Magnetostriiction of the Spin Gap System KCuCl$_3$

in High Magnetic Field

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High-field magnetostriiction measurements on the spin gap system KCuCl$_3$ have been performed by using strain gauges in pulsed magnetic fields up to 55 T at 1.3 K. For $H \parallel$ the $[0,1,0]$ direction, longitudinal magnetostriiction shows expansion and transverse magnetizations show shrinkage at the gap field $H_g$, at which finite magnetization appear. Both magnetostriictions saturate at the saturation field of magnetization. These results indicate a strong magnetoelastic coupling in KCuCl$_3$.

§1. Introduction

Recently, there has been great interest in the behavior of the quantum spin gap system in magnetic field. In a two-dimensional spin-gap material SrCu$_2$(BO$_3$)$_2$, magnetic superstructure in the magnetization plateau states is observed,$^1$ and lattice distortion in the magnetization plateaus is studied theoretically.$^2$ In a three-dimensional coupled spin-dimer system material TlCuCl$_3$, deformation of the crystal lattice at the magnetic transition implying strong spin-phonon coupling is observed.$^3$ Magnetoelastic properties in field-induced magnetic ordered phases are studied theoretically in these spin-gap materials.$^4$

KCuCl$_3$ has a monoclinic structure (space group $P2_1/c$) and its unit cell contains four Cu$^{2+}$ ions with spin $S = 1/2$.$^5$ The crystal structure is composed of the double chain of the planar dimers Cu$_2$Cl$_6$ along the a-axis. Magnetic susceptibility measurements reported that a singlet ground state separated by a finite spin gap $\Delta$ from triplet excited states.$^6$ The reduction and eventual suppression of the spin gap $\Delta$ at the gap field $H_g = \Delta/g\mu_B$ drives the quantum phase transition. The high-field magnetization measurements in static field reported that the gap field $H_g$, at which a finite magnetization appear, was estimated to be $H_g \approx 22$ T.$^7$ In addition, the high-field magnetization measurements in pulsed field reported that the magnetization increases rapidly and monotonically above $(g/2)H_g = 23$ T, and then saturates at $(g/2)H_s = 54$ T.$^8$

We report the results of magnetostriiction experiments under the pulsed magnetic field. We found a lattice deformation occurs at the magnetic transition.

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§ 2. Experimental

The high-field magnetostriction of KCuCl$_3$ was measured at $T = 1.3$ K with strain gauges and a multilayer pulse magnet at KYOKUGEN, Osaka University. The pulsed magnetic field is produced by the discharge of the capacitor bank of which maximum energy is 1 MJ. The maximum field of the long pulse magnet is 55 T. The pulse duration is about 20 msec. The magnetic fields were applied along the [0,1,0] and the [2,0,1] directions which are parallel to the cleavage (1,0,2) plane.

Longitudinal and transverse magnetostrictions were measured by using strain gauges which pasted on the sample so as to detect parallel and perpendicular strains along the direction of the external magnetic fields, respectively. Circuit lines of the sample and dummy gauges are connected in series in order to compensate background signals, and remaining field-induced signals are canceled by using a c-coil. We used a quartz as the dummy sample. Two sets of the data were recorded by changing the polarity of currents and they are subtracted with each other to extract the voltage change $\Delta V/V$ due to the magnetostriction $\varepsilon$ ($= \Delta l/l$) of the sample.

§ 3. Result and discussion

Figure 2 shows longitudinal magnetostriction (which is parallel to the [0,1,0] direction) under a pulsed magnetic field applied up to about 55 T along the [0,1,0] direction at 1.3 K with magnetization curve of KCuCl$_3$. There is almost no length change below about 22 T. The magnetostriction begins to increase rapidly and monotonically above 22 T which equals the gap field $H_g$, and almost saturates at about 52 T which equals the saturation field $H_s$ of magnetization. There are no hysteresis and no jump near the gap field $H_g$. The magnetostriction seems to be directly proportional to magnetization.
Figure 3 shows longitudinal and transverse magnetostrictions of KCuCl₃ for the field applied along the [0,1,0] direction at 1.3 K. The magnetostriction curves of all directions seems to be directly proportional to magnetization. The longitudinal magnetostriction increases to about $6.4 \times 10^{-4}$. The transverse magnetostrictions, which are parallel to the [2,0,1] and the [1,0,2] directions decrease to about $-7.2 \times 10^{-4}$ and $-3.0 \times 10^{-4}$, which are large strain.

Figure 4 shows longitudinal and transverse magnetostrictions for the field applied along the [2,0,1] direction at 1.3 K. The longitudinal magnetostriction which is parallel to the [2,0,1] direction decrease to about $-7.0 \times 10^{-4}$, and the transverse magnetostriction which is parallel to the [0,1,0] direction increase to about $6.5 \times 10^{-4}$. Both magnetostrictions shows the same behavior with those for H $\parallel$ the [0,1,0]. This result suggests that the magnetostrictions are independent with the directions of magnetic field.

Compared with magnetization, magnetostriction results indicate strong spin-phonon coupling in KCuCl₃. The deformation of the lattice is estimated by magnetostrictions of three directions for H $\parallel$ the [0,1,0] on the following two assumptions. At the first, we assume that the interdimer interactions are neglected, and that only the intradimer interactions are considered, since the interdimer interactions are much smaller than intradimer ones. Next, the distances between Cu and Cl ions are invariant and the deformation depends the angle of the superexchange path Cu-Cl-Cu in the planar dimers Cu₂Cl₆. The
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angle Cu-Cl-Cu calculated by using magnetostriction results for H $\parallel$ the [0,1,0] on these assumptions changes from 95.9° to 95.8°. When the angle is close to 90°, the interactions are reduced strongly. 4) As the result, magnetostriction on the planar dimers occur to compensate the energy loss due to generation of magnetization, although it’s wondered whether 0.1° change of angle is significant.

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References

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