Magnetic and electric properties of alkali atoms in solid helium

Daniel Nettels [1], Reinhart Müller-Siebert, Xueren Huang, Simone Ulzega, Antoine Weis

Département de Physique, Université de Fribourg, Chemin de Musée 3, CH–1700 Fribourg, Switzerland

Abstract

The magnetic properties of alkali atoms implanted in crystalline ^{4}He matrices are extremely sensitive to the symmetry of the local trapping sites. For Cs atoms trapped in the body-centered-cubic phase of ^{4}He spin relaxation times up to 1 s have been observed. In the hexagonal-close-packed phase on the other hand the Cs spins are readily depolarized and a number of phenomena specific for this phase, such as zero field magnetic resonance spectra, forbidden transitions and anomalous hyperfine shifts have been observed in magnetic resonance experiments with optical detection. Our present interest focuses on spin perturbations of implanted Cs atoms by strong (30 kV/cm) external electric fields. These perturbations are measured as shifts of the magnetic resonance lines using a phase-sensitive optical magnetic resonance technique.

Key words: solid helium; matrix isolation; optical spectroscopy; magnetic resonance

1. Introduction

Since the 1990s several lower temperature research groups have investigated atomic, ionic and molecular defects in superfluid ^{4}He (He II). Mainly optical and motional properties have been studied, whereas magnetic resonance studies were limited by the relatively short observation times. To overcome this problem we have chosen to use solid helium as a host matrix for high resolution spectroscopy of paramagnetic (alkali) impurity atoms. The solid matrix offers the advantage of extremely long trapping times. As in superfluid helium the impurity atoms reside in bubble-like cavities and have long spin relaxation times due to the diamagnetic character of ^{4}He. In particular in the body-centered-cubic (b.c.c.) phase of ^{4}He, where the trapping sites show a perfect spherical symmetry, longitudinal spin relaxation times T_1 of 1-2 seconds and intrinsic transverse relaxation times T_2 up to 100 ms have been measured [1]. The narrow magnetic resonance lines open the door to high resolution spectroscopy[2]. One challenging perspective for the use of solid He trapped heavy alkalis is the search for permanent electric dipole moments (edm) of atoms whose existence is forbidden unless the discrete symmetries P (parity) and T (time reversal) are violated[4]. The experimental signature of an edm is a tiny linear Stark shift of a magnetic resonance line. In this work we present our new setup for measurements in strong electric fields (up to 30 kV/cm)using a phase stabilized magnetic resonance technique.

2. Setup

A helium crystal is grown inside a copper pressure cell [3]. Five windows give optical access from three orthogonal directions. The cell is loaded from a solid Cs target by using laser ablation with a frequency-doubled Nd:YAG-laser beam. The cesium atoms are detected by monitoring their fluorescence at 888 nm induced by excitation of the D_1 transition at 850 nm with a diode laser. The optical absorption and emission lines are blue shifted with respect to the corresponding vacuum values. The pressure cell is surrounded by magnetic field coils. Two layers of μ-metal suppress laboratory

[1] Corresponding author. E-mail: daniel.nettels@unifr.ch

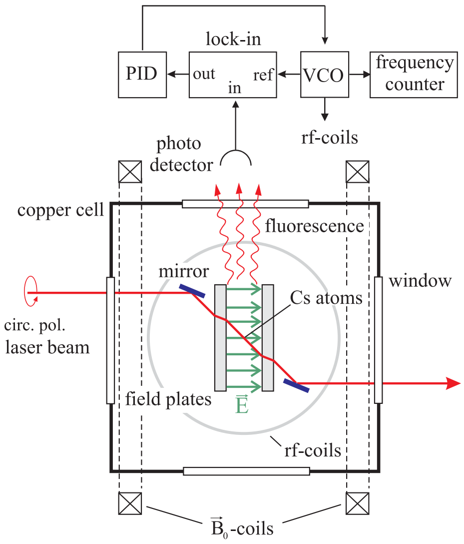

Fig. 1. Top view of the solid ^{4}He pressure cell and of the phase-sensitive detection scheme.

magnetic fields by three orders of magnitude. Radio-frequency coils and a pair of electric field plates are inside the cell. The electric field plates are made of float glass, which is coated on one side with a conducting layer of tin oxide. The advantage of these electrodes is their optical transparency (80%) at 850 nm and there extreme flatness and high conductivity at 1.5 K. Quartz spacers provide a defined separation of 0.6 cm between the plates. Fields up to 30 kV/cm were be applied.

3. The phase stabilized magnetometer

Spin perturbations of the Cs atoms are measured by operating the sample as a phase-locked magnetometer. The magnetometer is based on the facts that Cs atoms irradiated by circular polarized resonant D_1-radiation become spin polarized by optical pumping and that the optical absorption coefficient α of the atoms depends on the relative orientation of the spin polarization $\mathbf{P}$ with respect to the the $\mathbf{k}$-vector of the light.

The sample is situated in parallel static magnetic and electric fields $\mathbf{B_0}$ and $\mathbf{E}$. The laser beam has an angle of $\alpha = 45°$ with respect to the field directions (see Fig.1). The spin polarization produced by optical pumping along $\mathbf{k}$ precesses around the magnetic field. This precession is driven by an oscillating radio-frequency magnetic field $\mathbf{B_{rf}}$ perpendicular to $\mathbf{B_0}$ and produces a modulation of the absorption coefficient at the radio-frequency, which can be efficiently monitored by measuring the fluorescence light with a lock-in detector. The signal of interest is the phase between the rf-field and the system response, which shows a resonant dispersively-shaped enhancement when the rf-frequency matches the Larmor frequency of the static field. This signal is fed back via a PID-amplifier to a voltage-controlled oscillator (VCO) supplying the rf-coils. In this way the radio-frequency can be phase-locked to the Larmor frequency.

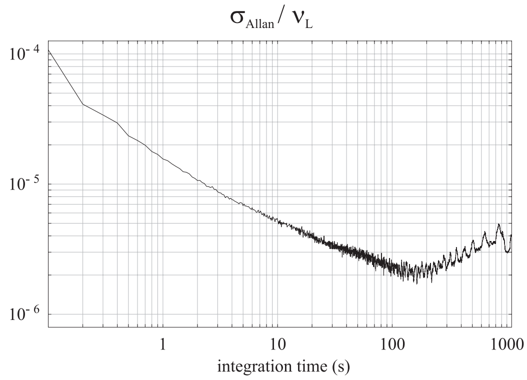

Fig. 2. Allen variance σ_{Allan} in units of the Larmor frequency $\nu_L = 77.2$ kHz against integration time.

We have investigated the magnetometric sensitivity and stability of the system by recording the Allan-variance of the Larmor frequency. Fig. 2 shows a typical result at a Larmor freqency $\nu_L = 77.2$ kHz. The falling slope up to an integration time of 100 s can be ascribed to the white noise characteristic of the current source driving the $\mathbf{B_0}$-coils. On longer time scales the system shows drifts of yet unexplained origin.

Stark effect measurements are in progress. Preliminary calculations have shown that the quadratic Stark splitting due to the tensor polarizibility of the Cs ground state can be measured with the presented magnetometer, too. The vaccum value has recently been remeasured by our group[5].

Acknowledgements

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References

[1] S. I. Kanorsky, S. Lang, S. Lücke, S. B. Ross, T. W. Hänsch, A. Weis, Phys. Rev. A **54**(1996) R1010.

[2] T. Eichler, R. Müller-Siebert, D. Nettels, S. Kanorsky, A. Weis, Phys. Rev. Lett. **88** (2002) 123002, and refs. therein.

[3] S. Lang , S. Kanorsky, T. Eichler, R. Müller-Siebert , T. W. Hänsch, A. Weis, Phys. Rev. A **60** (1999) 3867.

[4] E.M Purcell, N.F. Ramsey, Phys. Rev. **78** (1950) 807

[5] C. Ospelkaus, U. Rasbach, A. Weis, submitted to Phys. Rev. Lett.