Nuclear Spin Relaxation in Glass States of $^3$He-A in Stretched Aerogel

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Abstract We present results of pulse NMR investigations of superfluid A-like phase of $^3$He in stretched aerogel. In this case we have anisotropic orbital glass (OG) with two possible types of ordering in spin space—ordered spin nematic (OG-SN) or disordered spin glass (OG-SG) states. It was found that longitudinal relaxation of magnetization is non-exponential in both states and depends on temperature and on inhomogeneity of external steady magnetic field. At the same conditions the relaxation in OG-SG state is more rapid than in OG-SN state. For transverse orientation of the magnetic field relative to anisotropy axis the duration of free induction decay signal was longer than in normal phase. It may be explained by formation of coherently precessing spin state.

Keywords $^3$He · Aerogel

1 Introduction

Anisotropy of aerogel gives essential influence on NMR properties of both superfluid phases of $^3$He in aerogel. In particular, in case of large squeezing anisotropy the orbital vector $\hat{l}$ is oriented along the axis of anisotropy [1]. If the value of anisotropy is small then it is expected that the A-like phase is described by the Larkin-Imry-Ma (LIM) model with spatially random orientation of Anderson-Brinkman-Morel order parameter [2, 3]. The characteristic length of these inhomogeneities is about $\sim1\mu$m, i.e. much less than the dipole length. In anisotropic aerogel the LIM state
is also anisotropic. Then for uniaxial deformation along \( \hat{z} \) we obtain an anisotropic orbital glass (OG) in \( \hat{I} \)-space \([4]\). In this state for space averages of \( \hat{I} \) components we get \( \langle l_z^2 \rangle = \langle l_x^2 \rangle \) while \( \langle l_z^2 \rangle > 1/3 \) for squeezing and \( \langle l_z^2 \rangle < 1/3 \) for stretching deformation. Minimization of dipole energy results in homogeneous spatial distribution of spin vector \( \hat{d} \) in anisotropic OG state. Then in spin space we get “spin nematic” (SN) state. However, if large radiofrequency (RF) excitation is applied while cooling through the superfluid transition temperature then the distribution of \( \hat{d} \) also becomes random (“spin glass”, SG). Correspondingly we can obtain two possible glass states in the same sample: anisotropic orbital glass with oriented \( \hat{d} \) (OG + SN state) and anisotropic orbital glass with random \( \hat{d} \) (OG + SG state) \([4]\). This difference in spatial structure of \( \hat{d} \) essentially influences on properties of nuclear magnetic resonance (NMR), i.e. on NMR frequency shift, on its dependence on orientation of magnetic field \( H \) etc. In this paper we present results of investigations of longitudinal magnetic relaxation in OG+SN and in OG+SG states of the A-like phase of \(^3\text{He}\) in aerogel.

2 Experimental Details

The experimental chamber was described in our previous paper \([4]\). For measurements described below we have used aerogel sample (sample 2 in Ref. \([4]\)) with porosity of 98.2%. The sample had cylindrical form with the axis oriented along \( \hat{z} \), with diameter 3.8 mm and height 5 mm. As it was found in \([4]\) this sample had stretched anisotropy along \( \hat{z} \) with parameter of global anisotropy \( q = (3\langle l_z^2 \rangle - 1)/2 = -0.25 \), i.e. with \( \langle l_z^2 \rangle = 0.167 \).

Experiments were carried out in magnetic field of 105 Oe (corresponding NMR frequency is 341.5 kHz) and at pressure of 27.2 bar. We were able to rotate \( H \) by any angle \( \mu \) with respect to \( \hat{z} \)-axis in \( \hat{y} - \hat{z} \) plane. Additional gradient coils were used to apply the controlled magnetic field gradient and to compensate residual magnetic field inhomogeneity (down to \( 6 \times 10^{-5} \) for \( \mu = 0 \) and down to \( 3 \times 10^{-4} \) for \( \mu = 90^\circ \)).

The sample was surrounded by transverse NMR coil with the axis along \( \hat{x} \). The necessary temperature was obtained by nuclear demagnetization cryostat and was measured by quartz tuning fork, calibrated by Leggett frequency measurements in bulk \(^3\text{He}\)-B. To avoid paramagnetic signal from solid \(^3\text{He}\), the aerogel sample was preplated by \( \sim 2.5 \) monolayers of \(^4\text{He}\).

The longitudinal relaxation time \( T_1 \) of \(^3\text{He}\) in pulse NMR was measured by standard two-pulse method: initial amplitude of a free induction decay signal after the second tipping pulse gives the value of longitudinal magnetization at this moment.

3 Results of Pulse NMR Measurements

We investigated the longitudinal relaxation at temperatures 0.75–1.1 \( T_{ca}^* \), where \( T_{ca}^* \) is the temperature at which the temperature dependence of the NMR frequency shift in the A-like phase is extrapolated to zero. For our sample \( T_{ca}^* = 0.722 T_c \), where \( T_c \) is the superfluid transition temperature in bulk \(^3\text{He}\). Experiments were done in both OG-SN and OG-SG states and for two orientations of \( H \) relative to the axis of anisotropy, i.e. for \( \mu = 0 \) (parallel orientation) and for \( \mu = 90^\circ \) (transverse orientation).