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Neutron lifetime and density of states of fluoropolymers at low temperatures

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Accurate measurement of the neutron lifetime is of importance for obtaining the Standard Model parameter – the CKM matrix element V_{ud} and in astrophysics – for the theory of the Big Bang Nucleosynthesis [1, 2].

Two principally different experimental methods of measurement of the neutron lifetime: the beam method and the method of storage ultracold neutrons (UCN) in material or magnetic traps are in disagreement of about four standard deviations. The most probable cause of this difference are systematic errors in either of these two methods, but more exotic scenarios are discussed as a cause of neutron disappearance from the UCN traps: neutron – mirror neutron oscillations [3], or neutron propagation to brane world [4] (neutron-shining–through-a-wall experiments).

Losses of confined neutrons in storage volumes with material walls are caused by the neutron capture and thermal up-scattering in collisions with walls and with atoms of residual gas, and precision of the UCN storage method of the neutron lifetime determination depends on the value of these losses. The experimental efforts in improving this precision revolve around finding better way of extrapolating the measured UCN storage times to the value of the free neutron lifetime, and the most obvious way to improve precision and reliability of experimentally obtained value of the neutron lifetime is to decrease neutron losses in traps to maximal degree.

The UCN loss anomaly is well known: for the great majority of tested materials (the best choice for the walls of UCN traps are the low neutron capture materials at low temperatures: Be, C, D_2O ice, solid oxygen) significant disagreement exists between measured and calculated values of the neutron loss coefficients at the neutron collision with walls of storage volumes [5]. The only materials showing satisfactory agreement with theoretical estimates and simultaneously low UCN loss coefficients are hydrogen free fully fluorinated polymers in liquid [6] and frozen form [7, 8]. These fluoropolymers were used in the cited neutron lifetime measurements to cover the wall of storage volumes. Further progress in precision of the neutron lifetime measurement by this method can be reached only by the way of decreasing UCN wall losses to lower values, the latter is determined by dynamical properties of a substance and depends on temperature.

To obtain information about dynamical properties of fluoropolymers we performed in our previous work [9] the neutron inelastic scattering measurement of the excitation spectra of two different substances: Fomblin 18/8 and the low temperature one (PFPOM). To decrease destruction of the fluoropolymer deposits at low temperatures the fluoropolymers with the lowest known pour point ($\sim -125\,^{\circ}$C) [10] were proposed in [11]. It is relatively low-molecular weight perfluoropolyformaldehide (PFPF) with formula $CF_3(CF_2)_3$-OCF_2-O-$(CF_2)_3CF_3$. The goal was to further decrease UCN losses due to suppression of thermal up-scattering at a temperature lower than was used in [8].

In this experiment we investigated two substances: PFPF and Fomblin grease [12]. The latter material (it is suspension of microscopically small teflon balls in Fomblin oil) was used many times in the UCN storage installations and in recent neutron lifetime measurement [13].

As previously [9] the experiments were performed using the NERA – time-of-flight inverted geometry spectrometer [14] at the IBR-2 high flux pulsed reactor of the Joint Institute for Nuclear Research in Dubna. The measurement procedure of the inelastic neutron scattering spectra and deriving from these spectra density of states was the same as in [9]. From determined $G(\omega)$ we calculated the temperature dependent UCN loss coefficients.

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