Experimental report

26/04/2022

Proposal: 3-14-413 **Council:** 10/2020

Title: The cross section of UCN in solid ortho-deuterium at T=5K

Research area: Nuclear and Particle Physics

This proposal is a new proposal

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Samples: D2

Instrument	Requested days	Allocated days	From	To
PF2 EDM	35	35	09/06/2021	14/07/2021

Abstract:

In recent UCN transmission experiments on liquid and solid o-D2 we were able to successfully determine the UCN scattering cross section on the low-energy range (exp. rep. 3-14-311, 3-14-351 and 3-14-374). These experiments were extremely time-consuming, as good statistics had to be achieved over the whole range of UCN energies (100...2000 neV). Hence, the data collection so far was only possible for the liquid state (20 K, 23 K) and some temperatures of the solid (10 K, 15 K).
We now want to determine the scattering cross section of UCN in solid o-D2 at the lowest possible temperature in our cryostat, T=5K. This temperature is of outstanding interest, as T=5K is believed to be the optimal operating temperature for solid o-D2 based UCN sources (e.g. at PSI, Switzerland).
The sample container (cylindrical copper cell with quartz windows) has been successfully used in previous experiments, see the listed experimental reports.

Experimental Report

Proposal: 3-14-413 / PF2-EDM

The cross section of UCN in solid ortho-deuterium at T = 5K.

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Experimental period: 06.06.2021-17.07.2021

Motivation

Even after decades of neutron scattering work, the precise measurement of 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 [1-4] and even later attempts in the 1990 [5-6] only supplied us with inaccurate data, which can hardly be used for the calculation and design of cold neutron (CN) and UCN sources. Recent UCN experiments [7-9] 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) [10-12], which put the role of defects in solid D_2 on a quantitative basis.

Aim of the experiment

In continuation of our UCN work on solid deuterium at T ≥ 10 K [10-12], we aimed this time on the study of UCN cross sections at T = 5 K, which is often stated as the optimal temperature for the operation of D_2-based UCN sources [13].

The experiment

The experiment was conducted with the set up as described in our proposal (Proposal Fig. 2). Additional components are essential for the performance of the experiment:

1.The Oxisorb-unit

This apparatus works at temperatures about 20 K (liquid D_2) and converts natural D_2 to the desired o-deuterium, c_o = 96,4 % in our experiment. Due to a malfunction of the cryo-vacuum turbo pump of the Oxisorb-cell, this cell was heated up to room temperature and the o-D_2 gas was blown automatically into the D_2-tank (security value) over night (5.7 to 6.7.2021). This Oxisorb-unit has to be maintained (TUM) and a more reliable turbo pump should be installed (ILL?).

2. Sumitumo cold head compressor

This He- expansion machine delivers the cryo-temperatures for the sample cell. In our experiment, a temperature of only 7,5 K (not 5 K) was reached. A maintenance is necessary for this component (TUM/ILL?).

3. Separation of vacua: Chopper versus cryostat

In our experiment the chopper-vacuum (room temperature) and the cryo-vacuum (~ 100 K for shielding the sample cell) were not separated from each other. A separation by an additional Al-foil in the beam tube after the chopper would be desirable.

4. Chopper: Increased time resolution

The chopper used in our experiment had a minimal opening time of 17,9 ms (real), leading to a velocity resolution of dv/v = 0,4 (10 m/s-neutrons, tof-pathlength s_0=0,455 m). The application of an additional tof-path of 30 cm improved the resolution to 25%, but cost about

a factor 2 in intensity, due to even more UCN missing the detector by falling down on the longer flightpath (rate just R = 62 1/s for the free sample).

Hence a chopper opening time of Δt = 10 ms (nominal) would be desirable, to work with sufficient resolution and a tof-path of s_0 = 0,455 m for sufficient intensity. This item has to be discussed further.

Nevertheless, due to the generous beam allocation time provided by ILL, we could overcome all difficulties in the course of the experiment with the help of the ILL staff and took some preliminary data in the last week of our term.

Preliminary Results

Our preliminary data were taken at an ortho-concentration of c_0 = 0,80 at T = 7,5 K.

Due to a small, undetectable leakage (against air) all over the time of our experiment, the sample cell (T = 7,5 K) acquired a thin layer of water ice from air humidity. This layer was taken into account as a purely elastic scatterer, which determined the background. In the velocity domain this resulted in a constant background of 4,6 barn after correction for hydrogen absorption. This influence was subtracted from the data before further evaluation. To improve the unsatisfactory statistics of the original data (3000 time channels of 0,1 ms each), the data was binned to 100 channels each point and later deconvoluted, using a resolution function of width Δt = 17,9 ms in the time domain. In Fig. 1 the result of our preliminary data evaluation is shown.

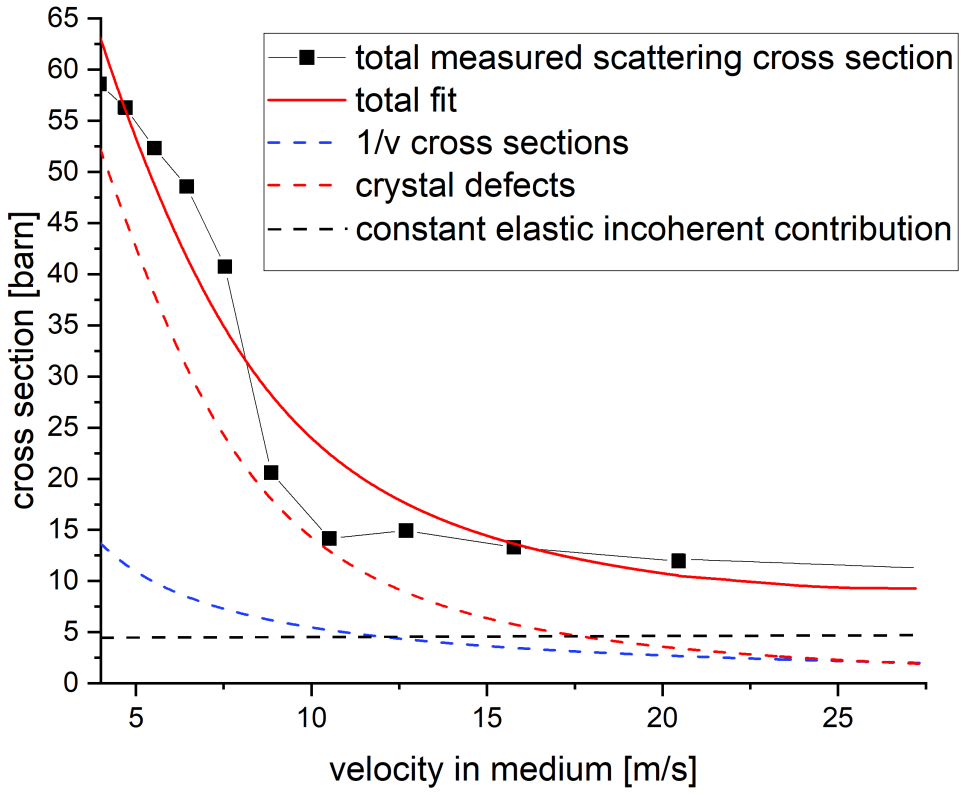

Fig. 1: Scattering cross section of solid deuterium at T= 7.5 K (c-ortho = 0.80).

A clear signature of defects in the crystal can be identified (red broken line).

Further contributions: see text.

Several contributions to the absorption corrected cross section in Fig. 1 have been taken into account: Firstly, the constant elastic incoherent contribution (σ^{inc} = 4,5 barn at c_0 = 0,80, black broken line) and secondly the collection of 1/v- cross sections, mainly 1-phonon and roton up-scattering (blue broken line). The main contribution at low velocities is seen to stem from defects, described here in Guinier-approximation as spherical voids in the crystal [11,14]:

$$\sigma^{def}_{(v)} = 4\pi * c_p * V_p^2 * \varrho^2 * \frac{1-e^{-x^2}}{x^2}, \quad (1)$$

where c_d is the defect concentration, V_d the defect volume with radius R_s, ϱ the scattering length density and $x = \frac{4}{5}(\frac{m}{\hbar} v\, R_s)^2$.

The red broken line in Fig. 1 gives the partial defect contribution (Equ. 1), the full red line displays the fit to the measured total cross section (black dots). The fit yields $c_d \sim 1{,}7 \times 10^{-11}$ for the defect concentration per D_2-molecule and a defect radius $R_s \sim 147$ (1/Å). Due to very poor statistics of the raw data (tot. scattering rate $R \leq 6$ 1/s at the detector), we have not made efforts to evaluate error bars for this preliminary data. These values differ from those numbers measured in a carefully annealed sample [11]. It is evident, that annealing is an important time-consuming requirement in a future experiment.

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