NEUTRON LIFETIME MEASUREMENT WITH U C N GRAVITATIONAL TRAP

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The precise neutron lifetime (τ_n) measurement was carried out by means of a long storage of ultra-cold neutrons (UCN) in a cryogenic gravitational trap.

Scheme of the experimental setup is shown in fig.1. Principles of its operation were described in the previous issue.

The obtained storage times (τ_n) were close to the neutron lifetime due to the use of low absorbing surfaces (Be, O_2) and low temperatures (10—15 *K*). A trap is a changeable part of the setup. The spherical trap using allowed to compare different regimes of covering the surfaces with oxygen and to obtain covers with the low losses coefficient. The losses in the trap's walls were controlled using its energy dependence. Measurements with the small cylindrical trap have been also carried out for the precise τ_n determination. The frequency of UCN blows with the walls increased ~2.5 times and the losses factor has been measured more reliably.

The losses in the walls were controlled with size extrapolation using the energy dependence. τ_n is defined by the neutron β-decay probability and by the losses in the walls:

$$\tau_{st}^{-1} = \tau_n^{-1} + \tau_{los}^{-1}, \qquad (1)$$

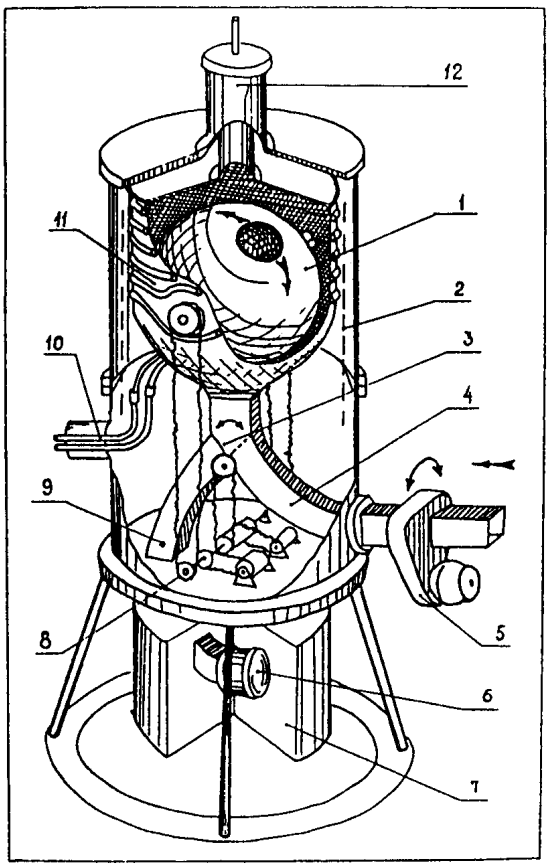

Fig.1. *1* — UCN storage trap, *2* — nitrogen screen, *3* — distribution valve, *4,9* — neutron guide, *5* — injection valve, *6* — detector UCN, *7* — detector shield, *8* — system for rotation, *10* — cryopipes, *11* — cryostat, *12* — system for cover frozening

τ_{los} — losses time (the time neutrons would store in trap without β-decay). It is necessary to obtain τ_{st} close to τ_n and to control the losses in the walls for the reliable τ_n measurement. In general case UCN losses probability τ_{los}^{-1} is proportional to losses coefficient η and depends on the size and the form of a trap, on neutron energy E, on limiting energy E_{lim}:

$$\tau_{st}^{-1} = \tau_n^{-1} + \eta \cdot \gamma \,(\text{Geometry}, E, E_{\text{lim}}) \ .$$

The parameter γ has the dimension 1/s and means effective frequency of UCN blows with trap walls, in this case η is numerically equal to losses probability per one blow. Using form.2 reverse neutron lifetime is a result of linear extrapolation $\tau_{st}^{-1}(\gamma)$ to value $\gamma = 0$. Losses coefficient is equal to tangent of inclination angle.

Extrapolations of reverse UCN storage times in the traps covered from within with oxygen and beryllium to τ_n are shown in fig.2. Different experimental points for the same surfaces materials are connected with the traps of different sizes and with different energy intervals of full UCN spectrum. Common using of spherical and narrow cylindrical traps (see fig.2) helped to obtain wide amplitude of variation for effective frequency of blows γ.

The main statistics have been obtained with oxygen surfaces owing to the more suitable UCN storage conditions. The measurements with beryllium surfaces have been fulfilled for UCN storage conditions investigation before oxygen covering.

Table 1

Surface of walls	Neutron lifetime, τ_n, s	Losses coefficient, η	χ^2
O_2	889.0± 3.1	$(6.1 \pm 0.6) \cdot 10^{-6}$	0.81
Be	885.0 ± 7.7	$(28.1 \pm 4.0) \cdot 10^{-6}$	1.41

The uncertainties are defined with statistical ones of τ_{st}. Fig.2 and table 1 show that both lines in the uncertainties limits are extrapolated into the same value τ_n. This fact demonstrates both the condition of UCN storage on Be sublayer and to some extent reliability of the method for the large losses coefficient. Reliability of the extrapolation is defined first of all by proximity of the obtained storage times and neutron lifetime:

Table 2

Surface of walls	$\tau_{los}(0), h$	$\tau_n - \tau_{st}(0), s$	$\bar{\tau}_{los}, h$	$\tau_n - \bar{\tau}_{st}, s$
O_2	17.0± 1.7	12.6± 1.3	≈9	≈23
Be	6.9 ± 1.0	30.7± 4.4	≈4	≈50

$\bar{\tau}_{los}$ and $\bar{\tau}_{st}$ — average losses time and storage time for spherical trap; τ_{los} (0) and $\tau_{st}(0)$ — losses time and storage time for UCN of lowest energy.

Table 3 contains the list of systematical uncertainties τ_n for the measurements with oxygen covering of the traps. The main part of the uncertainties is connected with the ones of effective frequency γ. They are in particular as follows: a dynamic correction caused by finite energy resolution of a gravitational spectrometer; a spectral correction connected with the measurements of the experimental spectrum; turbine effect caused by diffuse UCN reflections from the moving trap walls and leading to UCN spectrum diffusion in speed space and so on. The origin of other uncertainties is seen from table 3.

Table 3

Uncertainty of neutron lifetime measurement	$\Delta\tau, s$
dynamic correction	-0.9 ± 0.2
spectral correction	+0.3 ± 0.6
turbine effect	< 0.3
possible deviation $\mu(h)$ from model dependence	< 0.5
possible temperature dependence of losses	< 0.5
uncertainty of limit velocity determination	< 0.2
uncertainty of geometry parameters measurement	< 0.3
effect of He	< 0.3
spectral dependence of UCN detector syst. uncertainties of background measurement anisotropy of UCN in trap vibrations of trap effect of sublayer	—

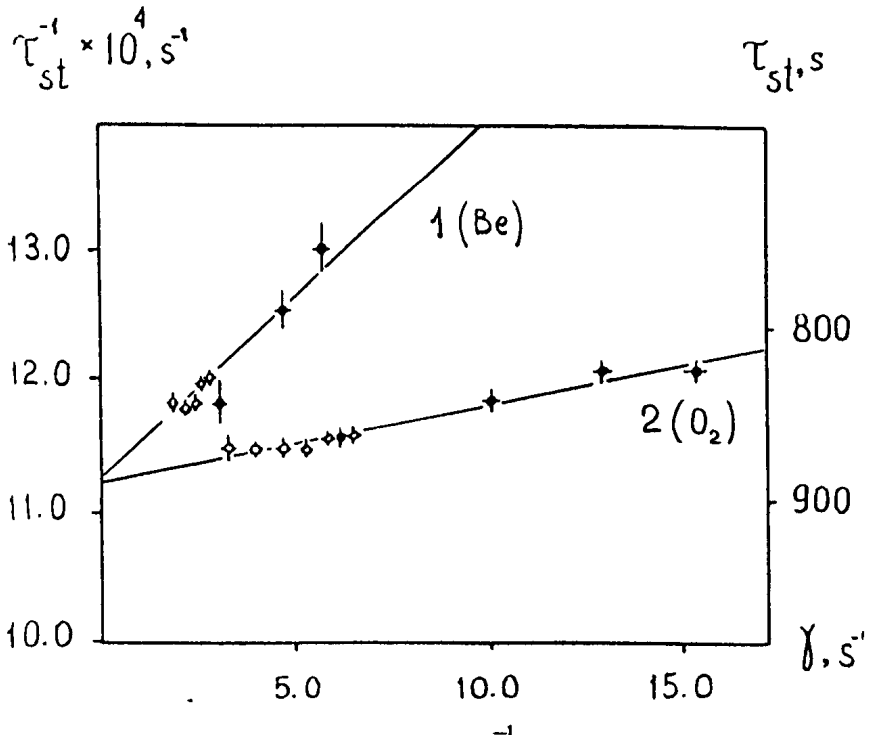

Fig.2. Results of UCN storage time measurements (τ_{st}^{-1}) as function of parameter γ. 1 (Be) — extrapolation to neutron lifetime (τ_n) from beryllium traps data, 2(O_2) — extrapolation to neutron lifetime (τ_n) from oxygen traps data. o — results of measurements with sphere traps. • — results of measurements with cylinder traps

Analyzing systematical uncertainties we obtain a little correction for τ_n: -0.6 ± 1.1 *s*. Before the correction τ_n was 889.0 ± 3.1 *s* for the measurements with oxygen covers. The final result is $888.4 \pm 3.1_{stat} \pm 1.1_{syst}$ *s*. The systematical uncertainties are caused by a number of independent factors, therefore it seams the be valid to write the result as 888.4 ± 3.3 *s* for the measurements with oxygen trap covers.

After the setup modernizing, with more intensive UCN flux and using experimental calibration method we hope to decrease the uncertainty of the neutron lifetime measurement to 1 *s*.