INDUCTIVE TECHNIQUE FOR MEASURING ELECTRICAL CONDUCTIVITY OF INTERCALATED GRAPHITE

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ABSTRACT

The A.C. inductive technique was used to measure the in-plan electrical conductivity of stage-6- F_eCl_3 intercalated graphite. The data indicate that there is a low temperature phase transition associated with the magnetic anomaly in these compounds.

INTRODUCTION

The electrical conductivity of stage-6 $FeC1_3$ intercalated graphite was measured in the vicinity of the 1.75k susceptibility anomaly[1,2] by measuring the out phase a.c. susceptibility. The measurements were made at frequencies between 40 and 1000 Hz and as function of the magnetic field. The electrical conductivity is one of the properties most drastically changed by intercalation both in acceptor and donor graphite intercalation compounds, [3] (GIC), and special attention has been paid to their in plane conductivity [4,5] which can be a factor of 10^6 greater than that along the c-axis(perpendicular to the plane).

our measurements were stimulated by the fact that we observed a maximum in the out-of-phase magnetic susceptibility, X, accompanying an in-phase susceptibility, X, maximum when the measuring field was parallel to the plane. No such maximum was observed with the field along the c-axis which would have measured the in-plane conductivity. X" the out-of-phase component, which is proportional to the conductivity, and with the measuring magnetic field parallel to the plane we are mainly sampling the changes in the conductivity along the c-axis. The maximum in X" comes at a temperature typically down by 2×10^{-3} k lower that of X' as shown in Figure (1).

EXPERIMENTAL

The samples were prepared by a standard technique and analyzed for staging fidelity by x-ray analysis. Mossbauer analysis verified the F_eCl_3 content and number of vacancies. Preparation of the sample and more details about the experimental technique can be found in Ref.[4]. The conductivity measurements were made by a standard ac bridge method operating at frequency in the range of 40-1000 Hz. By using a phase sensitive detector we were able to observe both the in-phase (related to the susceptibility) and the out-of-phase (proportional to the conductivity) signals. The orientation of the magnetic field at the sample was perpendicular to the c-axis, therefore the magnetic moments in the basal-plane and the conductivities the a-c in plane were measured with the variation coming from the conductivity along the c-axis.

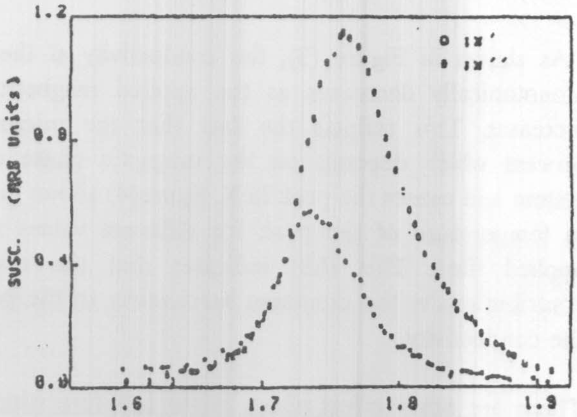

Figure 1. In-phase and out-of-phase components of the susceptibility as a function of temperature in zero field.

RESULTS AND DISCUSSION

The most striking result in this work is the temperature dependence of the c-axis conductivity which exhibits an anomaly in the form of a sharp peak at temperature near 1.73k in zero magnetic field. This conductivity behaviour is indeed correlated with the same anomaly which was seen in the in-plan magnetic susceptibility X and reported in Ref. [2]. As shown in Figure (2), the peak is very sensitive to any external appalied magnetic field, it disappears in field H = 5G and at frequency f = 39,7 Hz. The field dependence of the conductivity may relate this anomaly to the mechanism which causes the peak in X. An enhancement in the conductivity is expected when the system has a magnetic anomaly.

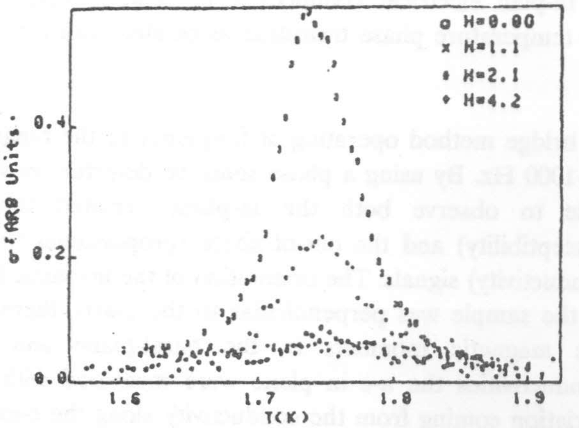

Figure 2. The in-plane conductivity as a function of temperature in an applied magnetic field.

As shown in Figure (3), the conductivity at the peak monotonically decreases as the applied magnetic field increases. This reflects the fact that the microscopic process which depends on the magnetic phase of the system and causes the peak in X. figure(4) shows the shift in temperature of the peak for different values of the applied filed. This shift indicates that the magnetic contributions is the dominant mechanism to the peak in the conductivity.

There are other effect which might interfere with these measurements, for example skin effect or size effect. For materials of a metalic-like conductivity, the skin effect can be eliminated if the frequency is in the range of $f < 2 \times 10^6 \rho^3$ (f in KHz, ρ in $\mu\Omega$cm). Within the limits of the resistivity of our sample,a typical value of f should be less than 2KHz which is much higher than the maximum frequency which has been used (f < 1KHz). The size effect would be a major factor only if the mean free path is comparable with the sample size. Therefore, we do not expect any contributions to our date from these effects.

We also have measured σ at different frequencies and Figure (5) shows the frequency dependence of σ at the peak. As shown in Figure(4) and Figure(5), the anomaly is present at all frequencies but we have observed a variation in the magnitude of the peaks, also they are shifted to different temperatures. This frequency behaviour was compared with reported data between the out-of-phase component and 1/fσ for a similar bridge [6], they were very consistent as far as the peak size is concerned although the temperature variation is real. Therefore, no frequency effects interfere which the date and the observed peak size variation is just a frequency dependence in the bridge itself.

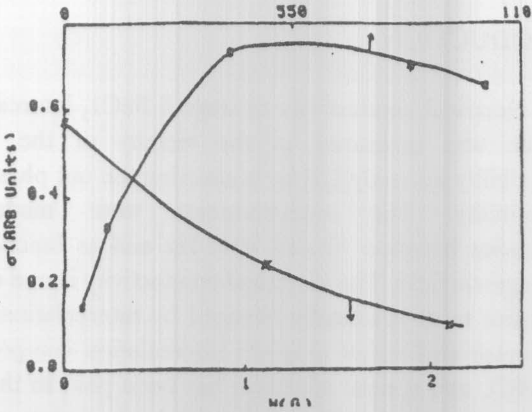

Figure 3. The conduuctivity at the peaks as a function of the applied magnetic field and the frequency.

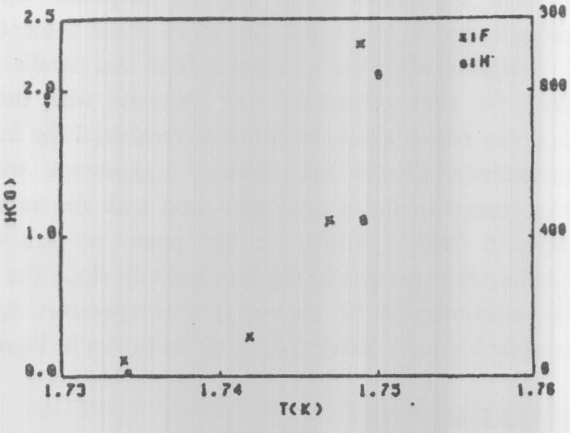

Figure 4. The temperature of the peaks as a function of the applied magnetic field and the frequency.

In conclusion, low temperature phase transition of c-axis conductivity has been seen in stage-6 GIC and is related to the same phenomenon which causes the peak in the magnetic susceptibility. The above anomaly is reminiscent of spin-glass behaviour where at a certain temperature the magnetic spins are frozen.

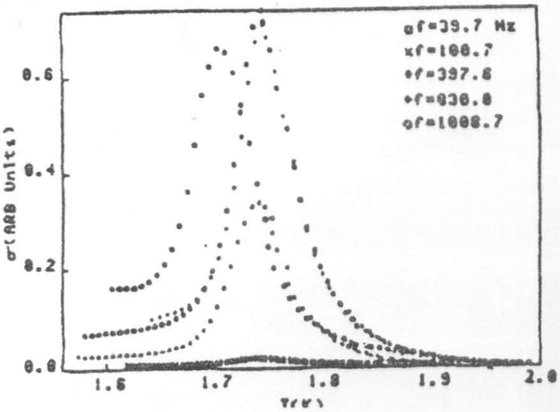

Figure 5. The in-plane conductivity as a function of temperature in a zero field and at different frequencies.

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