Thermoelectric Studies of Non-Thermal Equilibrium Charge Density Wave Dynamics

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Introduction

The hysteretic Landau diamagnetism previously observed in the organic charge transfer salt α-(BEDT-TTF)$_2$KHg(SCN)$_4$ is thought to originate from the current induced in extended edge states by a change in magnetic induction [1]. We report an experiment designed to test the hypothesis that a balance between Charge Density Wave (CDW) pinning and the Lorentz forces support the circumferential drift of these edge states. The results of this study not only confirm this picture but also reveal a new form of pyroelectric effect associated with the CDW sliding.

Experimental

This experiment involves a combination of magnetic torque and Nernst effect measurements in magnetic fields of up to 35 T at dilution refrigerator temperatures. The sample was mounted in intimate thermal contact with a high resistance (>10 kΩ) heater and immersed in the mixing chamber of a dilution refrigerator. The heater and sample were mounted on the moving plate of a torque magnetometer, which in turn was mounted on a cryogenic goniometer to enable precise alignment of the magnetic field 5º from the interlayer direction, determined via the 1/cos(θ) dependence of the quantum oscillation frequency. Electrical contact to the sample was made with Corbino geometry Hall contacts connected to a 100 MΩ input impedance differential preamplifier. In an analogous way to separating the Nernst and thermoelectric voltages via the symmetric and asymmetric sum in the sign of the magnetic field, we use the voltage combinations symmetric and asymmetric in the sign of *dB/dt* to separate the equilibrium and non-equilibrium contributions. The heater was excited with an ac current and the voltage measured at 2*f* using a lock-in amplifier with a 30 ms time constant. The frequency, heater power and sweep rate of the magnetic field were all varied to find the optimal conditions for the observation of the irreversible thermoelectric effects. The data in Figure 1 are all for the lowest heater power (1.25 μW) at a frequency of 93 Hz.

Results and Discussion

Sweeping the magnetic field applied perpendicular to the layers of a quasi-2D metal, causes the chemical potential to saw-tooth as it jumps between Landau levels. The presence of a CDW, whose period can change so as to act as a charge reservoir, alters the form of this behavior. At the edge of the sample the CDW can stretch such that the system to remains locally in equilibrium, whereas, pinning in the bulk of the material prevents the CDW stretching to accommodate the change in chemical potential associated with a change in Landau level filling. This spatial gradient in CDW periodicity is balanced by the pinning force, thus providing a mechanism for a change of magnetic field to drive the system from equilibrium. The extended edge-states can be thought of as inductive energy storage, which is released, as the CDW is thermally depinned.

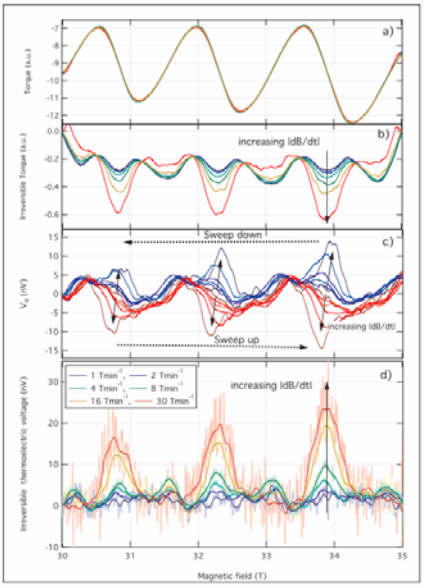

Figure 1: The magnetic torque and Hall voltage signals for different rates of sweeping the magnetic field. between 30 and 35 T. a) The reversible torque signal, notably independent of sweep rate . b) The irreversible torque signal, notably growing at integer filling with increasing sweep rate. c) The thermally induced Hall voltage showing increased hysteresis at integer filling with increasing sweep rate. d) The irreversible component of the thermoelectric voltage. All data is the average of multiple field sweeps.

Conclusions

For slow rates of change of magnetic field the system is never pushed very far from equilibrium before the temperature change collapses the critical state. However, as *dB/dt* increases the system is pushed further from equilibrium for each cycle of heater power, such that a larger non-equilibrium voltage is induced. The Oscillatory form of the irreversible thermoelectric voltage mirrors the irreversible torque; at integer Landau level filling the low density of states allows the system to be pushed further from equilibrium and a larger voltage is induced, see Figure1. In conclusion we have observed a new form of pyroelectric effect in which thermal de-pinning of a CDW causes the release of inductive energy stored by extended edge states.

Acknowledgements

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References

[1] N. Harrison *et al*, Phys. Rev. B **69** 165103 (2004).