Experimental report

21/01/2016

Proposal: **3-14-351** **Council:** 10/2014

Title: Measurement of UCN scattering cross section of liquid and solid deuterium

Research area: Physics

This proposal is a continuation of 3-14-311

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Samples:

Instrument	Requested days	Allocated days	From	To
PF2 EDM	28	69	17/06/2015	15/07/2015
			12/09/2015	23/09/2015
			12/11/2015	12/12/2015

Abstract:

In a recent UCN transmission experiment (3-14-311) on liquid and solid ortho-deuterium we could - for the first time - nearly perfectly interpret the measured scattering cross section in the liquid state (T = 20 K) with appropriate scattering laws.
The same attempt in the solid state (T = 16 K) revealed an excess cross section of about 30 barn relative to theory. This cross section turned out to be velocity-independent, as opposed to the usual 1/v behaviour in the UCN region, and is hence of elastic origin. In a first approach we ascribed this excess cross section to defects in sD2 (cracks, voids), i. e. to a volume effect. A simple Guinier approximation - scaled properly to the UCN region- yields a cross section of about 30 barns in sD2.
To scrutinize the bulk nature of the excess cross section, we plan a UCN transmission experiment performed with different sample thicknesses, strictly observing the necessary condition Sigma*D <1 to avoid uncorrectable multiple scattering.
This proposal is part of a beginning PhD-thesis "UCN scattering cross sections of the cold hydrogens".

Experimental Report
for Proposal Number: 3-14-351 (09/2014), at the instrument PF2 EDM

Measurement of UCN scattering cross section of liquid and solid deuterium

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Experimental Period: 17 June – 3 August 2015, 11 – 23 September 2015, 2 – 12 December 2015

Abstract

Since the advent of cold and ultracold neutron (UCN) sources for neutron scattering instruments the precise knowledge of deuterium scattering cross sections in the subthermal neutron energy range is a prerequisite for the successful development and improvement of these sources. Cold sources usually work with liquid deuterium at around $T = 20$ K and there are several designs of UCN sources which run on solid ortho-deuterium at $T = 5$ K.

Before commencement of the measrements the sample environment had been significantly improved over that of 2012 (see Exp. Rep. 3-14-311), so that much lower sample temperatures (down to 4.5 K) and smaller temperature gradients were achieved. Also, the ortho-deuterium concentration could be improved to $c_{\text{ortho}} = 98\%$.

In the experiments described here it was shown that the rough deuterium surface scatters away a significant fraction of the incoming UCN beam (~20%). Through the use of variously thick samples (3.3, 9.0 and 10.7 mm) it will be possible to correct this parasitic scattering behavior and extract the true bulk scattering cross sections of liquid and solid deuterium. This will be done by comparing the transmission through two samples of different thickness and using an iterative procedure to determine the UCN intensity scattered out of the beam by the deuterium surface. This data treatment is currently ongoing. From the corrected cross sections it will be possible to determine some parameters of the voids and cracks in the solid deuterium samples.

Aim of the Experiment

The precise measurement of UCN cross sections of the hydrogens (D_2 and H_2) has been a longstanding problem in the physics of cryo-moderators. Basic theoretical calculations of the nuclear cross section of deuterium – the case of this proposal – date back to the 1940s [1,2]. First reliable experimental data were taken only in the 1960s [3-7] and still today high-precision transmission experiments are in the focus of UCN moderator physics [8-12].

Following this line we have performed an UCN transmission experiment on solid and liquid ortho-deuterium followed by a thorough data evaluation. For the first time the UCN cross section of liquid ortho-deuterium ($c_{\text{ortho}} = 0.80$, $T = 20.6$ K) could be described nearly perfectly with a theoretical model, taking properly into account the liquid state of the sample [13]. In the solid state (T = 16 K) we were able to verify the well known 1/v-behaviour of the cross section, but found an "additional" elastic cross section of about 30 barn – independent of the UCN velocity.

The present experiment was performed in order to clarify the origin of this additional cross section (from bulk or from the sample surface).

The Experiment

In the present experiment we measured the transmission of UCNs through liquid and solid ortho-deuterium ($c_{\text{ortho}} = 0.98$) samples of various preparation methods (slow freeze [SF] and turbofreeze [TF] at two different temperatures each) and various thicknesses. The transmission through empty sample cells was measured as well. All experiments were carried out at the PF2-EDM beamline.

By comparing the transmission through the same sample, but at a different thickness we will be able to correct the scattering data for surface scattering using an iterative method. This data treatment is currently (February 2016) ongoing. To the corrected data we will apply the Guinier approximation as a suitable theory to describe voids and cracks in solid deuterium and their dependence on the crystal preparation method. We are convinced this will allow us to explain the „excess“ elastic cross section observed earlier [14].

Preliminary Results

After comparing two liquid deuterium measurements (see Fig. 1) it became obvious that not only the surface of the solid, but that of the liquid as well causes surface scattering. This is believed to be due to insufficient wetting of the inner surface of the aluminum sample container. In Fig. 1 the raw data (i.e. not corrected for surface scattering) of the thick and the thin sample show the expected $1/v$-behavior, but with a different „offset“, which is 6.7 barn for the thick and 16.8 barn for the thin sample.

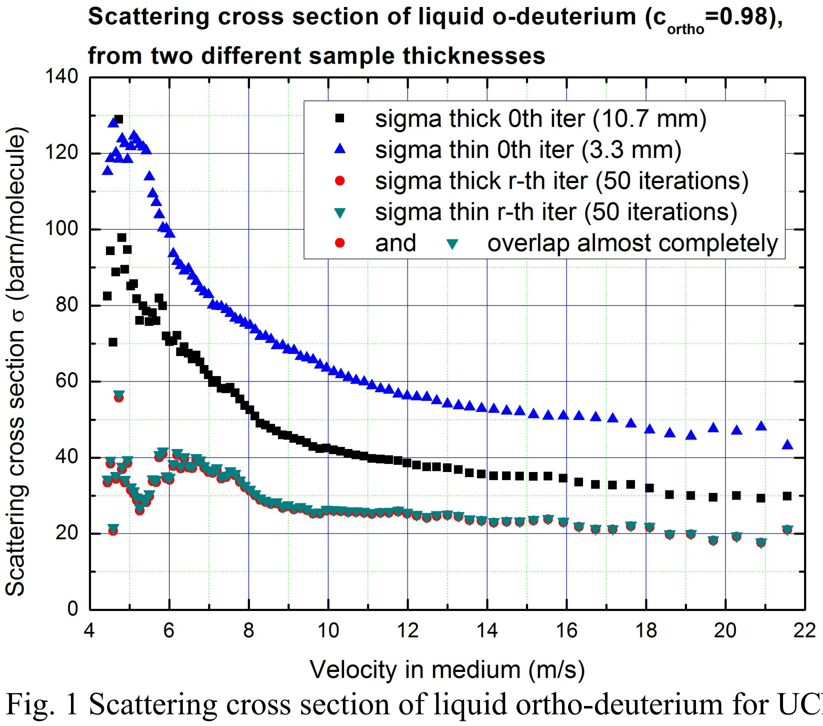

Fig. 1 Scattering cross section of liquid ortho-deuterium for UCNs.

In addition to liquid deuterium, transmission measurements were carried out for solid deuterium of various temperatures and preparation methods (i.e., freezing speeds and temperature cyclings). Figure 2 represents these results.

The turbofreeze (TF) deuterium crystals were frozen from the liquid as fast as possible from an average sample cell temperature of 19.2 K down to 4.8 K, where the first measurement data were taken. The slow freeze crystals (SF) were prepared much the same way, except that the crystal temperature was lowered with a gradient of -1K/hour. After the measurements at 4.8K had been taken, the crystal was warmed up to 16.0 K, where the second round of measurements started.

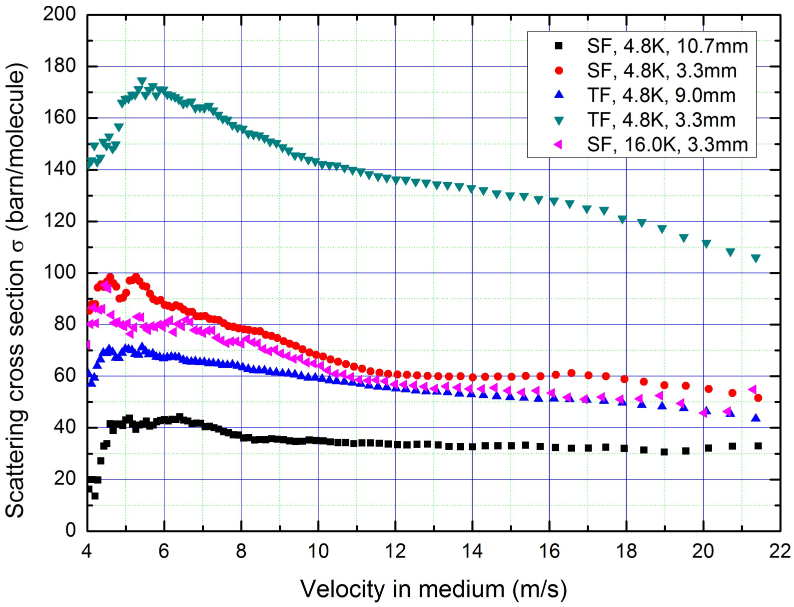

Fig. 2 Scattering cross section of solid ortho-deuterium crystals (slow freeze [SF] and turbofreeze [TF] with different thicknesses) for UCNs.

It is obvious that in both the slow freeze and the turbofreeze samples the scattering cross section per molecule is higher for the thinner sample cell (3.3 mm). This effect is due to surface scattering, which does not depend on the thickness of the sample. The ongoing data treatment will quantify the amount of surface scattering.

It is worth noting that the two data sets from 2012 and 2015 show a peak in the scattering cross section at around E_{kin} = 170 neV (5.6 m/s) in liquid deuterium and 150 neV (5.2 m/s) in the solid samples. It stems very probably from the hyperfine splitting (hfs) of the ground state of the deuterium molecule [13].

References

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