Relation between Heat Capacity and Magnetization in a Spin-Glass

In a recent Letter Fogle *et al.*[1] have presented some very precise specific heat, C, data on a CuMn spin-glass near the freezing temperature $T_{sg}(=3.9\text{ K})$. By determining the field dependence $C(H)$ at various T (for a field-cooled sample) they obtained a good fit to the data using $C(H, T)/T = A(T) + B(T)H^2$ where $B(T)$ did exhibit a well-defined minimum at T_{sg}.

Fogle *et al.*[1] also pointed out that thermodynamics requires only an anomaly in the magnetization M to be reflected in the field dependence of C by the Maxwell relation $[\partial^2 M/\partial T^2]_H = T^{-1}[\partial C/\partial H]_T$. Assuming M to be linear in H ($M = \chi H$), substituting the experimental dependence for $C(H)$, and performing the double temperature integration with an evaluation of the two constants of integration at $T = 4.25\text{ K} > T_{sg}$ results in the full temperature dependence of $\chi(T)$. This function was in strong disagreement with the measured $\chi_{ac}(T)$ (a sharp cusp at T_{sg}) or typical field-cooled $M_{dc}(T)/H$ (a flat plateau for $T \lesssim T_{sg}$)—see Fig. 1 of Ref. 1. The basic conclusion of this analysis was that thermodynamics failed to predict correctly the relation between heat capacity and magnetic susceptibility, and that spin-glasses are inherently *nonergodic* in nature.

In this Comment we wish to demonstrate that the above Maxwell relation is not necessarily violated if we evaluate the constants of integration far enough above T_{sg}. Several factors must be considered in determining the appropriate temperature φ at which the constants of integration are evaluated. First, the relation $\chi_{ac} = M_{dc}/H$ is probably not valid for temperatures near T_{sg} but only for $T \gg T_{sg}$. Secondly, strong nonlinear effects in M are observed near T_{sg} for small H which imply a H^4 term in $C(H)$ for $T \gtrsim T_{sg}$.[2,3] Since the quadratic field dependence of $C(H)$ is solely observed and only truly manifests itself for fields 400 to 1000 Oe,[1] the calculated $M(H, T)$ should be compared to experimental results measured in similar high fields as an overestimation of the magnetization slope for T near T_{sg} would occur for smaller fields. Alternatively, determination of the constants of integration at $\varphi \gg T_{sg}$ reduces the nonlinear effects such that M is essentially linear in H and C solely quadratic. In Ref. 1 the experimental values of $\chi_{ac}(H = 5\text{ Oe})$ and $d\chi_{ac}/dT$ at 4.25 K were used. This leads to results similar to the open circles in Fig. 1. By contrast, evaluations at $\varphi = 6.5$ K produce a M/H shown by closed circles in Fig. 1. This M/H with even a small maximum at T_{sg} is very similar to the typically measured field-cooled, equilibrium magnetization.[2] Therefore we maintain that the Maxwell relation is obeyed and the ergodicity is preserved.

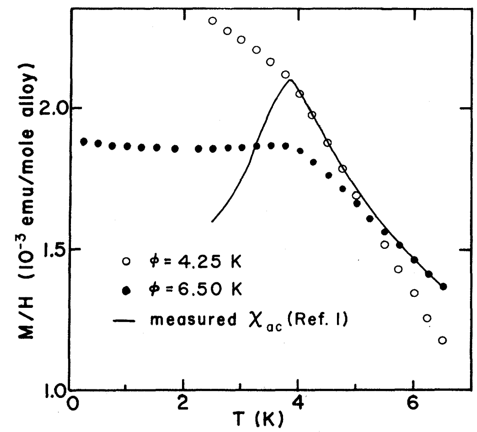

FIG. 1. Comparison of the calculated and measured magnetizations.

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