

GALVANOMAGNETIC PROPERTIES OF AMORPHOUS FERROMAGNETS

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Amorphous alloys with 80at%Fe-Ni and 20at%BP are particularly interesting because of their excellent soft magnetic properties which make them good candidates for the industrial applications. These alloys are also very interesting from the viewpoint of physics because their structures are expected to be approximately the same while their magnetic properties vary from paramagnetic to strongly ferromagnetic by changing the Fe/Ni ratio<sup>1)</sup>. The study of galvanomagnetic effect in such alloys is very important because they give a useful information both on their magnetic as well as transport properties. In particular while the Hall effect measurements in the amorphous ferromagnets directly relates to the magnetisation the magnetoresistance can be used to determine the magnetic contribution to the resistivity.

The Hall effect and magnetoresistance were measured in amorphous  $\text{Fe}_x\text{Ni}_{80-x}\text{B}_2\text{O}$  and  $\text{Fe}_x\text{Ni}_{80-x}\text{P}_{14}\text{B}_6$  alloys in a wide temperature range. The magnetoresistance was measured by the potentiometric set up while the Hall voltages were measured either with a standard a.c. or d.c. technique. The low temperature measurements were performed by using a superconducting magnets in the magnetic fields up to 8T while at higher temperatures a conventional magnet with maximum field 2T was used. The temperature was measured with the calibrated Ge thermometer and copper resistance thermometer at low and high temperatures respectively.

We will firstly discuss the results of the Hall effect measurements which give us the information about the magnetic state of our samples. The Hall resistivities ( $\rho_H$ ) at room temperature of all  $\text{Fe}_x\text{Ni}_{80-x}\text{B}_2\text{O}$  and  $\text{Fe}_x\text{Ni}_{80-x}\text{P}_{14}\text{B}_6$  alloys which are ferromagnetic at this temperature behave similarly<sup>2)</sup> and because of that in Fig.1 we show the variation in  $\rho_H$  with magnetic field only for four  $\text{Fe}_x\text{Ni}_{80-x}\text{P}_{14}\text{B}_6$  alloys. The Hall resistivities of the alloys with  $x=30, 40$  and  $60$  are typical for ferromagnetic alloys and can be fitted to empirical relation<sup>3)</sup>  $\rho_H = R_S M + R_0 B$ , where  $R_S$  is the spontaneous Hall coefficient.  $M$  is magnetisation,  $R_0$  is the ordinary Hall coefficient and  $B$  is the magnetic induction. The first term in the above expression corresponds to steep initial rise of  $\rho_H$  with  $B$  in Fig1, caused by the alignment of the domains in an external field. This process continues till all the domains are aligned leading to apparent saturation at higher field. At these fields the slope of  $\rho_H$  curves

is determined by  $R_0$ , the ordinary Hall coefficient. The intercept of the (extrapolated) low field and high field slopes (Fig.1) gives the value of  $M_s$  (saturation magnetization). The  $M_s$  values deduced in that manner<sup>2)</sup> agreed well with those obtained from magnetisation measurements<sup>1)</sup>.

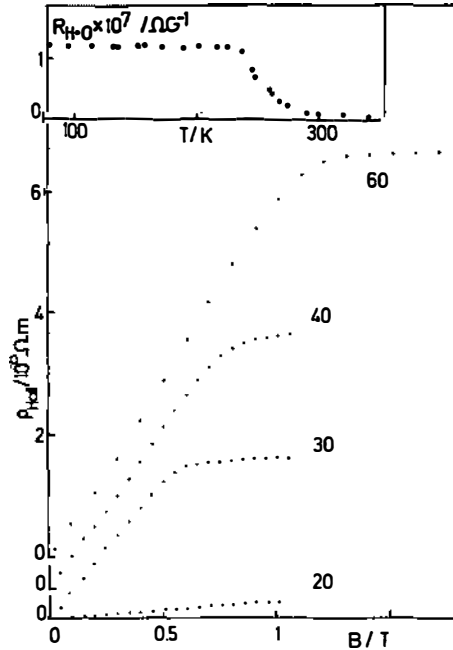


Fig.1. The Hall resistivities of four  $\text{Fe}_{20-x}\text{Ni}_{60-x}\text{P}_{14}\text{B}_6$  alloys vs magnetic field. Numbers denote Fe content (x). In the inset the coefficient of the anomalous Hall effect of  $\text{Fe}_{20}\text{Ni}_{60}\text{P}_{14}\text{B}_6$  alloy vs temperature

$\text{Fe}_{20}\text{Ni}_{60}\text{P}_{14}\text{B}_6$  alloy has the Curie temperature below room temperature and therefore its Hall resistivity at room temperature (Fig.1) has a different behaviour. Thus by investigating the Hall effect in a wider temperature range it is possible to deduce the Curie temperature ( $T_c$ ) at which the ferromagnetic state of the sample changes to the paramagnetic one. This is illustrated in the inset to Fig.1 where we show the dependence of the coefficient of the anomalous Hall effect ( $R_{H \rightarrow 0}$ ) on temperature for  $\text{Fe}_{20}\text{Ni}_{60}\text{P}_{14}\text{B}_6$  alloy which had  $T_c$  value in the experimentally accessible temperature interval. In this plot  $T_c$  is defined by the point at which a sudden decrease in  $R_{H \rightarrow 0}$  takes place. Again the values of  $T_c$  obtained in that manner agreed well<sup>2)</sup>

with those from independent measurements. Our measurements of the Hall effect give a consistent picture of the magnetic properties of  $\text{Fe}_x\text{Ni}_{80-x}\text{B}_{20}$  and  $\text{Fe}_x\text{Ni}_{80-x}\text{P}_{14}\text{B}_6$  alloys. They all seem to be soft ferromagnets below  $T_c$ . In order to get some insight about the eventual differences in their low temperature magnetic state the measurements of the magnetoresistance were performed.

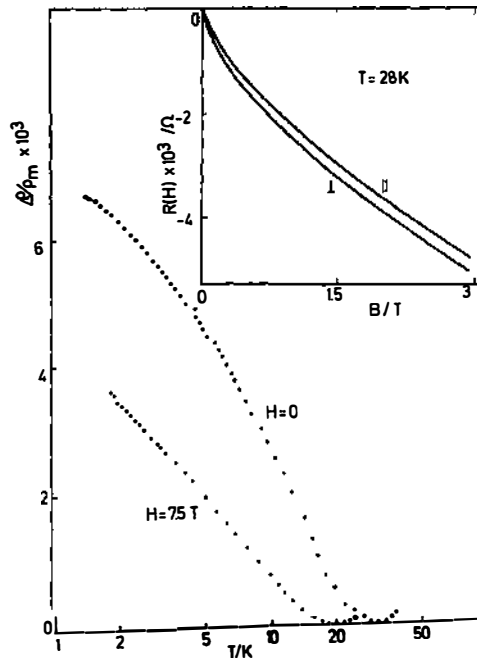


Fig.2. The relative change in resistivity of  $\text{Fe}_{10}\text{Ni}_{90}\text{P}_{14}\text{B}_6$  alloys with and without external magnetic field. In the inset longitudinal and transverse magnetoresistance of the same alloy at 28K.

The preliminary measurements of the magnetoresistance in  $\text{Fe}_{40}\text{Ni}_{40}\text{B}_{20}$  alloy both at low and room temperature are already reported<sup>4)</sup>. As the measurements on all the other alloys with  $T_c$  above room temperature had generally the same behaviour we will not discuss them here in any detail. We note however that also the magnetoresistance in these alloys is consistent with their description as soft ferromagnets. Here we are primarily interested in the alloys on the borderline between ferromagnetic and paramagnetic<sup>5)</sup> such as  $\text{Fe}_{10}\text{Ni}_{70}\text{P}_{14}\text{B}_6$ . The question we wish to answer<sup>5)</sup> is whether the unusually strong increase in the resistivity of  $\text{Fe}_{10}\text{Ni}_{70}\text{P}_{14}\text{B}_6$  alloy at the lowest temperatures is due to structural disorder only or is partially

of the magnetic origin. In the inset to Fig.2 we show the longitudinal and transverse magnetoresistance of  $\text{Fe}_{10}\text{Ni}_{70}\text{P}_{14}\text{B}_6$ . It can be seen that both longitudinal and transverse magnetoresistance of  $\text{Fe}_{10}\text{Ni}_{70}\text{P}_{14}\text{B}_6$  are negative and do not saturate with the magnetic field. Rather strong temperature dependence of the magnetoresistance was also observed. Both of these features are not characteristic for the soft ferromagnets<sup>4)</sup> and indicate that the magnetic field changes not only the magnitude of the resistivity but also its temperature dependence. Indeed from Fig.2 can be seen that the magnetic field of 7.5T decreases the depth of the resistance minimum to about half of its value in zero field, and that it also shifts the temperature of the minimum for more than 10K.

In conclusion we show that the anomalous resistivity behaviour of the  $\text{Fe}_{10}\text{Ni}_{70}\text{P}_{14}\text{B}_6$  alloys is partially of the magnetic origin. Further investigations are required in order to find out the exact mechanism which accounts for such resistivity behaviour.

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