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by

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ABSTRACT

Magnetic properties of the intermetallic compound $Ce(Fe_{0,8}Al_{0,2})_2$ are studied by means of magnetization measurements as a function of temperature and field. The low temperature magnetization curve vs. temperature shows a peak at 12.5K with remanent effects characteristic of a spin glass behavior. At higher temperatures a second peak was observed at 165K. The nature of this second peak is qualitatively discussed.

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Abstract. Magnetic properties of the intermetallic compound $Ce(Fe_{0,8}Al_{0,2})_2$ are studied by means of magnetization measurements as a function of temperature and field. The low temperature magnetization curve vs. temperature shows a peak at 12.5K with remanent effects characteristic of a spin glass behavior. At higher temperatures a second peak was observed at 165K. The nature of this second peak is qualitatively discussed.

The crystal structure and the magnetic properties of the intermetallic pseudo-binary systems $M(Fe,Al)_2$ with M = rare earth, (reviwed by Steiner 1979), or a transition metal Zr (Grössinger et al. 1981), Sc (Sankar et al. 1976) have been extensively investigated. Changes of structure from C15 $MgCu_2$ type to C14 $MgZn_2$ type and vice-versa depending on concentration were observed for all these systems. Also, the magnetic order breakdown in the disordered range takes place independently of the crystal structure. Difficulty to saturate and remanent effects are also observed for systems with M = Tb

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(Osterreicher 1973), Ho (Grössinger et al. 1976) and Er (Osterreicher 1971) and irreversible effects in magnetization of M=Y (Besnus et al. 1978). Furthermore, systems with Co in place of Al present the same characteristics and with a wide variety of magnetic behavior depending on concentration. For instance, $Y(Fe_xCo_{1-x})_2$ is paramagnetic for x = 0, behaves like a mictomagnetic below about x = 0,1 and long range ferromagnetic order appears at higher concentrations (Steiner 1979). Another interesting system is iron-aluminum with 30 at % Al which becames ferromagnetic below 400K, paramagnetic below 170K and mictomagnetic below 92K (Shull et al. 1976).

In the present investigation the system $Ce(Fe_{1-x}Al_x)_2$ with x = 0.2 was chosen. It is known that the boundary compounds are ferromagnetic (x=0) and antiferromagnetic (x=1). It will be interesting to investigate if a small concentration of Al just changes the ferromagnetic order or if a new magnetic state appears.

EXPERIMENTAL

The sample preparation was by arc furnace melting of the constituents in stoichiometric proportions, under purified argon atmosphere. After melting three times, homogeneity was obtained by annealing at 800ºC for a week in argon atmosphere. Crystal structure and lattice constant were determined by X-ray diffraction on powdered samples.

Magnetic measurements were made in a sample-extraction magnetometer in static fields up to 55KG, over a temperature range of 1 to 30K and in a PAR vibrating sample magnetometer in static fields up to 13KG, over a temperature range of 77 to 300K. Temperature was monitored using a carbon sensor and a Cu-constantan thermocouple. The absolute accuracy of temperature determination was about 0,2K.

RESULTS

The X-ray diffraction shows that the compound $Ce(Fe_{0,8}Al_{0,2})_2$ crystallizes in the cubic $MgCu_2$(C15) structure. A lattice parameter of 7,346 Å was derived by least-square analysis using Nelson-Riley's extrapolation.

- Fig. 1 shows the magnetic (DC) susceptibility of $Ce(Fe_{0,8}Al_{0,2})_2$ as a function of temperature for $1 \leq T \leq 30K$ and an applied field of H = 220G. The full curve was measured after the sample has been cooled in zero field from T = 77K to T = 1K. The susceptibility was then measured by increasing the temperature up to 30K. As it can be seen a sharp peak emerges at a temperature T = 12,5K. It is to be stressed that the isomagnetic magnetization versus T curve presents irreversibility effects for $T < Tg$ but is perfectly reversible for $T > Tg$. This is why the measurements have been made by increasing the temperature monotonically avoiding any backward variation in T. In the case of the dashed curve the susceptibility was also measured in H = 220G but now during the cooling process from 30K to 1K. Once the lowest temperature was obtained (1K) the magnetization was remeasured for increasing temperature and the variation was observed to be identical to that measured during cooling, always with H = 220G applied. This curve in thus perfectly reversible at least within the time scale of the experiment , few minutes per experimental points.

- In Fig. 2 the isothermal magnetization at 1K versus field curve for fields between -30 and +55KG, is represented. The magnetic loop was measured, after cooling in zero field, according to the sequence indicated by the arrows. We observed a Rayleigh like magnetic loop with a remanent magnetization M_r of about 0,7 emu/g and a coercive field H_e of 3,5KG. On the contrary, the isothermal magnetization at 85K shown in the same figure, does not exhibit any remanence. As will be discussed in some details the thermo-magnetic effects reported in Figs. 1 and 2 are characteristic of spin glass behavior.

- In Fig. 3 we present the magnetization of the same specimen as measured under H = 10KG for the temperature range of 77K to 300K. Here we note a second peak at T = 165K. We have performed the same kind of measurements as in the case of Fig. 1. But no detectable hystheris effects (or remanence) which would be associated with this second peak have been observed. Note however that if we cool the sample under 13KG and then measure the magnetization in a few hundreds Gauss we never recover the data obtained after cooling in zero field. The magnetization versus field up to 10KG for various temperature are plotted in fig. 4. The main feacture of these curves is that the magnetization is essentially linear with field for all temperatures quoted.

DISCUSSION

- High Temperature

Let us first focus on the high temperature data and try to understand the possible origin of the high temperature peak of magnetization. At first sight, since $CeFe_2$ is a ferromagnet with a Curie Weiss temperature of about 230K it seems reasonable that the addition of a small quantity of Al in place of Fe will not completely alter the ferromagnetic state but will result in some decrease of T_c. It is on the other hand well known that ferromagnetic to paramagnetic transitions can give rise to peaks in M vs T curves having the same shape as the one reported here, in presence of an anisotropy field. Also the occurrence of a transition from ferromagnetic to paramagnetic state on cooling was firstly observed in partially ordered Au_4Mn by Chakrabarti et al. 1972 and subsequently in $Fe_{0,7}Al_{0,3}$ by Shull R.D. 1976. The simplest way to check the above speculations is to observe if the magnetization versus field curve shows any saturation or remanent effects by applying a reasonable field. The M_g vs H curve at T = 85K of fig. 2(b) clearly shows that for a temperature lower than T_{max} = 165K (shown in fig. 3) but not so far, the magnetization is essentially linear with field up to 55KG, thus excluding any saturation or remanence. Further confirmation is provided by the M_g vs H curves (Fig. 4) for fields up to 10KG at 145, 150, 155, 160 and 165K which does not show any sign of saturation. This behavior strongly suggest that in this range of temperature the alloy is "paramagnetic" and that the high temperature peak of M_g cannot be associated with any true ferromagnetic phase.

Now, if we analyse the decreasing of M_g from the T_{max} to 300K, the χ^{-1} vs T curve shows a Curie Weiss law behavior with a positive paramagnetic temperature θ_p = 140K and an effective moment of $2.51\mu_B$/Fe.

Concerning the magnetic behavior in the range of about 140K up to T_{max} we assume some sort of "paramagnetic" phase which we claim is different in nature from that observed for $T >> T_{max}$. An heuristic way for dealing with this is to assume an "effective Curie-Weiss law" as suggested by the linear behavior shown in figs. 2(b) e 4. From that a paramagnetic temperature θ_p^{inv} = 172K was extracted.

This result can suggest that the high temperature peak is due to a tendence of this material to order as the temperature decreases without however attaining any long range order even at the maximum of the peak. With further decreasing of the temperature a mechanism, which tends to destroy the partial order achieved, takes place and leads the system, after passing probably by some intermediates phases, to the spin glass regime.

- Low Temperature

As already noted the χ vs T curve and Mg vs H loop present all the characteristic behavior of a spin glass alloy. We note that although time after effects have been observed for $T < Tg$ no systematic measurements of this have been done. Our data strikingly resembles that observed in the archtypicals Au-Fe (Borg et al. 1973, Cannela et al. 1972) spin glass alloys. Although it is probable that the spin-spin interactions, which are responsable of the spin glass behavior, in the two cases are different, it is interesting to compare the behavior of the two systems.

1) As in AuFe case the magnetic loop has the characteristic of a Rayligh like cycle. We recall that CuMn spin glass alloys has a displaced square like cycle (Kouvel 1961).

2) The saturated remanent magnetization per Fe atom ($M_r = 1,87 \times 10^{-2}$ μ_B/Fe) for $T < Tg$ is comparable with that of Fe in AuFe (at low concentration 2×10^{-2} μ_B/Fe).

3) Finally we note that the spin glass freezing temperature found in $Ce(Fe_{0,8}Al_{0,2})_2$ of 12,5K corresponds to that found for about at 1.8% iron concentration in AuFe.

In conclusion, the substitution of 20% Fe by Al in $CeFe_2$ destroys the ferromagnetic order and a new magnetic state appears at low temperature with all characteristics of a spin glass.

ACKNOWLEDGEMENTS

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CAPTIONS

Fig. 1 - Magnetic DC susceptibility at 220K vs. temperature. The sequence of the measurements are in the text.

Fig. 2 - a) Hysteresis loop of magnetization at 1K. The sequence of the measurements is indicated by arrows.

b) Isothermal magnetization vs. field at 85K.

Fig. 3 - Magnetization vs. temperature at 10KG.

Fig. 4 - Magnetization vs. field isotherms.

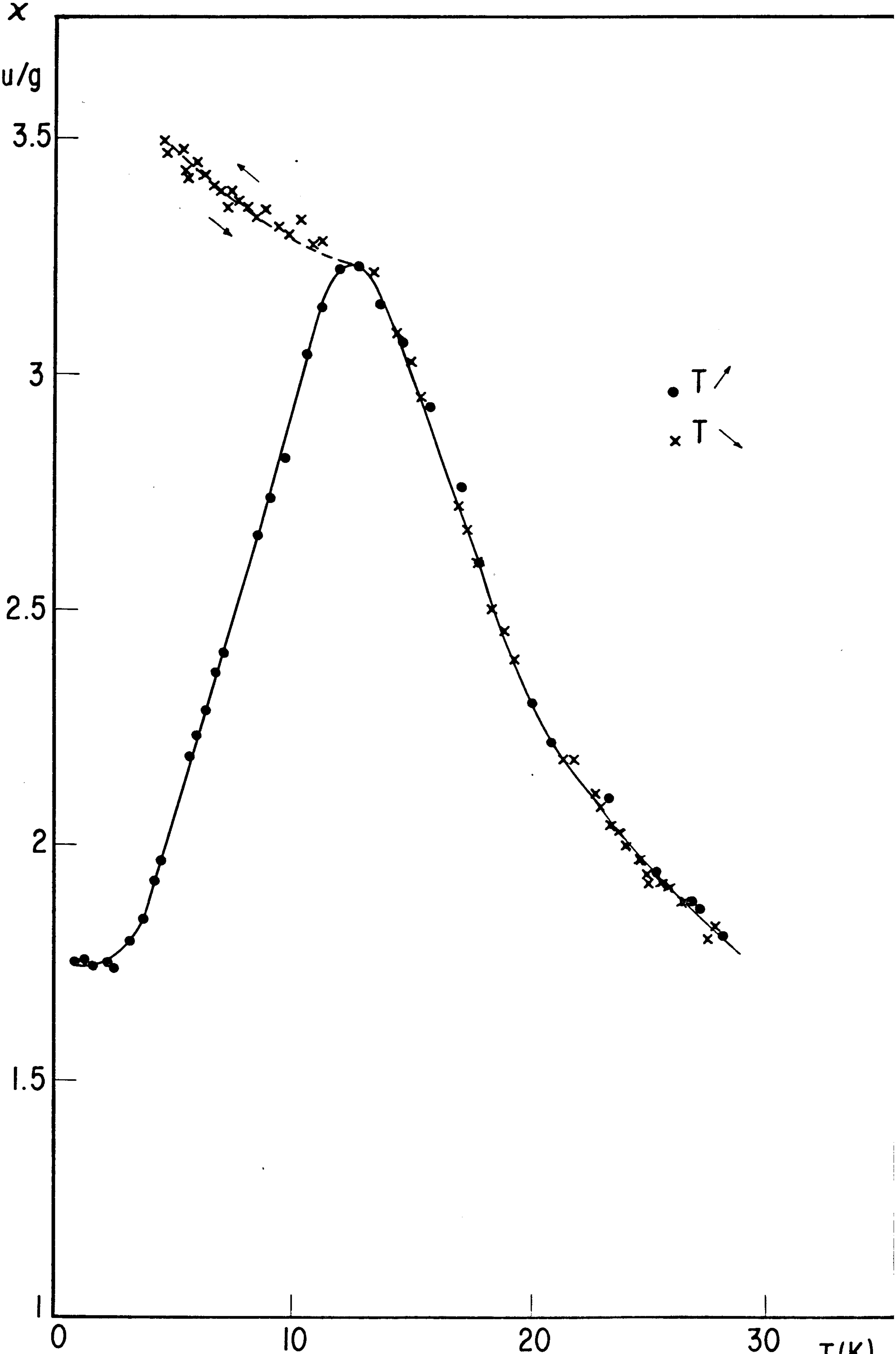

Fig. 1

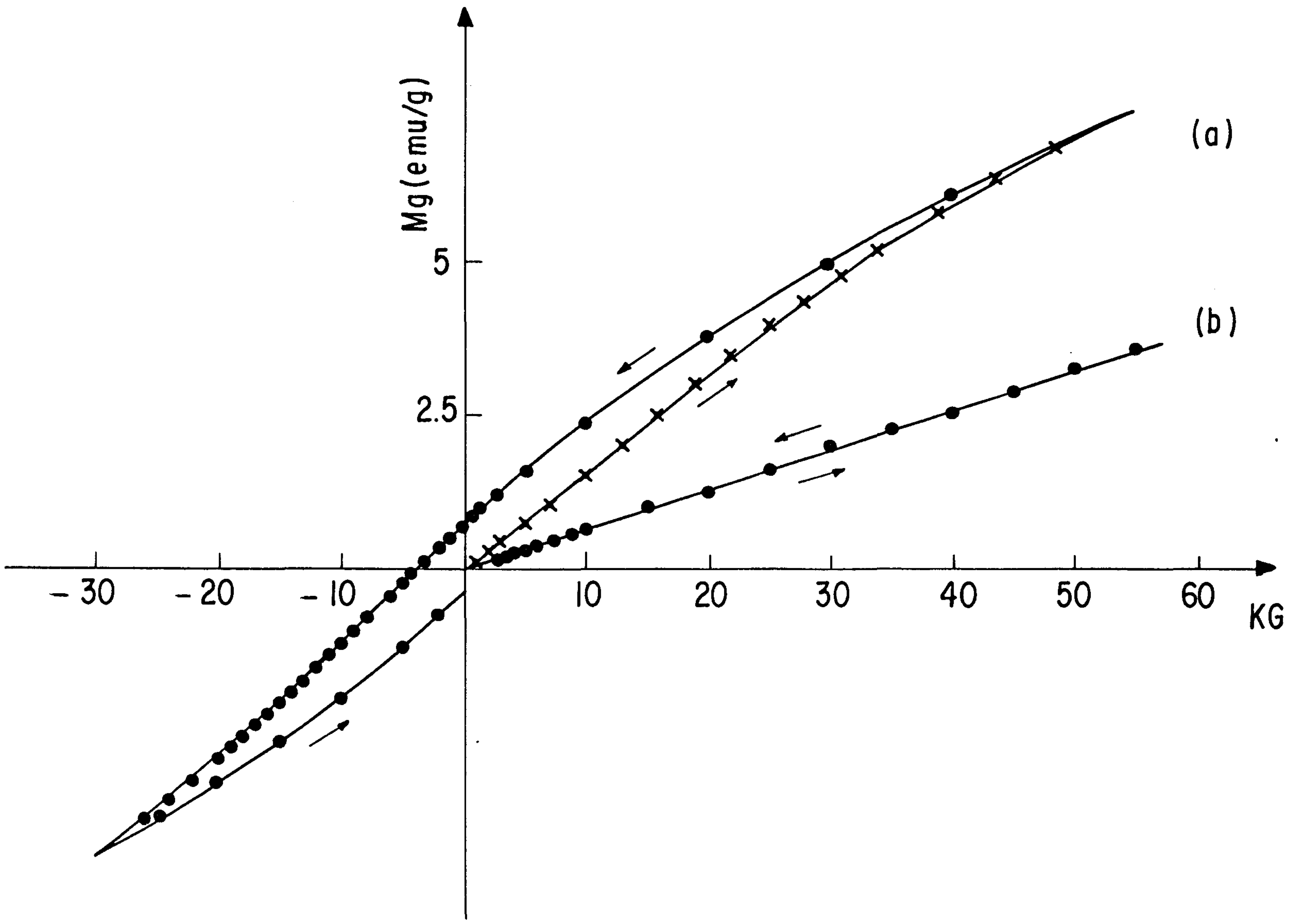

FIG.2

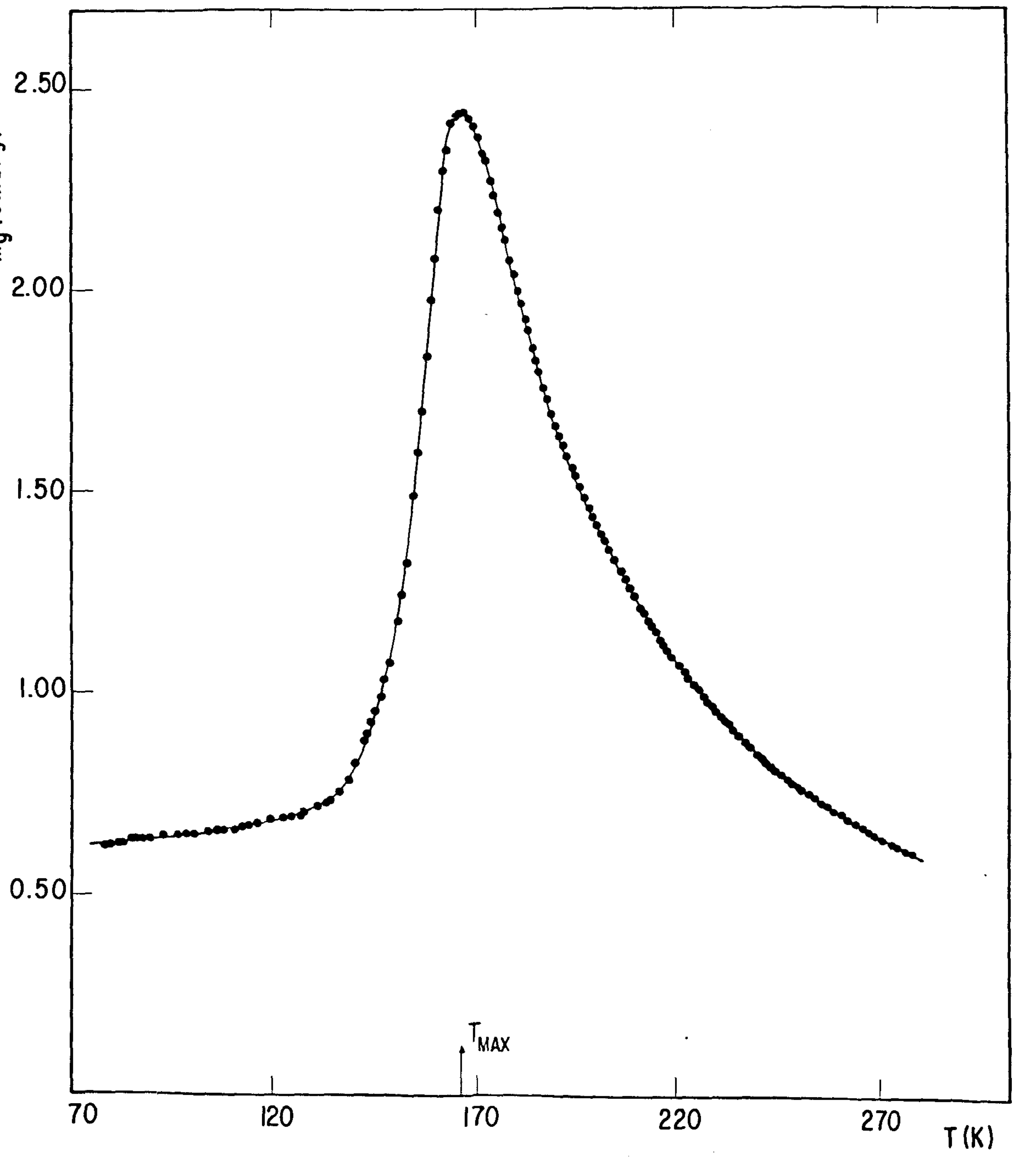

FIG.3

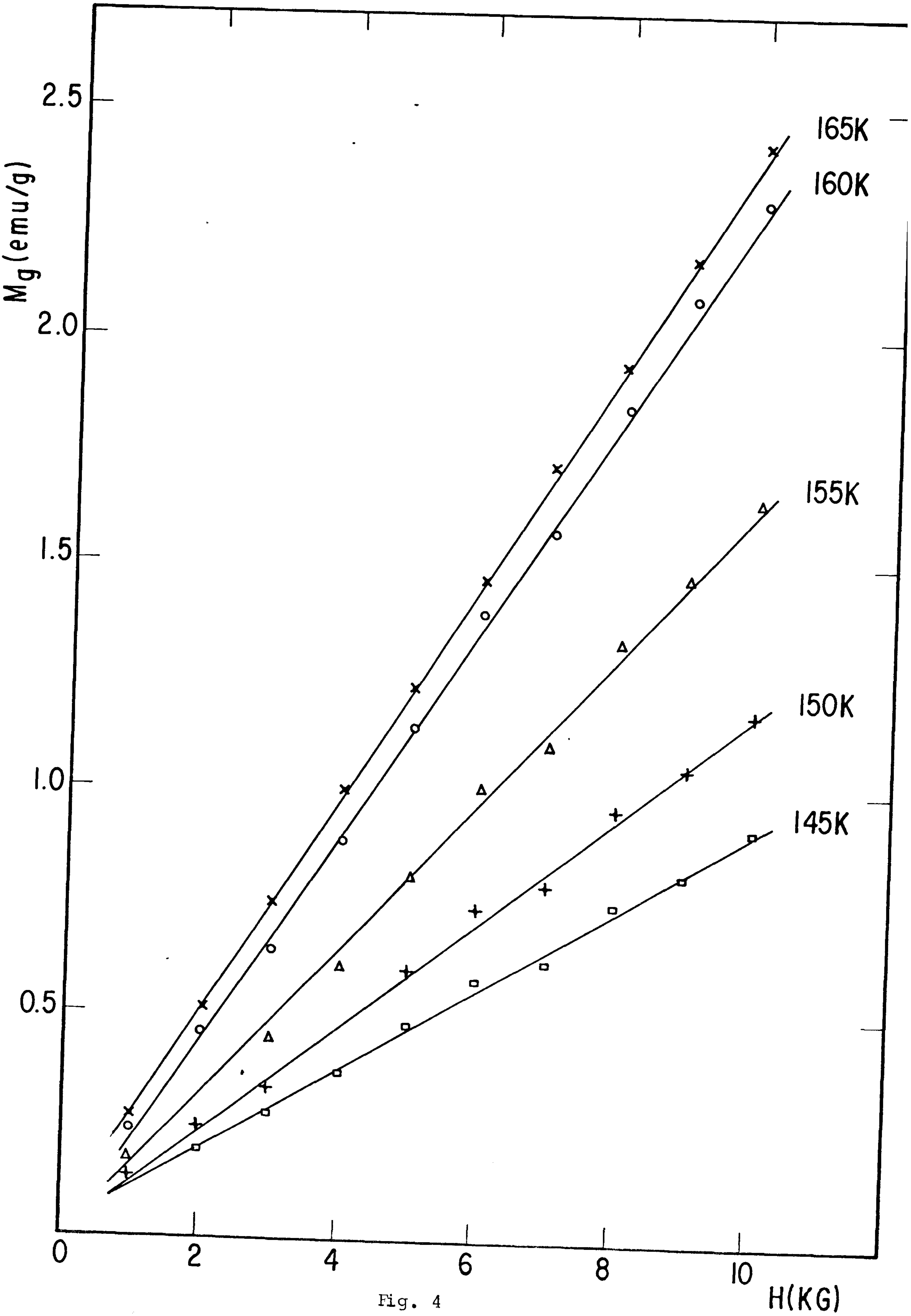

Fig. 4