

MAGNETIC SUSCEPTIBILITY OF HYDROGEN DOPED 4d - 3d METALLIC GLASSES

I.Kokanović*, B.Leontić*, J.Lukatela**

* - Physics Department, Faculty of Science, Zagreb .

** - Institute of Physics of the University, Zagreb

The magnetic susceptibilities of hydrogen doped 4d-3d metallic glasses have been measured in the temperature range from 2K to 300K. It has been found that $\chi(T)$ decreases substantially with increasing hydrogen content. This behaviour is primarily attributed to reductions in the density of the Fermi level electronic states. The form and magnitude of the observed anomalous temperature dependence of the magnetic susceptibility $\sim T^{1/2}$ are in agreement with recent electron interaction theories which predict quantum corrections to the susceptibility. Hydrogen has been found to influence strongly the quantum-mechanical interference at defects, thus slowing down the spin diffusion and enhancing the susceptibility at low temperatures.

Weak localization /1,2/ and enhanced electron-electron interaction /3,4/ have successfully explained the temperature and magnetic field dependence of the electrical conductivity in metallic glasses /5-8/. It has been shown /3,9/ that the interaction between electrons in disordered conductors also gives rise to corrections in the density of states at the Fermi level. Thus, in the case of the electron repulsion the temperature and field dependences of the conductivity electron magnetic susceptibility imitates the Curie-Weiss law. Our earlier results have shown a significant influence of hydrogen on the quantum corrections to the conductivity of metallic glasses /8,10/.

The samples were cut from ribbons prepared by rapid solidification of the melt on a single-roll spinning copper wheel under a high purity argon atmosphere and were doped with various hydrogen concentrations using an electrolytic method. The content of absorbed hydrogen was determined using a previously established relationship between the gain in resistance and volumetrically determined hydrogen concentration /10/. Magnetic susceptibility measurements were carried out using the Faraday method with a Cahn electrobalance and a conventional magnet (0,94T). A precision range of 10^{-7} JT⁻²mol⁻¹ was maintained in this measurement.

The magnetic susceptibility data for Zr_{0,67}Ni_{0,33}H_x (x=0;0,13;0,33) and Zr_{0,60}Cu_{0,40}H_x (x=0;0,11) samples vs.the square-root of temperature are shown in Fig.1. The susceptibility in both systems is nearly independent of temperature except for temperatures below 30K where a slight in-

crease is observed and is lowered upon hydrogenation while the low temperature upturn is increased. Both effects are more pronounced for Zr-Cu system.

The temperature-independent magnetic susceptibility is expressed as:

$$\chi_{\text{exp}} = \chi_{\text{el}}^{\text{P}} + \chi_{\text{ion}} + \chi_{\text{orb}} \quad (1)$$

where χ_{ion} and χ_{orb} are the ionic core diamagnetism and orbital paramagnetism respectively and $\chi_{\text{el}}^{\text{P}}$ is the Pauli susceptibility given as:

$$\chi_{\text{el}}^{\text{P}} = \mu_{\text{B}}^2 N_0(E_{\text{F}}) / (1 - I_{\text{eff}} N_0(E_{\text{F}})) \quad (2)$$

with μ_{B} the Bohr magneton, $N_0(E_{\text{F}})$ the bare density of states at the Fermi level and I_{eff} the effective exchange integral within the d- band.

While χ_{ion} is relatively small for all the ionic cores in the systems investigated, the orbital magnetic moments are not completely quenched [11] and are of the same order of magnitude as the Pauli spin term (Table 1).

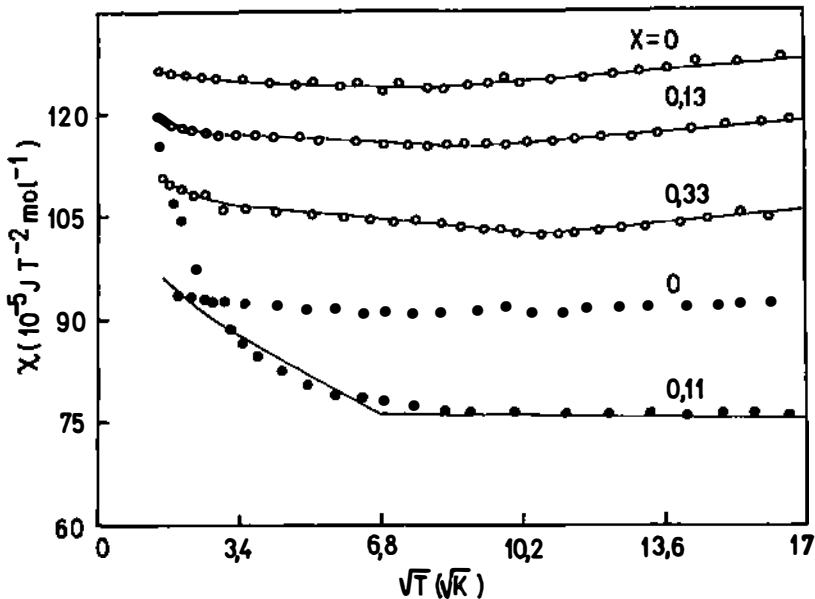


Fig.1 The magnetic susceptibility of Zr-Ni (○) and Zr-Cu (●) metallic glasses doped with hydrogen vs. the square-root of temperature

A summary of measured and calculated values are given in Table 1.

The hydrogen atoms migrate mainly to Zr-rich sites where their s-electrons hybridise with the zirconium d-band [12]. Since the density of states at E_{F} of the early-late transition metal glass is dominated by the early transition element (Zr in our case) we expect and indeed observe a strong dependence of the density of states and hence of the Pauli susceptibility on the hydrogen concentration. The influence of the hydrogen

electron hybridisation with the zirconium d-band does not seem to influence greatly the orbital paramagnetism. Measurements of $N_0(E_F)$ as a function of hydrogen concentration /13/ give values which indicate that our observation of susceptibility suppression can be wholly attributed to a change in the Pauli term. In the Zr-Cu system the hydrogen influence is stronger since copper is in the d 10 state in all its alloys and no hydrogen migrates to Cu-rich sites.

Table 1. Magnetic susceptibility data for $Zr_{0,67}Ni_{0,33}H_x$ and $Zr_{0,60}Cu_{0,40}H_x$ metallic glasses

sample	$\chi_{exp} \cdot 10^5$ (JT ⁻² mol ⁻¹)	$\chi_{ion} \cdot 10^5$ (JT ⁻² mol ⁻¹)	$\chi_0 \cdot 10^5$ (JT ⁻² mol ⁻¹)	$\chi_{el}^p \cdot 10^5$ (JT ⁻² mol ⁻¹)	$\chi_{orb} \cdot 10^5$ (JT ⁻² mol ⁻¹)	$\chi_{N_0(E_F)}$ (states/eVat)
$Zr_{0,67}Ni_{0,33}$	128	-20	42	73	75	1,3
$Zr_{0,67}Ni_{0,33}H_{0,13}$	120	-20	39,2	65	75	1,21
$Zr_{0,67}Ni_{0,33}H_{0,33}$	105	-20	33,3	50	75	1,03
$Zr_{0,60}Cu_{0,40}$	93	-17,8	31,5	50,4	60,4	0,98
$Zr_{0,60}Cu_{0,40}H_{0,11}$	76	-17,8	20,9	33,4	60,4	0,65

Interaction between electrons in disordered conductors leads to a weakly temperature dependant magnetic susceptibility. The quantum corrections to the orbital magnetic susceptibility in the Cooper channel are given as /9/:

$$\delta\chi_0 = -2\chi_0(\pi/6)^{1/2} \zeta(1/2)(T\tau/\hbar)^{1/2} \ln^{-1}(T_c/T) \quad (3)$$

where χ_0 is the diamagnetic susceptibility of electrons, $\zeta(x)$ is the Riemann zeta function, τ is the momentum relaxation time and T_c is the superconducting transition temperature.

Besides corrections to the orbital susceptibility there exist corrections to the spin susceptibility in the Cooper channel $\delta\chi_S^C$ and in the diffusion channel $\delta\chi_S^D$ /9/:

$$\delta\chi_S = \delta\chi_S^C + \delta\chi_S^D = \frac{\zeta(1/2)(g\mu_B)^2 T^{1/2}}{16 \cdot 2^{1/2} \pi^{3/2} (D\hbar)^{3/2}} (2 \ln^{-1}(T_c/T) - \lambda^{(j=1)}) \quad (4)$$

where $\lambda^{(j=1)}$ is a constant for the electron-hole interaction and g is the g-factor of conduction electrons.

The experimental data were fitted (full line) for temperatures $T_c < T < T_{min}$ (where T_{min} corresponds to the minimum in the magnetic susceptibility) to the relation:

$$\delta\chi = -AT^{1/2} - BT^{1/2} \ln^{-1}(T_c/T) + c_1 \quad (5)$$

and for temperatures $T > T_{min}$ to the relation:

$$\delta\chi = -BT^{1/2} \ln^{-1}(T_c/T) + C_2 \quad (6)$$

where A, B and C_2 are the parameters of the fit and $C_1 = C_2 + AT_{\min}^{1/2}$. The values of the parameters T_{\min} and T_c are given in Table 2.

Table 2. Coefficients of fit of experimental data to relations (5) and (6)

Sample	A ($10^{-5} J T^{-2} \text{mol}^{-1} K^{-1/2}$)	B ($10^{-5} J T^{-2} \text{mol}^{-1} K^{-1/2}$)	C_2 ($10^{-5} J T^{-2} \text{mol}^{-1}$)	T_{\min} (K)	T_c (K)
Zr _{0,67} Ni _{0,33}	0,6	4,0	115,5	60	1,5
Zr _{0,67} Ni _{0,33} H _{0,13}	0,85	4,4	106,3	80	0,95
Zr _{0,67} Ni _{0,33} H _{0,33}	1,15	4,95	91,7	115	0,85

Coefficient A is enhanced relatively to B upon hydrogenation. The enhancement of the spin susceptibility relatively to the orbital part upon hydrogenation is in agreement with our data /8/ which show that hydrogen reduces the spin-orbital scattering rate, thus reducing the mixing of spin-up and down subbands. In addition hydrogen is found to enhance the relative contribution of the elastic scattering thus reducing the effective diffusion constant. The slowing down of the spin diffusion is expressed as an enhancement of the low temperature susceptibility.

In conclusion, we may say that the observed behaviour of these highly disordered systems may be accounted for in terms of the theoretical models outlined and that there is a good quantitative agreement between the predictions of the models and the experimental data.

- /1/ E.Abrahams, P.W.Anderson, D.C.Licciardello and T.V.Ramakrishnan, Phys. Rev.Lett.42, 673 (1979)
- /2/ Y.Imry, Phys.Rev.Lett.44, 469 (1980)
- /3/ B.L.Altshuler and A.G.Aronov, Solid State Commun.36, 115 (1979)
- /4/ B.L.Altshuler, D.Khmel'nitskii, A.I.Larkin and P.A.Lee, Phys.Rev.B22, 5142 (1980)
- /5/ S.J.Poon, E.J.Cotts and K.M.Wong, Solid State Commun.52, 519 (1984)
- /6/ M.A.Howson, J.Phys.F: Met.Phys.14, L25 (1984)
- /7/ C.L.Tsai and F.C.Lu, J.Non-Cryst.Solids 61&62, 1403 (1984)
- /8/ B.Leontić, J.Lukatela, P.Dubček and I.Kokanović, Phys. Rev. Lett. 58, 1479 (1987)
- /9/ B.L.Altshuler, A.G.Aronov and A.Yu.Zyuzin, Zh.Eksp.Teor.Fiz. 84, 1525(1983)
- /10/ E.Babić, B.Leontić, J.Lukatela, M.Miljak, M.G.Scott, in Proceedings of the Fourth International Conference on Rapidly Quenched Metals, edited by T.Masumoto and K.Suzuki (Sendai The Japan Institute of Metals,

1982), Vol.2, p.1617

'11/ R.Kubo, Y.Obata, J.Phys.Soc.Japan 11, 547 (1956)

'12/ K.Tanaka, Y.Yamada, K.Kai and K.Suzuki, J.Phys.Soc.Japan, 53,
1783 (1984)

'13/ V.Mizutani, S.Ohta, T.Matsuda, J.Phys.Soc.Japan 54, 3406 (1985)