Unusual Magnetization in Superconducting State of Sr$_2$RuO$_4$ with H||c

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Introduction

There is strong evidence that the Cooper pairs in superconducting Sr$_2$RuO$_4$ have $p$-wave triplet pairing$^1$. Experiments including the Kerr-effect$^2$ suggest that the pairing order parameter is of the chiral form $\pi(k_x + i k_y)$, as in superfluid $^3$He-A. The chiral pairing symmetry implies that the magnetic response should have highly unusual features which may be observable in the magnetization $M$. However, to date, there have been no $M$ vs. $H$ reports in the geometry with $H||c$ at temperatures $T < T_c$ (= 1.38 K).

Experimental

We carried out torque magnetometry experiment on Sr$_2$RuO$_4$ single crystals in a $^3$He cryostat at Princeton University, and extended the torque experiments to mK temperatures $T$ in the SCM1 superconducting magnet at the NHMFL.

Results and Discussion

Figure 1a (left) shows the $M$-$H$ curves taken at different tilt angles $\theta$ of field $H$ at $T = 20$ mK. At each $\theta$, $M$ traces out a hysteretic loop as $H$ is cycled between $H_{c2}$ and $-H_{c2}$. Pronounced skewness of the hysteretic loops is observed. With increasing $\theta$, the amplitude of the hysteresis increases, as does the effective $H_{c2}(\theta)$. The $M$-$H$ curves display several anomalous features. For example, $M$ displays a distinct break-in-slope whenever $H$ changes sign. This is clearly shown (as dashed lines) in the lower branch of the $M$-$H$ curve at $T = 310$mK in Fig 1b (right). We also observe a highly unusual reversible behavior in the field intervals $(0, H_p)$ and $(-H_p, 0)$ on the lower and upper branches ($H_p \sim 60$ Oe is the field at which $M$ peaks). Although the sample is in the critical state, $M$ is fully reversible inside this interval. The numbers 1…6 indicate the “turning fields” $H_i$ in various field-sweep cycles.

Fig. 1a (Left panel): Curves of magnetization $M$ vs. $H$ at $T = 20$ mK at different $\theta$. Figure 1b (right): Curves of $M$ vs $H$ at $\theta \sim 15^\circ$ and $T = 310$ mK, showing unusual reversible behavior. Arrows labeled $j = 1$…6 mark the turning points $H_i$. On the upper branch, $M$ retraces itself if the turning points are at 2, 3 and 4.

Conclusions: We uncovered an unusual reversibility of $M$ in the Bean critical state in Sr$_2$RuO$_4$ which suggest an unusual mixed state. These will be explored further in future studies.

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References: