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SEARCH FOR AN ANOMALOUS TRANSMISSION OF ULTRACOLD NEUTRONS THROUGH METAL FOILS

Al.Yu.Muzychka, Yu.N.Pokotilovskii[1], *P.Geltenbort**

Joint Institute for Nuclear Research
141980 Dubna, Moscow region, Russia

**Institute Laue–Langevin,*
B.P.156 F-38042 Grenoble, France

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The results are presented of the search for the anomalous transmission of ultracold neutrons (UCN) through beryllium (thickness ~ 0.14 mm), stainless steel (0.05 and 0.015 mm) and copper (0.01 and 0.018 mm) foils. This anomalous transmission is considered as one of the possible reasons for UCN "disappearance" from beryllium bottles, discovered in the experiments at St.Petersburg Nuclear Physics Institute and was recently observed in the experiment [3]. No transmission was found in our measurements at the level 10^{-7} except for the case of copper foils which we attribute to the admixture in the UCN flux of neutrons with the energies higher than the boundary energy for copper.

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1. Introduction. There is the well-known and long-standing puzzle of ultracold neutron (UCN) storage times in closed volumes or, equivalently, of anomalous losses of UCN upon reflection from the inner surfaces of UCN traps. The most surprisingly large discrepancy in the experimental and predicted loss coefficients was observed for the most promising materials for high UCN storage times: cold beryllium [1] and solid oxygen [2]. The anomaly observed in [1, 2] consists in an almost temperature independent (in the temperature interval $10-300$ K) wall loss coefficient ($\sim 3\cdot 10^{-5}$), corresponding to the extrapolated inelastic thermal neutron cross section $\sigma^* \sim 0,9b$. This experimental figure for Be is two orders of magnitude greater than the theoretical one, the latter being completely determined at a low temperature by the neutron capture in Be ($0.008b$). The experiment/theory ratio for a very cold oxygen surface achieves three orders of magnitude [2]. The approximate universality of the loss coefficient for beryllium and oxygen, and the independence of the Be figures of temperature, forces one to suspect a universal reason for this anomaly. A series of experiments to find the channel by which UCN leave the trap are described in [1]. None of the suspected reasons has been confirmed: surface contaminations by dangerous elements with large absorption cross sections, penetration of UCN through possible micro-cracks in the surface layers of Be, the hypothetical process of milliheating of UCN due to collisions with a low frequency vibrating surface, the upscattering of UCN due to thermal vibrations of the wall nuclei.

Recently the experiment was published [3] describing the observation of sub-barrier penetration of UCN in the energy interval $\sim (0.5-1.8)\cdot 10^{-7}$ eV through the rolled beryllium foil. The thickness of the foil was 56μm, the calculated boundary energy E_b for beryllium according to the usual formula $E_b = 2\pi\hbar^2 Nb/m$, where N is the atomic density and b is the coherent scattering length, is $2.4\cdot 10^{-7}$ eV. The measured penetration

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[1] e-mail: pokot@nf.jinr. ru

probability per one UCN collision with the foil surface was found to be $(5 \pm 1) \cdot 10^{-7}$ which is in serious contradiction (is many orders of magnitude greater) with the simple quantum mechanical calculation of the probability of subbarrier penetration. The authors [3] think that the observed phenomenon may have close relation to the mentioned anomaly in the measured UCN loss coefficients.

Several different reasons may cause the observed effect.

1. Penetration through the foil by UCN with the energies higher than the boundary energy for beryllium. These UCN could survive in the storage chamber during comparatively long times on some trajectories. This phenomenon being interesting itself hardly may be considered as a radically new one.

2. Sub-barrier UCN penetration through matter due to some new mechanism, e.g. of the type proposed recently in [4]. According to this mechanism the sub-barrier quantum particles diffuse through a very long (in comparison with the wavelength) distance as a result of neutron incoherent scattering inside the matter (in [3] $kL \geq 5 \cdot 10^3$, where k is the neutron wave vector in vacuum, and L is the foil thickness). This phenomenon is new, and unusual, and inexplicable up to now in the frame of the accepted now (see [5] and referencies therein) quantum theory of multiple scattering of waves and particles in application to neutrons.

3. Weak UCN heating (acquiring of energy of the order of the UCN energy or less) during collisions with the chamber walls. In this case the measured effect has unexpectedly large probability since numerous calculations show that with the probability, which is orders of magnitude greater, UCN must be heated to the energy range close to the wall temperature. The trivial effect of acqusition of energy due to wall mechanical vibrations was excluded according[2].

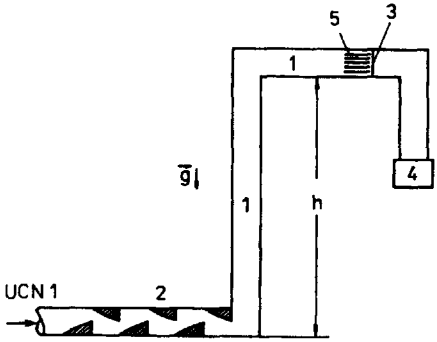

Fig.1. The scheme of the experiment for the search for the anomalous transmission of UCN through metal foils: *1* – vacuum stainless steel neutron guides $\phi 60$ mm, *2* – spectral filter for UCN *3* – foil *4* – Detector of UCN (^{3}He proportional counter) 5 – Additional UCN scatterer

2. Experimental method. The measurements were performed on the test channel of the UCN turbine source at ILL [6]. The scheme of the experiment is shown in Fig.1. UCN spread over the stainless steel cylindrical neutron guides *1* ($\phi = 60$ mm) and collide with the surface of the foil *3* tightly shutting off the UCN path to the UCN detector *4*. It was possible to change the UCN spectrum at the foil by the changing the height h of the part of the guide with the foil. In some experiments the additional UCN scatterer *5* ($\sim 0.1\,\mu$m Be layer deposited on the surface of $50\,\mu$m Al foil) was placed near the foil. It was supposed that if the anomalous transmission is the result of the weak (of the order

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[2] V.V.Nesvizhevsky, private communication.

of UCN energy) upscattering the placing of the scattering specimen with enlarged surface would encrease the transmission effect. The scatterer had the form of a corrugated ribbon rolled into a spiral with an overall area of $\sim 600\,\mathrm{cm}^2$.

The density of the UCN flux at the foil was measured with the ^{3}He proportional counter *4* through a small $0.5\,\mathrm{cm}^2$ hole in the membrane placed in the foil position. The counter background count rate depends on the width of the pulse amplitude window and is equal $(6.5 \pm 1.8) \cdot 10^{-5}\mathrm{s}^{-1}$ when only the total energy peak in the counter spectrum has been taken into account (64% of the counter neutron response total pulse spectrum), and $(1.12 \pm 0.22) \cdot 10^{-4}\mathrm{s}^{-1}$ for ~ 2.5 times wider part of the pulse spectrum.

The UCN spectrum in the chamber in the vicinity of the foils was not measured directly but was estimated from height-energy considerarion: i.e. after passing the vertical (or inclined) section of the neutron guide all UCN change their energy by gh, where g is the gravity acceleration and h is height difference. The important feature of experiments with UCN is the fact that the spectra of neutrons, emerging from neutron guides transporting UCN from moderators to experimental installations, usually contain a significant admixture of neutrons with higher energies. This surplus of more energetic neutrons often surpasses the flux of UCN by many times. There are some cases in which the presence of neutrons with energies higher than some strictly determined critical energy (super-barrier neutrons) is detrimental to the correct interpretation of the experiment. The described experiments belong to this class – it is important to be confident that the measured flux of transmitted neutrons is not caused by the transmission of UCN with energies larger than the boundary energy of the reflecting surface, and which penetrate deeply into the bulk of the wall substance. The same applies to experiments searching for the anomalous upscattering of sub-barrier UCN. In both of these cases super-barrier neutrons might imitate the searched for effect. For example, a 1% admixture of the super-barrier neutrons with energies surpassing the boundary energy by 1% percent gives, at the isotropic angular distribution of incoming neutrons, a penetration probability into the bulk as high as $1 \cdot 10^{-4}$.

Over the years, different devices have been used for preliminary preparation of the UCN spectrum before allowing neutrons to enter the experimental chambers. The task of such devices was to restrict, as much as possible, the access of UCN with energies higher than some critical energy into the irradiation chamber and to let UCN with lower energies pass with the smallest losses. The general idea of such devices consists in arranging some kind of geometric labyrinth or trap for UCN, in which the more energetic neutrons will "die out" at a higher rate due to their larger probability of penetrating the bulk and being captured in the wall. Quantitative analysis of the merits and demerits of different kinds of such devices has been published [7]. In the described experiments we used one of these UCN "filters" (*2* in Fig.1).

3. Experimental results. We obtained the following results for the penetration probability T of subbarrier UCN through foils. For the UCN spectra in the energy range $[0, \sim 90\,\mathrm{neV}]$: $T = (-0.8 \pm 1.6) \cdot 10^{-7}$ for Be foil, $T = (1.05 \pm 1.6) \cdot 10^{-7}$ for stainless steel foil $15\,\mu$m thick, and $T = (-1.18 \pm 1.4) \cdot 10^{-7}$ for stainless steel foil $50\,\mu$m thick.

For the UCN spectra in the energy range $[0, \sim 160\,\mathrm{neV}]$: $T = (1.0 \pm 1.2) \cdot 10^{-7}$ for Be foil, and $T = (-2.7 \pm 1.5) \cdot 10^{-7}$ for stainless steel foil $15\,\mu$m thick.

The transmission measurements for copper foils gave the following results for the UCN spectrum in the energy range $[0, \sim 90\,\mathrm{neV}]$: $T = (2.6 \pm 0.4) \cdot 10^{-5}$ for the copper foil $10\,\mu\mathrm{m}$ thick, and $T = (1.19 \pm 0.09) \cdot 10^{-5}$ for the copper foil $18\,\mu\mathrm{m}$ thick.

For the UCN spectrum in the energy range $[0, \sim 160\,\mathrm{neV}]$: $T = (7.5 \pm 0.6) \cdot 10^{-5}$ for the copper foil $10\,\mu\mathrm{m}$ thick.

The placing of the additional UCN scatterer 5 in the UCN flux in the vicinity of the copper foil decreased the measured transmission. For the UCN energy interval $[0, \sim 90\,\mathrm{neV}]$: $T = (1.67 \pm 0.28) \cdot 10^{-5}$ for the copper foil $10\,\mu\mathrm{m}$ thick, and for the UCN energy interval $[0, \sim 160\,\mathrm{neV}]$: $T = (5.8 \pm 0.8) \cdot 10^{-5}$ for the copper foil $10\,\mu\mathrm{m}$ thick. At this stage we are unable to exclude the possible presence in the neutron flux of UCN with energies higher than the boundary energy for copper ($\sim 165\,\mathrm{neV}$) which could propagate through the copper foils.

One of the possible reasons for nonobservation of UCN transmission through Be and stainless steel foils in our measurements (if this phenomenon does exist at all) may be the larger UCN loss probability in our foils. The other difference consisting in the lower detector position in our measurement (in [3] the UCN detector was placed at the same level with the foil) does not seem essential.

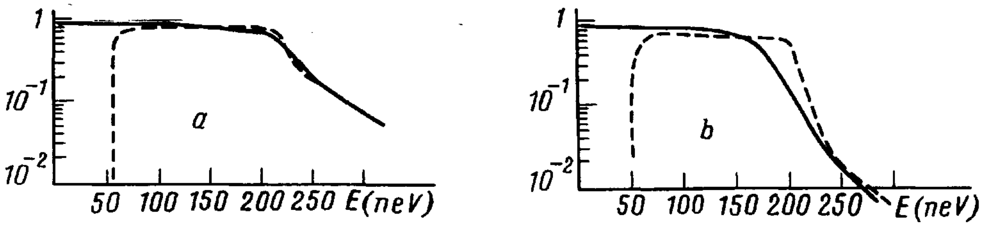

Fig.2. Results of Monte Carlo simulations of UCN detector (^{3}He counter with aluminium membrane) efficiency for two different positions of the detector in respect to the foil position: dashed line – horizontal one, and solid line – at the level 60 cm lower, and for two different probabilities η of UCN diffuse reflection during the transport from the foil to detector through the stainless steel neutron guide with diameter 60 mm: a – $\eta = 0.1$; b – $\eta = 0.5$

The Fig.2 shows the results of Monte Carlo simulations of the UCN detector (^{3}He counter with aluminium membrane) efficiency for two different positions of the detector in respect to the foil position: horizontal one and at the level 60 cm lower, and for two different probabilities of UCN diffuse reflection during the transport from the foil to detector through the stainless steel neutron guide with diameter 60 mm. It is seen that the efficiencies do not differ significantly over all the energy interval except for the low energy part (below $\sim 60\,\mathrm{neV}$), where the lowered detector has higher efficiency.

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