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ULTRA COLD NEUTRONS COOLING DURING ITS LONG DWELLING IN A TRAP

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We have observed cooling of ultra cold neutrons during its long dwelling in a trap with the probability estimated by $1 \cdot 10^{-6}$/reflection and with the energy transfer about 3 neV.

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The main process of the ultra cold neutrons (UCN) interaction with a matter is the elastic reflection from the vacuum/matter border [1,2] that permits to store UCN in a trap almost up to their beta-decay [3−5]. The probability of UCN inelastic scattering from a thermal lattice vibration is about $(10^{-3} \div 10^{-6})$ per reflection into energy range of $kT \sim 2 \div 3$ meV. Then, a part of neutrons scattered into the UCN energy range $(0 \div 10^{-7})$ eV has to be negligible. Nevertheless the experimental data [6,7] witness that the UCN with energy lower than the primary one appeared during UCN storage. This phenomenon could arise from an inelastic UCN reflection with energy loss. The present experiment was perfomed to seach the UCN reflection with the energy loss.

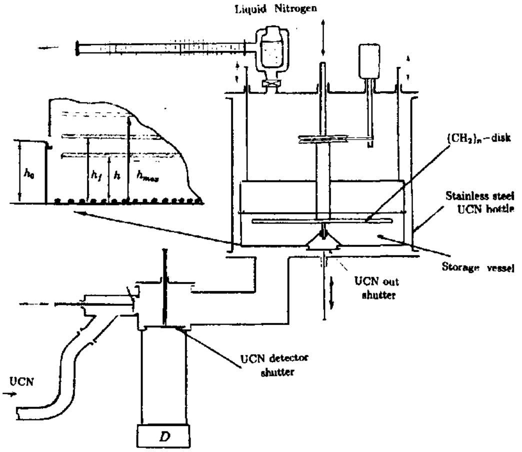

Fig.1. The experimental layout where D shows the position of the UCN detector, h_0 is the entrance barrier height, h_f is the height of the position of the absorber disk made of polyethylene $(CH_2)_n$ during filling, h is the height position of the absorber disk during scanning, h_{max} is the same but during the evolution time

The UCN storage vessel (trap), see Fig.1, had a cylindrical shape with a diameter of 65 cm and a flat bottom. It was placed inside a vacuum housing made of stainless steel. UCN entered the vessel passing over the edge of the vertical bottom cylinder wall of height $h_0 = 123$ mm, i.e. overjumped the gravity barrier $E_b = mgh_0$. During filling, a second, moveable cylinder was at its maximum height, leaving a slit for UCN passage into the trap. After filling, this upper cylinder was moved down to close the gap and prevent UCN from jumping back over the edge. In order to significantly increase the reflection frequency as well as to randomize the distribution of reflection angle the bottom of the vessel was covered with a layer of lead balls of diameter 3.5 mm. All inner surfaces of the vessel as well as balls were coated with Fomblin grease. The energy distribution of the UCN gas in the trap was cut from above by use of a polyethylene disk as absorber, which was positioned at height h_f during filling and which was also used for scanning the spectrum after various storage time.

Thus the UCN accumulating in the trap had the energy over the range of $E_b < < E < mgh_f$, i.e. the energy spectrum was rather narrow with width $\delta E = mg\delta h$, where $\delta h = h_f - h_0 \ll h_0$.

A measuring cycle consisted of the six successive steps:

1) trap filling at the disk height h_f (T_f =300 s);

2) spectral precleaning (sharpening of the upper cut-off) while the filling gap was closed and the disk remained at height h_f (T_p =100 s);

3) free spectral evolution during period T_e. To eliminate interference with the UCN gas, the disk was at its maximum height h_{max} = 155 mm (T_e =20, 620, 1200 s);

4) scanning of the spectrum by lowering the disk to the variable height h and leaving it there sufficiently long for good spectral cleaning (T_m = 200 s);

5) emptying the trap and counting the surviving UCN while the disk remained at height h (200 s);

6) measurement of background (50 s).

It gave the integral spectrum $N(h)$ which is related to the differential energy spectrum $F(x)$ in the form $N(h) = \int_0^h F(x)dx$. Here and below we use an energy scale expressed in the height units (mm).

Precise investigation was carried out using the UCN spectra with δh = 11.75 mm. The measured storage time was τ = 680.0(9.5) s, and the calculated frequency of wall collisions, f, was about 20 Hz.

Fig.2 and Fig.3 present the spectra $N(l)$, where $l = h - h_f$, for T_e = 20, 620 and 1200 s, which were normalized to $N_{20}(l)$, measured for T_e = 20 s, correcting for the exponential losses determined by τ. All spectra $N(l)$ were fitted using the Gaussian Commulative Distribution Function (GCDF) which puts the center of energy distribution x and its dispersion σ^2. The criterion of confidence $\sqrt{\chi^2}$ of such fit was about unity only for energy range above gravity barrier E_b while for energy $E < E_b$,i.e. $h < h_0$, it was much more unity. So for this energy range a parabola fit was used.

Fig.2 clearly shows that the UCN spectra had no shift but became broader in the central part which GCDF fits well. The origin of this broadening $\Delta\sigma$ could be either the wall vibration or any unknown process with a small energy transfer per a collision.

The spectra broadening due to wall vibration one can estimate in a "diffusion" approach $\Delta\sigma = \sqrt{2DT_e}$ [8]. The diffusion coefficient $D = (\Delta E)^2 f/2$ was obtained for an energy transfer per collision, ΔE, using an estimate $\Delta E/E \approx 8\Delta v/3\pi v$, where Δv is the amplitude of wall velocity and v is the neutron velocity. The maximal value of $\Delta\sigma \approx \approx 1$ mm for T_e =1200 s, v =160 cm/s, f = 20 Hz and the maximal measured Δv = 100 μm/s. Compairison of this value with the experimental one, $\Delta\sigma$ = 1.8 mm, shows that the spectra broadening could be partly explained by vibration.

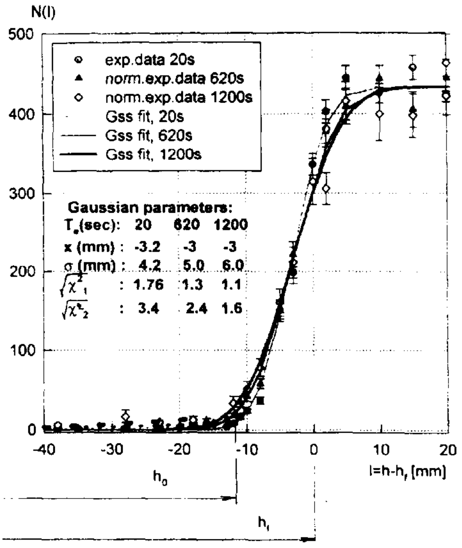

Fig.2. Measured spectra $N(l)$ with GCDF fit curves. In parameter Table x is the center position of Gaussian, σ^2 is its dispersion, the criterion of confidence: $\sqrt{\chi_1^2}$ is calculated for $h > h_0$, $\sqrt{\chi_2^2}$ is calculated for all h range

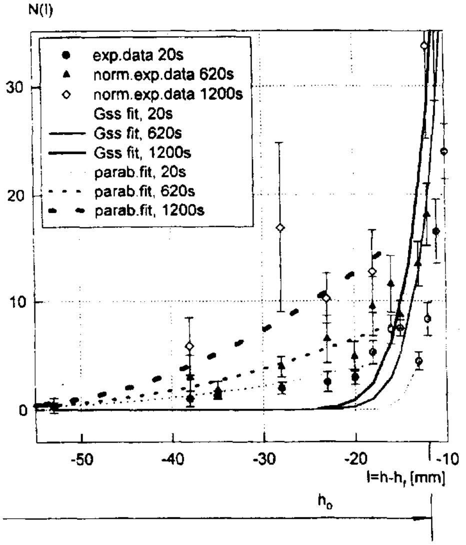

Fig.3. Measured spectra $N(l)$ with GCDF and parabolic fit curves

However the UCN spectra shape below the input barrier h_0 cannot be explained by trap wall vibration. Fig.3 shows that the relative amount of UCN with energy $h < h_0$ increased with increasing of the evolution time in the trap. The integral spectra of UCN could not be fitted by GCDF in this range. So the UCN with energy noticebly lower E_b could appear only due to a rare process of UCN cooling with an energy transfer $\Delta h \approx 20 \div 30$ mm $\geq \delta h$ per one reflection. Probably the analogous process was observed earlier in experiment [7] where it was not interpreted.

Let us make an estimation of the cooling probability w for the range below $l_1 = -18$ mm where the GCDF contribution is negligible. In Table $w = p/f/T$ was estimated under a proposition of a rare process at one reflection. The real time for UCN cooling T could be estimated as a sum $T \approx T_e + T_p + aT_f + bT_m$ where factors $a, b < 1$. The uncertainty of T was determined by uncertainties of these factors. $p = \Delta N/N$ where ΔN is the UCN number with $l < l_1$, N is the total UCN amount.

The result of the estimates for the cooling probability w

T_e (s)	20	620	1200
T (s)	270(100)	870(100)	1450(100)
$T/270$ s	1	3.2(1.2)	5.37(2.02)
p(%)	0.95(23)	1.74(46)	3.21(69)
w (10^{-6})	1.8(1.3)	1.0(3)	1.1(3)

Table confirms the linear dependence of p on the real cooling time T with the criterion of confidence $\sqrt{\chi^2} = 1.1$. In the case of any systematic effect, for instance, bad spectrum cleaning by the absorber disk, the value of p had to be equal to a const(T). This hypothesis corresponds to $\sqrt{\chi^2} = 2.3$. The weighted mean value of the cooling probability is equal to $\overline{w} = 1.1(2) \cdot 10^{-6}$.

Observed cooling could not be explained in framework of standard theory [1,2]. It breaks traditional point of view on the UCN reflection as absolute elastic process and asks more detailed investigation.

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