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MAGNETIC SUSCEPTIBILITY OF AuFe: T_g AND CURIE-WEISS PARAMETERS

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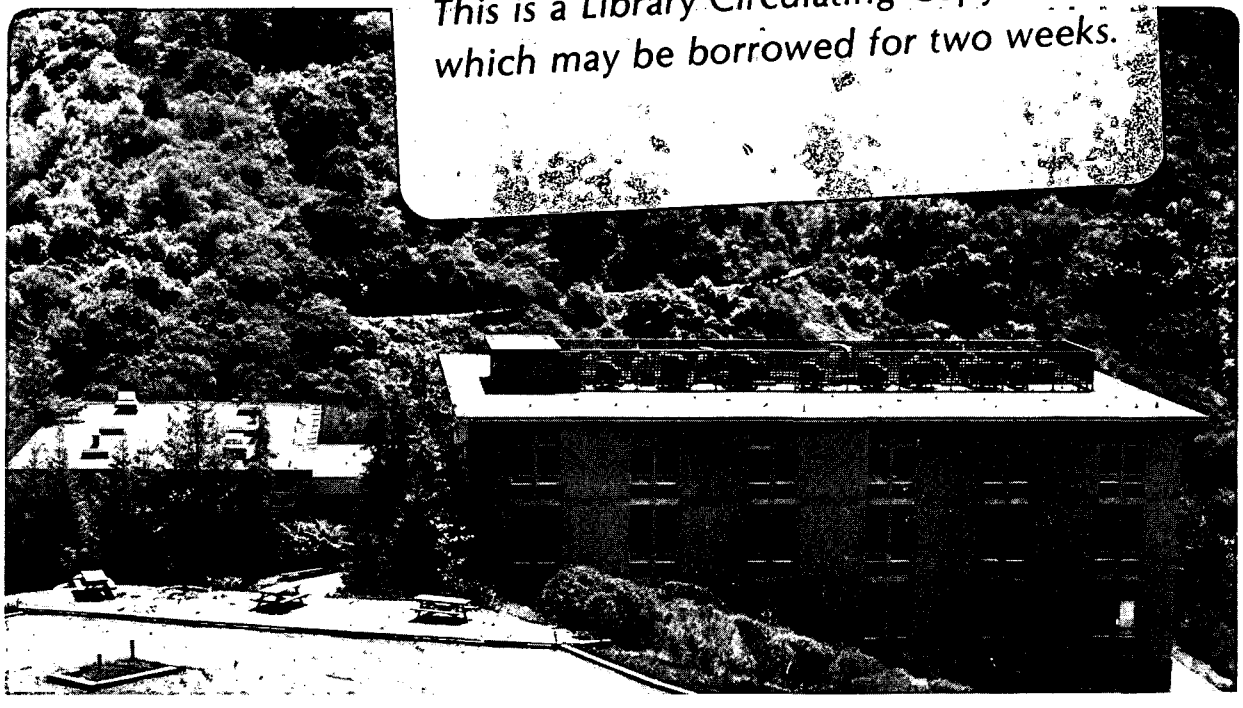

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MAGNETIC SUSCEPTIBILITY OF AuFe: T_g AND CURIE-WEISS PARAMETERS*

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The dc field-cooled susceptibilities, χ, of annealed AuFe with nominal concentrations, c, of 0.5, 1 and 2 at.% Fe have been measured in the ranges $2<T<150K$ and $1<H<50000G$. Spin-glass temperatures, T_g, were determined from the cusps in χ at low field. Analysis of the data above $3T_g$ determined the Weiss constants, Θ, and the effective magneton numbers, p. Assuming S=3/2 for Fe, values of g, the spectroscopic splitting factor, were derived from p.

It was first shown in AuFe [1] that the low field ac susceptibility of a spin-glass has a cusp marking the "transition temperature", T_g. Martin [2] has suggested that the specific heat of Fe in AuFe alloys, C_{Fe}, has a broad "knee" in C_{Fe}/T at T_g. Recently, he measured C for three carefully prepared and well characterized AuFe samples of nominal concentration 0.5, 1 and 2 at.% Fe [3]. At the conclusion of the measurements, 5mm x 5mm right circular cylinders were cut from the samples to determine T_g from dc measurements of χ. A correlation was found between a C_{Fe}/T "knee" and T_g [3]. In this paper we report the results of the field-cooled χ determinations used by Martin [3].

Preparation and heat treatment of the samples has been described by Martin [2,3]. Briefly, the samples were prepared by inductively melting Au (99.99%) and Johnson-Matthey electrolytic iron rod in a flowing hydrogen atmosphere, chillcasting under vacuum, homogenizing in hydrogen and then degassing at 1120K overnight before furnace cooling to ambient temperature. The χ measurements were made on annealed samples. However, since specific heat measurements [2,3] show no difference between annealed and un-annealed samples it is probable that χ also would not be different. Two methods of analysis were used to determine the Fe concentration, c: atomic absorption, AA, and inductively coupled plasma atomic emission spectroscopy, ICPAES [3]. The results were (ICPAES given in brackets): 0.51 [0.48], 1.04 [1.03] and 2.06 [1.93] at.% Fe. In this paper we use the AA determined values of c, which should be accurate to within 1%.

χ was measured with an SHE magnetometer that had been checked with an NBS Pt standard. A superconducting Sn sphere was used to determine magnetic fields for $H<200G$. Values of χ are believed accurate to within 1%, with higher precision between values at adjacent temperatures and constant H. After each change of field the sample temperature was raised to at least $3T_g$ and H held constant until all measurements in that field had been completed.

Typical low-temperature χ data for the 1 at.% Fe sample are shown in Fig. 1. Results for the 0.5 and 2 at.% Fe samples are similar. Figure 2 is a plot of $(\partial\chi/\partial T)_H$ for the three Fe concentrations obtained from point-to-point differences of χ vs T at H=5G. Both χ and the derivative show the characteristic features associated with spin-glass ordering. T_g was taken as the cusp temperature for $H<5G$. For $H<50G$ χ was essentially field independent. Figure 3 is a plot of χ vs T for the three samples at H=5G. Note that as c increases the magnitude of χ per mole of Fe decreases for $T<T_g$. There is also a decrease in the cusp height as c increases. Above about $3T_g$ the susceptibility per mole of Fe is nearly independent of c for a given temperature. (The same behavior was also found for CuMn [4]).

For $T \geq 3T_g$ and for H/T not too large, χ can be well represented by a Curie-Weiss relation

$$(\chi-\chi_d) = A/(T-\Theta), \qquad (1)$$

where $\chi_d = \chi_{Au} = -1.37 \times 10^{-7}$ emu/g. χ_{Au} was determined for Au (99.999%) at 10 and 20 kG between 5 and 200K. Fig. 4 shows $1/(\chi-\chi_d)$ vs T for the 1 at.% Fe sample below 50K. For clarity not all of the fields are shown. The straight line is the least-squares fit to the data for $3T_g \leq T \leq 10T_g$ and $H/T \leq 1$kG/K. Similar fits were made for the other two samples. About 50 points were used for each of the fits. An increase in the low-temperature cutoff T for the least-squares fit to 4 and $5T_g$ produced no significant change in either the rms deviation or derived parameters. (We believe it is important not to extend the leastsquares fitting to data at temperatures that are too high since the precision of χ decreases as T increases.) Values of T_g and parameters determined from the Curie-Weiss fits are listed in Table I along with the rms deviations, and are plotted as a function of c in Fig. 5. The effective magneton number, p, was derived from

$$A=N_A g^2 S(S+1)\mu_B^2/3k_B \equiv N_A p^2 \mu_B^2/3k_B. \qquad (2)$$

Negative values of Θ indicate antiferromagnetic interactions for the 0.5 and 1 at.% Fe samples, while a positive Θ for the 2 at.% Fe sample indicates a ferromagnetic interaction, with the crossover at 1.8 at.% Fe. If either g or S is known, Eq. (2) can be used to calculate the other from p. The values of g given in Table I are based on the assumption S=3/2. CuMn [4] showed similar behavior for Θ and g.

The change of Θ with c for the present results is in qualitative agreement with those determined previously [5]; however, the values are much smaller in magnitude and the crossover is at a lower temperature. In the same reference [5], p was stated to be concentration independent between 1 and 6 at.% Fe, while we find an increase of 12% for p between 0.5 and 2 at.% Fe. We have no explanation for the discrepancy. Prior measurements on CuMn [4] agreed well with the results of reference [5] for that system. Values of T_g as derived from previous measurements are in generally good agreement with the present results [1,6]. χ for the AuFe system and derived parameters are similar to those found for the CuMn system [4,7].

We thank Dr. D. L. Martin for providing us with the samples used in this research.

REFERENCES

*Supported by the Director, Office of Energy Research, Office of Basic Energy Sciences, Materials Sciences Division of the U.S. Department of Energy under Contract DE-AC03-76SF00098.

1) V. Cannella, J.A. Mydosh and J.I. Budnick, J. Appl. Phys. 42, 1689 (1971); V. Cannella and J.A. Mydosh, Phys. Rev. B6, 4220 (1972).
2) D.L. Martin, Phys. Rev. B21, 1906 (1980).
3) D.L. Martin, Phys. Rev. B, to be published.
4) R.A. Fisher, E.W. Hornung and N.E. Phillips, to be published.
5) A.F.J. Morgownik and J. A. Mydosh, Solid State Commun. 47, 321 (1983).
6) V. Larsen, Solid State Commun. 22, 311 (1977); P.A. Beck, Prog. Mat. Sci. 23, 20 (1978).
7) R.A. Fisher, E.W. Hornung, N.E. Phillips and J. Van Curen, Proc. LT-17 (Elsevier, NY), 437 (1984).

Table I. Values of Parameters Derived from χ.

c (at.% Fe)	p	g(S=3/2)	Θ(K)	rms(%)	T_g(K)
0.51	3.84	1.98	-4.4	1.5	5.0
1.04	4.03	2.08	-3.0	2.0	8.4
2.06	4.29	2.21	1.2	1.9	13.0

FIGURE CAPTIONS

Fig. 1. χ vs T at constant H for AuFe.

Fig. 2. $(\partial\chi/\partial T)_H$ vs T at H=5G for AuFe.

Fig. 3. χ vs T at H=5G for 0.5, 1 and 2 at.% Fe in AuFe.

Fig. 4. $1/(\chi-\chi_d)$ vs T for AuFe.

Fig. 5. Parameters derived from Curie-Weiss fit to χ data for AuFe.

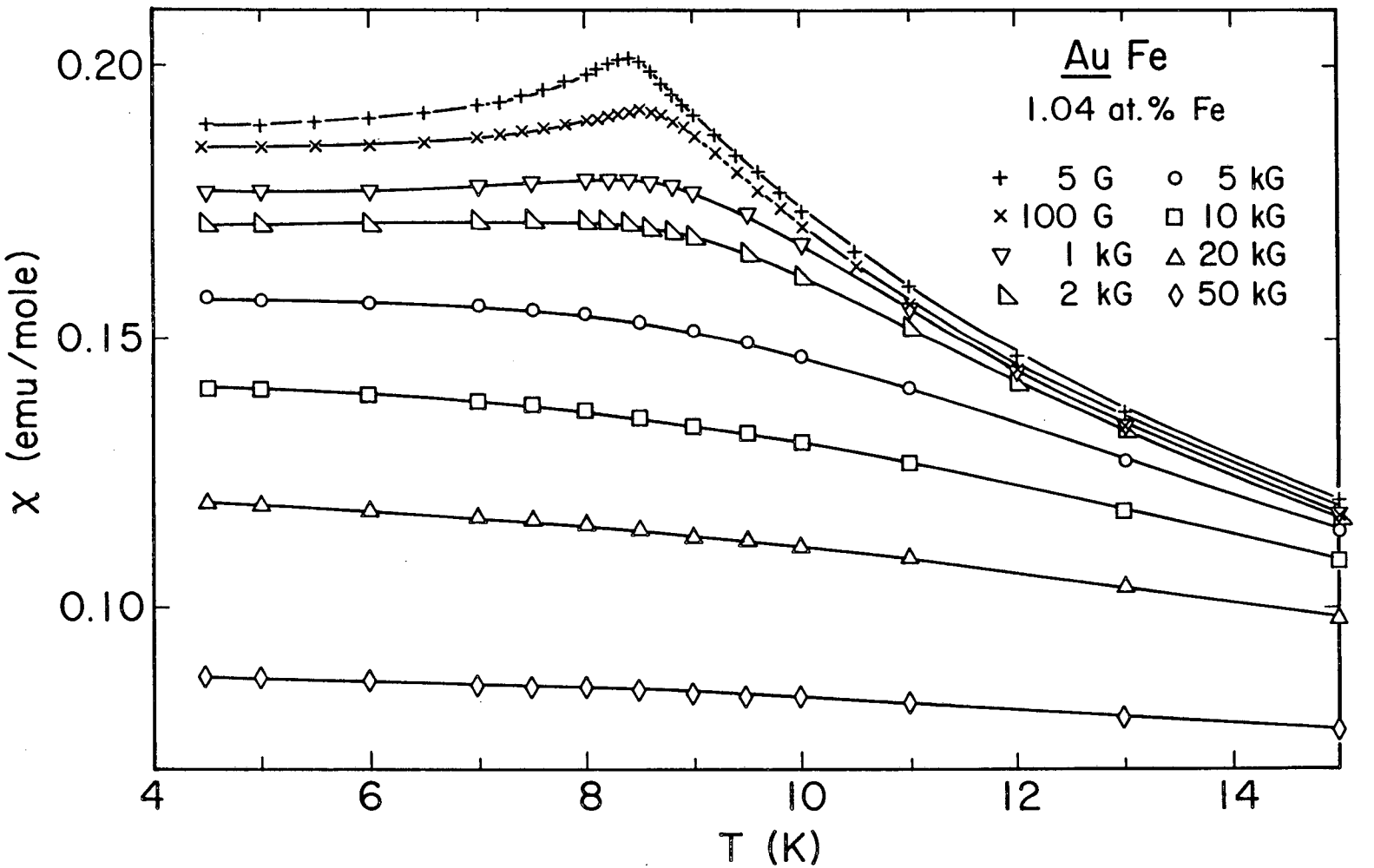
Au Fe
1.04 at.% Fe
+ 5 G
× 100 G
▽ 1 kG
◺ 2 kG
○ 5 kG
□ 10 kG
△ 20 kG
◊ 50 kG
0.20
0.15
0.10
χ (emu/mole)
4
6
8
10
12
14
T (K)

FIGURE 1

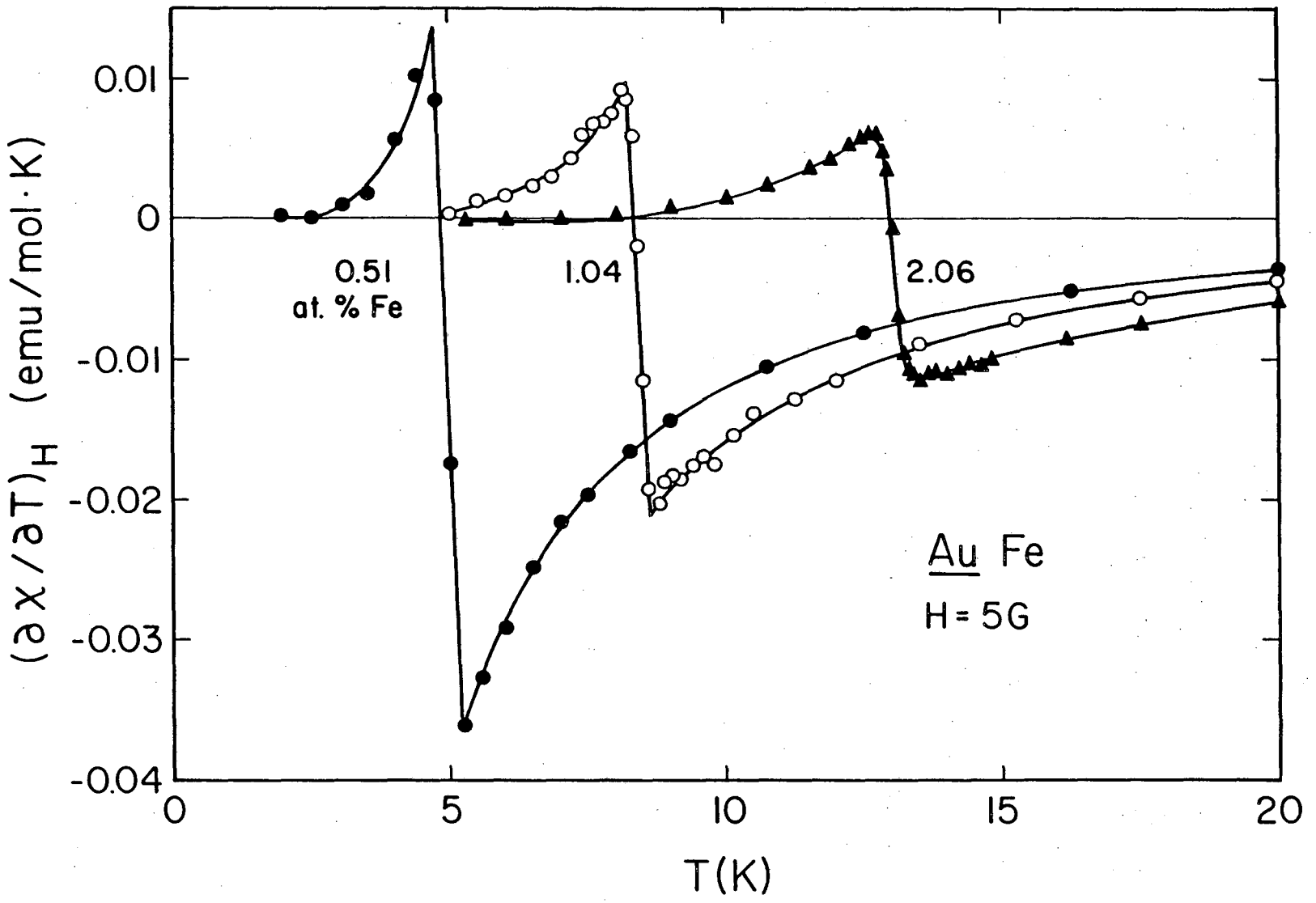
0.01
0
-0.01
-0.02
-0.03
-0.04
$(\partial\chi/\partial T)_H$ (emu/mol·K)
0
5
10
15
20
T(K)
0.51
at. % Fe
1.04
2.06
Au Fe
H = 5G

FIGURE 2

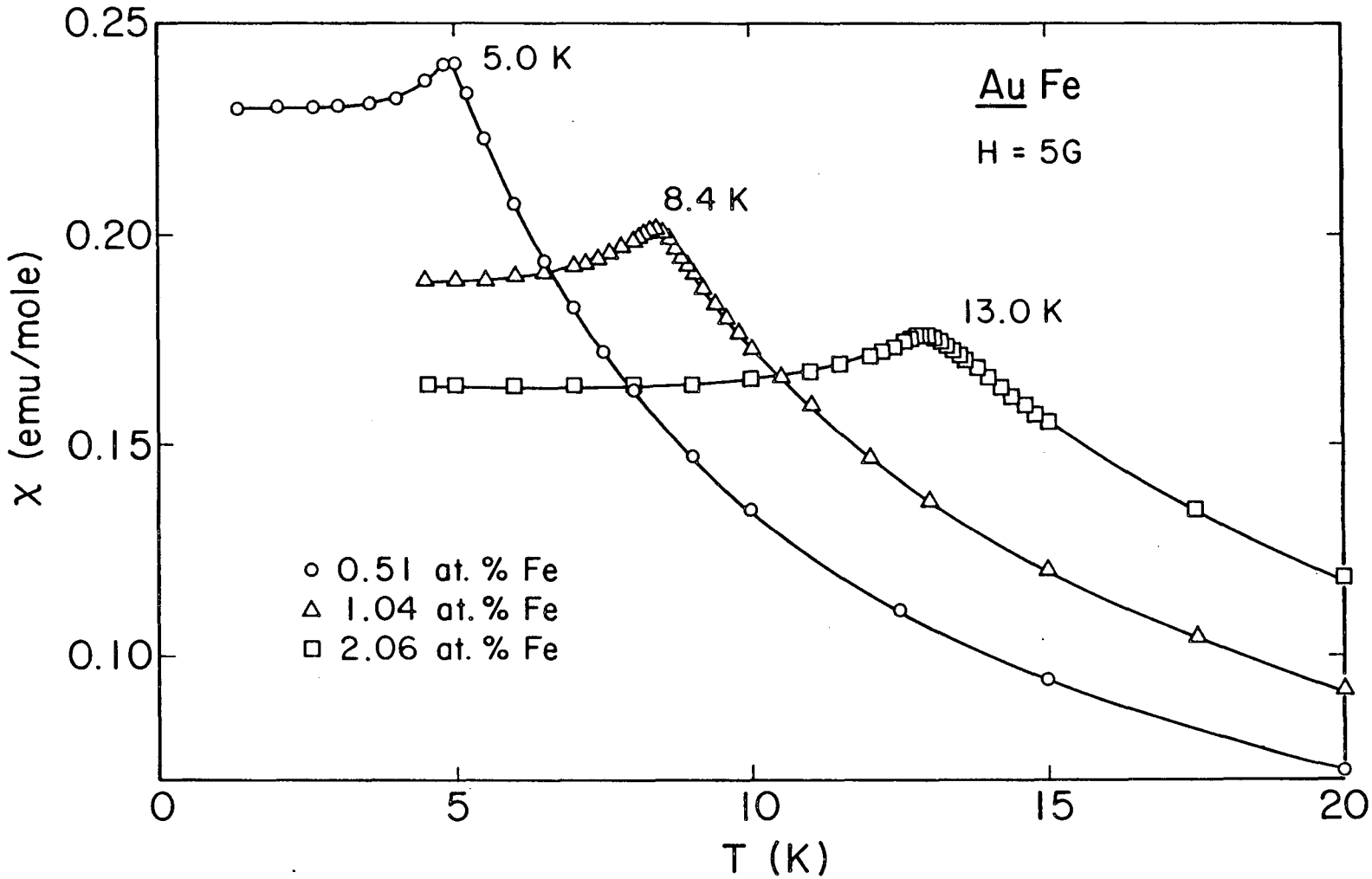
0.25
0.20
0.15
0.10
χ (emu/mole)
0
5
10
15
20
T (K)
5.0 K
8.4 K
13.0 K
Au Fe
H = 5G
○ 0.51 at. % Fe
△ 1.04 at. % Fe
□ 2.06 at. % Fe

FIGURE 3

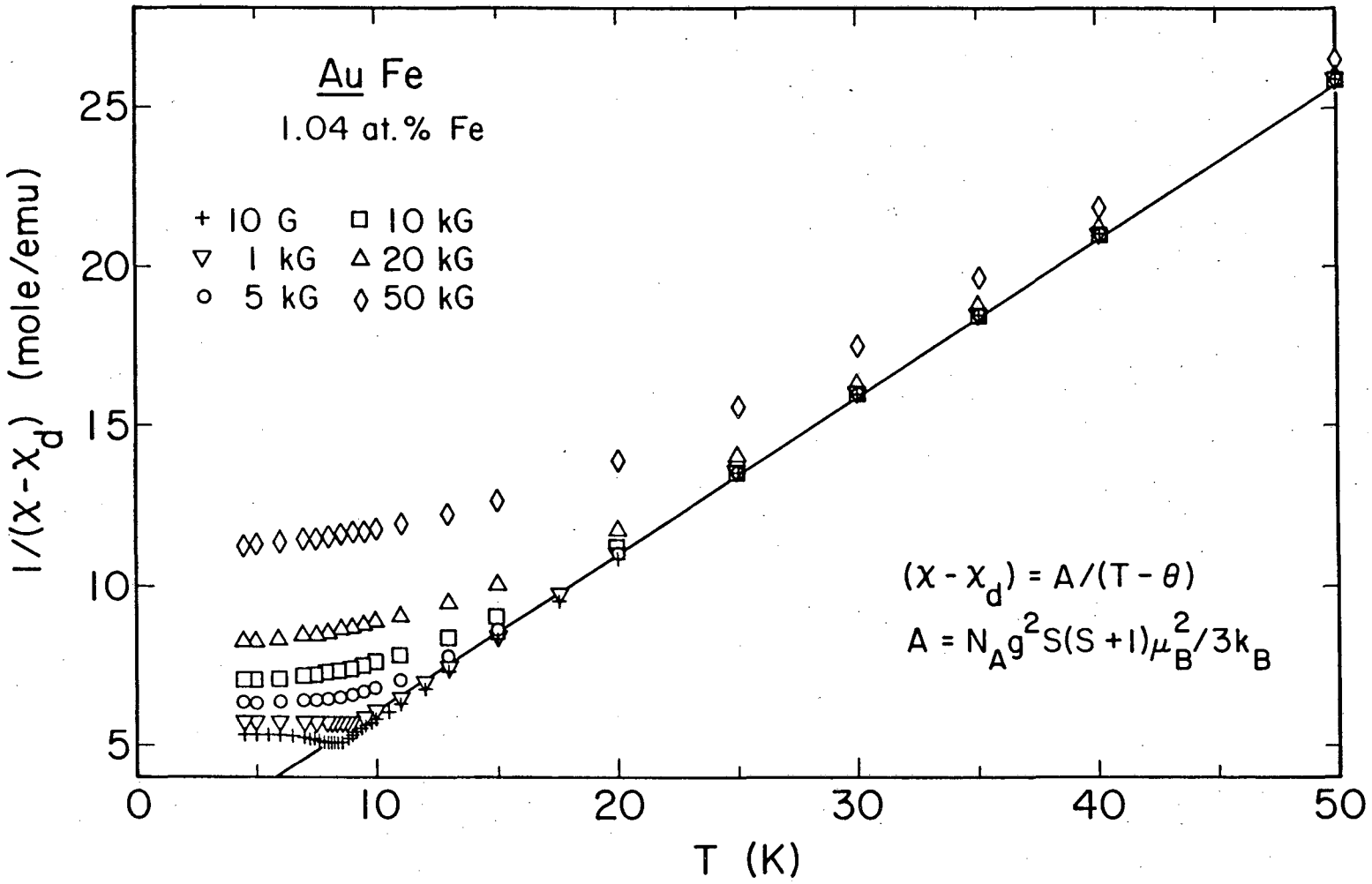
Au Fe
1.04 at.% Fe
+ 10 G
□ 10 kG
▽ 1 kG
△ 20 kG
○ 5 kG
◊ 50 kG
$(\chi - \chi_d) = A/(T - \theta)$
$A = N_A g^2 S(S+1)\mu_B^2/3k_B$
$1/(\chi - \chi_d)$ (mole/emu)
T (K)
0
10
20
30
40
50
5
10
15
20
25

FIGURE 4

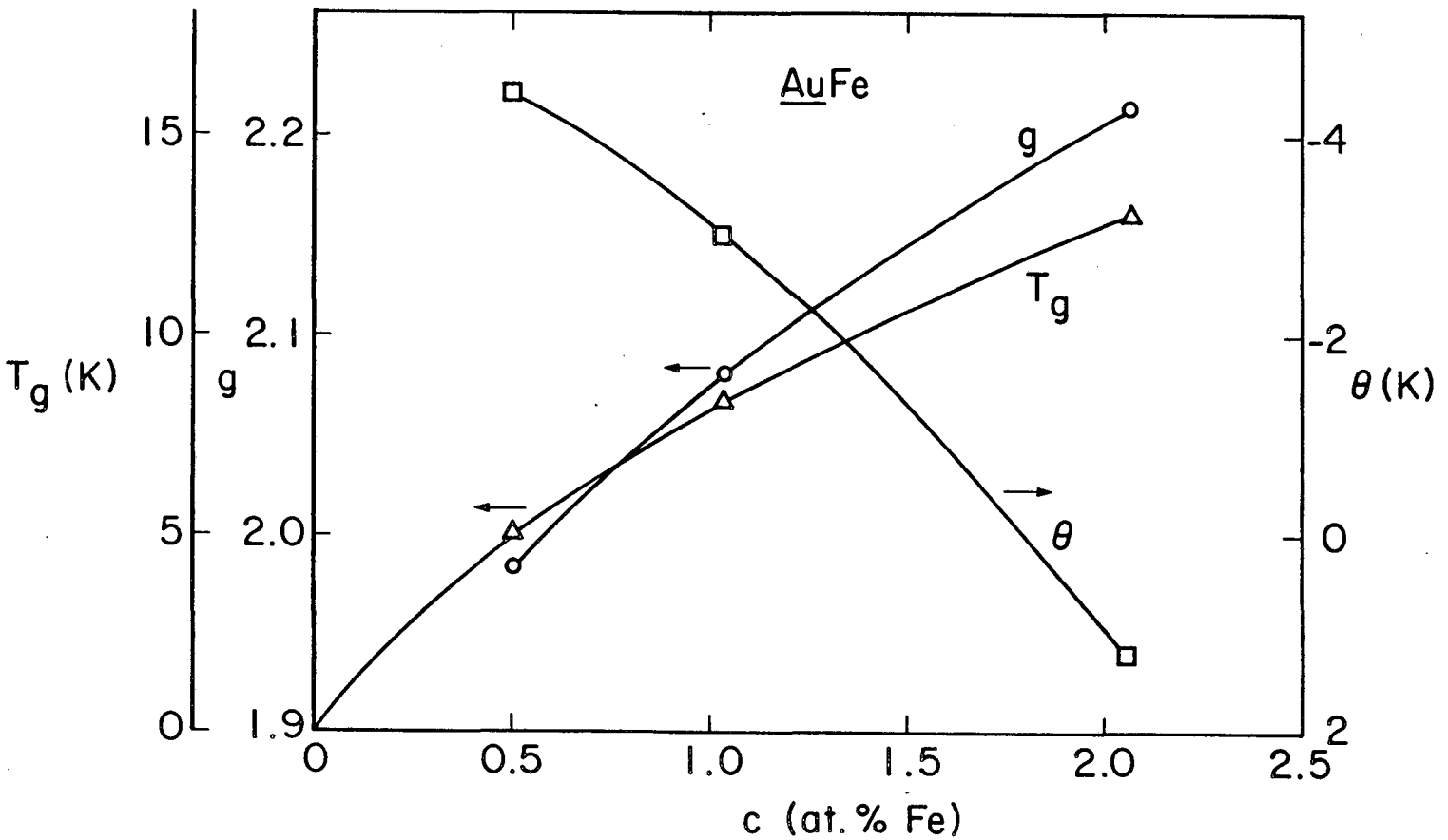

FIGURE 5

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