Residual resistivity in Ni-Fe-Cr/V alloys and the two-current model

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Abstract. The resistivity of a large number of Ni-Fe-Cr/V alloys has been measured at 77 K. An attempt has been made to explain the concentration dependence of resistivity in the light of Mott's two-current model. It is seen that contrary to earlier observation, the model is applicable to a larger range of concentration for the Ni-Fe-Cr series. Appreciable deviation from the model starts for Fe concentration exceeding about 15 at. % and Cr about 7 to 8 at. %. However, for similar concentration range in Ni-Fe-V series, disagreement between the experimental and theoretical results is more pronounced.

Keywords. Resistivity; ternary alloys; two-current model.

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1. Introduction

Recently we have reported the extraordinary Hall effect (Gangopadhyay et al 1984a) and detailed magnetization measurements (Gangopadhyay et al 1984b) on a series of nickel-rich Ni_{1-x-y}Fe_{x}Cr_{y} and Ni_{1-x-y}Fe_{x}V_{y} alloys. Although the resistivity data for these alloy series were also reported (Gangopadhyay et al 1984a), no attempt was made to explain the change in resistivity with alloy concentration. In this paper we have tried to explain the resistivity in terms of the “two-current model.” It should, however, be mentioned that the applicability of the two-current model has been tested earlier (Dorleijn 1976) in the dilute alloy limit (impurity concentration < 5 at. %). We have tried to check whether it can also be applied to fairly concentrated alloys (impurity concentration in the range 15 to 30 at. %).

To explain the anomalous temperature dependence of resistivity in Ni and Pd, Mott (1936) suggested the two-current model according to which electronic conduction takes place in parallel, through spin-up and spin-down electrons in transition metals. The idea was developed by Fert and Campbell (1968) and later extended by Leonard et al (1969), Dorleijn (1976) and others. The basic philosophy behind this model is that in transition metals, the relaxation times of the spin-up (S↑) and spin-down (S↓) electrons are quite different and they conduct in parallel. The observed large deviation from Mathiessen’s rule (DMR) in transition metal alloys lends strong support to this hypothesis. Different band occupancies of the d-electrons, which are split into S↑ and S↓ bands in the presence of exchange field, provide the main reason for the different relaxation times for electrons with opposite spins. Basically the mechanisms responsible for resistivity in transition metals are: (i) the direct s-s scattering as in normal
metals, (ii) the indirect s-d-s scattering, and (iii) the s-d scattering. If in a particular metal like Ni, the S ↑ band is full, the resistivity contribution of the S ↑ electrons (ρ ↑) will be considerably less than ρ ↓ since the third process mentioned above cannot take place for the S ↑ electrons.

During the last 15 years considerable data in terms of the two-current model have been published on resistivity (Dorleijn 1976 and references cited therein) of transition metals and alloys, thermoelectric power in various Ni and Co-based transition metal alloys belonging to the 3d, 4d and 5d series (Cadeville and Roussel 1971), ferromagnetic anisotropy of resistance and extraordinary Hall effect in dilute Ni and Fe-based transition metal alloys (Dorleijn 1976; Dorleijn and Miedema 1976, 1979). Also the so-called “period effect,” which is characterised by: (i) a maximum in ρ↑ (Durand and Gautier 1970), (ii) sign change of the thermoelectric power (Cadeville and Roussel 1971) and (iii) a maximum in the specific increment of the electronic specific heat coefficient (Caudron et al 1973), finds suitable explanation in the framework of the two-current model. This “period effect” is observed when various elements, starting from the beginning of the transition metal series are added into Ni (or some other element of the series) and the changes in the various physical properties mentioned earlier, are monitored. A distinct anomaly is observed when Ni is diluted with Cr of the first transition series, Ru of the second and Os of the third series. This is attributed to the coincidence of the virtual-bound state of the impurity atom with the Fermi-level of the host element.

Using such a well-tested model to our resistivity data, we have observed that within the limitations of the model, our results agree with the model predictions for alloys in the Cr-series reasonably well. However, considerable deviations have been observed for the alloys in the vanadium series.

2. Experimental

Since the details of the alloy preparation and measurement techniques were reported earlier (Gangopadhyay et al 1984a), we briefly discuss only the experimental procedure. The composition of the alloys was chosen mainly as a function of Cr/V concentration and in some cases as a function of increasing Fe concentration. Induction melt ingots were homogenized at 1050°C for 48 hr, quenched in water and finally annealed (900°C, 24 hr) and again quenched in water (to retain the disordered structure) after various metallurgical processes. The alloy compositions were analyzed using atomic absorption spectrometry. Resistivity was measured using the usual four-probe d.c. method.

3. Results and discussion

In table 1 are presented the 77 K resistivity data for some Ni-Fe-Cr/V alloys. The error bars shown in the data (inclusive of all possible factors) mainly come from the dimension measurements of the samples of which the lowest dimension i.e. the thickness contributes the maximum. Since all the alloys considered are fairly concentrated, impurity contribution to resistivity dominates all other effects, e.g. thermal contribution etc. Hence the change in resistivity between 77 K and 4 K will be