Experimental report

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Proposal: 1-10-30 **Council:** 4/2016

Title: Investigation of a possible hyperfine splitting in the hydrogen molecule at neV energies -- precursor toa hfs spectrometer using UCN

Research area: Physics

This proposal is a new proposal

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Samples: Hydrogen

Instrument	Requested days	Allocated days	From	To
IN16B	1	1	20/01/2017	21/01/2017

Abstract:

In previous experiments at the ILL the transmission of ultracold neutrons (UCN) through liquid and solid ortho-deuterium was measured. While the general 1/v-behavior of the scattering cross section in ortho-D2 was confirmed, i.e. the cross section is inversely proportional to the neutron speed in the UCN energy range, we also observed a peak at around E_kin = 170 neV in both the solid and liquid deuterium data sets. This peak is also visible in the data taken by a PSI group in 2004, who used a different experimental setup. It stems very probably from the hyperfine splitting (hfs) of the deuterium molecule.
The experiment proposed here will provide proof of whether or not the peak observed at 170 neV in ground-state ortho-deuterium (J = 0) and the equivalent peak in hydrogen both stem from an inelastic excitation. If the experiment at IN16B is successful, it will be conclusive proof that hfs splitting in the low-neV energy range can be directly detected with ultracold neutrons. To our knowledge, this has never been done before.

Experimental Report

for Proposal Number: 1-10-30 (02/2016), instrument IN16B, exp. period 24–25 January 2017

Investigation of a possible hyperfine splitting in the hydrogen molecule at nano-eV energies – precursor to a hfs spectrometer using ultracold neutrons (UCNs)

Experiment staff: Stefan Doege (main proposer), Christoph Morkel, Bernhard Frick, Kristijan Kuhlmann (co-proposers)

Abstract

In previous experiments at the ILL the transmission of ultracold neutrons (UCN) through liquid and solid *ortho*-deuterium was measured. While the general $1/v$-behavior of the scattering cross section in *ortho*-D_2 was confirmed, i.e. the cross section is inversely proportional to the neutron speed in the UCN energy range, we also observed a peak at around E_{kin} = 170 neV in both the solid and liquid deuterium data sets [1,2]. This peak is also visible in the data taken by a PSI group in 2004, who used a different experimental setup [3]. It stems very probably from some intramolecular excitation, possibly the hyperfine splitting (hfs) of the deuterium molecule.

The experiment proposed here will provide proof of whether or not the peak observed at 170 neV in ground-state *ortho*-deuterium (J = 0) and the equivalent peak in hydrogen both stem from an inelastic excitation. If the experiment at IN16B is successful, it will be conclusive proof that hfs splitting in the low nano-eV energy range can be directly detected with ultracold neutrons. To our knowledge, this has never been done before.

Aim of the Experiment

The inelastic scattering experiment at IN16B was supposed to provide proof of whether or not the peak observed at 170 neV in ground-state *ortho*-deuterium (S = 0,2; J = 0) stems from an inelastic excitation. Since the energy of 170 neV was less than the energy resolution of IN16B (~500 neV), it was proposed to search for the **analogous** peak in *ortho*-hydrogen (S = 1; J = 1), which we expected to lie between 730 neV (hyperfine splitting of a hydrogen atom) [4] and about 1000 neV, the hfs of a metastable state of the hydrogen molecule [5].

With sufficient energy resolution one expects on IN16B three resolution-broadened peaks with equal intensity due to hfs and arising from incoherent spin-flip scattering – one elastic peak and two symmetric peaks at ±ΔE, corresponding to the hf ground-state splitting [6].

Results

During online data analysis while performing the experiment, the conjectured hfs was not observed in *normal*-H_2 (c_{ortho} = 75%). Only the elastic resolution-broadened peak was visible. A more detailed data treatment will follow, but it is unlikely to reveal a hfs signal.

References

[1] S. Döge (Doege) et al., Scattering cross sections of liquid deuterium for ultracold neutrons: Experimental results and a calculation model, Phys. Rev. B **91**, 214309 (2015); preprint on arXiv:1511.07065 [nucl-ex] (2015).
[2] S. Döge (Doege) et al., New Experimental Results for the Scattering Cross Sections of Liquid and Solid Deuterium for Ultracold Neutrons and an Approach to their Calculation, Proceedings of ISINN-23, Dubna/Russia, (2016).
[3] F. Atchison et al., Measured total cross sections of slow neutrons scattered by gaseous and liquid $^2H_2$. Phys. Rev. Lett. **94**, 212502 (2005).
[4] H. Haken, H. C. Wolf, The Physics of Atoms and Quanta, Springer, Berlin (2005), ch. 20: Nuclear Spin and Hyperfine Structure; Christoph Morkel, priv. comm.
[5] D. A. Frey and M. Mizushima, Hyperfine structure of the hydrogen molecule in its metastable $^3\Pi_u$ state, Phys. Rev. **128**, 2683 (1962).
[6] A. Heidemann, Measurement of Internal Magnetic Field in V_2O_3 Using Inelastic Spin-Flip-Scattering of Neutrons, Zeitschrift für Physik **238**, 208 (1970).