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ELECTRICAL RESISTIVITY OF $Y(Fe_{1-x}Al_x)_2$ IN THE SPIN GLASS CONCENTRATION RANGE

by

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ABSTRACT

The temperature dependence of the electrical resistivity of the $Y(Fe_{1-x}Al_x)_2$ system ($0.125 \leq x \leq 0.25$) was measured. This system exhibits a minimum at low temperatures for the concentration range where the phase diagram presents a spin glass-ferromagnetic transition. A negative temperature coefficient is observed at high temperatures for $x \geq 0.18$ and was attributed to the high value of the electrical resistivity in this concentration range.

Key-words: Electrical resistivity; $Y(Fe_{1-x}Al_x)_2$; Spin-glass; Negative temperature coefficient; Resistivity minimum.

INTRODUCTION

The low temperature dependence of the electrical resistivity of intermetallic systems showing a spin glass phase exhibits a variety of behaviours depending on the impurity type or concentration [1]. In dilute magnetic alloys usually the resistivity increases with increasing temperature and passes through a maximum at a temperature T_{max} which can be larger or not than the freezing temperature T_f. In other alloys, mainly in the more concentrated, the resistivity decreases with increasing temperature and passes through a minimum at a temperature T_{min} which again may be larger or not than of T_f. Other characteristics of the low temperature electrical resistivity of spin glasses are an increase of the residual resistivity due to the scattering by disorder frozen spins or clusters and also a term in $A(x)T^{3/2}$ which can be positive or negative [2] depending on the impurity potential.

For the various behaviours described above there is no sistematic experimental studies concerning the role of the type of magnetic impurity or concentration.

In recent works we have studied the electrical resistivity [3] and the magnetization [4] of the pseudo-binary compounds $Ce(Fe_{1-x}Al_x)_2$. All the freezing temperatures (for $x > 0.10$) determined by magnetization measurements are situated below the low temperature resistivity minimum in a region of negative slope.

In this work we are interested in observe how the electrical resistivity behaves in a system like $Y(Fe_{1-x}Al_x)_2$ where a well stablished spin glass state appears between $x = 0.10$ and $x = 0.35$. This series of compounds has been widely studied mostly by magnetization, Mössbauer spectroscopy and recently by NMR measurements [5,6,7]. Besides the existence of these investigations this system is just particularly interesting as it is isostructural with $Ce(FeAl)_2$, and in both cases the magnetic properties are associated to Fe atoms.

Finally and more important, its phase diagram presents transitions from ferromagnetic and from paramagnetic to spin glass phase. So we have performed measurement of electrical resistivity in function of temperature for concentrations specially situated in the phase diagram.

EXPERIMENTAL

Samples for $0.125 \leq x \leq 0.25$ and $x = 0$ were prepared by arc furnace melting under argon atmosphere. In order to compare our results mainly with that of Hilscher [6] and Besnus [5], samples were prepared off-stoichiometry, $Y(Fe_{1-x}Al_x)_{1.8}$. Casting in a cylinder form (1.5mm diameter and 12mm long) specimens were cut before annealing at 800°C in vacuum for one week. The X-ray powder diffractograms reveals for all samples the cubic $MgCu_2$ Laves phase structure. Lattice parameters a_0 derived by least-square analysis of the Nelson-Riley function are presented in fig. 1 together with that obtained by Besnus [5]. Good agreement can be observed with small tendency of higher values, as observed in [7], although in this later work stoichiometry was used in the sample preparation.

Electrical resistivity measurements were made by a dc four-point method carried out over a temperature range of 1.5 - 300K.

The absolute error was estimated to be about 1% maximum.

In view of the high sensitiveness of the magnetic and structural phases of these systems to stoichiometry and to different annealing processes, we have performed in our samples, measurements of magnetization in a vibrating sample magnetometer or of ac magnetic induction variation [8] to determine critical temperatures.

RESULTS

The temperature dependence of the total electrical resistivity over the temperature range of 1.5 - 300K is shown in fig. 2. Since the variation of the total resistivity is very different for each concentration we have presented the results in several figures with different resistivity increments. Measurements were made in increasing and decreasing temperature and no hysteresis was observed.

Firstly we remark that, independently of the extrapolation method used, is evident that the residual resistivity ρ_0 increases with increasing Al concentration. Also the total resistivity variation shows a decrease with increasing Al concentration.

For $x = 0$, the well known YFe_2, a ferromagnetic behaviour was observed. For $0.125 \leq x \leq 0.18$ the same behaviour was observed, except at low temperatures where a minimum appears, the temperature of which increases with x.

For $x = 0.1875$ and $x = 0.19$ this minimum still persists although less well defined but, at higher temperatures, the resistivity shows a negative temperature coefficient until room temperature. As we can observe in fig. 2 this negative coefficient at higher temperatures is more accentuated for concentrations $x = 0.22$ and

$x = 0.25$ for which the low temperature minimum disappear.

DISCUSSION

The residual resistivity ρ_0 of a magnetic metallic system have many origins. Scattering of conduction electrons by impurities, lattice defects are the more frequent, together with scattering by resonance near the Fermi surface. In systems with a spin glass state another component to ρ_0, as observed in the introduction, is the scattering by the disorder frozen spins or clusters. So the enormous increasing of ρ_0 in our system and also the decreasing in the total variation of the resistivity with increasing x was expected, as usually in other pseudo-binary systems. If we take ρ_0 as $\rho_{T\to 0}$ its dependence with concentration is as shown in fig. 3.

The electrical resistivity of YFe_2 was measured by Ikeda between 4 and 1,000K [9]. In our results we have observed at low temperatures the normal spin wave scattering term AT^2 with $A = 2\times10^{-4}\,\mu\Omega cm/K^2$ up to 19K. This value of A is relatively high when comparing with other ferromagnetic binary compounds.

As Fe is substituted by Al between 10 and 35% at of Al the system presents a transition from ferromagnetism to paramagnetism until about 20% and at low temperatures both phases are dominated by a spin glass regime. We ascribe the low temperature negative slope in the temperature variation of the electrical resistivity in this range of concentration to the spin glass state. We can observe in fig. 2 that as the concentration of Al decreases this slope decreases. This is expected as we pass in concentration from a disorder paramagnetic Al rich region to an order Fe rich region. In the range of concentration where the system has a transition for increasing temperature, from spin glass to ferromagnetism, the resistivity $\rho(T)$ has a deep minimum. We try to correlate the temperature of this minimum with the freezing temperature in the following way.

In the concentration range where the magnetic phase diagram shows a spin glass-paramagnetic transition, the freezing temperatures were determined by magnetization measurements in function of temperature. In the ferromagnetic concentration range the freezing temperatures were determined by ac magnetic induction variation in function of temperature. This results are shown in fig. 4 where we can observe a good agreement of the present results with those reported in the literature.

In fig. 5 is shown the temperature of the resisitivity minima T_{min} and the freezing temperatures T_f plotted as a function of concentration. If the T_{min} had been correlated only to the spin glass state we would expect that T_{min} and T_f vary in the same way but this was not observed. Examples of similar behaviour are PtMn [10], RhFe [11] or $(U_{1-x}Gd_x)Al_2$ [12] although in these systems no transition to long range order was observed. Thus we conclude that, although related, the correlation between the T_{min} and T_f is more complex.

It is probable that this minimum in our system occurs due to the transition from the spin glass phase to the ferromagnetic phase. Note that the depth of the minimum increases with increasing Al concentration.

At high temperatures the most striking feature of the resistivity is the appearance of a negative temperature coefficient even in the concentration range where the system have a ferromagnetic phase as for $x = 0.1875$ and $x = 0.19$. The plateau between about 50 and 100K in $x = 0.19$ is ascribed to remainder scattering of ferromagnetic phase. In the paramagnetic range ($x = 0.22$ and $x = 0.25$) the negative temperature coefficient increases with increasing Al concentration and the low temperature minimum disappear.

At this point we must remark that as Fe is substituted by Al high atomic disorder takes place and we passe from a low to a high resistivity material with the increasing of ρ_0 and decreasing of the total resistivity variation. We attribute the high temperature resistivity behaviour mainly to potential scattering processes than to magnetic effects. In this way only a small anomaly is observed at the Curie temperature.

It can be observed that at high temperatures the values of resistivity are lower than the residual resistivity. This fact suggests that Mooij correlation [13] can be applied say, the larger the resistivity the larger the negative contributions to the derivative of ρ.

CONCLUSION

In conclusion it can be stressed that the resistivity reflects the transition from the ferromagnetic to the paramagnetic concentration regions in the spin-glass range in a gradual way the first been characterized by the existence of a low temperature minimum and the second by a negative temperature coefficient at high temperatures. This negative temperature coefficient arises from the high values of the electrical resistivity in this concentration range.

ACKNOWLEDGMENTS

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CAPTIONS

Fig. 1 - The concentration dependence of the lattice parameter for $Y(Fe_{1-x}Al_x)_2$.

Fig. 2 - The temperature dependence of the total electrical resistivity for various concentrations.

Fig. 3 - The concentration dependence of the residual resistivity ρ_o taken as $\rho_{T\to o}$.

Fig. 4 - The temperature dependence of $\chi_g = M_{g/H}$ (a) and (b) and of the magnetic induction (c); The phase diagram of the $Y(Fe_{1-x}Al_x)_2$ (d); open simbols are results of this work and full simbols are of ref. 6.

Fig. 5 - The concentration dependence of the freezing temperatures T_f (◆) and of the T_{min} (●).

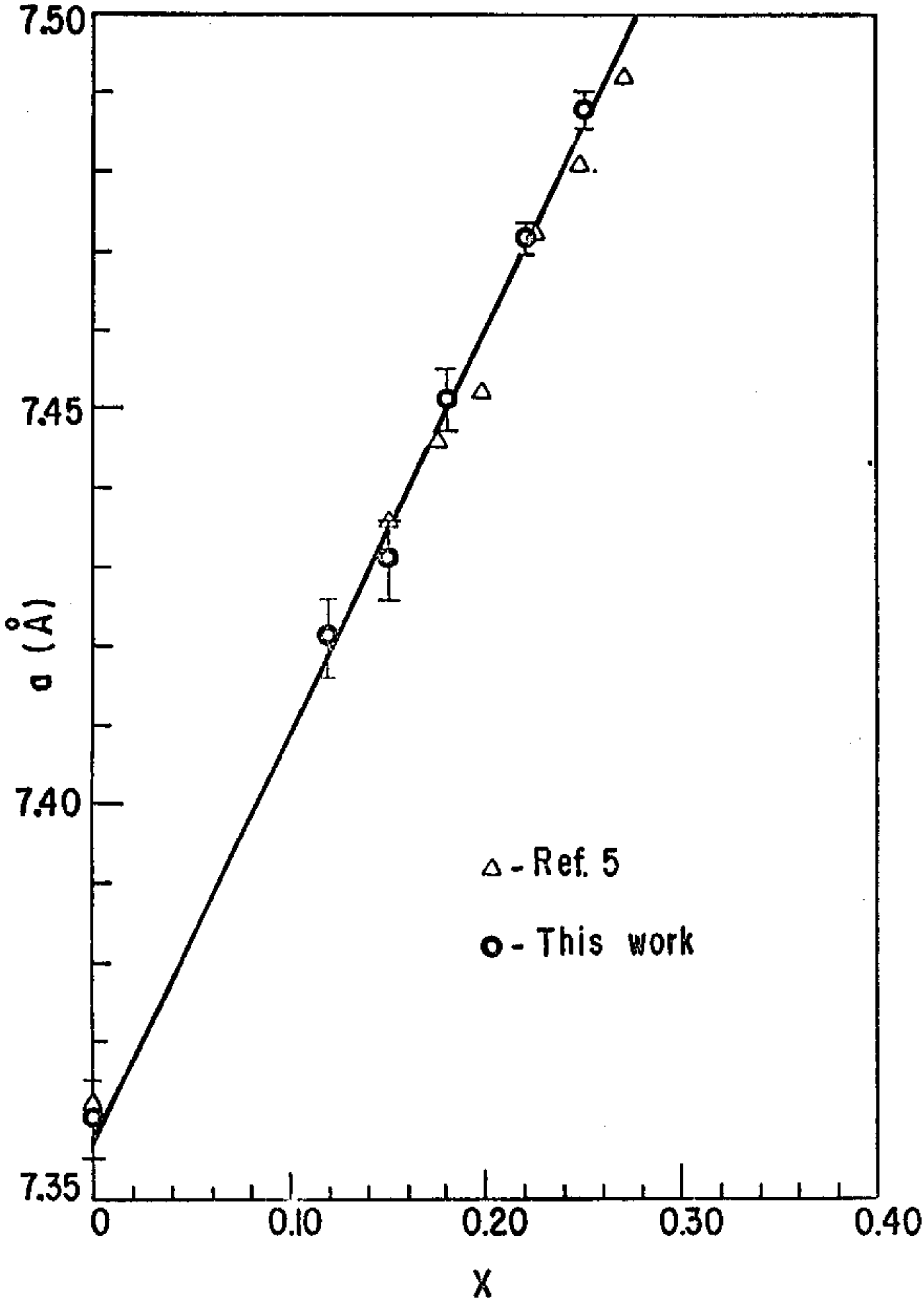

Fig. 1

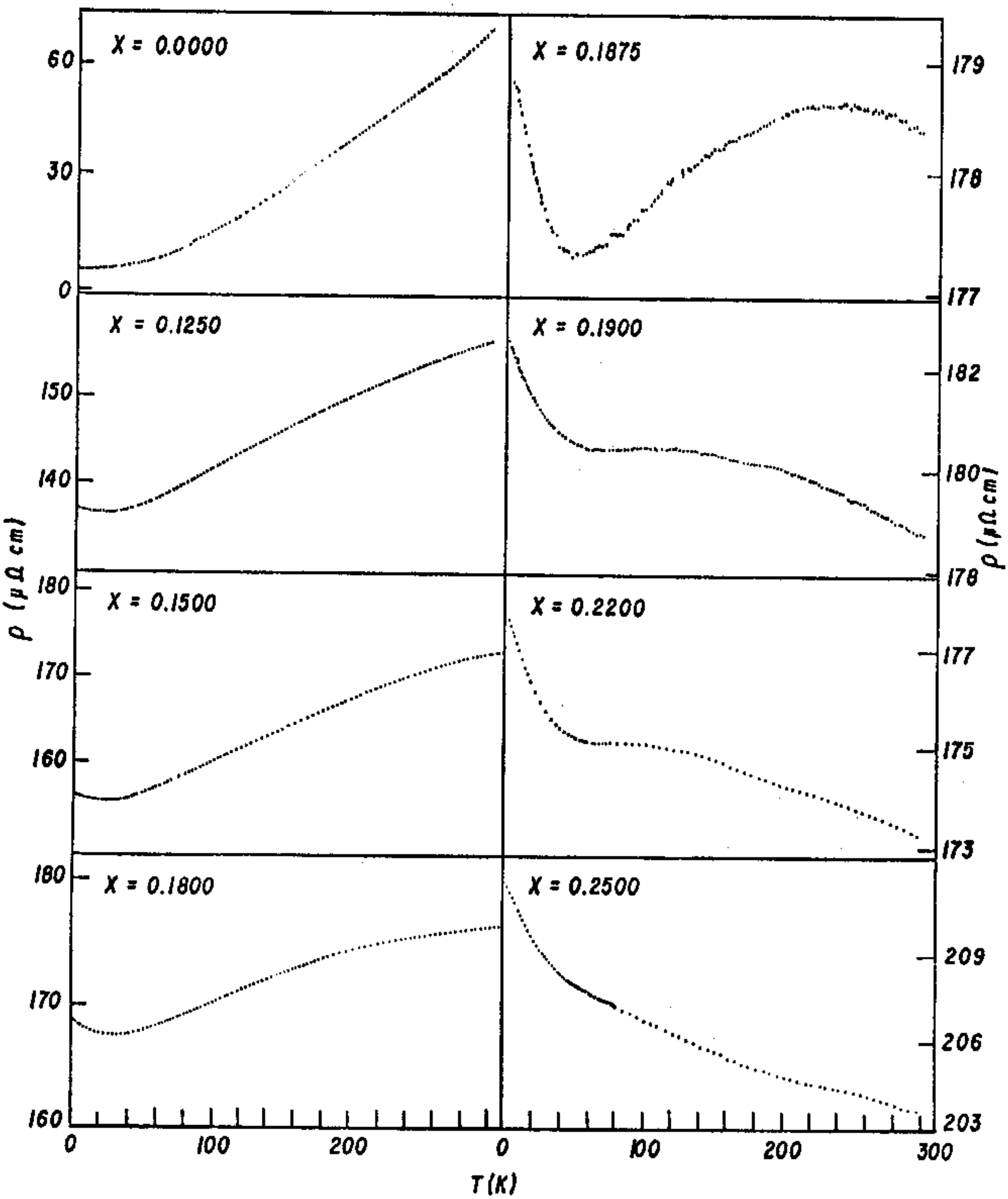
X = 0.0000
X = 0.1875
X = 0.1250
X = 0.1900
X = 0.1500
X = 0.2200
X = 0.1800
X = 0.2500
ρ (μΩ cm)
T (K)
60
30
0
150
140
180
170
160
180
170
160
179
178
177
182
180
178
177
175
173
209
206
203
0
100
200
0
100
200
300

Fig. 2

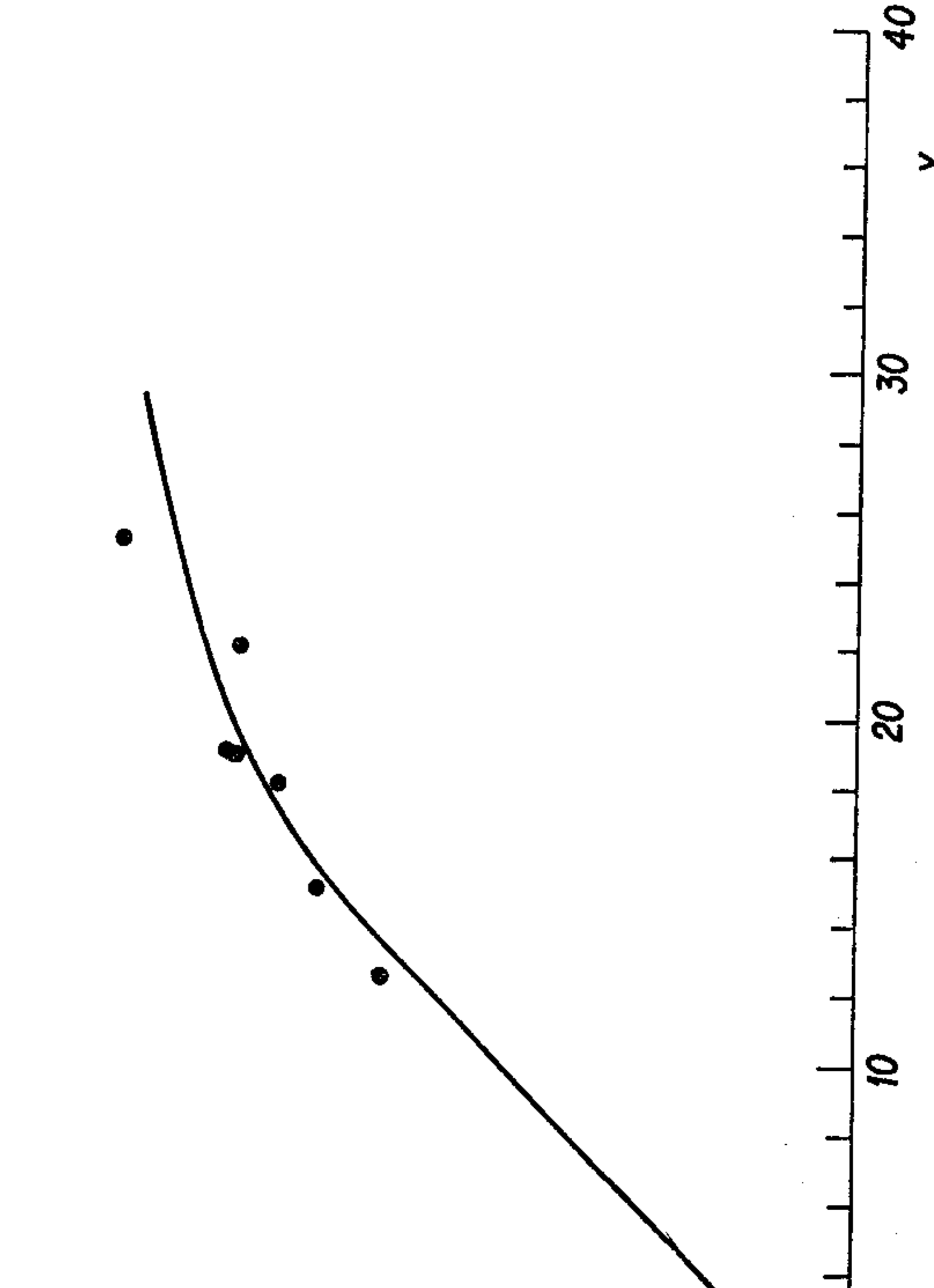

Fig. 3

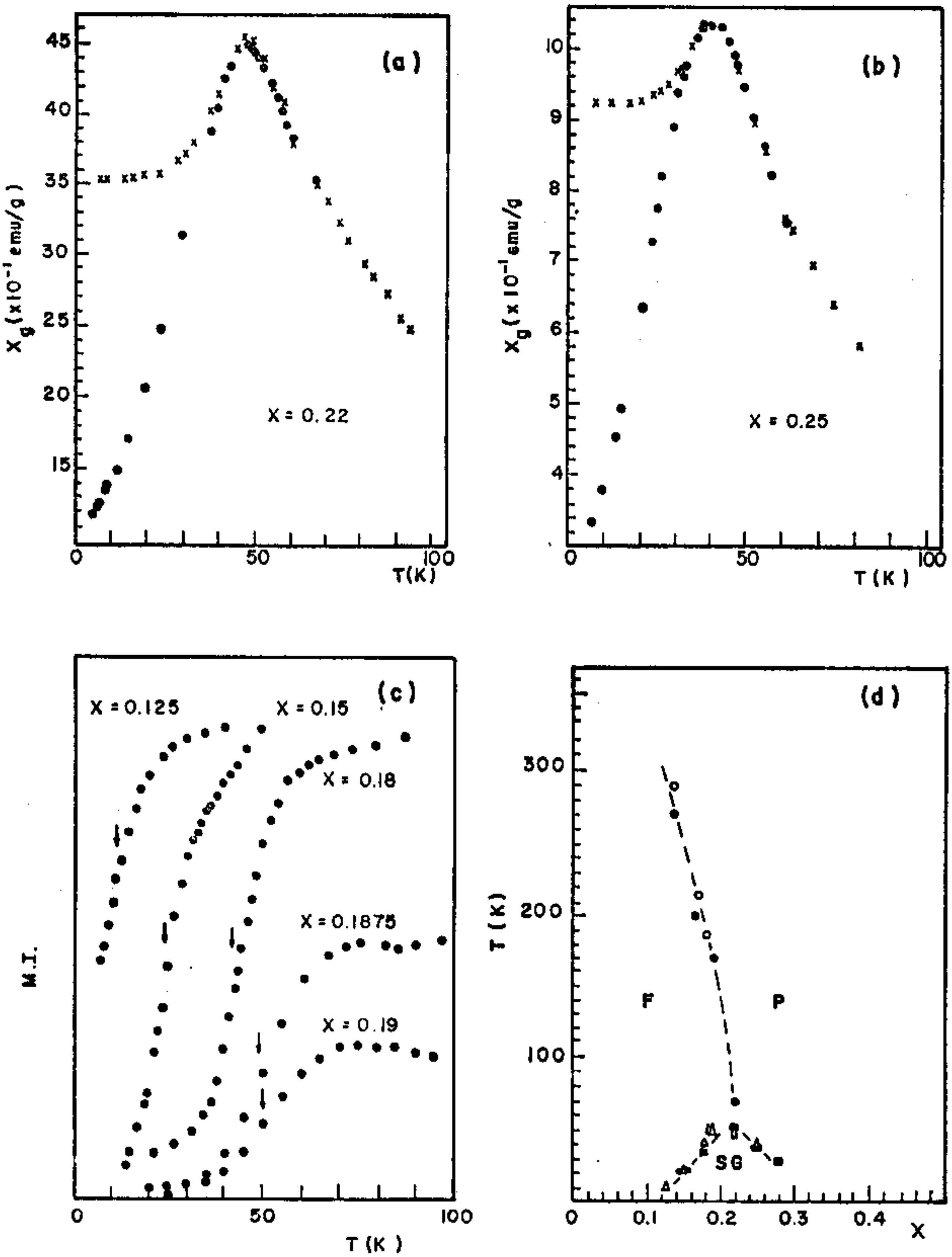
(a)
X = 0.22
X_g (x10^{-1} emu/g)
T(K)
(b)
X = 0.25
X_g (x10^{-1} emu/g
T (K)
(c)
X = 0.125
X = 0.15
X = 0.18
X = 0.1875
X = 0.19
M.I.
T (K)
(d)
F
P
SG
T (K)
X

Fig. 4

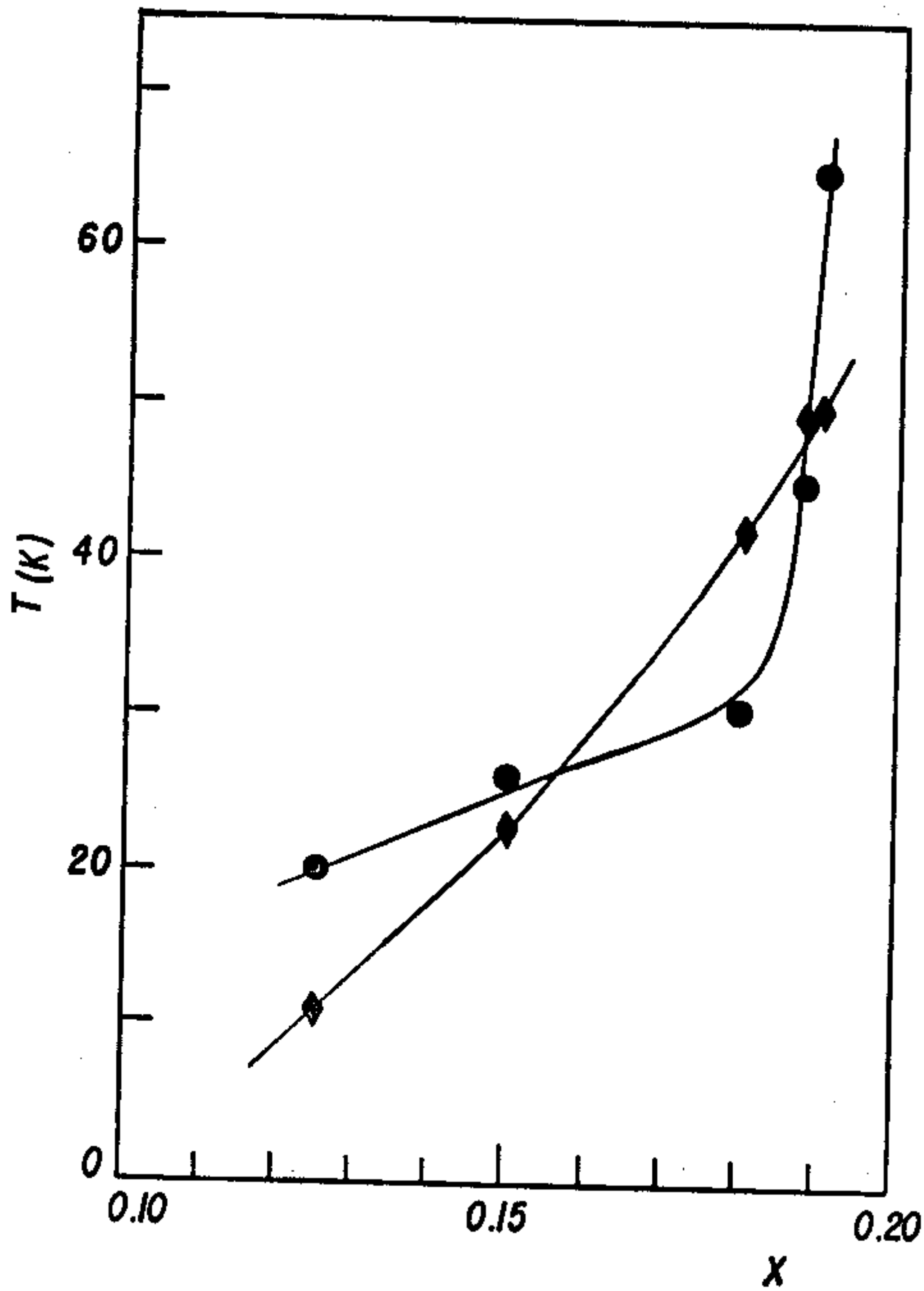

Fig. 5

REFERENCES

1. Schilling J.S., Ford P.J., Larsen U., Mydosh J.A. - Phys. Rev. B, 14, nº 10, 4370 (1976); Mydosh J.A., AIP Conf. Proc. 24, 131 (1975).
2. River N.-J. Phys. F. Metal Phys. 4, L249 (1974)
3. Takeuchi A.Y. and da Cunha S.F. - J. Magn. Magn. Mat. 49, 257 (1985).
4. Franceschini D.F. and da Cunha S.F. - J. Magn. Magn. Mat. 51, 280 (1985).
5. Besnus M.J., Bauer P. and Génin J.M. - J. Phys. F. Metal Phys. 8, nº 1, 191 (1978).
6. Hilscher G., Grössinger R., Sechovsky V. and Nozar P. - J. Phys. F: Met. Phys. 12, 1209 (1982).
7. Ichinose K. et al. - J. Phys. Soc. Japan, 54, nº 3, 1103 (1985).
8. Pereira F.R. Rui, Meyer Erich and da Silveira F. Máximo - Rev. Sci. Instrum. 54 (7), 899 (1983).
9. Ikeda K. and Nakamichi T. - J. Phys. Soc. Japan, 39, 963 (1975).
10. Sarkissian B.V.B. and Taylor R.H. - J. Phys. F: Metal Phys., 4, L243 (1974).
11. Murani A.P. and Coles B.R. - J. Phys. C: Metal Phys. Suppl., nº 2, S159 (1970).
12. Ping J.K. and Coles B.R. - J. Magn. Magn. Mat. 29, 209 (1982).
13. Mooij J.H. - Phys. Stat. Sol. (a), 17, 521 (1973).