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Hysteresis Losses of Deuterated κ- (BEDT-TTF)$_2$Cu[N(CN)$_2$]Br Organic Superconductor

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***Abstract*—The hysteresis cycles have been studied and hysteresis losses have been calculated by integrating the area of the hysteresis cycle on deuterated organic superconductor (κ-D$_8$-Br) κ-(BEDT-TTF)$_2$Cu[N(CN)$_2$]Br. The measurements were obtained for different temperature values and as a function of the cooling rate through the order-disorder transformation near 80 K. Our results showed that the hysteresis cycles areas and hysteresis loss of these compounds depend strongly on the temperature and the cooling rate V$_C$.**

***Keywords*— κ-D$_8$-Br, Hysteresis, hysteresis loss, cooling rate, magnetization.**

I. INTRODUCTION

The molecular κ -(BEDT-TTF)$_2$ X (with X =Cl or Br) is a quasi-two-dimensional organic superconductor called Berchgaard salt, X is an inorganic monovalent anion and BEDT-TTF designed bis (ethylenedithio) tetrathiafulvalene (or ET for short). This compound may have a deuterated form where hydrogen binder's dimers BEDT-TTF are replaced by deuterium atoms. We report on systematic investigations of the relationship between the superconducting properties (T_C = 11.6 K) and the structural transition occurring around 80 K in the fully deuterated organic salt κ-(BEDT-TTF)$_2$Cu[N(CN)$_2$]Br. At a higher temperature, the ethylene molecule such as BEDT-TTF rapidly oscillates between two different conformations. Upon cooling, the thermal fluctuations gradually slow down and simultaneously a long-range order among the ethylene groups builds up [1, 2]. They undergo a structural transition involving the ethylene groups, also called glassy transition, on the vicinity of 80 K [3-6], that can influence very strongly the physics of the vortex lattice and the associated magnetic properties. The effect is very pronounced for deuterated κ-(BEDT-TTF)$_2$Cu[N(CN)$_2$]Br which is presumably at the boundary between the magnetic and superconducting phases, with both superconducting and transitions magnetic [7, 8]. This type of materials exhibits interesting magnetic and superconducting phase transitions.

It is of interest to note that hysteresis phenomena are associated with some dissipation energy. In this paper, we report on measurements of hysteresis cycles and calculate loss hysteresis in the κ-(BEDT-TTF)$_2$Cu[N(CN)$_2$]Br organic superconductor. We show that the loss hysteresis and the cycles shape are profoundly affected by cooling the sample at rapid and slow rate through 80 K.

II. EXPERIMENTAL SECTION

The sample studied in this work is a single crystal of an organic superconductor of κ-(BEDT-TTF)$_2$Cu[N(CN)$_2$]Br. It was synthesized at the Jean Rouxel Institute of Materials. The dimensions of the sample are 1 x 1 x 0.25 mm^3, this crystal undergo a superconducting transition temperature of about 11.6 K. The magnetic measurement was done with a quantum design SQUID. The magnetic hysteresis cycles M (H) ($0 < H_m < 1000$ Oe typically) were measured between 2 and 15 K.

Before the start of each measurement, sample was first warmed up to a specific temperature far beyond T_C. Once the residual field was eliminated, the sample was zero field cooled (ZFC) or field cooled (FC) to a desired temperature.

III. RESULTS AND DISCUSSION

We present in figure 1, the hysteresis cycles illustrating the variation of the magnetization as a function of the applied magnetic field ranging from -10 Oe to 10 Oe. The curve represents the hysteresis cycles of a κ-D$_8$-Br sample at slow and rapid cooling rates and for two temperatures (T= 8 K, T= 9.5 K). The sample cooling process is: In the slow cooling rate we cool the sample from 160 K to 90 K at a cooling rate of about 2 K/min, and from 90 K to 70 K with a cooling rate of 0.1 K/min, then we keep it at this temperature for 20 hours, the sample was then directly cooled to 2 K at a cooling rate of 5 K/min. In the rapid cooling condition, the sample was immerged directly in the Dewar at 2 K. We noticed that the area of hysteresis cycle obtained in the case of the slow cooling rate is larger compared with the case of the rapid cooling rate. As depicted in curve (a), rapid cooling might suppress superconducting phase and increases the magnetic phase. This was explained by Kawamoto et al [9] that rapid cooling through 80 K drives the superconducting phase into a disordered magnetic phase in the deuterated κ-(BEDT-TTF)$_2$Cu[N(CN)$_2$]Br compound. Figure 1 (b) shows that the hysteresis cycle area decreases quickly with increasing temperature. These results show that the magnetization strongly depends on the temperature, a rapid decrease in the magnetization with increasing temperature was observed.

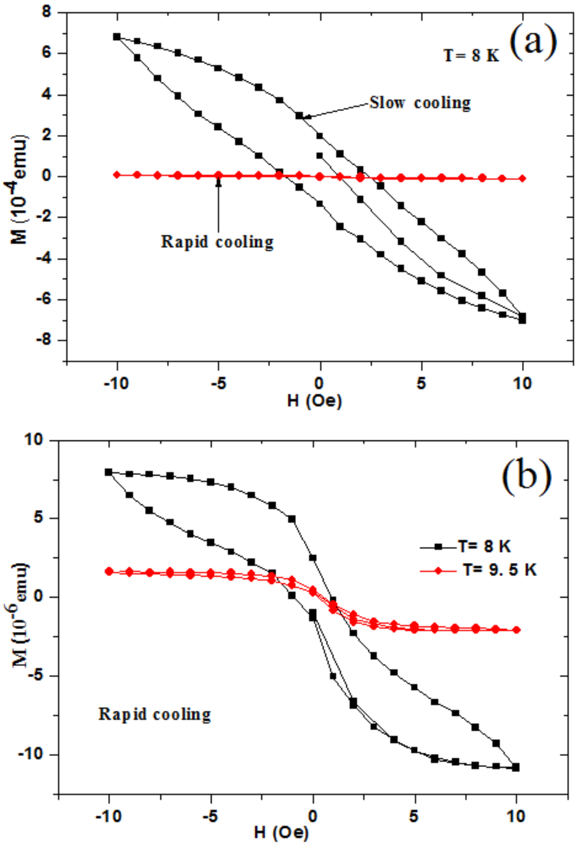


Fig. 1. Magnetic hysteresis cycles at 8 K for slow and rapid cooling and at 8 K and 9. 5 K for rapid cooling

The presence of the hysteresis cycles at low fields is due to the penetration of the applied magnetic field in the sample κ-D$_8$-Br. The possible explanation of these effects of hysteresis would be the presence of weak links between adjacent clusters and the pinning of Josephson vortices within these weak links [6, 10]. We find that hysteresis starts at $H_m < 1$ Oe and increases gradually up to our highest measuring field. This shows that the Josephson junctions are highly distributed through the sample [11].

Magnetic hysteresis cycles were obtained at zero filed cooled. In Figure 2, we show the evolution of M (H) cycles at different temperatures after slow cooling rate. One can note a strong dependence of the magnetization on the temperature.

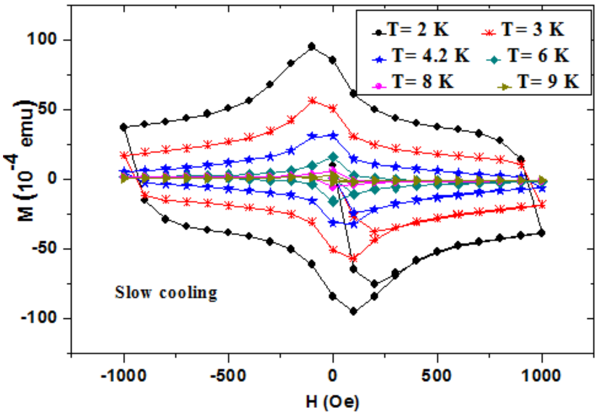


Fig. 2. Hysteresis cycles at different temperatures in slow cooling of deuterated κ-(BEDT-TTF)$_2$Cu[N(CN)$_2$]Br.

The hysteresis cycles shape as a function of the temperature and the applied magnetic field is studied. The magnetization depends strongly on the temperature, a decrease of the magnetization with increasing temperature is observed. We show that the vortex pinning depends strongly on both temperature and magnetic field. The higher is the temperature or the magnetic field, the pinning could disappear. The vortex pinning and the amplitude of the hysteresis loops depend strongly on the temperature, this may be caused by the large thermally activated flux motion in κ-(BEDTTTF)$_2$Cu[N(CN)$_2$]Br system. As noted previously. By increasing the temperature, the thermal excitations cause the vortex lattice to agitate, the vortices move and they begin to escape from their pinning centers. The dissipation appears gradually and the diamagnetism is not perfect.

The penetration of the external magnetic field within organic superconductor involves magnetic energy dissipation as hysteresis losses. Figure 3 shows two hysteresis cycles at T = 3 K indicating slow and rapid cooling rates. The loss during a complete cycle is equivalent to the area of the hysteresis loop "Equation (1)". Therefore the hysteresis cycles are proportional to the hysteresis losses and are calculated using equation "Equation (2)" giving the loss of hysteresis [12] where d is the diameter of the sample; J_C is the critical current density which is estimated using the Bean's model and H_m is the maximum applied magnetic field.

$$\frac{Q_{hys}}{V} = \int M dH \qquad (1)$$

V is the volume of the sample

$$Q_{hys} = \frac{1}{10} J_C H_m d \qquad (2)$$

The table below shows the values of the losses for 3K corresponding to the hysteresis cycles of figure 3.]

TABLE 1.VALUES OF THE HYSTERESIS LOSSES OBTAINED FOR OUR SAMPLE AT 3K

Hysteresis loss	Rapid Cooling	Slow cooling
$Q_{hys}\left(10^{-6} Oe.A.m^2\right)$	1. 48	76.05

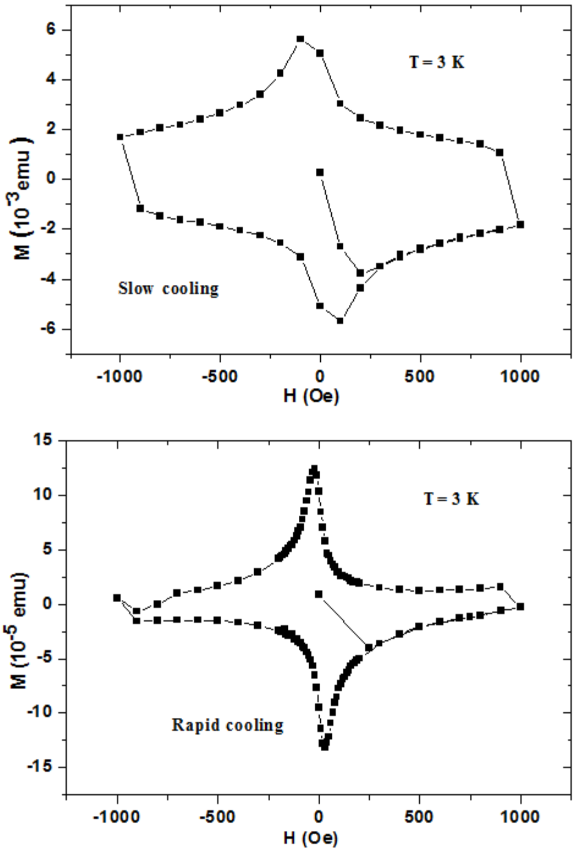
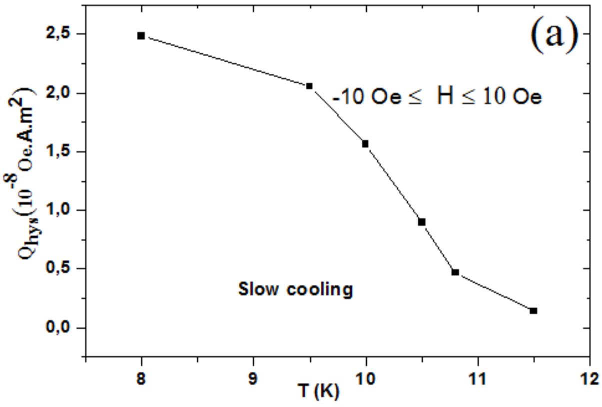


Fig. 3. Magnetic hysteresis cycles at 3 K for slow and rapid cooling of deuterated κ- (BEDT-TTF)$_2$Cu[N(CN)$_2$]Br sample.

Hysteresis loss is the manifestation of motion of the vortex. The loss depends on the amount of flux penetration into the sample. The hysteresis losses occurring in our organic superconductor depend strongly on the cooling rate and the applied magnetic field. In fact, when the sample is in the mixed state, the critical current decreases when the temperature increases, therefore the number of vortex in motion increases, which produces an increase in the dissipated power.

When a type II superconductor is penetrated by an external magnetic field, an electromagnetic energy dissipation called hysteresis loss occurs in the superconductor. Hysteresis losses Q_{hys} of the deuterated (κ-D$_8$-Br) sample are shown in Figure 4 a and 4 b as a function of the temperature for two different maximum applied magnetic fields H_m.



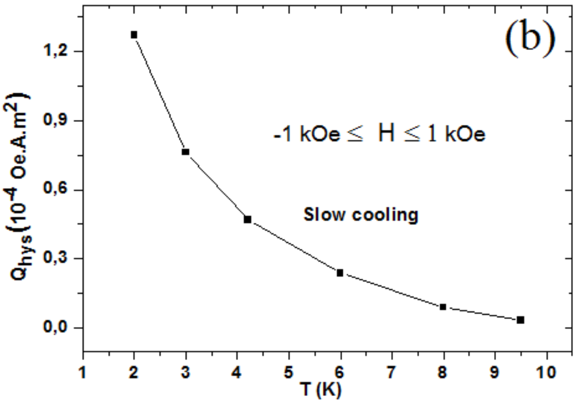


Fig. 4. Hysteresis loss in slow cooling of deuterated κ-(BEDT-TTF)$_2$ Cu[N(CN)$_2$]Br sample.

These values were obtained by calculating the area between the magnetizing and demagnetizing M (H) curves at different temperatures after slow cooling rate. The curve 4(a) shows the studied hysteresis loss as a function of the low applied magnetic field up to H_m= 10 Oe. The second curve 4(b) is the hysteresis loss with the applied magnetic field up to H_m= 1 kOe. As can be seen in this figure, the hysteresis loss decreases with increasing the temperature.

The hysteresis loss in a (κ-D$_8$-Br) superconducting is a result of magnetic field penetration in the mixed state. The pinning is among fundamental reason of hysteresis loss in the type II superconductors. It is well known that the hysteresis losses due to the applied magnetic field arise from pinning of vortex. In very small fields (-10 Oe ≤ H_m ≤ 10 Oe), the loss hysteresis of the sample is due to currents circulating at the surface of the sample through Josephson junctions within clusters. In this investigation, the dissipation is dominated by flux-pinning and the current density. As the pinning is large, the applied magnetic field remains appreciably out of equilibrium with irreversible magnetic field H_{irr} during the cycle, the area of the hysteresis cycle is relatively large, and the losses are significant. If the applied magnetic field is small, the area of the hysteresis cycle and hysteresis losses are small as shown in figure 4a. Notably, the hysteresis loss can be determined using the AC magnetic susceptibility by studying the imaginary part (χ'') of the susceptibility χ [13].

IV. CONCLUSION

We have determined loss hysteresis using the hysteresis loops for the deuterated κ-(BEDT-TTF)$_2$Cu[N(CN)$_2$]Br sample. We have found that the cooling rate and the temperature have a considerable effect on our results. The loss hysteresis strongly depends on the temperature, the magnetic field and the cooling rate of the compound.

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