FLEXIBLE NEUTRON GUIDE MADE OF POLYVINYL CHLORIDE PLASTIC TO TRANSPORT ULTRACOLD AND VERY COLD NEUTRONS

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Abstract

We present experimental results on transport of ultracold neutrons (UCN) through flexible tubes with the length of up to 3 m and the internal diameter of 6-8 mm made of polyvinyl chloride plastic. Shiny surface of internal walls of such tubes provide high transmission of UCN even if the tube is curved to arbitrary direction. The transmission increases up to 85% if the internal tube surface is covered with layer of liquid fluorine polymer. We discuss an option to use such tubes for building portable sources of UCN and thermal neutrons as well as for capture therapy using low energy neutrons.

Introduction

Slow neutrons are transported over long distances through neutron guides with specular internal walls made of materials with high nuclear-optical potential and low neutron looses. Such guides are expensive; their production is a complex task particularly for non-trivial guide shapes. Here we report on first experimental observation of efficient guiding of slow neutrons through cheap commercially-available polyvinyl-chloride plastic tubes that could be turned to arbitrary direction.

Experimental results

The density of polymer polyvinyl chloride $(CH_2\text{-}CHCl)_n$ is 1.4 g/cm^3; its molecular weight varies in the range of 30000 – 100000 at.u. The coherent scattering lengths for Hydrogen, Carbon and Chloral are equal to b_H = -3,74 fm, b_C = 6,65 fm, b_{Cl}= 9,58 fm respectively (1 fm=10^{-13} cm). The critical energy of this polymer is equal to 39.7 neV; its critical velocity is equal to 2.8 m/s. Transmission of UCN through flexible tubes made of this polymer was investigated at the beam position PF2 at the ILL reactor using the set-up shown at Fig.1a.

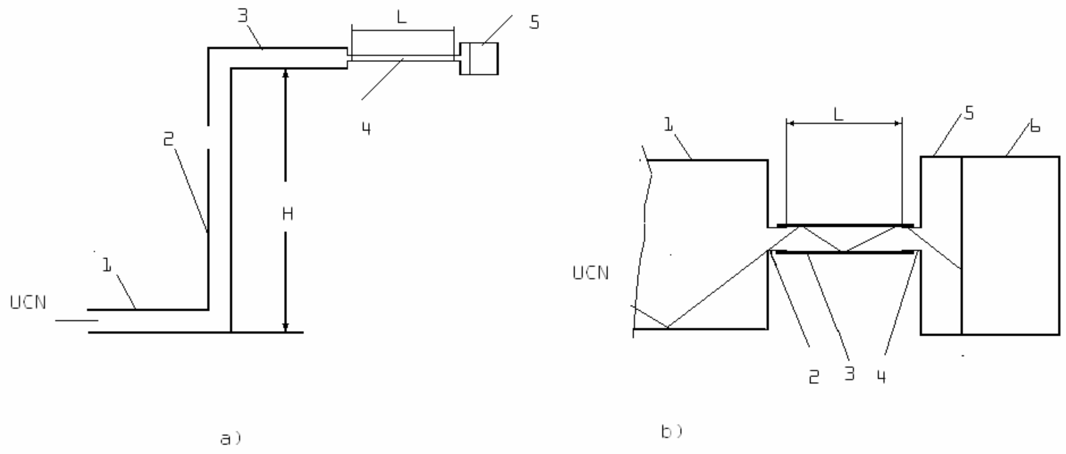

Fig.1. A scheme of the experimental set-up; a) a general view of the set-up: 1 – horizontal neutron guide; 2 – vertical neutron guide; 3 – horizontal neutron guide with the output socket; 4 - flexible polyvinyl chloride plastic tube; 5 – neutron detector. b) an insert enlarging the flexible tube with its connections: 1 – horizontal neutron guide; 2 – output socket of the guide; 3 – flexible plastic tube; 4 – input socket of the detector section; 5 – intermediate chamber; 6 – detector.

UCN with energy in the range of approximately 52 – 360 neV arrive from PF2TEST beam port to the experimental set-up via stainless steel neutron guides with the internal diameter of 7 cm shown in Fig.1a: horizontal section 1, vertical section 2 with the length of 160 cm, and short horizontal section 3. The energy of UCN at the height of the section 3 is lower than that at the height of the section 1 by about 160 neV as UCN are decelerated in the vertical guide section due to the Earth's gravitational field. Flexible plastic tubes with the diameter of 6-8 mm of various length and shape could be connected to the output socket of the guide section 3. ^{3}He-filled proportional gaseous counter measures UCN flux at the exit of a flexible tube. The diameter of thin entrance Al window of the counter is 9 cm. The tubes ends are hermetically connected with the neutron guide and the detector section; vacuum inside the tubes is equal to $\sim 10^{-3}$ mbar. As the critical energy of Al is equal to 52 neV, the corresponding minimal velocity of neutrons which can come inside detector is equal to 3.2 m/s. So, registered neutrons have velocity at the range of 3.2 – 6.3 m/s.

The probability of UCN return from the intermediate chamber back to a polyvinyl chloride tube is negligible as a tube cross-section is much smaller than the detector one; also the UCN detection efficiency is high. The input UCN flux was measured when the sockets of the detector and the guide section 3 were connected with no space in between: L=0, see Fig.1; a short flexible tube was used for vacuum seal of set-up only. The total neutron flux is equal to I_0=20.8(1) s^{-1}. Transmission of a tube depends on its cross section shape; maximal transmission is provided by round tube cross-section along its total length. In actual measurements, the shape varied from circle to ellipse.

Fig.2 shows the transmission probability $W = \frac{I(L)}{I_0}$ as a function of the tube length; here the tube diameter equals d=8 mm, the tube length L ranges from 4 cm to 290 cm, correspondingly L/d ranges from 5 to 360. Even if the flexible tube is as short as 4 cm the transmission probability *W* decreases sharply to 0.36. For larger lengths *W*-value decreases slowly as a function of the tube length and reaches the value of *W*=0.07 when L=290 cm. This result could be understood as follows: UCN with the radial velocity component V_r> 2.8 m/s penetrate into the wall material in first their collisions with the tube wall. Such UCN are captured or inelastically scattered; in both cases they are lost. UCN with V_r< 2.8 m/s are reflected many times therefore they could be transported over large distance.

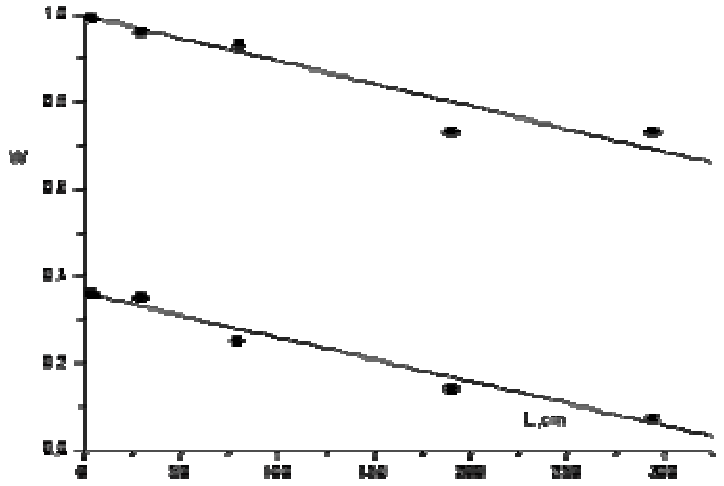

Fig.2. The probability of transmission W as a function of the tube length; the internal tube diameter equals 8 mm. Lower curve and data points correspond to measurements with clean polymer tube, the upper ones indicate results for the tube with thin layer of fluorine polymer on its internal surface.

Consider UCN with the initial radial velocity component V_r <2.8 m/s. These UCN could be lost if the tube cross-section is not precisely round and/or reflections are not specular; thus the radial velocity component could become larger than 2.8 m/s; other reasons for losses include under-barrier capture and/or inelastic scattering. Otherwise, such UCN could travel over large distance through the tube.

In order to increase the critical velocity and the probability of specular reflection as well as for decreasing losses of sub-barrier UCN, we covered internal surface of the tubes with thin layer of Fluorine polymer YH VAC 18/8 with the thickness of 0.05-0.1 mm and the critical energy of 106 neV corresponding to the critical velocity of 4.56 m/s. Upper curve and data points in Fig.2 indicate the corresponding results; the transmission probability decreases from W=0.98 for L= 4 cm down to $\boldsymbol{W}$=0.75 for L= 290 cm. Thus, higher critical velocity of 4.56 m/s allowed us to transmit total UCN initial flux; eventually lower losses of sub-critical neutrons increased the characteristic transport length. The high critical velocity prevented UCN penetration into wall material as well as their under-barrier capture.

Fig.3a presents the relative transmission probability T of UCN through polyvinyl chloride plastic tube as a function of the tube shape when the tubes are curved (twisted) in the horizontal plane with the curvature radius of 10 – 20 cm; $T= I_{conf} / I_{str}$, where I_{str} is equal to the UCN flux at the exit of a strait tube, and I_{conf} is the UCN flux at the exit of a curved tube; the tube length is constant, the internal tube diameter equals 8 mm. It is clear that the tube curvature decreases the relative transmission rather slightly; even for the triply circled tube it is as high as 45%. Result of a measurement with the tube coated inside with Fluorine polymer is shown at Fig.3b.

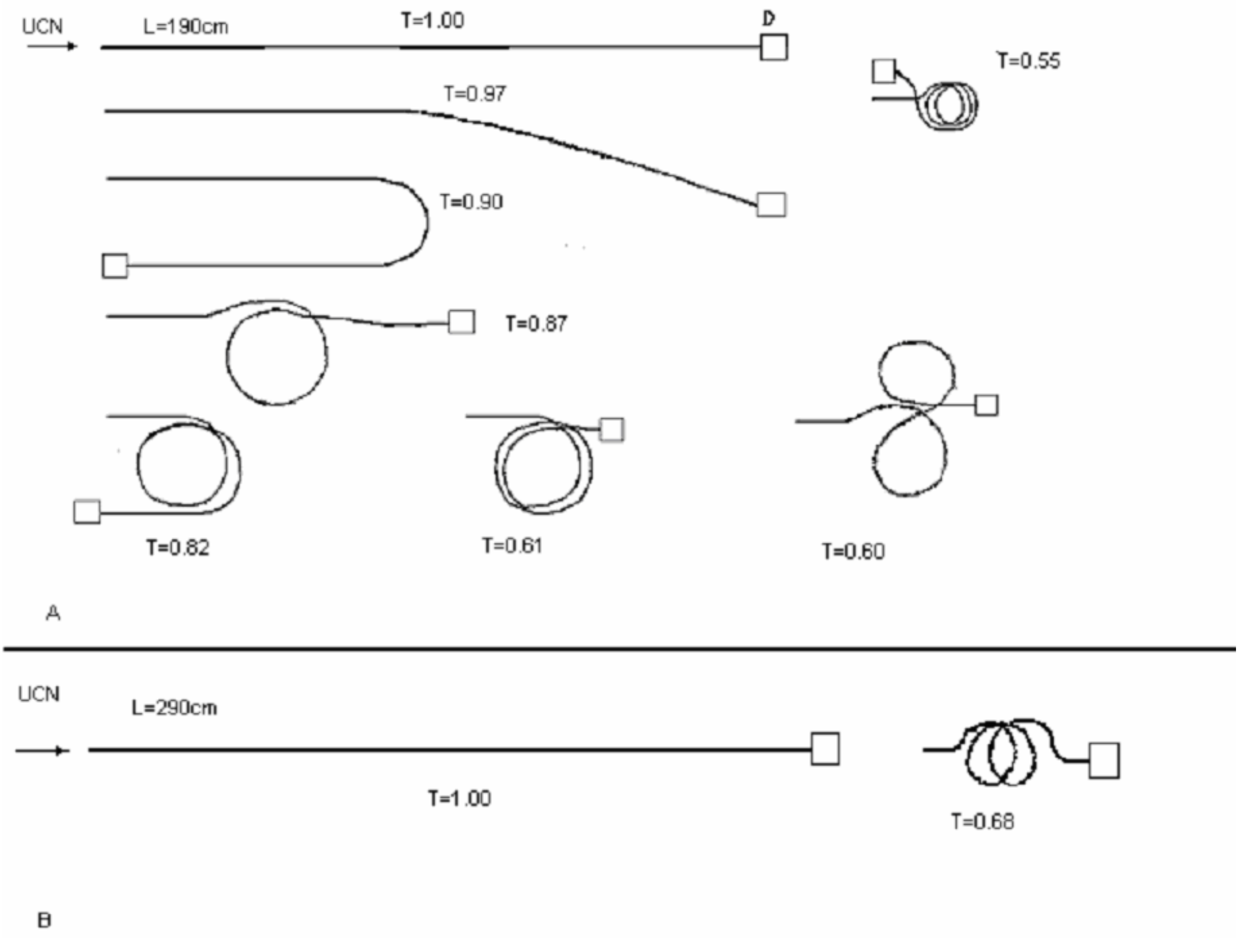

Fig.3. The relative probability of UCN transmission (*T*) through polyvinyl chloride plastic tubes is shown as a function of the tube shape. A) The tube length equals L=190 cm. B) The tube length equals L=290 cm; the tube is coated inside with thin layer of Fluorine polymer.

The presented qualitative results allow us to conclude:

1. Surprisingly high specular reflectivity of the internal surface of polyvinyl chloride plastic tubes is discovered. Physical reasons for such high reflectivity have to be studied. In particular a role of gigantic molecules with the weight of 30000 – 100000 at.u. in the tube surface is of interest. The specular reflectivity increases if thin layer of fluid Fluorine polymer is applied; its critical energy is higher and the capture cross-sections is lower than those for polyvinyl chloride plastic. The transmission of such coated tubes is as high as 70 – 75% even if the ratio L/d is as high as 360. An analogous polyvinyl chloride neutron guide with the diameter of 8 cm would transport UCN over the distance of about 30 m.
2. The flexibility of polyvinyl chloride tubes allows us to transport UCN from UCN source to any point in arbitrary direction over large distance along complicated path shape. In particular, such tube could be used as

catheters in neutron-capture therapy of bad tumors. Another option consists in using such thin-wall tubes made of polyvinyl chloride plastic for production tiny portable sources of UCN as well as thermal neutrons. In former case a thin polyethylene cork has to be installed to the tube exit in order to scatter UCN inelastically to the thermal energy range.

3. Transmission of such tubes for neutrons of higher velocity should be further investigated.