Fizika Nizkikh Temperatur, 1996, v. 22, No 2, p. 171–173

Local field effects in the spectroscopy of Cs atoms trapped in solid ^{4}He

S. Lang, M. Arndt, T. W. Hänsch, S. I. Kanorsky*, S. Lücke, S. B. Ross, and A. Weis

Max-Planck-Institut für Quantenoptik, H. Kopfermannstr. 1, 85748 Garching, Germany
E-mail:sfl@zeus.ipp-garching.mpg.de

* *Permanent adress: P. N. Lebedev Physical Institute, Moscow, Russia*

Our main interest in the spectroscopy of paramagnetic atomic impurities in solid ^{4}He matrices is its potential applicability to high resolution spin physics experiments and, in particular, to the search for permanent atomic electric dipole moments (EDM) [1,2]. The anticipated particular features of such samples were

– the long storage and observation times of practically immobile and cold atoms;

– the isotropy of the local trapping site,

– the possibility to efficiently polarize the spins of the implanted atoms by optical pumping.

These features, together with the known large electrical break-down voltage in solid helium, should allow the development of an EDM-experiment with a particularly large signal/noise ratio. Besides statistical considerations, experiments aimed at detecting low-level symmetry breaking effects require a careful examination of possible systematic effects. Among these, the anisotropies of the atomic trapping sites are of particular concern.

In contrast to the heavier noble gas crystals which all crystallize into the fcc structure, ^{4}He at low pressures has both an isotropic cubic bcc and an anisotropic hexagonal hcp phases (Fig. 1). In this paper we report first experimental results of the influence of these crystal symmetries on the properties of implanted Cs atoms in the optical, microwave and radiofrequency domains. While the optical spectra of implanted atoms have been used in the past to obtain information on the gross structure of the trapping site, the fine structure (i.e. deformations) thereof can be investigated using high resolution magnetic resonance techniques.

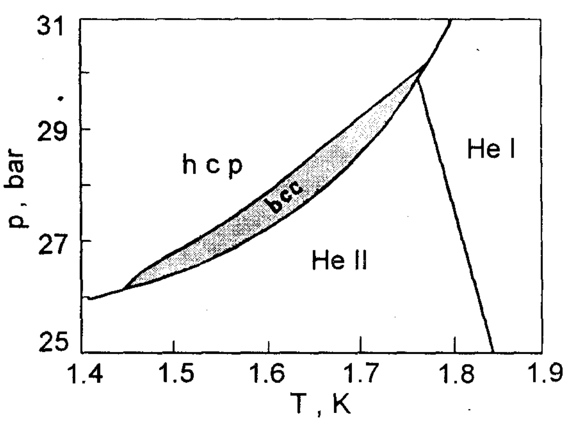

Fig. 1. Part of the phase diagram of ^{4}He relevant for present work.

Two years ago we have developed a technique for implanting foreign atoms into solid He [3]. Since, then we have studied the optical excitation and emission spectra, demonstrated optical pumping of Cs in solid He [2], measured spin relaxation times [4], and performed rf [2] and microwave [5] optical double resonance experiments. Recently precise control of the He pressure has allowed us to selectively perform experiments in the bcc and hcp phases, thereby opening up the way to investigate local field effects.

The resonance frequency and line shape of the optical D_1 excitation line (at 850 nm) of Cs atoms are little affected by the bcc to hcp transition. In both cases the transition frequency is blue shifted by 5% with respect to the free atom and the line has a width of 8 nm. The emission line, in contrast, is strongly affected by He lattice structure. When crossing the phase boundary at constant temperature, the fluorescence peak shifts from 880 nm in hcp to 888 nm in bcc.

The most dramatic changes, however, are observed in the optical-rf double resonance spectra. In the *bcc phase*, Cs atoms can be optically pumped with high efficiency. Magnetic resonance can thus be detected by optical means, yielding a contrast of up to 70%. In the *hcp phase*, on the other hand, contrasts do not exceed 15%. Using the method of relaxation in the dark we measured longitudinal electronic spin relaxation times T_1 in the range of 1 to 2 seconds for the bcc

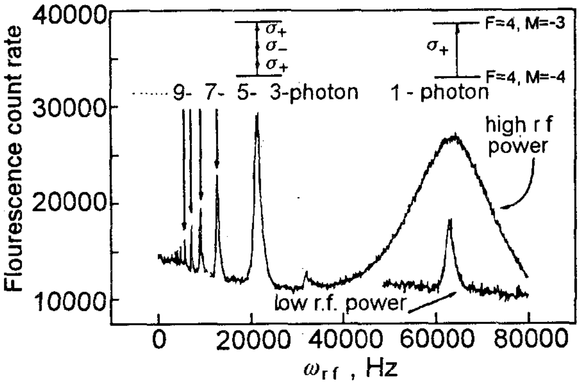

Fig. 2. Observation of multiphoton transitions in the magnetic resonance spectrum of Cs atoms in the bcc phase of solid ^{4}He.

phase. These are among the longest ever observed for alkali atoms. Furthermore we found that T_1 is independent of the strength of the holding magnetic field. In the hcp matrix, T_1 is about three orders of magnitude shorter and does depend on the magnetic field strength. When irradiating the sample with odd subharmonics of the Larmor frequency, magnetic resonances involving up to 23 radiofrequency photons could be detected in the bcc phase (Fig. 2). However, in the hcp phase no such multiphoton processes could be observed under otherwise identical experimental conditions. Conversely, in hcp samples we observed forbidden $\Delta M = 2$ and 3 magnetic-dipole transitions which do not occur in bcc samples (Fig. 3).

We have further investigated the ground-state hyperfine transition of Cs at 9.2 GHz. The transition could only be detected in the bcc phase. The resonance frequency was blue shifted by approximately 2.2% with respect to the free-atom line with a pressure dependence of about 1.4 MHz/bar [5].

Similarly to electrons, foreign atoms in helium matrices form bubbles, i.e. cavities from which helium is expelled. Theoretical modeling of these structures can be used to infer the bubble size from measurements of the optical properties of implanted atoms.

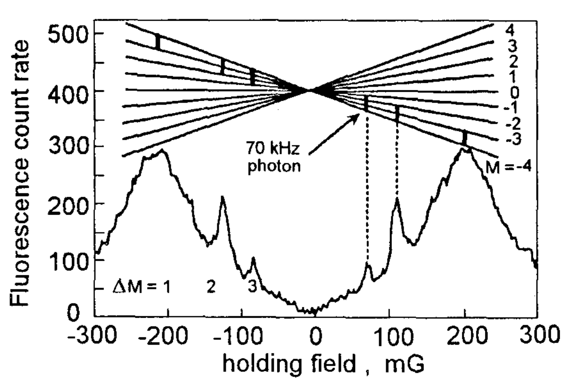

Fig. 3. Observation of forbidden magnetic dipole transitions in the ground state of Cs atoms in a hcp matrix of solid He.

We have applied the bubble model to successfully describe the shift and lineshape of the optical resonance excitation lines of Ba atoms [6,7].

Because of the weak binding of He atoms in the condensed phase, the strong repulsion exerted by Cs atoms on the surrounding He atoms imposes restrictions stemming from the symmetry of the electronic wave function of a Cs atom on the forming cavity. The experimental evidence described above seems to indicate that this no longer holds for hcp matrices. In particular, the appearance of forbidden magnetic resonance lines in the hcp phase indicates a beakdown of the cylidrical symmetry brought about by the magnetic field. Most likely, deformed bubbles are responsible for this break-down. The hcp structure has a uniaxial symmetry and it can be assumed that the Cs-He repulsion is not strong enough to completely overcome the hexagonal symmetry imposed by the matrix. From the intensity of the forbidden lines one could thus infer — within the frame of the bubble model — the scale of the bubble derormations. Quantitative calculations of this effect are currently in progress. From first estimates we can nonetheless state that the bubble deformations are very small as compared to the average bubble size. On the other hand, the abscence of forbidden lines in the bcc phase can be used to set upper limits on bubble deformations in this phase. This knowledge is of primary importance if experiments in search of symmetry violating effects (P,T violation) are to be performed on such samples.

The coupling of the ground-state angular momentum to the local fields in deformed bubbles is perhaps also responsible for the low efficiency of the optical pumping process and for the rather short spin relaxation times, while the B-field dependence of T_1 in the hcp state can be attributed to a decoupling of the spins from the lattice fields. The absence of the hyperfine transition in the hcp matrix is most likely a consequence of the low optical pumping efficiency.

In this paper we have described several experimental observations of matrix effects in the optical and magneto-optical properties of paramagnetic Cs atoms in solid ^{4}He matrices. First qualitative explanations of the findings in terms of local field effects are presented. The bcc phase of solid ^{4}He can be used as a trap for foreign atoms with long storage times, in which the isotropy of the trapping sites allows high resolution spin physics experiments to be performed. On the other hand, we have given first evidence that paramagnetic spin polarized atoms can be used as a highly sensitive probe for the investigation of local fields in hcp He matrices.

1. M. Arndt, S. I. Kanorsky, A. Weis, and T. W. Hänsch, *Phys. Lett.* **A174**, 298 (1993).
2. A. Weis, S. Kanorsky, M. Arndt, and T. W. Hänsch, in: *Proc. Symp. Ions and Atoms in Superfluid Helium* (Heidelberg, May 1995), H. Günther, G.zu Putlitz, and B. Tabbert (eds.), *Z. Phys.* **B98**, 359 (1995).
3. S. I. Kanorsky, M. Arndt, R. Dziewior, A. Weis, and T. W. Hänsch, *Phys. Rev.* **B49**, 3645 (1994).
4. M. Arndt, S. I. Kanorsky, A. Weis, and T. W. Hänsch, *Phys. Rev. Lett.* **74**, 1359 (1995).
5. S. Lang, S. I. Kanorsky, M. Arndt, S. B. Ross, T. W. Hänsch, and A. Weis, *Europhys. Lett.* **30**, 233 (1995).
6. S. I. Kanorsky, M. Arndt, R. Dziewior, A. Weis, and T. W. Hänsch, *Phys. Rev.* **B50**, 6296 (1994).
7. S. I. Kanorsky, A. Weis, M. Arndt, and T. W. Hänsch, in: *Proc. Symp. Ions and Atoms in Superfluid Helium* (Heidelberg, May 1995), H. Günther, G.zu Putlitz, and B. Tabbert (eds.), *Z. Phys.* **B98**, 371 (1995).