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SEARCH FOR LOW-ENERGY UPSCATTERING OF ULTRACOLD NEUTRONS FROM A BERILLIUM SURFACE WITH THE INDIUM FOIL ACTIVATION METHOD

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Поиск низкоэнергетического нагрева ультрахолодных нейтронов на поверхности бериллия методом активации индиевых фольг

Представлены предварительные результаты экспериментов по поиску аномального низкоэнергетического рассеяния ультрахолодных нейтронов от поверхности бериллия. Такое рассеяние рассматривается как одна из возможных причин «исчезновения» УХН из очень холодных бериллиевых ловушек, обнаруженного в экспериментах ПИЯФ (Гатчина). В представленной работе удалось исключить интервал скоростей рассеянных нейтронов 40—100 м/с.

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Search for Low-Energy Upscattering of Ultracold Neutrons from a Berillium Surface with the Indium Foil Activation Method

Preliminary results are presented of the search for the anomalous low-energy upscattering of ultracold neutrons from berillium surface. This upscattering is considered as one of possible reasons of UCN «disappearance» from very cold berillium bottles, observed in experiments of St.-Petersburg Nuclear Physics Institute. The Indium foil activation method was used for the measurement of the very low intensity flux of upscattered UCN. The 40—100 m/c velocity interval of upscattered UCN is excluded in these measurements with CL 90%.

The investigation has been performed at the Frank Laboratory of Neutron Physics, JINR.

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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 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 higher than the theoretical one, the latter being completely determined at 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]. Approximate universality of the loss coefficient for beryllium and oxygen, and the independence of the Be figures from 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. This last item deserves special and more careful consideration.

According to the description of the experiment [1], upscattered neutrons prior to entering the neutron detector passed through 1.5 mm of copper, 1.1 mm of stainless steel and 2 mm of Al. For the isotropic distribution of upscattered neutrons this means that the efficiency of the registration of upscattered neutrons with energies of 0.5meV was less than 0.2 and decreasing at lower neutron energies. The reported [1] cross section of the upscattering of UCN from a Be surface at a surface temperature of 80 K was equal to 0.14b with an uncertainty of 30%, therefore, it is quite possible that the UCN upscattering takes place into the energy range below 1meV. This hypothesis does not contradict the observed temperature independence of anomalous losses of UCN **if the vibrations causing this upscattering are not thermal in nature.** The frequency of these vibrations (possibly, surface waves) is in the range of $10^8 - 10^{12} Hz$. From the purely experimental point of view (without going into any hypotheses about reasons for the UCN anomalous losses) this low-energy upscattering channel is almost the only one that has not yet been investigated.

The registration of such upscattering with the use of an external gas neutron detector surrounding the UCN trap, encounters the same difficulties as the experiments in [1] – absorption of upscattered UCN in the walls of the trap, of the upscattered neutrons detector, and of the cooling system (e.g. a liquid nitrogen vessel). The use of activation foils as the neutron detector permits one to eliminate all absorbers in the upscattered neutron trajectory (except the wall of the UCN trap) and, in this way, to decrease the low-energy boundary of the registered upscattered neutrons significantly.

2 Experimental method

The measurements were performed on the test channel of the UCN turbine source at ILL [3]. The scheme of the irradiation is shown in Fig.1. UCN enter the stainless steel cylindrical chamber 1 ($\phi = 60mm$, wall thickness 0.5mm) through the vertical (height 120cm) stainless steel neutron guide 2, and bounce from the surface of the specimen 3 made of Al foil covered with a Be

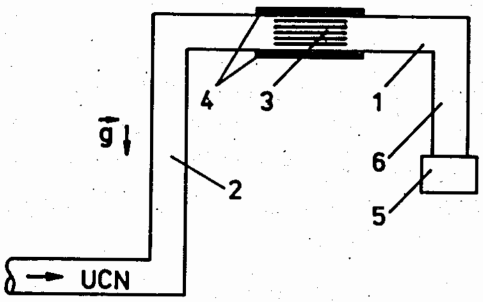

Fig.1 The scheme of the experiment for the search of the low energy upscattering of UCN from Be surface.

1. Vacuum stainless steel chamber $\phi 60x0.5mm$.
2. Vertical UCN guide $\phi 60x0.5mm$, hegiht $120cm$.
3. Rouleau of aluminium foils with beryllium deposition.
4. Cylindrical stack of In foils.
5. Detector of UCN (He^3 propotional counter).
6. Vertical UCN guide $\phi 60x0.5mm$, height $60cm$.
7. Shielding (borated polyethylene).

layer (thickness of the deposition is $(2-3)\cdot 10^3$ Å). The specimen has the form of a corrugated ribbon rolled into spiral with an overall area of $0.25m^2$. The upscattered neutrons leaving the trap penetrate the cylindrical stack of In foils surrounding the tube and activate them with the activation cross section according to the inverse velocity law. The In foils are $5-50\mu$ thick and were manufactured by means of electrolytic deposition on 10μ copper foil. The homogeneity of the In thickness was verified thoroughly by the method of cutting the test foils into numerous small specimens and weighting these small specimens, and was found to be better than 5%. The density of the UCN flux in the trap was calibrated by means of the activation measurement of the flux of upscattered UCN from small polyethylene sample located in the center of the irradiation chamber and monitored with a ^3He proportional counter 5 located after the UCN trap and connected the trap with a vertical neutron guide 6 through a small hole.

The response function of the activation of the In foil stack was calculated by the Monte Carlo method. The upscattered neutrons were assumed to fly out of the Be scatterer isotropically, having their starting points on the surface of the Be spiral. The reflection and absorption of upscattered neutrons along their trajectories was taken into account.

Detailed results of these simulations will be published elsewhere [4].

The activity of the In foils was measured with the high efficiency ($\sim 70\%$) 4π scintillation β-counter with active (4π plastic anticoincident counter) and passive (lead) shielding. The area of the In foils which the activity is measured simultaneously is $\sim 200cm^2$. The measured background of the counter was about $1.2s^{-1}$ in these measurements. The efficiency of the counter was carefully measured for different thicknesses of irradiated In and Cu foils. The description of the counter and results of the calibration will be published in [4].

This method of measuring the slow neutron spectra with the help of the activation of a stack of In foils was calibrated by means of the irradiation of such stacks in the beams of monochromatic thermal neutrons and in the precisely measured (with the time of flight method) quasi-Maxwellian spectrum of cold and thermal neutrons. The measured and calculated distributions of the foil activity along the stacks were in good agreement.

The measured In foil activity as a function of position in the stack (thickness coordinate) was approximated under the assumption that the spectrum of upscattered neutrons consists of two Maxwellian components: one with $v_0 = 2.2 \cdot 10^5 cm/s$ ("normal" upscattering from room temperature Be) and a second with low v_0, the latter being chosen in the interval $10 - 300 m/s$ (anomalous upscattering). It was demonstrated by rigorous Monte Carlo simulation [4] that it is possible not only to distinguish the low energy component of the upscattering from the thermal one, but also to perform rough spectrometry of this low energy part of the spectrum.

3 Results and Discussion

Fig.2 shows an example of the measured activity of irradiated In foils as a function of the thickness coordinate, together with the results of the Monte Carlo simulation of such activity in the flux of "normally" and anomalously upscattered UCN in the geometry of the experiment.

Fig.3 represents the 90% exclusion contours for the cross sections σ^*_{anom} and σ^*_{norm} deduced from In foil activation measurement of upscattered UCN fluxes from a normal temperature Be surface.

The contours are presented for different characteristic velocities v_0 of anomalously (low-energy) upscattered UCN; the spectra

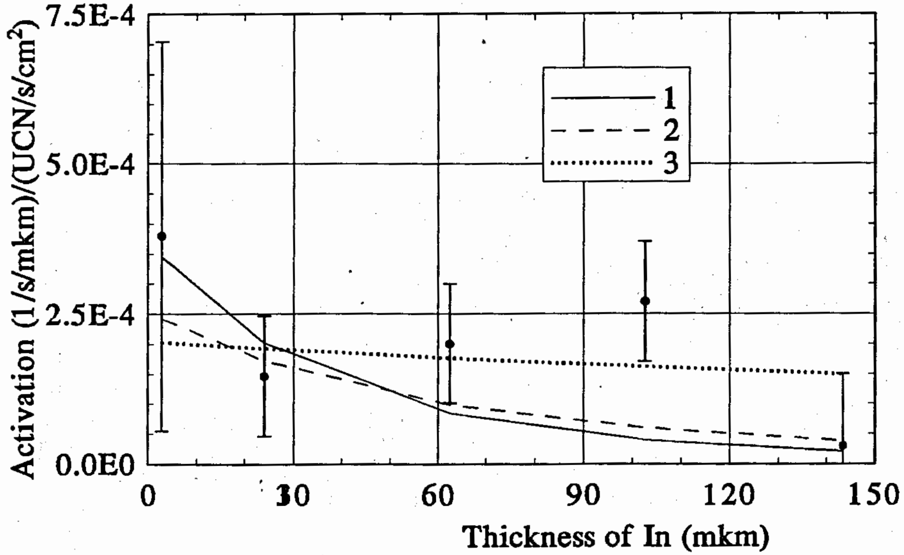

Fig.2 Measured In foil activation points and Monte Carlo simulation examples of activation for: 1 - "anomalous" UCN upscattering to Maxwellian spectrum with characteristic velocity $v_0 = 100 m/s$, $\sigma^* = 0.9b$; 2 - the same for $v_0 = 200 m/s$; 3 - "normal" scattering, $v_0 = 2200 m/s$, $\sigma^* = 5b$.

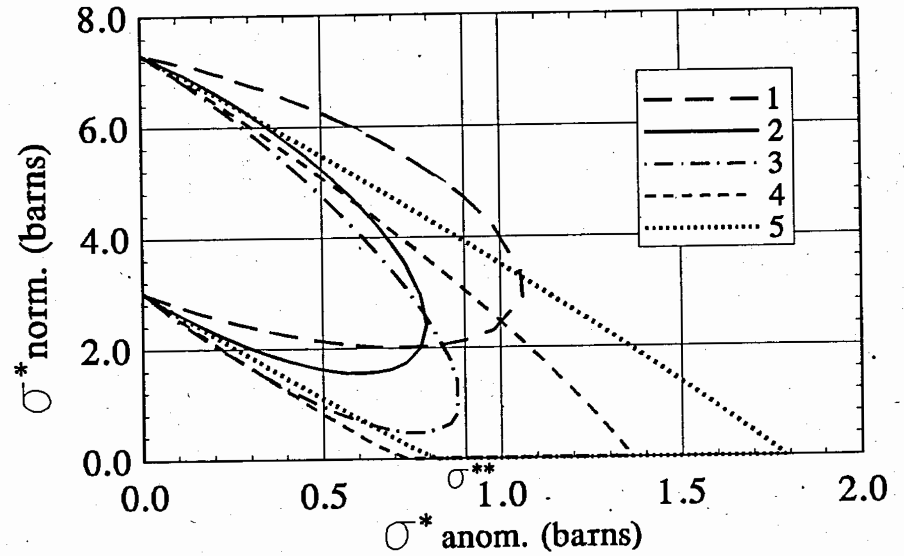

Fig.3 The 90% CL exclusion contours in the σ^*_{anom} vs σ^*_{norm} plane deduced from the In foil activation measurement of upscattered UCN fluxes from a normal temperature Be surface. $\sigma^{**} = 0.9b$ is the value of the experimentally found anomalous reduced UCN loss cross section [1] ("Gatchina anomaly").

The In foil activation points were considered as a result of activation in a neutron flux consisting of two Maxwellian components - "normal" with characteristic velocity $2200m/s$, and "anomalous" with different characteristic velocities v_0 of anomalously (low energy) upscattered UCN: 1 - $v_0 = 25m/s$; 2 - $v_0 = 50m/s$; 3 - $v_0 = 100m/s$; 4 - $v_0 = 200m/s$; 5 - $v_0 = 300m/s$; $v_{0norm} = 2200m/s$.

of upscattered UCN were assumed to have a Maxwellian form:

1 - $v_0 = 25m/s$; 2 - $v_0 = 50m/s$; 3 - $v_0 = 100m/s$; 4 - $v_0 = 200m/s$; 5 - $v_0 = 300m/s$.

The following formulae were used in this consideration.

Reduced UCN loss cross section $\sigma^* = (\sigma_{inel} + \sigma_c)$ at $v = 2200m/s$. $Imb = \sigma(\lambda)/2\lambda$. $\eta = Imb/Reb$.

Averaged over isotropic angular distribution loss coefficient of UCN with a velocity v upon reflection from the surface with the boundary velocity v_b: $\bar{\mu}_{loss} = 2\eta(arcsin(y) - y\sqrt{1-y^2})/y^2$, where $y = v/v_b$.

$\tilde{\mu} = \int_0^{v_{lim}} \bar{\mu} f(v)dv$ is UCN loss coefficient averaged over the normalized UCN flux spectrum $f(v) = 4v^3/v_{lim}^4$, which is the low- energy tail of the Maxwellian spectrum. In our case, $v_{lim} = 3.9m/s$.

As may be seen from fig.3 we were not be able to exclude completely in this preliminary experiment low energy UCN upscattering in all energy interval of interest: $1-10^3 \mu eV$. The main reason for that was comparatively high β-counter background (higher than $1s^{-1}$), and short measurement time. After upgrading the beta-counter with lowering the background to $0.2-0.3s^{-1}$ it will be possible to increase significantly the sensitivity of the activation method applied in this investigation.

4 Acknowledgments

The preliminary In foil activation measurements with upscattered UCN and the partial calibrations of the method in the cold and thermal neutron beams were performed at the reactor of the St.Petersburg Nuclear Physics Institute (SPNPI) in Gatchina. We are grateful to Drs. A.P.Serebrov, A.G.Kharitonov, V.V.Nesvizhevsky, and R.R.Taldaev for their kind permission to use the UCN channel of SPNPI and for their very valuable help. We thank them also for placing at our disposal the Be sample. The authors thank Dr.P.Yajdjiev (ILL) for supplying us with the proportional ^3He counter for monitoring the UCN flux. We also express our appreciation to the ILL reactor staff.

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