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MAGNETORESISTANCE OF Fe-Ni AMORPHOUS ALLOYS

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Various physical properties of amorphous alloys have been rather extensively investigated in the last few years. Such interest has been encouraged by the development of new techniques\(^1\) capable of producing samples of desirable shape and predictable quality, the possibility of their industrial applications and their unusual properties.

There exist a great variety of different amorphous systems; one of the most studied are metal-metalloid alloys. Among these, (Fe-Ni)\(_{80}\)-(P-B)\(_{20}\) alloys have some interesting characteristics, typical of soft ferromagnets.

Generally, amorphous alloys have rather high, but very weakly temperature dependent resistivities. For the metal-metalloid ones, the electrical resistivity exhibits some common features: a saturation at very low temperatures, logarithmic dependence at higher temperatures followed by a resistivity minimum. The origins of such behaviour are still not fully explained; but at present an explanation in terms of Kondo type scattering seems more favorable than a non-magnetic structural model\(^2\).

Extensive studies of Fe\(_x\)Ni\(_{80-x}\)P\(_{14}\)B\(_6\) system have been made and have somewhat clarified this controversy. The low temperature resistivities\(^3\) and room temperature coefficients of the resistivity\(^3\) have shown a rather strong dependence on the Fe/Ni ratio in the alloy, and such effects cannot be accounted for in the TLS approach\(^2\). Likewise, the existence of a magnetic contribution has been observed in Hall effect\(^4\) and thermoelectric power\(^5\) of the same system. The magnetoresistance results presented here support further this conclusion.

The transverse and longitudinal magnetoresistance were measured with a potentiometric set-up (with relative accuracy of few parts in 10\(^6\)) on samples in a form of ribbon. Their dimensions and relevant data have been given elsewhere\(^3\). The experiments were done mostly up to 35K, and in magnetic fields up to 8T (superconducting solenoid).

![Fig. 1. The relative change of magnetoresistance for three Fe\(_x\)Ni\(_{80-x}\)P\(_{14}\)B\(_6\) alloys (\(\Delta R/R_{\text{min}}\)) is shown for the alloy with x=10.](image)

For x=0 and 10, H=7.5T, for x=20, H=3T. In the inset, the field variation of the logarithmic slope of \(\Delta R/R_{\text{min}}\) (o) and resistivity minimum temperature (+) is shown for the alloy with x=10.
The temperature variation of the transverse magnetoresistance for three Fe$_x$Ni$_{80-x}$P$_{14}$B$_6$ alloys is shown in figure 1. These data (dashed lines) were obtained in fixed magnetic field and are compared with zero field resistivities (dotted lines) with respect to the iron concentration (x), the data can be summarised as follows:

1) $x=0$. There is a small positive magnetoresistance which decreases a little as the temperature is increased (for $T$ up to nearly $2T_{\text{min}}$). Both $R(H\parallel)^{(x)}$ and $R(H\perp)$ are proportional to $H^n$, with $1<n<2$, and within the experimental error are the same (i.e. there is no anisotropy-Fig 3a). The measured positive magnetoresistance seems to indicate that for this particular alloy the anomalous resistivity term does not come from the Kondo effect.

2) $x=10$. This alloy represents a borderline between ferromagnetic and paramagnetic region, and its magnetoresistance depends very strongly on temperature and magnetic field. In figure 1 we have given only the $R(H\parallel)$ curve for the highest field, and it shows that the log $T$ term of the resistivity is suppressed to nearly half of its value for $H=0$. This is also evident from the inset of Fig.1, where the coefficient $A^{(x)}$ of the log $T$ term is plotted as a function of the applied field: we believe that for magnetic fields $>10T$, coefficient $A$ would be completely saturated. The effect of the field is also to shift the temperature of the minimum to lower values and this is nearly proportional to $H$ (inset of Fig.3). Similar $A(H)$ and $T_{\text{min}}$ variations have been reported for other amorphous systems(6), and clearly are the result of the presence of a magnetic effect in this alloy. The shape of the $R(H)$ curves (Fig.3c) does not change significantly up to 65 K; $R(H\parallel)$ is always slightly more negative then $R(H\parallel)$, giving a very small positive anisotropy which decreases a little as $T$ is increased. The field dependence of $R(H\parallel=T=\text{const})$ which is in Fig.3c shown only for low fields - indicates that this system does not behave as a real ferromagnet (in which sufficiently strong field would reduce the magnetic scattering to zero and therefore lead to saturation of the magnetoresistance). Here the results resemble more to the behaviour of a quasi ferromagnetic PdMn alloy(7) for which true saturation is reached only for extremely high applied fields.

![Fig.2. Isotropic magnetoresistance, (R(H||)+2R(H\perp))/3, vs. temperature for x=10 alloy. Dashed line represents the effect for x=20 alloy in 3T.](image-url)
However, we think that in Fe_{10}Ni_{70}P_{14}B_{6} alloy the physical situation is even more complex. If the isotropic magnetoresistance is plotted versus temperature (figure 2), its strong field and temperature dependence is again evident. There is a change of slopes at 55K which corresponds rather well to the Curie temperature of this alloy. Also the transition through T_c is rather wide in temperature which one would not expect for a proper ferromagnet. (We note that, similarly, the coefficient of anomalous Hall effect (4) does not change in a typical ferromagnetic fashion around T_c). But even for quasiferromagnetic alloy the isotropic magnetoresistance should show a clear peak at T_c as a function of temperature for fixed field, and this we have not observed: for T<T_c the magnetoresistance is even more negative. We believe that this can be understood, at least qualitatively, if the Kondo type magnetic scattering is also taken into account, where the dominant magnetoresistance dependence (9) is through N^2 (M is the sample magnetization). At low temperatures this would (for a fixed field and supposed small characteristic temperature) yield R(H)=T^-2. Consequently, the observed variation of the magnetoresistance could be regarded as a result of the presence of the two effects; one of which is weakly temperature dependent for T<T_c, has a peak at T_c and decreases again for T>T_c, and a second one (more dominant at T<T_c) proportional to T^-2. Even if this qualitative picture is not fully correct, it is clear that in Fe_{10}Ni_{70}P_{14}B_{6} the anomalous low temperature behaviour is not compatible with the structural model (2), but that it has a magnetic origin.

3) x=20. This alloy has also a negative magnetoresistance (Fig.1) but the effect of the field is not so pronounced, nor we were able to detect any significant change of T_{min} with field. For temperatures up to 30K (which is much less then T_c (230 K)) the isotropic magnetoresistance (in a fixed field) does not vary very much with temperature, as compared to the effect for x=10 alloy. Data at 3T are shown in Fig. 2 as a dashed line. Although the effect is much smaller, it can still be seen that there is a small negative contribution at lowest temperatures. This again could be associated with Kondo effect and neither this alloy could be considered as a completely homogenous ferromagnet. There is also a qualitatively different behaviour of R(H||) and R(H⊥) (Fig. 3b) at low fields, which

![](image)
is due to the demagnetizing field.

In order to determine the type (weak or strong) of ferromagnetism present, we have looked at the relative resistance anisotropy. This quantity is defined as the ratio of anisotropic \( \frac{\zeta(H||) - \zeta(H\perp)}{\zeta(H\perp)} \) and isotropic magnetoresistivities and, at low temperatures, it is directly related to the ratio \( \zeta \) of spin \( \downarrow \) and spin \( \uparrow \) resistivities:

\[
\Delta \rho/\rho = \zeta (\alpha - 1)
\]

(In our calculations we have taken \( \zeta \) value determined for Ni-based alloys\(^{(11)}\)). The analysis of data for \( x=20 \) alloy yields \( \alpha \gg 1 \), which indicates that the scattering is dominated by the minority-spin electrons. Theoretical arguments\(^{(12)}\) have suggested the same conclusion if \( \zeta(H||) > \zeta(H\perp) \). Therefore, \( \text{Fe}_{20}\text{Ni}_{60}\text{P}_{14}\text{B}_{6} \) alloy seems to be the case of strong ferromagnetism.

We have so far discussed in details the results for alloys with low \( x \), as more interesting ones. By increasing the iron concentration, ferromagnetic character of \( \text{Fe}_{x}\text{Ni}_{80-x}\text{P}_{14}\text{B}_{6} \) alloys is more pronounced\(^{(4)(8)}\). Longitudinal and transverse magnetoresistances retain the field dependence as found for \( x=20 \) alloy (Fig.3b), and from the positive anisotropy it follows again that \( \alpha \gg 1 \), i.e. they behave as soft ferromagnets. (Similar behaviour was found\(^{(13)}\) as well for \( \text{Fe}_{40}\text{Ni}_{40}\text{B}_{20} \) alloy). A more detailed study of the magnetoresistance for the alloys with \( x > 20 \) is in progress.

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References

11. I.A.Campbell and A.Fert, to be published in "Ferromagnetic Materials" (ed.P.Wohlfarth)

\[ A = \frac{dp}{d \log T} \text{ (ref. 3)} \]

\[ R(H) = A_{R}(H) = R(H) - R(H=0) \]