tube SR-4 of the new Munich high flux reactor FRM-II a high density source for ultra-cold neutrons (UCN) shall be installed, the Mini-D_2 UCN source.

UCN can be stored in material bottles or magnetic traps, if their energies are smaller than the effective potential of the walls (250 neV for Be, 240 neV for $B = 4\,\mathrm{T}$). In UCN storage experiments the observation time of the neutrons is extremely long. This offers the possibility for most precise measurements of properties of fundamental importance of the free neutron, e.g. the lifetime and the electric dipole moment, allowing tests of modern theories beyond the standard model. For further improvements UCN sources have to be developed with much higher intensities compared to the best present source at ILL in Grenoble with $\approx 50\,\mathrm{UCN/cm^3}$ at the exit of the turbine.

The Mini-D_2 UCN source has a small converter ($\approx 200\,\mathrm{cm^3}$) of solid D_2, positioned in the SR-4 beam tube near to the cold source (see Fig.1). The principle of the source is as follows. The temperature of the D_2 is kept as low as $\approx 5\,\mathrm{K}$, so that the UCN losses due to up-scattering are smaller than the unavoidable absorption losses. Then the mean lifetime of the UCN in the D_2 will be $\approx 0.08\,\mathrm{s}$, leading to a maximum density of $\approx 1.5 \cdot 10^4\ \mathrm{UCN/cm^3}$ in the converter for a cold neutron flux of $\approx 3 \cdot 10^{13}/\mathrm{cm^2s}$. This is almost a factor of 100 more than for liquid D_2 at $\approx 20\,\mathrm{K}$. The converter is contained inside a 8 m long cold tube, which extends from inside the SR-4 to the experimental hall outside the reactor shield. This tube has a UCN valve at the experiment-near end. The inner wall of the tube is covered with Be; hence UCN with energies $< 250\,\mathrm{neV}$ can be stored. The solid D_2 is condensed directly from the gas phase onto the very cold end of the tube. When leaving the converter, the UCN gain the potential energy of the D_2 (100 neV). Outside the D_2 the mean lifetime of the UCN is expected to be $\approx 150\,\mathrm{s}$, limited only by the loss probability of $\approx 5 \cdot 10^{-5}$ per wall collision. When the UCN valve is closed a density of the order of $10^4\ \mathrm{UCN/cm^3}$ will build up in the tube. When opening the valve, some $2 \cdot 10^8$ UCN can be supplied to the experiment. Operated in the continuous mode, the source will provide a UCN flux of up to $5 \cdot 10^3\,\mathrm{UCN/cm^2\,s}$.

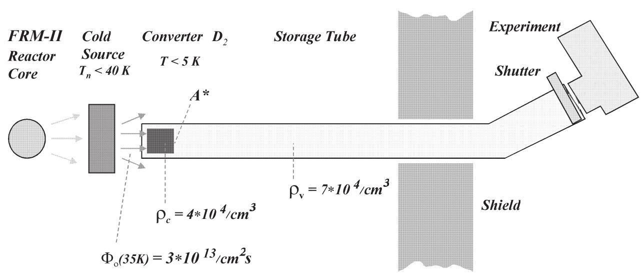

Fig. 1: Schematic view of the MINI-D_2 source.

In preparing the documents for the technical approval many details of the design were elaborated:

1. The UCN storage tube (Al 6061)is double-walled with supercritical He flowing back and forth in between. The UCN valve and the Al windows with supporting grids were designed. Some studies were made concerning the production of the cup for the D_2 converter, welding of the tubes, and polishing of the inner surfaces. For good specular reflection the surface has to be smooth with respect to the UCN with wavelengths as low as 60 nm. After polishing the Al 6061 tubes mechanically a root mean square roughness of 10 nm and a width of the remaining grooves of $\approx 200\,\mathrm{nm}$ was measured.
2. The cryostat for the UCN storage tube is a double-walled tube ($\phi = 108\,\mathrm{mm}$) made of Zircaloy 4, with circulating He coolant in between (≈ 300 K). It may be moved from outside into the beam tube SR-4. To this end the width of the channel in the internal beam shutter has to be enlarged from 80 mm to 120 mm. The in-pile part of the cryostat is connected to the end-plate of the SR-4 by means of a long bellow. By this the cryostat can be drawn back by 1.8 m out of the high radiation region near to the reactor core, without breaking the He gas protection inside SR-4.
3. A detailed plan for the D_2 gas system including the para/ortho converter, the vacuum system and all He cooling circuits were drawn up.
4. In order to study if the D_2 condensates without internal cracks, how the radiation affects the thermal conductivity, and finally what UCN-production efficiency may be reached, a double-walled test cryostat with He protection was designed. The cryostat may be operated in vertical and horizontal position, and different cooling schemes may be applied. An extension tube may be added to the cryostat providing a long UCN storage tube.
5. All available data on scattering cross sections for the calculation of UCN production rates and up-scattering were used. The UCN density distributions in the different parts of the source were studied systematically by means of the diffusion theory. Good agreement was obtained with some selected Monte-Carlo calculations.
6. The UCN density is expected to depend strongly on the D_2 temperature. The temperature distribution in the D_2 converter was studied. Unfortunately the thermal conductivity of the solid D_2 under realistic conditions is not well known. It might be reduced by radiolysis of the D_2 molecules by γ-radiation. Therefore the experimental investigations of the solid D_2 as converter are of crucial importance.

References

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