Two-current conduction model and residual resistivity in pseudo-binary amorphous Fe-Co alloys

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Abstract. The residual resistivity ρ_0 as a function of composition has been measured on the pseudo-binary glassy alloy series $(Fe_{100-x}Co_x)_{90}Zr_{10}$ and $(Fe_{100-x}Co_x)_{80}B_{20}$, respectively, in the concentration range $0 \leqslant x \leqslant 100$. Absolute values for ρ_0 are found to exceed those of corresponding crystalline disordered Fe–Co alloys by at least a factor of ten. The observed composition dependence of ρ_0 in the glassy alloys finds a straightforward explanation in terms of the two-current conduction model, adapted to the peculiarities of the amorphous structure, and substantiates our earlier finding of significant magnetic contributions to the total resistivity in such amorphous systems.

1. Introduction

In spite of the prodigious efforts in both experiment and theory over a decade, the question of the physical effects on electrical resistivity in metallic glasses associated with the occurrence of only partially filled d bands and long-range ordered ferromagnetic phases is still the subject of the scientific debate. Recently, Ocko and Babic (1988) have reported the results of electrical resistivity, ρ, measurements on some pseudo-binary amorphous TM–B–Si alloy series with TM denoting a combination of the 3d transition elements Fe, Co and Ni. A comparison of these results with resistivity data taken on corresponding liquid binary alloys (Kita and Morita 1984) has revealed a satisfactory agreement in both magnitude and dependence on composition at high temperatures, while the behaviour of the residual resistivity, ρ_0, in the glassy alloys may exhibit features markedly different from those observed in the liquid state. However, no attempts have been made until now to ascertain which of the existing theories quantitatively describes the residual resistivity behaviour in amorphous ferromagnetic alloys.

With a view to bringing out clearly the different aspects of these low-temperature data, in the present paper results of similar measurements performed on amorphous $(Fe_{100-x}Co_x)_{90}Zr_{10}$ alloys at a fixed temperature of 4.2 K, substantiated with our previously reported data taken on $(Fe_{100-x}Co_x)_{80}B_{20}$ (Kettler *et al* 1982) metallic glasses, will be presented and discussed within the framework of theoretical models proposed so far. These alloy systems provide the unique opportunity to investigate the role that the magnetic state (characterised by weak or strong itinerant ferromagnetism) plays in determining the residual resistivity behaviour. It is shown that among the theoretical approaches only the two-current conduction (TCC) model (which is briefly resumed in

§ 2) gives a straightforward explanation for the variation of ρ_0 with composition in the amorphous alloy series investigated.

2. A brief resumé of the TCC model

It is widely accepted that the resistivity behaviour in crystalline ferromagnetic alloys can be well accounted for in terms of the TCC model originally proposed by Mott (1964) and mainly developed by Campbell and Fert (1982). Within this model, which has recently been adapted by Herzer (1983) to the peculiarities of amorphous ferromagnets, the residual resistivity, in its general form, may be written as

$$\rho_0(x) = (\rho_0^\uparrow(x)\rho_0^\downarrow(x))/(\rho_0^\uparrow(x) + \rho_0^\downarrow(x)) \tag{1}$$

where $\rho_0^\sigma(x)$ denotes the partial residual-resistivity contribution of the spin σ band. Due to the two-current nature of the electronic transport, Matthiessen's rule is only obeyed within the respective sub-bands, i.e.

$$\rho_0^\sigma(x) = \sum_i \rho_{0,i}^\sigma(x) \tag{2}$$

with $\rho_{0,i}^\sigma(x)$ representing the partial resistivity contribution arising from the ith scattering mechanism. In ferromagnetic amorphous systems ρ_0^σ basically comprises two contributions stemming from the scattering of conduction electrons from the disordered array of ion cores carrying a muffin-tin potential, and magnetic spin scattering of mobile charge carriers from moment-bearing atoms, respectively. These partial structural (s) and magnetic (m) contributions can be expressed (Herzer 1983) as

$$\rho_{0,s}^\sigma(x) = \frac{24\pi\Omega_c}{\hbar e^2(v_F^\sigma)^2} \int_0^1 |\mathbf{t}^\sigma(q)|^2 a_s(q)\left(\frac{q}{2k_F^\sigma}\right)^3 \mathrm{d}\left(\frac{q}{2k_F^\sigma}\right) \tag{3}$$

and

$$\rho_{0,m}^\sigma(x) = \frac{24\pi\Omega_c}{\hbar e^2(v_F^\sigma)^2} \int_0^1 \langle S_i\rangle_c^2 |J_{sd}(q)|^2 a_m(q)\left(\frac{q}{2k_F^\sigma}\right)^3 \mathrm{d}\left(\frac{q}{2k_F^\sigma}\right) \tag{4}$$

respectively, where k_F^σ and v_F^σ are the Fermi wavevector and velocity of the spin σ band, $\Omega_c = a^3$ is the mean atomic volume, $\mathbf{t}^\sigma$ is the single-site on-shell $\mathbf{t}$-matrix

$$a_s(q) = \frac{1}{N}\sum_{i,j} \exp[-i q(\mathbf{R}_i - \mathbf{R}_j)] - N\delta_{q,0} \tag{5}$$

is the static geometric structure factor, J_{sd} is the sd-exchange coupling constant, $\langle S_i\rangle_c$ is the configurational average of local magnetic spin quantum numbers (S_i), and

$$a_m(q) = \frac{1}{N}\sum_{i,j} \frac{S_i S_j}{\langle S_i\rangle_c^2} \exp(-i q(\mathbf{R}_i - \mathbf{R}_j)) - N\delta_{q,0} \tag{6}$$

denotes the longitudinal part of the static magnetic structure factor, while e and $\hbar$ have their usual meanings.
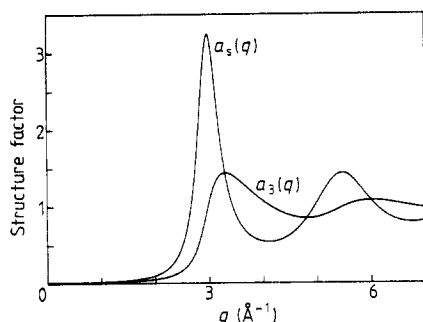
Figure 1. Typical variation of the static geometric structure factor $a_s(q)$ (equation (5)) and of the corresponding weighted integral $a_3(q)$ (equation (10) of text using $S_i = S_j = S$) with scattering vector for ferromagnetic metallic glasses.

Presuming the partial structural-resistivity contribution $\rho_{0,s}^\sigma$ to exceed greatly the corresponding magnetic term, i.e. $\rho_{0,s}^\sigma(x) \gg \rho_{0,m}^\sigma(x)$, applying moreover the approximation $k_F^\uparrow \simeq k_F^\downarrow \equiv k_F$ (which leads to $\rho_{0,m}^\uparrow \simeq \rho_{0,m}^\downarrow$), and introducing the resistivity ratio $\alpha = \rho_{0,s}^\downarrow / \rho_{0,s}^\uparrow$, equation (1) may be written as

$$\rho_0(x) \simeq (\rho_{0,s}^\uparrow(x)\rho_{0,s}^\downarrow(x))/(\rho_{0,s}^\uparrow(x) + \rho_{0,s}^\downarrow(x)) + 2[(1 + \alpha^2)/(1 + \alpha)^2]\rho_{0,m}(x) \qquad (7)$$

with

$$\rho_{0,m} = \rho_0^c a_3(2k_F)\langle S_i\rangle_c^2. \qquad (8)$$

In this relation the quantity

$$\rho_0^c = (3\pi/2)(m\Omega_c/e^2\hbar E_F)J_{sd}^2 \qquad (9)$$

(E_F = Fermi energy) denotes a characteristic resistivity that for crystalline as well as amorphous 3d metals and alloys takes on a common value of $\rho_0^c = (31.3 \pm 2)\mu\Omega$ cm (Weiss and Marotta 1959, Kettler and Rosenberg 1989a). The weighted integral

$$a_3(2k_F) = 4\int_0^1 a_m(q)\left(\frac{q}{2k_F}\right)^3 d\left(\frac{q}{2k_F}\right) \qquad (10)$$

over the longitudinal part of the static magnetic structure factor (6) is a measure for the concentration of magnetic atoms and the present magnetic short-range order. Typical variation of $a_s(q)$ and $a_3(q)$ with scattering vector for metallic glasses has been sketched in figure 1.

3. Experimental details

Precision resistivity measurements were performed on amorphous $(Fe_{100-x}Co_x)_{90}Zr_{10}$ and $(Fe_{100-x}Co_x)_{80}B_{20}$ alloy ribbons $(0 \leqslant x \leqslant 100)$, having typical dimensions of $0.02 \times 2 \times 30$ mm^3 and prepared by the single-roller quenching technique in an inert gas atmosphere, at a constant temperature of 4.2 K. The amorphous nature of the ribbons and the nominal compositions were verified by x-ray diffraction and electron microscopic techniques, respectively. The sample temperature was monitored by a pre-calibrated carbon–glass resistance sensor. Absolute values for ρ have been deduced using the density data of Shirakawa *et al* (1980) in the calculation of the cross-sectional area of each sample, leading to an absolute accuracy of the resistivity data of better than 5%. For further details concerning the sample preparation and electronic equipment used

for the measurements the reader is referred to a preceding paper (Kettler and Rosenberg 1989a).

4. Results and discussion

Results of the residual-resistivity measurements performed on the pseudo-binary a-$(Fe_{100-x}Co_x)_{90}Zr_{10}$ and a-$(Fe_{100-x}Co_x)_{80}B_{20}$ alloy series are shown in figure 2, along with the respective average magnetic moment per 3d transition-metal atom (Deppe *et al* 1984, 1986, O'Handley *et al* 1976). For the sake of comparison corresponding data of the crystalline $Fe_{100-x}Co_x$ alloy system taken from the literature (Freitas and Berger 1988, Kouvel 1969) have also been included in this figure. The essential features that figure 2 presents can be summarised as follows. (i) Residual resistivity, ρ_0, in the $(Fe_{100-x}Co_x)_{90}Zr_{10}$ glasses over the entire concentration range exceeds that obtained in the a-$(Fe_{100-x}Co_x)_{80}B_{20}$ alloy series. (ii) While values for ρ_0 in the $(Fe_{100-x}Co_x)_{80}B_{20}$ glasses monotonically decrease with increasing Co-content, in the a-$(Fe_{100-x}Co_x)_{90}Zr_{10}$ system replacement of Co for Fe at first gives rise to a steep increase of residual resistivity till a value of $x \simeq 10$ is reached, beyond which ρ_0 monotonically decreases at a rate slightly exceeding that observed in the a-$(Fe_{100-x}Co_x)_{80}B_{20}$ alloy system. (iii) The total residual resistivities in the pseudo-binary amorphous Fe–Co alloys surpass those values obtained for the corresponding crystalline disordered $Fe_{100-x}Co_x$ alloys (Freitas and Berger 1988) by at least a factor of ten. (iv) In both amorphous and crystalline Fe–Co alloy series the variation of ρ_0 with composition closely resembles that observed for the average magnetic moment per 3d transition metal atom, μ.

It has been a common practice to completely disregard the magnetic state of the glassy alloys under consideration and to explain the resistivity data in terms of the diffraction model (see e.g. Cote and Meisel 1981), which takes into account the scattering of the conduction electrons by the ion cores that carry a muffin-tin potential. Albeit this extended Faber–Ziman model correctly predicts the order of magnitude and the decreasing trend of ρ_0 in liquid 3d metals when going from Fe to Co, it fails to account for the non-monotonic variation of residual resistivity in the a-$(Fe_{100-x}Co_x)_{90}Zr_{10}$ alloy series. Such a non-monotonous variation of ρ_0 with composition has also been observed in the crystalline disordered $Fe_{100-x}Co_x$ alloys (figure 2). In both cases the peak position in $\rho_0(x)$ at $x \simeq 15$ corresponds to a Co concentration, where a transition from weak $(x \lesssim 20)$ to strong $(x \gtrsim 20)$ itinerant ferromagnetism occurs. These observations, when combined with the close similarity in the observed trends in $\rho_0(x)$- and $\mu(x)$-dependence, assert that the change in ρ_0 with alloy composition is expected to originate essentially from magnetic scattering processes, while the structural contribution should exhibit only a weak concentration dependence. Moreover, detailed analysis of the temperature dependence of resistivity in the $(Fe_{100-x}Co_x)_{80}B_{20}$ glasses has already demonstrated that besides a dominant structural contribution there exists a significant magnetic contribution to the total resistivity in such glasses (Kettler *et al* 1982).

The theory that accounts for such effects is the TCC model briefly summarised in § 2. According to this model the total residual resistivity, ρ_0, of an amorphous ferromagnetic alloy can be separated into purely structural (first term in (7)) and magnetic (second term in (7)) contributions. Besides the magnetic and electronic quantities appearing in (8), the magnitude of the effective magnetic contribution to ρ_0 depends sensitively upon the partial residual-resistivity ratio $\alpha = \rho_{0,s}^{\downarrow}/\rho_{0,s}^{\uparrow}$ that characterises the magnetic state of a material. In weak ferromagnets $\rho_{0,s}^{\uparrow}$ and $\rho_{0,s}^{\downarrow}$ possess comparable values, since in
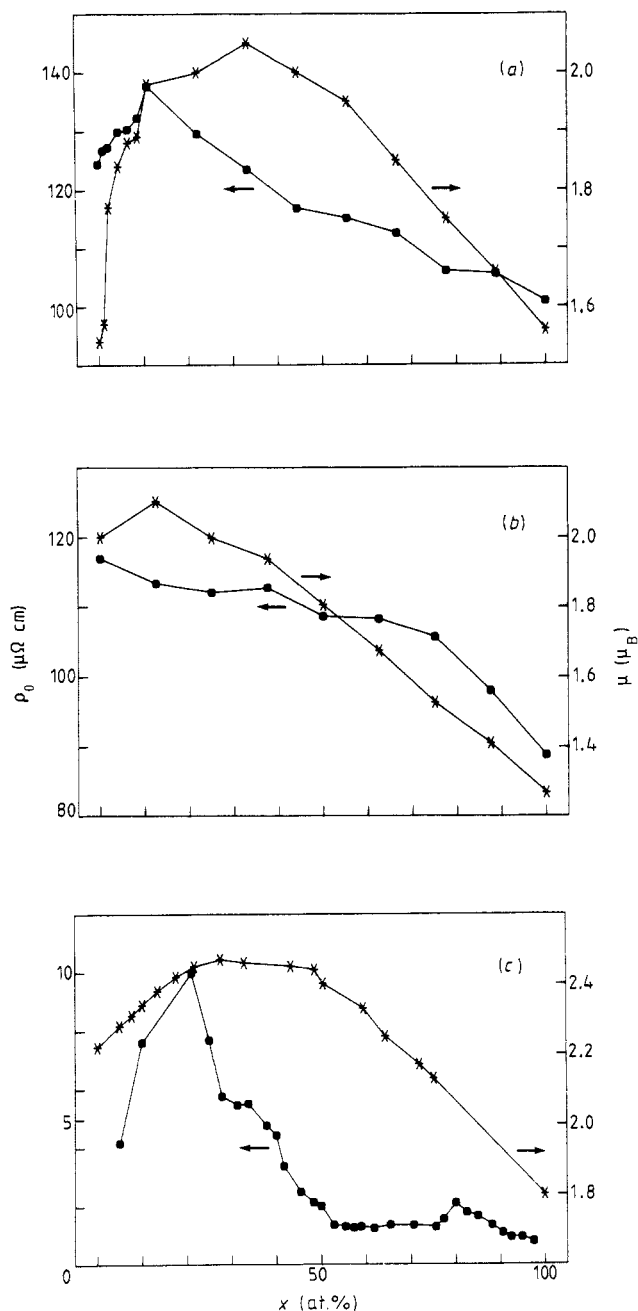
Figure 2. Variation of the residual resistivity (closed symbols), ρ_0, and the average magnetic moment per 3d transition metal atom (stars), μ, taken at a fixed temperature of 4 K, in (*a*) amorphous $(Fe_{100-x}Co_x)_{90}Zr_{10}$ and (*b*) $(Fe_{100-x}Co_x)_{80}B_{20}$ (Kettler *et al* 1982) alloys, respectively, with composition. Absolute accuracy for the ρ_0 data obtained can be estimated to be better than 5%. Magnetic data for μ have been taken from Deppe *et al* (1984, 1986) and O'Handley *et al* (1976). (*c*) For the sake of comparison corresponding data for ρ_0 (Freitas and Berger 1988) and μ (Kouvel 1969) obtained on crystalline disordered $Fe_{100-x}Co_x$ alloys have been included in this figure. Solid curves drawn through the data points serve only as a guide to the eye.
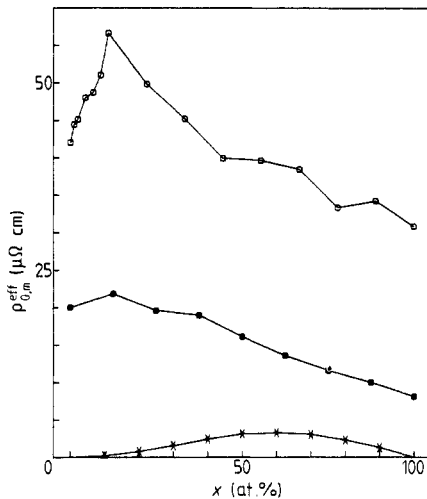
Figure 3. Concentration dependence of the effective magnetic contribution, $\rho^{eff}_{0,m}$, to the total residual resistivity in ferromagnetic $(Fe_{100-x}Co_x)_{90}Zr_{10}$ (open symbols) and $(Fe_{100-x}Co_x)_{80}B_{20}$ (closed symbols) metallic glasses, respectively, and crystalline disordered $Fe_{100-x}Co_x$ alloys (stars). For calculational details of $\rho^{eff}_{0,m}$ see text. The solid lines connecting the data points serve only as a guide to the eye.

both d $\uparrow$ and d $\downarrow$ sub-bands vacant states at the Fermi level, E_F, are available for s electrons to make transitions. Thus the ratio α is supposed to be close to unity, and (7) simply reduces to Matthiessen's rule in the case of one-current conduction. On the other hand, in strong ferromagnets $\rho^{\downarrow}_{0,s}$ may greatly exceed $\rho^{\uparrow}_{0,s}$ because s–d scattering is allowed only for spin-down electrons, as there are no vacant d $\uparrow$ states at E_F. Accordingly, α is expected to take on values significantly larger than unity, and the pre-factor of $\rho_{0,m}$ in (7) may reach values close to two, giving rise to a considerable enhancement of the magnetic contribution to ρ_0.

According to the classification outlined above, $Co_{80}B_{20}$ glass is supposed to exhibit weak itinerant ferromagnetism (Kaul 1983), while a-$Fe_{80}B_{20}$ is just on the verge of becoming a strong itinerant ferromagnet (Kaul and Rosenberg 1983), so that in the a-$(Fe_{100-x}Co_x)_{80}B_{20}$ alloy series α is expected to stay close to unity over the entire composition range. To arrive at a numerical estimate of the magnetic contribution to residual resistivity ρ_0 in these glasses, one can start from the homogeneous limiting case $a_3(2k_F) \simeq \langle S_i^2 \rangle_c / \langle S_i \rangle_c^2 \simeq 1$ (this result is obtained by assuming a random distribution of local magnetic moments over an amorphous matrix and inserting experimental values for the average local spin quantum numbers (Dey *et al* 1981)) which is supposed to provide a lower bound for the weighted integral over the magnetic structure factor and to a certain extent also for $\rho_{0,m}$ (8). Inserting in (8) experimental values for μ (O'Handley *et al* 1976) and ρ^S_0 (Weiss and Marotta 1959, Kettler and Rosenberg 1989a) reveals that in the amorphous $(Fe_{100-x}Co_x)_{80}B_{20}$ system $\rho_{0,m}$ closely follows the trend of the average magnetic moment (see figure 3) exhibiting a maximum at $x \simeq 15$ and values of about 20 $\mu\Omega$ cm for a-$Fe_{80}B_{20}$ and 8 $\mu\Omega$ cm for a-$Co_{80}B_{20}$, respectively. In a-$Fe_{80}B_{20}$ the experimental value of $\alpha \simeq 1.61$, which has been previously deduced by Kaul and Rosenberg (1983) from a detailed analysis of spontaneous magnetic resistivity anisotropy data, entails only a minute enhancement of $\rho_{0,m}$ to about $\rho^{eff}_{0,m} \simeq 21 \mu\Omega$ cm (second term in (7)), so that the remaining structural contribution (first term in (7)) to the total residual resistivity can be calculated as $\rho_{0,s} \simeq 96 \mu\Omega$ cm. In view of the weak ferromagnetic behaviour in the Co-rich compositions (Kaul 1983), above estimated $\rho_{0,m}$ values in the entire a-$(Fe_{100-x}Co_x)_{80}B_{20}$ alloy series can be taken as effective magnetic contributions to ρ_0, leading, e.g., in a-$Co_{80}B_{20}$ to a structural contribution of $\rho_{0,s} \simeq 81 \mu\Omega$ cm. Remembering that $\rho_{0,s}$ in Pauli paramagnetic amorphous $Ni_{80}B_{16}Si_4$ amounts to about 73 $\mu\Omega$ cm

(Kettler and Rosenberg 1989a) estimated $\rho_{0,s}$ values for the a-$TM_{80}B_{20}$ alloys (TM = Fe, Co, Ni) in magnitude as well as trend compare favourably with corresponding data (when extrapolated to $T \to 0$ K) obtained for the liquid 3d transition metals (Kita and Morita 1984).

As already mentioned, the amorphous $(Fe_{100-x}Co_x)_{90}Zr_{10}$ system exhibits a clear transition from weak (at the Fe-rich side) to strong (at the Co-rich side) ferromagnetic behaviour that should be almost complete for alloys containing more than about 20 at.% Co (Rosenberg *et al* 1988). In this case the residual resistivity ratio $\alpha = \rho_{0,s}^{\downarrow}/\rho_{0,s}^{\uparrow}$ is a strongly varying function of composition (i.e., $\alpha \simeq 1$ for $x \simeq 0$ and $\alpha \gg 1$ for $x \to 100$, respectively) and has to be taken into account in a quantitative comparison between theory and experiment. Estimated values for $\rho_{0,m}$ (8) in the amorphous $(Fe_{100-x}Co_x)_{90}Zr_{10}$ alloy series fall within the range of about 15 (for $x = 0$ and 100, respectively) to 27 $\mu\Omega$ cm (for $x \simeq 30$) presuming again $a_3(2k_F) \simeq 1$. While this assumption for the a-$(Fe_{100-x}Co_x)_{80}B_{20}$ alloys is certainly a well founded approximation, the amorphous $(Fe_{100-x}Co_x)_{90}Zr_{10}$ alloys investigated exhibit a more complex behaviour. Detailed analysis of the resistivity behaviour in a glassy $Fe_{90}Zr_{10}$ alloy (Kettler and Rosenberg 1989b) for instance has inferred a lower bound for $a_3(2k_F)$ of at least 2.77 that drastically increases the estimated magnetic residual resistivity contribution $\rho_{0,m}$ in this particular alloy composition to more than about 42 $\mu\Omega$ cm. This value by no means is unreasonable and leads to an upper bound for the non-magnetic (structural) residual resistivity contribution of $\rho_{0,s} \simeq 83$ $\mu\Omega$ cm, which is only slightly lower than that estimated for a-$Fe_{80}B_{20}$. On the other hand, Mössbauer spectra taken on the amorphous $(Fe_{100-x}Co_x)_{90}Zr_{10}$ alloy series (Deppe *et al* 1984, 1986) strongly suggest that the Co-rich compositions are magnetically more homogeneous than the Fe-rich alloys, so that $a_3(2k_F)$ should gradually decrease with increasing x. This decrease, in turn, is to some extent compensated by an enhancement of the pre-factor $2(1 + \alpha^2)/(1 + \alpha)^2$ of $\rho_{0,m}$ in (7). Since large values for α are connected with the appearance of strong ferromagnetism, this pre-factor should approach the value two, leading to a significant enhancement of the magnetic term in (7) for Co-rich alloys, as well as to a reduction of the first (structural) term, so that in a-$Co_{90}Zr_{10}$ $\rho_{0,s}$ should be located around 70 $\mu\Omega$ cm. Hence, in conformity with the behaviour of $\rho_{0,s}$ in the class of a-$TM_{80}B_{20}$ alloys, Zr-containing metallic glasses obviously exhibit the same trend in resistivity behaviour when going from Fe to Co, although absolute values for $\rho_{0,s}$ in the former system slightly exceed those values estimated for the latter alloys. These differences in absolute values of $\rho_{0,s}$ ultimately reflect the effect of diverse glass-forming additives (B, Zr) in the amorphous alloy series investigated. Approximating the non-magnetic part of ρ_0 in the glassy $(Fe_{100-x}Co_x)_{90}Zr_{10}$ system by a linearly decreasing function of x reproducing the estimated values for $\rho_{0,s}$ at $x = 0$ and 100, respectively, leads to an effective magnetic contribution $\rho_{0,m}^{eff}$ (second term in (7)) to ρ_0 that is compared in figure 3 with the corresponding data obtained on the a-$(Fe_{100-x}Co_x)_{80}B_{20}$ alloy series. In both cases $\rho_{0,m}^{eff}$ attains its maximum value at a concentration where a transition from weak to strong (or nearly strong) ferromagnetic behaviour occurs. The above considerations indicate that the positions of the maxima observed in both $\rho_0(x)$ and $\mu(x)$ behaviour should not necessarily coincide, since in addition to the dependence of $\rho_{0,m}$ on the average magnetic moment, μ, the topological and compositional disorder, as expressed in the quantity $a_3(2k_F)$, dictate the transport behaviour.

By comparison, the absence of topological disorder in the crystalline Fe–Co alloy system (Freitas and Berger 1988) reduces the residual resistivity by more than one order of magnitude (see figure 2). However, in the crystalline disordered case ρ_0 should

likewise comprise magnetic contributions that Goedsche *et al* (1979), within the frame-work of TCC model for a binary ferromagnetic alloy, have calculated as

$$\rho_{0,m} = \rho_0^c x_a x_b (S_a - S_b)^2, \tag{11}$$

where x_a and x_b denote the concentrations of both constituents. The magnitude of $\rho_{0,m}$ now essentially depends upon the difference of the individual atomic spin contributions $(S_a - S_b)$, whereas in amorphous ferromagnets it is the average local magnetic spin moment $\langle S_i \rangle_c$ that enters into the theoretical $\rho_{0,m}$ expression (compare with (8)). Insert-ing in (11) experimental values for the average local magnetic moments (Kouvel 1969) of c-$Fe_{100-x}Co_x$ alloys yields values for $\rho_{0,m}$ of up to 3.3 $\mu\Omega$ cm for $x \simeq 60$ (see figure 3; the Nordheim behaviour of (11) is slightly modified through the concentration depen-dence of the individual atomic spins). However, a quantitative agreement between theory and experiment over the whole concentration range cannot be expected, since (11) does not account for short-range ordering effects that might play an important role in determining the concentration dependence of $\rho_{0,m}^{eff}$. The above discussion of $\rho_0(x)$ behaviour in the amorphous ferromagnets has not only demonstrated that the degree of magnetic and compositional short-range order exerts strong influence on the magnitude of magnetic residual resistivity contribution, but also that the spin-splitting of the conduction band in certain cases leads to a considerable enhancement of $\rho_{0,m}$, which has to be taken into account in a quantitative comparison between theory and experiment.

Finally, attention should be drawn to recent numerical resistivity calculations (Bal-lentine 1985, Ostermeier *et al* 1988) that have indicated substantial contributions of d-electrons to conductivity in both liquid and amorphous 3d transition metal systems and hence raised reasonable doubts as to the applicability of Faber–Ziman theory (for $\rho_{0,s}$) to understanding electronic charge transport in these materials. It may be said in favour of the applicability of the diffraction model that in liquid Ni the s-band contribution is expected to dominate the conductivity, but on the other hand in liquid Fe d-states should contribute about 85% of the conductivity and therefore just the opposite conditions emerge to those that will justify the use of the diffraction model (Ballentine 1985). Such calculations for the classes of amorphous alloys investigated are at present lacking, with the exception only of a-$Fe_{100-x}B_x$ alloys (Ostermeier *et al* 1988). For instance, the calculated value for ρ_0 in a-$Fe_{80}B_{20}$ does indeed agree to within 13% with experimental data: however, since none of the theories proposed by Ballentine (1985) and Ostermeier *et al* (1988) take magnetic scattering into account at all despite the fact that it has been proven to have a marked influence on the electronic charge transport in amorphous ferromagnets (see e.g. Kettler and Rosenberg 1989a)—this agreement would seem to be rather accidental. Clarification of these inter-relations certainly deserves further theoretical efforts.

5. Conclusions

Measurements of the residual resistivity ρ_0 have been performed on pseudo-binary rapidly quenched $(Fe_{100-x}Co_x)_{90}Zr_{10}$ and $(Fe_{100-x}Co_x)_{80}B_{20}$ alloy series, representing two important classes of ferromagnetic metallic glasses. Of all the theories proposed so far in the literature to understand the residual-resistivity phenomenon in amorphous ferromagnets, only the TCC model gives a simple and plausible explanation for the composition dependence of residual resistivity observed in these magnetic glasses.

Quantitative analysis of the results has confirmed anew that, besides a dominant structural contribution $\rho_{0,s}$, there exists a significant magnetic contribution $\rho_{0,m}$ to the total residual resistivity ρ_0 that, in both classes of amorphous ferromagnets investigated, is mainly responsible for the marked composition dependence of ρ_0. The magnitude of the effective magnetic contribution to ρ_0 is strongly influenced by the degree of quenched static magnetic disorder, as well as by the magnetic state of a material, i.e., whether an alloy exhibits weak or strong itinerant ferromagnetism.

Acknowledgments

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