Measurements on Chromium Potassium Alum below 1°K

E. AMBLER AND R. P. HUDSON
National Bureau of Standards, Washington 25, D. C.
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Measurements of the real part, χ', and imaginary part, χ'', of the ac susceptibility, the ballistic susceptibility, and the remanence were made on chromic potassium alum in the range of temperature below 1°K. The results provide confirmation of earlier measurements in the region above 0.1°K, but show some discrepancies at lower temperatures, particularly in the behavior of χ''. Some absolute temperature determinations, in the region of the "Curie point," were also made and these are of particular interest in view of wide discrepancies between such measurements made at Oxford and at Leiden.

INTRODUCTION

IN a recent series of investigations on the magnetic behavior of chromic methylamine alum at very low temperatures,[1] marked differences were found from that of chromic potassium alum, as reported by de Klerk, Steenland, and Gorter.[2] Specifically, the entropy *versus* susceptibility curve showed a tendency to flatten out at the expected value of $S=R\log_e 2$; the out-of-phase component of the ac susceptibility, χ'', attained measurable values only in an extremely small range of entropy and exhibited a very sharp maximum. Finally, when ballistic measurements were made of the susceptibility with a 5.6-sec period galvanometer very marked time effects were observed, and the remanence plotted as a function of entropy showed a maximum.

It was therefore thought of interest to investigate a specimen of the potassium alum with the same apparatus, and the results are reported here, inasmuch as they provide confirmation of earlier measurements in the region above 0.1°K,[2,3] show some discrepancies at lower temperatures, particularly in the behavior of χ'', and include some independent determinations of absolute temperatures in the region of the "Curie point" which are of particular interest in the light of wide discrepancies between such measurements made at Oxford[4] and at Leiden.[2]

RESULTS

The specimen used was a spherical single crystal, radius 25.4 mm, mass 15.61 g, and its susceptibility was determined along the direction of a cubic axis.

In the first series of experiments the crystal had been ground immediately before mounting it in the apparatus and was cooled from room temperature to 77°K at a fairly uniform rate in 12 hr. The same crystal was used in the second series of experiments, the only difference being that it had been reheated to room temperature in the meantime. (It was felt worth while to point out this fact, in view of some differences which were obtained in the two series of runs for the values of the ac susceptibility below the maximum.)

Values of the real part of the ac susceptibility χ' measured at 210 cps, and of the ballistic susceptibility χ obtained by reversing a field of 3.44 oersteds, are shown in Fig. 1. Agreement with the theory of Hebb and Purcell using the Onsager approximation for the internal field is obtained for temperatures down to 0.2°K, if the splitting between the electronic doublets is taken as 0.25_0 deg. This is in good agreement with the splittings obtained by de Klerk *et al.* (0.251 deg) and by Bleaney (0.245 deg) which, however, do not fit the data obtained from paramagnetic resonance.[5] There is a sharp maximum of χ' corresponding to a minimum in T^* of 0.029_7 at an entropy $S/R=0.40_6$. In contrast, the ballistic susceptibility shows a very flat maximum at somewhat lower entropy; we obtain for the minimum in T^* measured ballistically, 0.028_3 at $S/R=0.31_0$. These results are in satisfactory agreement with the results of de Klerk *et al.*, and in fairly good agreement with those of Daniels and Kurti. (The latter authors, using the ballistic method, obtained $T^*_{\min}=0.035$ deg at $S/R=0.35$.)

In Fig. 2 are plotted the values of the out-of-phase part of the ac susceptibility which does not show the maximum reported by de Klerk *et al.* down to an en-

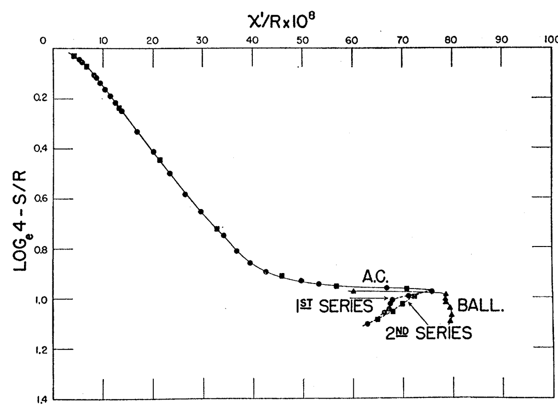

FIG. 1. Susceptibility as a function of entropy: ● and ■ ac susceptibility, first and second series respectively; ▲ ballistic susceptibility.

[1] R. P. Hudson and C. K. McLane, Phys. Rev. **95**, 932 (1954).
[2] de Klerk, Steenland, and Gorter, Physica **15**, 649 (1949).
[3] B. Bleaney, Proc. Roy. Soc. (London) **A204**, 216 (1950).
[4] J. M. Daniels and N. Kurti, Proc. Roy. Soc. (London) **221**, 243 (1954).
[5] B. Bleaney, Proc. Roy. Soc. (London) **A204**, 203 (1950).

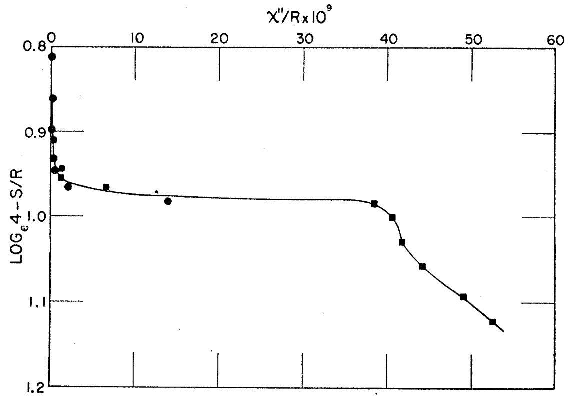

FIG. 2. Imaginary part of ac susceptibility, χ'', as a function of entropy.

tropy $S/R=0.26$; instead, there is a point of inflection at about the same entropy as that for which these authors report their maximum.

The values of the remanence obtained by reversing a field of 3.44 oersteds are plotted in Fig. 3. It was found that remanence sets in at an entropy $S/R=0.42$ (which lies between the figures quoted by Kurti, Lainé, and Simon[6] and by de Klerk *et al.*) then increases steadily with falling entropy to $\Sigma/R=4.6\times10^{-8}$ degree oersted^{-1} at $S/R=0.28$. Time effects, indicative of a sluggishness of the magnetic moment in following reversals of the external field, were not observed with this salt.

Absolute temperature determinations were made using the χ'' heating method, with χ' as a thermometric parameter. This method is naturally confined to the range where χ'' is usefully large and where χ' varies fairly rapidly with entropy, i.e., for $S/R<0.44$. In addition, we confined our measurements to the range above the χ' maximum in order to minimize uncertainties which arise because of inhomogeneous heating due to extraneous heat influxes. We obtained the following results:

$(\ln 4-S/R)$	T^* ac	T°K
0.945	0.0435	0.02_0
0.962	0.0364	0.01_9
0.970	0.0317	0.01_7

These absolute temperatures are very much greater than those quoted by de Klerk *et al.* for the same entropies, and somewhat greater than the corresponding values of Daniels and Kurti.[7]

It is obvious that serious discrepancies exist in the absolute temperature determinations of various workers, although the reasons for these are not too clear. Undoubtedly the problem of allowing for the effect of the extraneous heat influx plays an important part, and therefore there is great need for developing apparatus where this heat influx is always kept to a very small value—say less than 5 ergs per minute. At the same time it is desirable for the same workers to carry out absolute temperature determinations using both methods (i.e., by χ'' heating and by γ-ray heating) on the same specimen. The authors hope to carry out such experiments in the near future.

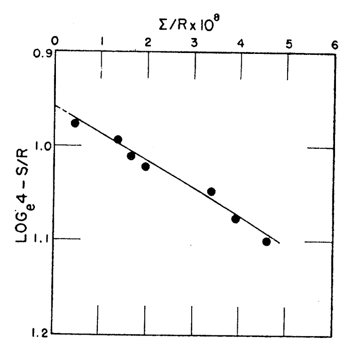

FIG. 3. Remanence as a function of entropy; measuring field 3.44 oersteds.

[6] Kurti, Lainé, and Simon, Compt. rend. **204**, 675 (1937).

[7] The discrepancy between these results and those of Daniels and Kurti is undoubtedly due in part to the deviation of the former by assessing the "drift heating" on the assumption of uniform heating. In this connection it is of some interest to note that the actual experimental values of specific heat obtained by Daniels and Kurti in this region of entropy [Fig. 5, reference 4] deviate from their own drawn curve in such a direction that they would yield higher derived values of T.