

THE HALL EFFECT IN Cr-Fe ALLOYS

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Abstract: The Hall effect of several Cr-Fe alloys containing 0.2, 1.0, 1.5 and 14.2 at%Fe was measured in the temperature range 2-30 K. It was found that the Hall coefficient is of positive sign and decreases with increasing iron concentration, whereas it is almost temperature independent in the measured temperature range. The number of conduction electrons, calculated from the Hall coefficient data, was found to increase from about 5×10^{21} el/cm³ in the alloys with the low iron concentration to 12×10^{21} el/cm³ in the alloy with 14.2 at%Fe. The Hall mobility of conduction electrons, calculated from our Hall and resistivity measurements data, shows a rapid decrease with increasing iron concentration.

1. Introduction

Pure Cr has an antiferromagnetic phase below the Néel temperature (312 K) which is described as a sinusoidal modulation of a simple antiferromagnetic structure⁽¹⁾. The wavelength of this modulation is uncommensurate with the lattice parameter and has been related to the structure of the Fermi surface of chromium⁽²⁾.

The effect of various impurities on the magnetism of chromium has been studied and mostly interpreted, within the rigid band model, in terms of a change in electron per atom ratio. In this model, when the electron per atom ratio is increased, the distance \vec{Q} between the centres of the electron and the hole Fermi surfaces increases and the period of sinusoidally modulated antiferromagnetic structure tends toward commensurability. A commensurate structure is more stable than an uncommensurate one, and the Néel temperature should increase. When the electron per atom ratio decreases, \vec{Q} decreases, antiferromagnetic structure becomes more uncommensurate and the Néel temperature should

decrease. Iron, being on the right side of chromium in the periodic table, increases the electron per atom ratio in Cr-Fe alloy, but the Néel temperature of this alloy actually is lower than the Néel temperature of pure Cr. It means that the magnetic properties of Cr-Fe alloys cannot be explained on the basis of this model alone.

It was shown⁽³⁾ that the scattering of conduction electrons by paramagnetic impurities in an itinerant antiferromagnet such as Cr plays an important role and this mechanism may lead to a reduction of the Néel temperature. The effect of interaction between impurities with localised moment and conduction electrons on an itinerant antiferromagnet was further studied, taking into account that the depairing effect comes from both spin scattering and potential scattering whereas the pairing effect arises from the antiferromagnetic alignment of impurity spins⁽⁴⁾. It was found that under certain conditions, when the impurity potential is strong enough, the Néel temperature may decrease with increasing impurity concentration, which is in qualitative agreement with the experimental results obtained for Cr-Fe alloys.

In the present work the Hall effect and electrical resistivity of Cr-Fe alloys have been measured and analysed in order to get a better insight into the electronic properties of these alloys.

2. Experimental

The polycrystalline specimens of Cr-Fe alloys were prepared by Perrier de la Bathie from Cristaltech Grenoble. The samples for the Hall and resistivity measurements were cut off from cylindrical ingots in the rectangular form of approximate dimensions 10 mm x 5 mm x 0.5 mm. The Fe concentration of the samples was determined by chemical analysis. Current leads and the Hall and resistivity probes have been tin alloyed to the samples in a high vacuum. Liquid helium temperature refrigerator was used to obtain temperatures in the measured range 2-30 K. The voltage measurements were performed in both current and magnetic field directions in order to minimize the effects of thermal e.m.f.'s and other parasitic potentials.

3. Results and discussion

The results of our Hall coefficient measurements in Cr-Fe alloys containing 0.2, 1.0, 1.5 and 14.2 at%Fe are presented in Table 1 and plotted in Fig.1. We have found that the Hall coefficient of these alloys is almost temperature independent in the measured temperature range, but it decreases with increasing iron concentration. Such concentration dependence should be confirmed and examined in details, specially in the range of concentration 1.5-14 at%Fe.

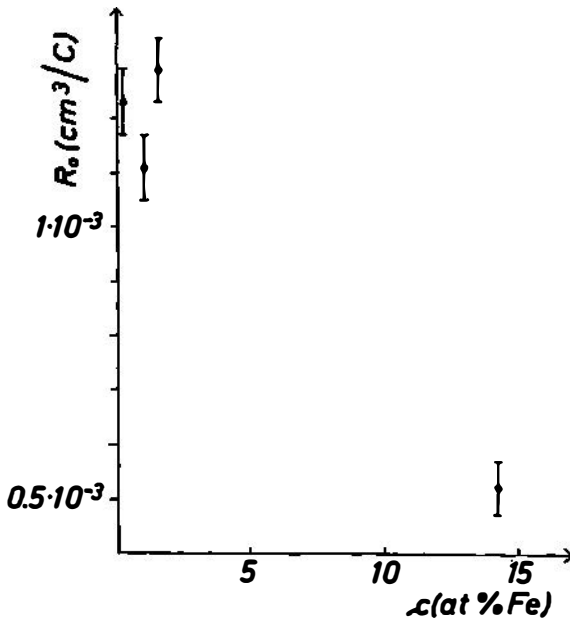


Fig.1. Hall coefficient in Cr-Fe alloys as a function of iron concentration ($T=2\text{K}$)

The Hall coefficient of dilute Cr-Fe alloys with 0.2, 1.0 and 1.5 at%Fe was calculated from the ratio $R_0 = U_H t / IH$, where U_H is the Hall voltage, I -current, H -applied magnetic field and t -thickness of

the sample. But it was shown, that in Cr-Fe alloys with concentration greater than 2.4 at%Fe, ferromagnetic component appears in magnetization curves which was explained as being due to ferromagnetically coupled iron moments in Fe-Fe pairs and in clusters with a larger number of iron atoms^(8,9). These ferromagnetic clusters, behave as superparamagnetic entities at low temperatures and order themselves in applied magnetic field so that the net magnetization exists in the direction of the field. The Cr-Fe alloy with 14.2 at%Fe, studied in this work, has such resultant magnetization in the direction of the applied magnetic field and it was assumed that the Hall effect of this alloy consists of two parts, an ordinary part proportional to the applied magnetic field, and an extraordinary part proportional to the magnetization of the alloy: $U_H t / I = R_0 H + R_s M$, where R_0 is the ordinary Hall coefficient, R_s the extraordinary Hall coefficient describing the influence of magnetization on the Hall effect and M is the magnetization of the sample in the direction of the magnetic field H . We used the magnetization data of the alloy with 14.2 at%Fe from the previous magnetization measurements⁽⁹⁾ and calculated R_0 and R_s from the two successive measurements of the Hall voltage for two different values of the magnetic field. The coefficient R_s of the alloy with 14.2 at%Fe is found to be: $15.6 \times 10^{-3} \text{ cm}^3/\text{C}$ at $T=2\text{K}$; $20.4 \times 10^{-3} \text{ cm}^3/\text{C}$ at $T=9\text{K}$; and $16.0 \times 10^{-3} \text{ cm}^3/\text{C}$ at $T=20\text{K}$. It is seen that R_s is about thirty times greater in magnitude than the coefficient R_0 (see Table 1).

We have found that the sign of the Hall coefficient R_0 in Cr-Fe alloys is positive, and that the sign of the thermoelectric power ρ_T in these alloys is also positive. It is known that a certain number of metals as Be, Zn, Cd, V etc. have positive Hall coefficient⁽⁵⁾. Such effect has been explained by the existence of electrons in states in the upper half of an unfilled energy band which contribute to the electrical conductivity. Electrons in these states accelerate in the applied electric field in the direction opposite to the direction of Lorentz force, they have negative effective mass and give rise to a positive Hall coefficient. Positive Hall coefficient observed in Cr-Fe alloys indicates that the electrons of such properties are charge carriers in these alloys.

Taking the simple formula for the Hall coefficient $R_0 = 1/ne$, we calculated the number of conduction electrons, n , and the results are summarized in Table 1 and Fig.2. One can see that this number increases with increasing iron concentration from about 5×10^{21} el/cm³ in the alloys with low iron concentration to 12×10^{21} el/cm³ in the alloy with 14.2 at%Fe. From these values the number of conduc-

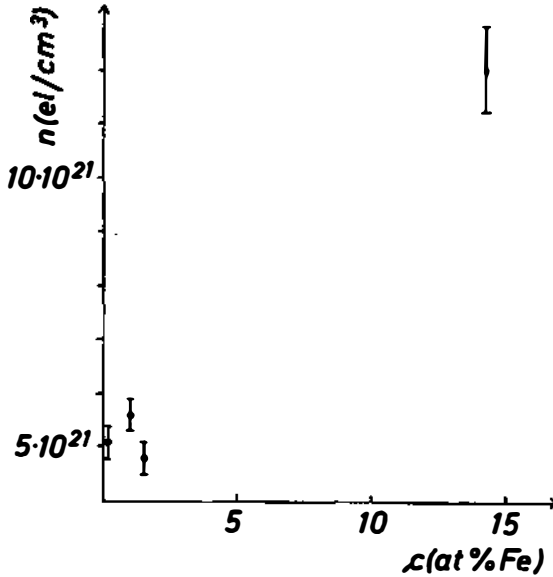


Fig.2. Number of conduction electrons in Cr-Fe alloys as a function of iron concentration ($T=2K$).

tion electrons per atom was estimated to be about 0.07 per atom in the alloys with 0.2, 1.0 and 1.5 at%Fe and 0.14 per atom in the alloy with 14.2 at%Fe. Such low values for the conduction electron number in Cr-Fe alloys are probably related to the small density of states near the Fermi energy in Cr⁽⁶⁾ and any change in the density of states due to alloying should be small at least for the low impurity concentration.

Table 1

Alloy	T (K)	R_0 ($10^{-3} \text{cm}^3/\text{C}$)	n ($10^{21} \text{el}/\text{cm}^3$)	ρ ($\mu\Omega\text{cm}$)	μ_H (cm^2/Vsec)
Cr-0.2at%Fe	2	$1,23 \pm 0,06$	$5,1 \pm 0,3$	$4,98 \pm 0,04$	248 ± 12
	10	$1,03 \pm 0,06$	$6,1 \pm 0,3$	$4,94 \pm 0,04$	209 ± 10
	19	$1,11 \pm 0,06$	$5,6 \pm 0,3$	$4,96 \pm 0,04$	223 ± 10
	30	$1,05 \pm 0,06$	$6,0 \pm 0,3$	$4,91 \pm 0,04$	213 ± 10
Cr-1at%Fe	2	$1,11 \pm 0,06$	$5,6 \pm 0,3$	$9,04 \pm 0,07$	123 ± 6
	19	$1,13 \pm 0,06$	$5,5 \pm 0,3$	$9,04 \pm 0,07$	125 ± 6
	29	$1,11 \pm 0,06$	$5,6 \pm 0,3$	$9,04 \pm 0,07$	122 ± 6
Cr-1.5at%Fe	2	$1,29 \pm 0,06$	$4,8 \pm 0,2$	$11,78 \pm 0,07$	110 ± 6
	8	$1,26 \pm 0,06$	$4,9 \pm 0,2$	$11,82 \pm 0,07$	107 ± 6
	20	$1,31 \pm 0,06$	$4,8 \pm 0,2$	$11,85 \pm 0,07$	110 ± 6
	27	$1,30 \pm 0,06$	$4,8 \pm 0,2$	$11,87 \pm 0,07$	109 ± 6
Cr-14.2at%Fe	2	$0,52 \pm 0,04$	12 ± 1	$48,1 \pm 0,4$	11 ± 1
	9	$0,52 \pm 0,04$	12 ± 1	$48,0 \pm 0,4$	11 ± 1
	20	$0,54 \pm 0,04$	$11,5 \pm 1$	$47,3 \pm 0,4$	11 ± 1

The resistivity value of the alloy with 1at%Fe was estimated on the basis of the measured resistivities of the alloys with 0.2 and 1.5at%Fe

The electrical resistivity of Cr-Fe alloys containing 0.2, 1.5 and 14.2 at%Fe was also measured in the temperature range 2-30K (see Tble 1). We didn't observe any temperature variation in the resistivity of these alloys in the measured temperature range. Recently reported resistivity minimum in dilute Cr-Fe alloys at low temperatures⁽⁷⁾ we couldn't observe because the magnitude of this anomaly (0.1%) is within the error of our measurements (0.8%).

On the basis of our Hall and resistivity measurements data, the Hall mobility was determined as $\mu_H = R_H / \rho$, where R_H is the Hall coefficient and ρ -specific resistivity. These results are also presented in Table 1. One can see that the Hall mobility rapidly decreases with increasing iron concentration indicating a strong interaction between the conduction electrons and Fe atoms.

We believe that the above experimental results may contribute to better understanding of electronic and magnetic properties of Cr-Fe alloys.

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