Experimental report

02/07/2017

Proposal: **3-14-370** **Council:** 4/2016

Title: Measurement of the UCN/VCN cross sections of liquid and solid para-hydrogen

Research area: Physics

This proposal is a new proposal

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Samples: Hydrogen
Deuterium

Instrument	Requested days	Allocated days	From	To
PF2 VCN	40	0		
PF2 EDM	28	68	26/08/2016 07/11/2016	23/09/2016 17/12/2016

Abstract:

In recent UCN transmission experiments on liquid and solid ortho-deuterium we could successfully determine the UCN scattering cross sections of ortho-D2 in the low energy range from 100 to 1000 neV (Exp.No. 3-14-311, 3-14-351).
In continuation of our work we here propose to measure the UCN cross sections of liquid and solid para-hydrogen with improved precision due to the reduction of surface scattering from the windows of the sample cell. Para-hydrogen is a purely coherent scatterer in the UCN region as opposed to ortho-deuterium and therefore may show quite different UCN cross sections. The precision of existing experimental UCN data (Seiffert,1970) does not fullfil nowadays requirements that are neccessary for calculation and design of advanced UCN sources. Moreover there appeared new data for p-H2, that differ a factor of 3 from the Seiffert data base in the low energy region (E<1meV)[1,2], which makes a confirmation also in the UCN region mandatory and interesting.
This proposal is part of the PhD-thesis "UCN scattering cross sections of the cold hydrogens", a collaboration between ILL Grenoble, Technische Univ. München/Germany and Universita degli Studi di Firenze/Italy.

Experimental Report

for Proposal Number: 3-14-370 (02/2016), at the instrument PF2 EDM

Measurement of the UCN/VCN cross sections of liquid and solid para-hydrogen

Christoph Morkel (main proposer), Stefan Doege, Eleonora Guarini, Erwin Gutsmiedl, Bernhard Lauss, Peter Geltenbort (co-proposers)

Experimental Period: 26 August – 4 October 2016, 4 November – 22 December 2016

Abstract

Even after decades of neutron scattering work, the precise measurement of ultracold neutrons (UCN) cross sections of the cold hydrogens (H_2 and D_2) in the solid and liquid state is yet an unfinished story. First results were obtained in the 1960 [3-6] and even later attempts in the 1990 [7-8] only supplied imprecise data, which can hardly be used for the calculation and design of CN- and UCN-sources. Recent UCN experiments [9-11] put a new emphasis on the physics of UCN moderators and led us to a first series of UCN transmission experiments on liquid and solid *ortho*-deuterium (*o*-D_2) [12-13].

Aim of the Experiment

In continuation of our UCN work on cold hydrogens, we proposed to measure the counterpart of *ortho*-deuterium, namely *para*-hydrogen (*p*-H_2). While *o*-D_2 is a partially incoherent UCN scatterer, its counterpart *p*-H_2 (both with the rotational quantum number $J = 0$) scatters purely coherently in the UCN regime. Hence a quite different behavior must be expected for the UCN cross section in the case of *p*-H_2. The cross section of liquid *p*-H_2 [1] is known in the thermal and cold energy range down to 0.4 meV and was recently carefully revisited by the work on H_2 of the Florence group [2]. However, the UCN data base for *p*-H_2 is poor [6].

Preliminary Results

A large part of the beamtime was devoted to caracterizing the UCN spectrum at the beam positions PF2-UCN, PF2-EDM and PF2-Test. This was done to have a better base for planning future experiments and to assist the ongoing qBounce experiment at PF2-UCN with properly aligning their vacuum chamber. These data are currently being evaluated in detail, taking into account the UCN transmission through electropolished beam tubes.

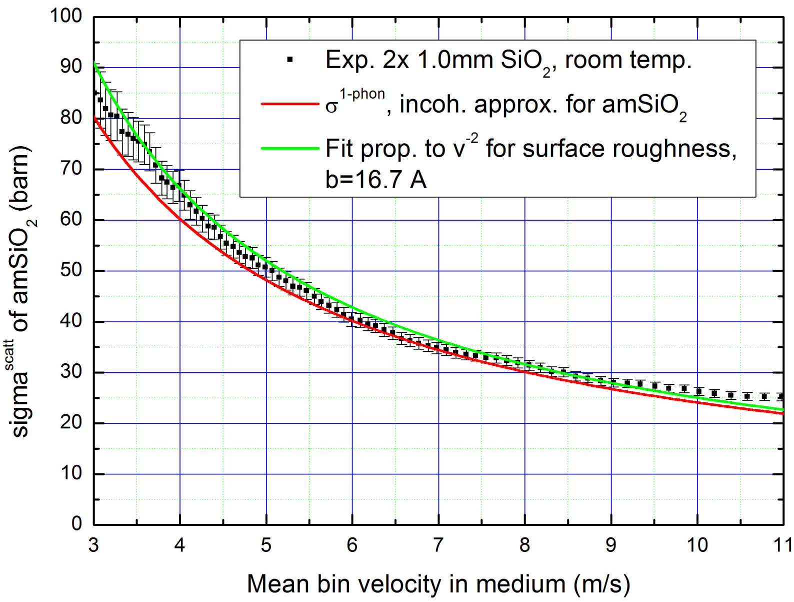
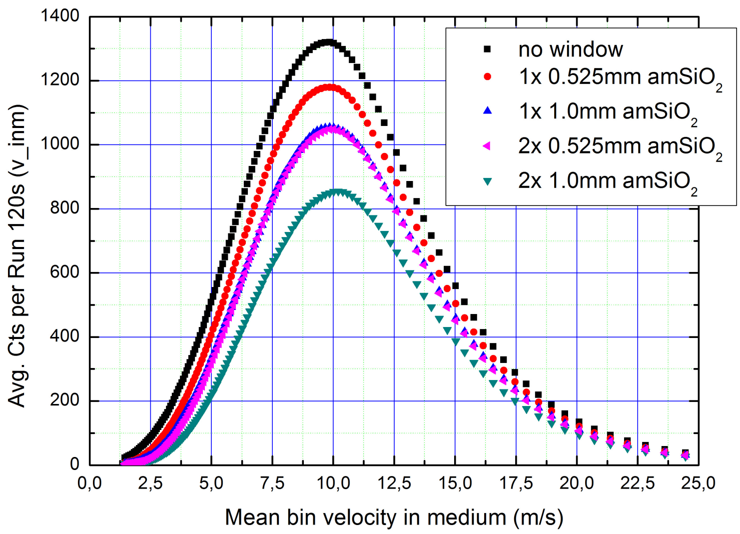


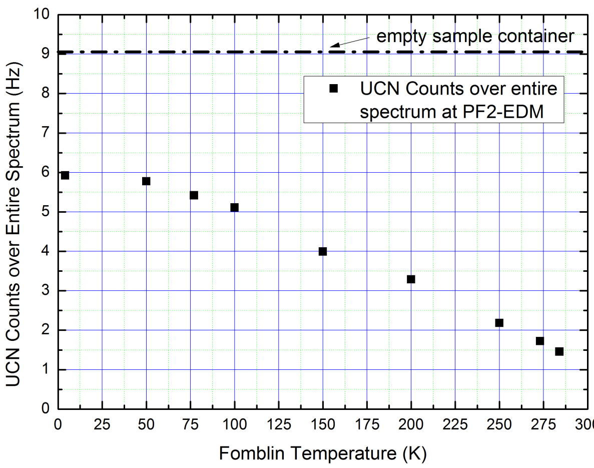
Fig. 1 (right) Total experimental UCN scattering cross section per SiO_2 unit (black squares), 1-phonon approximation for amorphous quartz (red line) and the scattering contribution from the polished quartz surface (green line). The Steyerl theory on surface scattering yields a mean surface roughness of 16.7 Angström, which is in line with the specifications of the manufacturer of the quartz windows.

Then, the new sample cell windows made from double-side polished amorphous quartz (SiO_2) were tested and compared to the previously used machined aluminum windows. Quartz showed a significantly better UCN transmission, about three times as much as the aluminum windows. These tests were also used to verify the applicability of the Steyerl theory on surface scattering [14] (Fig. 1). Transmission measurements showed that the new quartz sample cell windows have little to no UCN scattering on the surface. Fig. 2 shows that two quartz windows of 0.5mm thickness have the same UCN transmission as one 1.0mm thick window.

Fig. 2 (right) UCN transmission through amorphous quartz windows of various thicknesses.



Additionally, the UCN transmission through Fomblin oil was measured in a test experiment. Fomblin oil, i.e. fully fluorinated hydrocarbon chains with a high molecular weight between 1000 and 10'000 grams per mole, is widely used in storage experiments with UCNs. The optical potential of fomblin is 106 neV [15] and allows for the almost loss-free storage of neutrons with a kinetic energy below this potential. Therefore Fomblin is the material of choice for inner wall coatings of vessels used in experiments that measure the lifetime of the free neutron [16,17,18]. In order to increase the accuracy of the results from these experiments and minimize systematic errors, it is important to know all neutron loss channels to a very high precision. However, to date the exact interaction of slow neutrons with Fomblin is unknown.



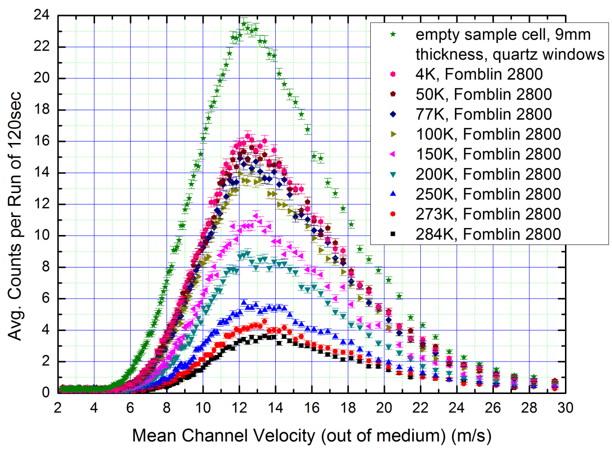


Fig. 3 (left) Temperature dependence of the UCN transmission through Fomblin (2800 g/mole).
Fig. 4 (right) UCN transmission spectra through a sample of Fomblin oil (2800 g/mole, 9.0 mm thick, quartz sample container) at various temperatures, data acquisition time was 3 hours per temperature.

The transmission of UCNs through Fomblin is generally believed not to depend much on temperature at low temperatures. However, this test measurement showed that the UCN transmission increased almost linearly until down to 50K (Fig. 3). This points to UCN loss channels being present even at liquid nitrogen temperatures. Fig. 4 shows the UCN velocity spectrum transmitted through the Fomblin sample depending on the sample temperature. Additional experiments with better statistics are needed in order to investigate this phenomenon in detail.

The measurement of hydrogen proved to be very intricate. The cryogenic seal – indium – needed a lot of attention when assembling the sample cell and putting high pressure on the fragile quartz disks. Once the sample cells sustained a pressure of about 600 mbar against vacuum, the UCN transmission of hydrogen was measured. Preliminary results are shown in Fig. 5 and 6.

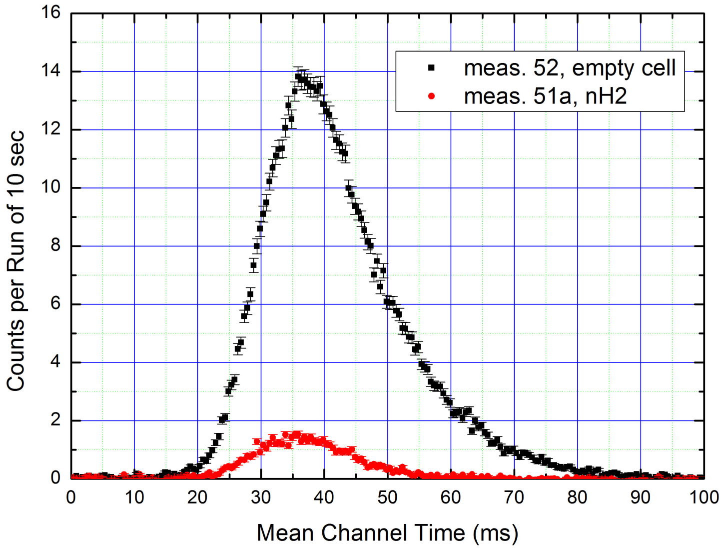


Fig. 5 (right) Comparison of UCN transmission through an empty sample cell (two 1.0mm quartz windows, black squares) and a sample cell filled with a 1.0mm thick sample of normal-hydrogen (75% ortho-H_2, 25% para-H_2, red squares).

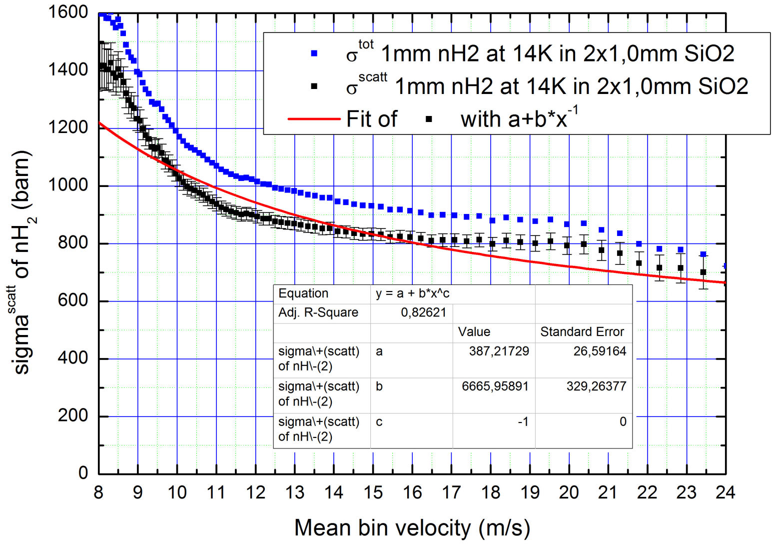


Fig. 6 (right) Cross sections of liquid normal-hydrogen at 14K, same data as shown in Fig. 5.

Due to the the high nuclear cross section of *n*-H_2 (168 barn at thermal neutron energies) and the 1/*v* behavior of the 1-phonon cross section, the total cross section reaches up to 1000 barn per molecule in the UCN energy region. A detailed evaluation of these data is ongoing.

References

[1] K. B. Grammer et al., Phys. Rev. B 91, 180301(R) (2015).
[2] E. Guarini et al., Phys. Rev. B 92, 104303 (2015), also seminar talk at ILL Grenoble (2 June 2015).
[3] J. Young, J. Koppel, Phys. Rev. 135, A603 (1964) .
[4] P. Egelstaff, B. Haywood, F. Webb, Proc. Phys. Soc. 90, 681 (1967).
[5] V. F. Sears, Canad. J. of Phys. 44, 1279 (1966).
[6] W. Seiffert, Report No. EUR 4455d (1970).
[7] F. Bermejo et al., Phys. Rev. B 47, 15097 (1993).
[8] M. Mukherjee et al., Europhys. Lett. 40, 15 (1997).
[9] F. Atchinson et al., Phys. Rev. Lett. 95, 182502 (2005) and Phys. Rev. Lett. 94, 212502 (2005).
[10] A. Frei et al., Phys. Rev. B 80, 064301 (2009) .
[11] C. Liu et al., Phys. Rev. B 62, R3581 (2000).
[12] S. Döge et al., Phys. Rev. B 91, 214309 (2015).
[13] S. Döge et al., ISINN-23, conference proceedings, Dubna/Russia, (2016).
[14] A. Steyerl, Z. Phys. 254, 169 (1972).
[15] R. Golub, D.J. Richardson, S.K. Lamoreaux, Ultra-Cold Neutrons, Adam Hilger, Bristol (1991) and V.K. Ignatovich, The physics of ultracold neutrons, Clarendon Press, Oxford Series on Neutron Scattering in Condensed Matter (1990).
[16] W. Mampe, L. N. Bondarenko, V. I. Morozov, Y. N. Panin, A. I. Fomin, JETP Lett. 57, 82 (1993).
[17] S. Arzumanov, L. Bondarenko, S. Chernyavsky, P. Geltenbort, V. Morozov, V.V. Nesvizhevsky, Yu. Panin, A. Strepetov, Phys. Lett. B, 745, 79 (2015).
[18] A. Serebrov, et al., Phys. Lett. B 605, 72 (2005) and A. Serebrov, et al., Phys. Rev. C 78, 035505 (2008).