



Improved measurement of the neutron absorption cross section for very low velocities



J. Schroppenegger^{a,d,*}, P. Fierlinger^b, A. Hollering^d, P. Geltenbort^c, T. Lauer^d, H. Rauch^a, T. Zechlau^d

^a Technische Universität Wien-Atominstitut, A-1020 Wien, Austria

^b Physik-Department E18, Technische Universität München, D-85748 Garching, Germany

^c Institut Laue-Langevin, F-38042 Grenoble, France

^d Forschungs-Neutronenquelle Heinz Maier-Leibnitz (FRM-II), 85747 Garching, Germany

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ABSTRACT

The absorption cross section of natural Gd and isotopic enriched ^{157}Gd for ultra-cold neutrons (UCN) as a function of the velocity has been measured within a time-of-flight-experiment. Particular attention is paid to small velocities in the region of a few m/s. This is intended to determine the validity of the $1/v$ -law governing absorption cross sections in this region and the resulting divergence at $v = 0$. The experiment does not show any significant violation of $1/v$ for $v > 3$ m/s.

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1. Introduction

The neutron absorption cross section can be described, leaving aside resonance phenomena, in the first order approximation by a $1/k$ or $1/v$ law [1]:

$$\sigma_a = \frac{4\pi}{k} a'', \quad (1)$$

where a'' is the imaginary part of the scattering length, v is the neutron velocity and k is the neutron wave-vector. This equation raises the question of the divergent tendency of the absorption cross section at low velocities close to $v = 0$ and of its physical meaning. In [2] a deviation of the $1/v$ law is predicted. The authors arrived at this result by theoretical calculation of the interaction between an absorbing nucleus and a neutron. It is expected that the cross section is proportional to v in the region below 4–5 m/s. The authors of [3] however, conclude that the result found in [2] concerns only the effective cross section for a nucleus occurring in a dense medium and not for a single nucleus or for an absorber dissolved in a solvent at low concentration. The present work incorporates these conclusions. In [4] the authors show the validity

of the $1/v$ -law for velocities between 6 and 35 m/s by verifying the independence of the transmission through an absorbing film from the neutron velocity component parallel to the sample surface.

Another way for testing the $1/v$ -law is examined in [5] by using a time-of-flight-setup. Using this method the absorption cross section for all velocities contained in the spectrum of the neutron source can be measured simultaneously. The authors show in their results a possible violation of the $1/v$ law. The measurements described in the present work can be considered as a continuation of the experiments performed in [5].

2. Experimental approach

In this experiment gadolinium, the stable element with the highest neutron absorption cross section¹ dissolved in heavy water (D_2O), is used as an absorber. This enables the smallest amount of absorbent material to be brought into solution whilst maintaining ideal proportions for the transmission coefficient. The low concentration of the absorber in the D_2O -matrix does not noticeably change the real part of the scattering length density in the

* Corresponding author at: Forschungs-Neutronenquelle Heinz Maier-Leibnitz (FRM-II), 85747 Garching, Germany.

E-mail address: juri.schroppenegger@tum.de (J. Schroppenegger).

¹ Thermal neutron absorption cross sections: nat. Gd $\sigma_a = 49700$ barn, isotipcal enriched ^{157}Gd $\sigma_a = 259000$ barn.

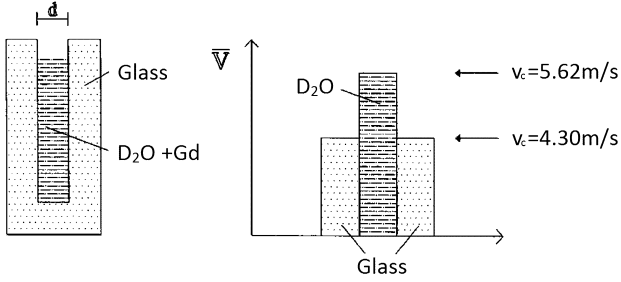


Fig. 1. Geometrical form and neutron optical wall potential of the transmission samples.

transmission sample. The advantage of the method is its large scattering length and the resulting high Fermi-potential. As they enter the potential of the D₂O neutrons lose a part of their kinetic energy and decelerate. The velocity inside the sample is given by

$$v = nv_0 = \sqrt{v_0^2 - v_c^2} \text{ with } v_c^2 = \frac{4\pi\hbar^2 Nb_c}{m^2} \quad (2)$$

where n is the refraction index, v_0 is the velocity outside the potential, N is the particle density, b_c is coherent scattering length and m is the mass of the neutron. By decelerating the neutrons in the sample it is possible to achieve lower velocities, than those present in the neutron source's spectrum. The liquid solution is brought into the neutron beam within a glass cell. In Fig. 1 the potential for a neutron crossing the sample is shown. To determine the absorption cross section of the gadolinium, a second identical sample without dissolved gadolinium is used. By comparing the transmission through both samples the absorption cross section σ_a can be calculated as:

$$T = e^{-Nd\sigma_a} \rightarrow \sigma_a = -\ln \frac{T}{Nd} \quad (3)$$

with T the transmission, N the particle density and d the thickness of the absorber. To calculate the transmission and the related absorptions cross section as a function of the velocity, the sample is installed within a time-of-flight setup. The ratio of the count rate for the samples with gadolinium to the count rate without gadolinium provides the absorption cross section.

3. Experimental setup

The time-of-flight-measurements (TOF) described were performed at ultra-cold and very-cold neutron facility PF2 of the ILL in Grenoble (France). Two different beam ports were used: PF2/UCN and PF2/TES.

In order to soften the spectrum and thus shift the neutron velocity spectrum to lower energies, the TOF setup presented in Fig. 2 was mounted 60 cm higher than the existing turbine exit of the PF2/UCN port. At the PF2/TES port, however, it was mounted at the same height as the exit port. An UCN chopper [6] composed of two linear motors moving two titanium grids against each other forms the first element of the TOF setup. The grids in their starting position overlap 1 mm. In this position the beam is closed, so that no neutron can pass through. Shifting the grids by 2 mm opens a 3 mm slit and enables the neutrons to pass. A chopper of this type provides variable opening times and duty cycles, in contrast to a rotating disk chopper. This allows the open-to-close ratio to be optimized and thus increases the number of the usable neutrons. The chopper is set to open the beam for 7 ms with a repetition rate of 10 Hz. The corresponding opening function, measured with light, is shown in Fig. 3. The chopper setup is a well characterized

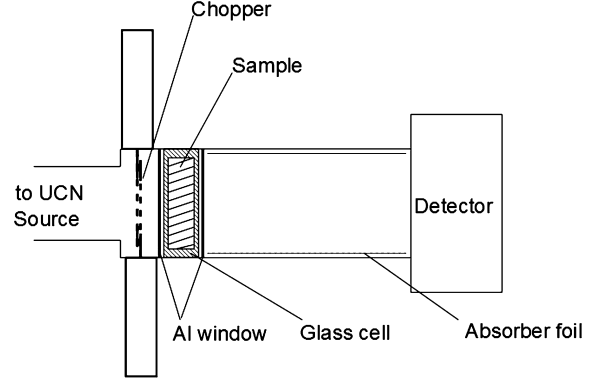


Fig. 2. Sketch of the time of flight setup on the UCN beam port on the PF2 beamline at ILL.

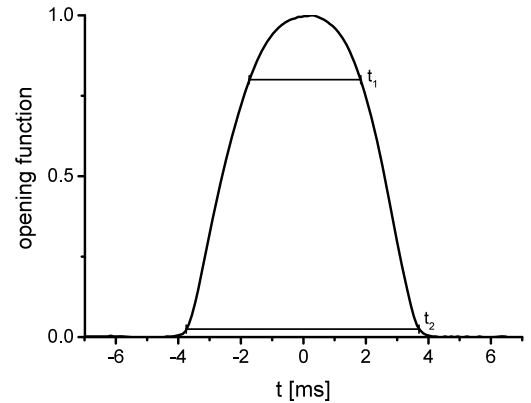


Fig. 3. Measured opening function of the linear chopper with $t_1 = 3.44(14)$ ms: duration of the opening larger than 90%, $t_2 = 7.47(7)$ ms: duration of the opening larger than 2.5%.

system; the variation of the open function is less than 1%. A cell holder for the heavy water samples integrated into the stainless steel chopper housing is positioned almost at the beginning of the flight path. The chopper vacuum, the UCN feed guide and the flight path are separated from the glass cell by two 0.2 mm thick foils of AlMg₃. By keeping the sample at atmospherical pressure it can be changed easily without breaking vacuum.

The glass cell itself is composed of three layers of sodium-glass glued together with ultraviolet curing glue. A cavity in the center layer forms the filling volume of the cell. The internal dimensions of the cell are $60 \times 90 \times 1.02$ mm³. The thickness of the outer glass plates is 0.9 mm. The flight path, a stainless steel tube with a diameter of 100 mm and an effective flight path length of 263.5 mm is installed on the backside of the cell holder. A polyethylene foil, placed on the inside of the tube acts as an absorber, removing neutrons which would otherwise be reflected by the tube. This ensures that any diffusive scattering, which would falsifying the TOF spectrum, is suppressed. This effect was investigated in a separate measurement, performed with and without the polyethylene foil. The spectra of the neutron passing through the cell filled with D₂O were observed. The results shown in Fig. 4, obtained without the PE foil, show a relatively increased number of neutron at the slow velocity side of the spectrum, caused by diffuse scattering. The flight path follows a CASCADE U-100 [8] detector.

The transmission experiment was performed with four different gadolinium solutions, varying in particle density and the isotopic distribution. The four Gd solutions measured were natural gadolinium with a particle density of $6.66 \cdot 10^{23}$ 1/m³ and of $4.04 \cdot 10^{23}$ 1/m³ and isotopic pure ¹⁵⁷Gd with a particle density

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