Relaxation of the remanent magnetization of $Zn_xCd_{1-x}Cr_2Se_4$ spin glasses with a cubic magnetocrystalline anisotropy

V. G. Veselago, A. A. Minakov, and A. V. Myagkov
P. N. Lebedev Physics Institute, Academy of Sciences of the USSR, Moscow

(Submitted 13 June 1983; resubmitted 26 July 1983)
Pis'ma Zh. Eksp. Teor. Fiz. **38**, No. 5, 255–257 (10 September 1983)

The relaxation of the remanent magnetization M_R of $Zn_xCd_{1-x}Cr_2Se_4$ spin glasses with various cubic-magnetocrystalline-anisotropy constants has been studied. The results show that the relaxation of M_R can be described by a power law.

PACS numbers: 75.60.Lr, 75.50.Kj

Soukoulis *et al.* have recently shown that the properties of spin glasses cannot be described without taking into account the magnetic anisotropy. In the present experiments we have studied single crystals in the $Zn_xCd_{1-x}Cr_2Se_4$ system as a particular case in which we can trace the effect of magnetocrystalline anisotropy on the properties of spin glasses, since the single crystals of this system have a cubic magnetocrystalline anisotropy, and the magnitude of this anisotropy can be varied over the range 10^3–10^5 erg/cm^3 by doping with Ag (Ref. 2). The $Zn_xCd_{1-x}Cr_2Se_4$ single crystals are ferromagnetic at $x \leqslant 0.3$ and antiferromagnetic at $x \geqslant 0.5$; at $x \sim 0.4$ they are spin glasses.[3] These spin glasses are of further interest in that their magnetic subsystem is formed by ions of a single type, Cr^{3+}, which are arranged in a periodic fashion at the sites of a crystal lattice; only the random arrangement of diamagnetic Cd^{2+} and Zn^{2+} ions gives rise to spatial fluctuations in the exchange interactions. This magnetic structure corresponds to the most refined theoretical models.[4,5]

We studied the relaxation of the remanent magnetization M_R at 4.2 K of spin glasses of two types: The samples of type 1 were from the $Zn_xCd_{1-x}Cr_2Se_4$ system with $x = 0.46$, doped with Ag to ~ 5 mole%. The first cubic-magnetocrystalline-anisotropy constant of the samples was $K_1 \sim 10^5$ erg/cm^3. The samples of type 2 were undoped samples of the system $Zn_xCd_{1-x}Cr_2Se_4$ with $x = 0.4$ and $K_1 \sim 10^3$ erg/cm^3. The "freezing" temperature T_f determined from the temperature dependence of the susceptibility at 600 Hz was 30 and 21 K for the samples of types 1 and 2, respectively.

The curves of the thermostatic remanent magnetization (TRM) and the isothermal remanent magnetization (IRM) against the magnetizing field H for $t = 50$ s (t is the time elapsed after the removal of the field) have the shape typical of spin glasses. The curve for the TRM has a maximum, while that for the IRM shows saturation. The saturation level of the remanent magnetization at $t = 50$ s is ~ 40 G and ~ 3.5 G for the samples of types 1 and 2, respectively.

Most experimental investigators have reported that the relaxation of M_R of spin glasses can be described by a logarithmic law: $M_R \sim 1 - s\ln t$. The reason is that the relaxation is ordinarily studied at times $t \lesssim 10^3$ s, and at this values of t it is difficult to

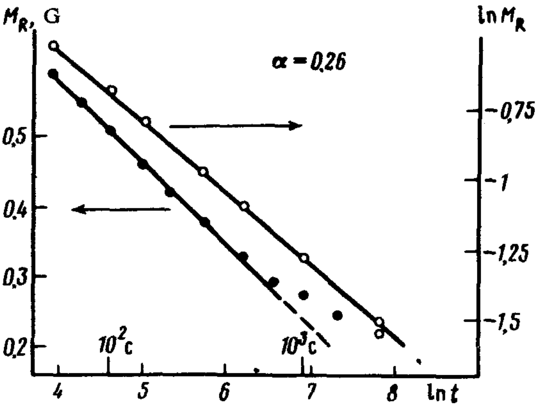

FIG. 1. Relaxation of the isothermal remanent magnetization of a sample of type 1 in the coordinates $\ln M_R$, $\ln t$ (O) and in the coordinates M_R, $\ln t$ (●) for magnetization for 30 *s* by a field $H = 200$ Oe.

experimentally distinguish a logarithmic relaxation law from a power law $M_R \sim t^{-\alpha}$ if $\alpha \ll 1$, since

$$t^{-\alpha} \equiv \exp(-\alpha \ln t) = 1 - \alpha \ln t + \frac{1}{2}(\alpha \ln t)^2 - \ldots \quad .$$

By increasing the t interval to 10^4 s, we found that the relaxation of M_R in the samples of both types can be described by a power law; with increasing α, the deviation from the logarithmic law is observed at shorter values of t (Fig. 1). Figure 2 shows the H dependence of α. We find that α depends on the duration of the magnetization. Figure 2 shows the behavior of the value of α corresponding to the IRM as the duration of the magnetization is raised from 30 to 1000 s.

These experimental results (the power-law relaxation and the H dependence of α) agree qualitatively with the results of Refs. 4 and 5, where the Edwards–Anderson

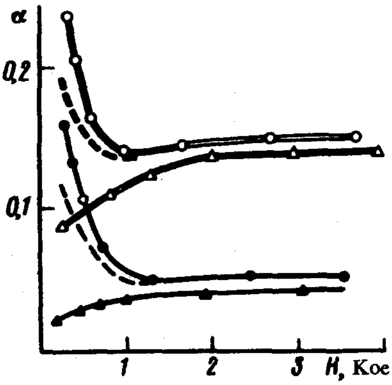

FIG. 2. Dependence of α on the magnetizing field H. ▲—TRM of a sample of type 1 with magnetization for 30 s; ●—IRM for a sample of type 1 with magnetization for 30 s; △—TRM for a sample of type 2, magnetization for 30 s; O—IRM for a sample of type 2, magnetization for 30 s. The dashed curves show the H dependence of α for IRM with magnetization for 1000 s.

model of a spin glass with Ising spins was studied by numerical methods. This correspondence suggests that the nature and magnitude of the magnetocrystalline anisotropy do not qualitatively change the behavior of the remanent magnetization of the spin glass. However, as can be seen from our results, the magnitude of the remanent magnetization increases significantly, and the corresponding values of α decrease upon an increase in the magnetocrystalline-anisotropy energy.

[1]C. M. Soukoulis, G. S. Grest, and K. Levin, Phys. Rev. Lett. **50**, 80 (1983).

[2]A. A. Minakov and A. V. Filatov, II Vsesoyuznuĭ seminar po amorfnomu magnetizmu (Second All-Union Seminar on Amorphous Magnetism), Krasnoyarsk, 1980, p. 129.

[3]A. A. Minakov and V. E. Makhotkin, Izv. Akad. Nauk SSSR, Ser. Fiz. **44**, 1473 (1980).

[4]C. Dasgupta, S.-K. Ma, and C.-K. Hu, Phys. Rev. **B20**, 3837 (1979).

[5]W. Kinzel, Phys. Rev. **B19**, 4595 (1979).

Translated by Dave Parsons
Edited by S. J. Amoretty