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MAGNETIC PARTICLES AND NANOCRYSTALLINE MATERIALS

Magnetic Properties of Nanoparticles of Cenospheres from Energetic Ashes[1]

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Abstract—The application of magnetic cenospheres including ferrospinel nanoparticles as a "transport container" in medicine and biology is quite attractive. Their nanoscale size, high porosity, and well pronounced magnetic properties provide good consumer choice. In this contribution, we report on the magnetic properties of microspheres from energetic ashes of Ekibastuz coals.

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The dependences of the magnetization σ on the temperature T (in the range of 4.2–300 K) and the magnetic field H (up to 70 kG) have been studied using a vibrating-sample magnetometer with a superconducting sole-

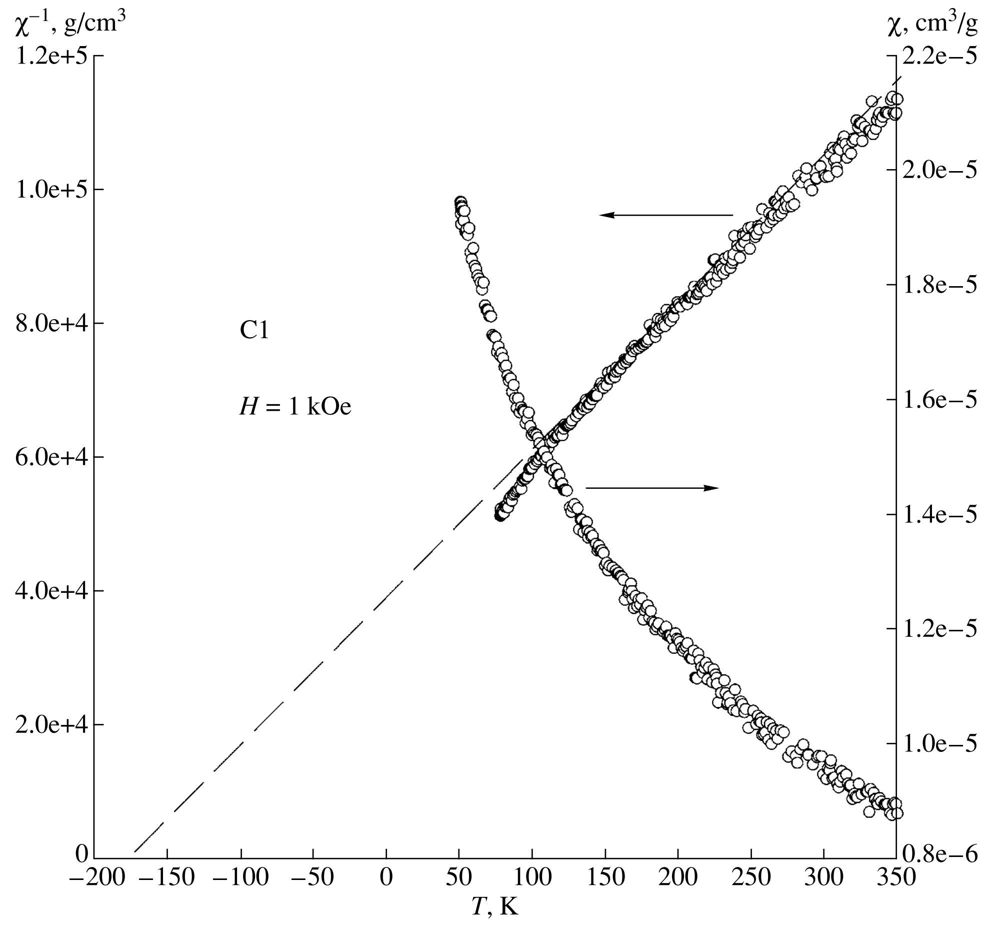

Fig. 1. Temperature dependence of the magnetic susceptibility of sample C1 (parent sample for C2–C5 fractions).

[1]The text was submitted by the authors in English.

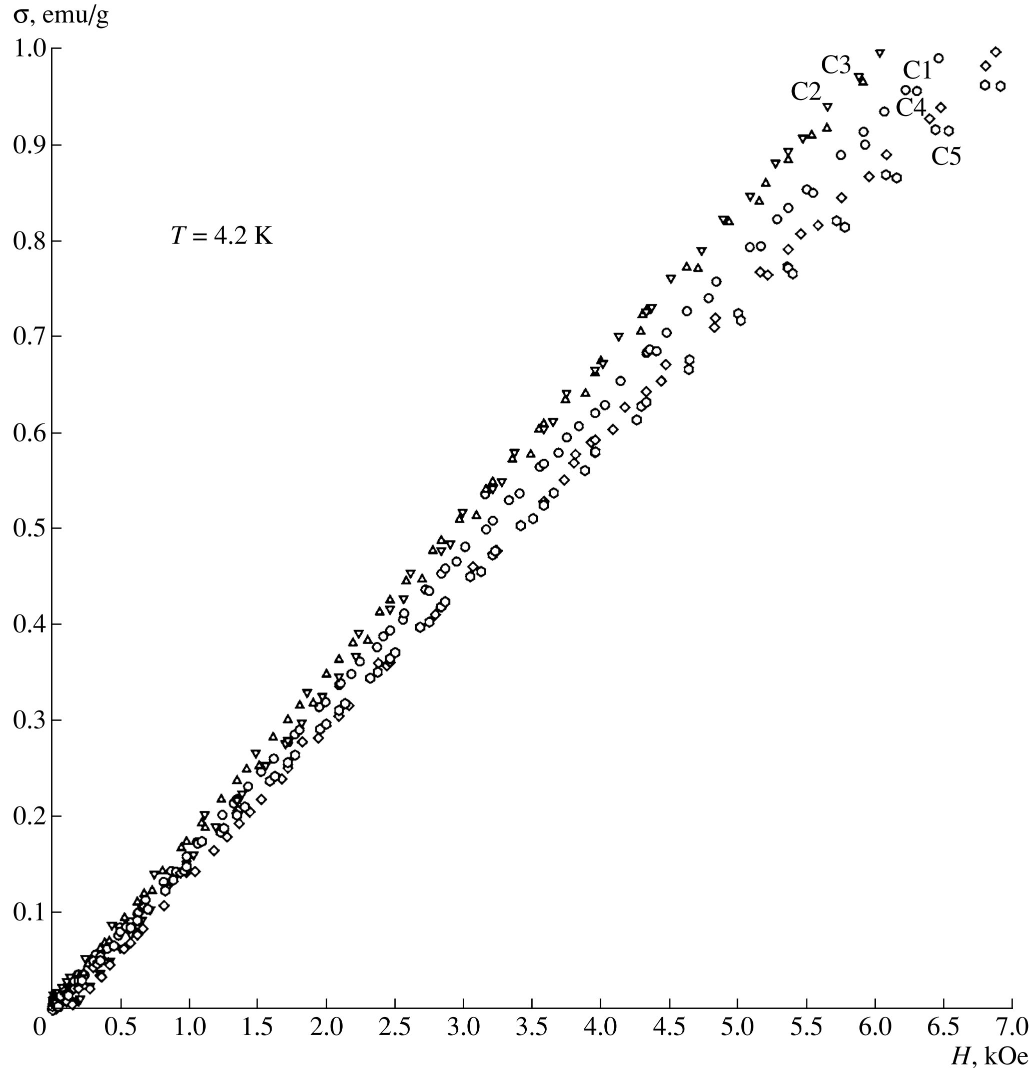

Fig. 2. Field dependences of the magnetization of samples C1–C5 revealing a nonlinearity of the $\sigma(H)$ dependence in small fields.

noid [1]. Typical $\sigma(H)$ and $\sigma(T)$ dependences of sample C1 are shown in Figs. 1–3. It is seen from Figs. 1 and 3 that sample C1 is paramagnetic. However, a nonlinearity of the $\sigma(H)$ dependence in the low-field range is seen in Fig. 2. This indicates the existence of a small amount (~1 %) of a phase with ferromagnetic properties. In order to obtain a detailed information on the magnetic properties of the magnetic fraction of ash (C1), we performed magnetic separation under conditions of $B \cdot \mathrm{grad}B$ = 750, 900, 1560, 2900 kG^2/cm. We denote samples obtained after the separation as C2, C3, C4, and C5, respectively. Mössbauer measurements of these samples show that the main phase containing Fe has a spinel structure [2]. On the other hand, the extrapolation of the inverse susceptibility of all the samples C1–C5 gives negative temperatures θ_a (see Fig. 1 and table) This fact supports the conclusion made from Mössbauer measurements. A negative exchange interaction is an intrinsic property of magnetic order in spinels. The paramagnetic contribution (see Fig. 1) varies by about two orders of magnitude. For this reason, it should be more correctly to use the magnitude of the magnetic moment at T = 4.2 K at a constant field as a characteristic value of magnetic properties. Figures 2 and 3 show $\sigma(H)$ dependences in low (up to 7 kG) and high (up to 70 kG) fields, respectively. The magnitudes of σ measured in fields of 6 and 60 kG are listed in the table. The magnetic susceptibility $\chi = \Delta\sigma/\Delta B$ was determined from the linear parts of the $\sigma(B)$ dependences in the range of 2–6 kG. The data on χ are listed in the table. The table also contains the magnitudes of σ at 77 K.

There is a correlation between $B \cdot \mathrm{grad}B$ and σ and χ. The values of σ and χ averaged over samples C2–C5 coincide with those for sample C1 within the accuracy of measurements. The simple averages are σ =

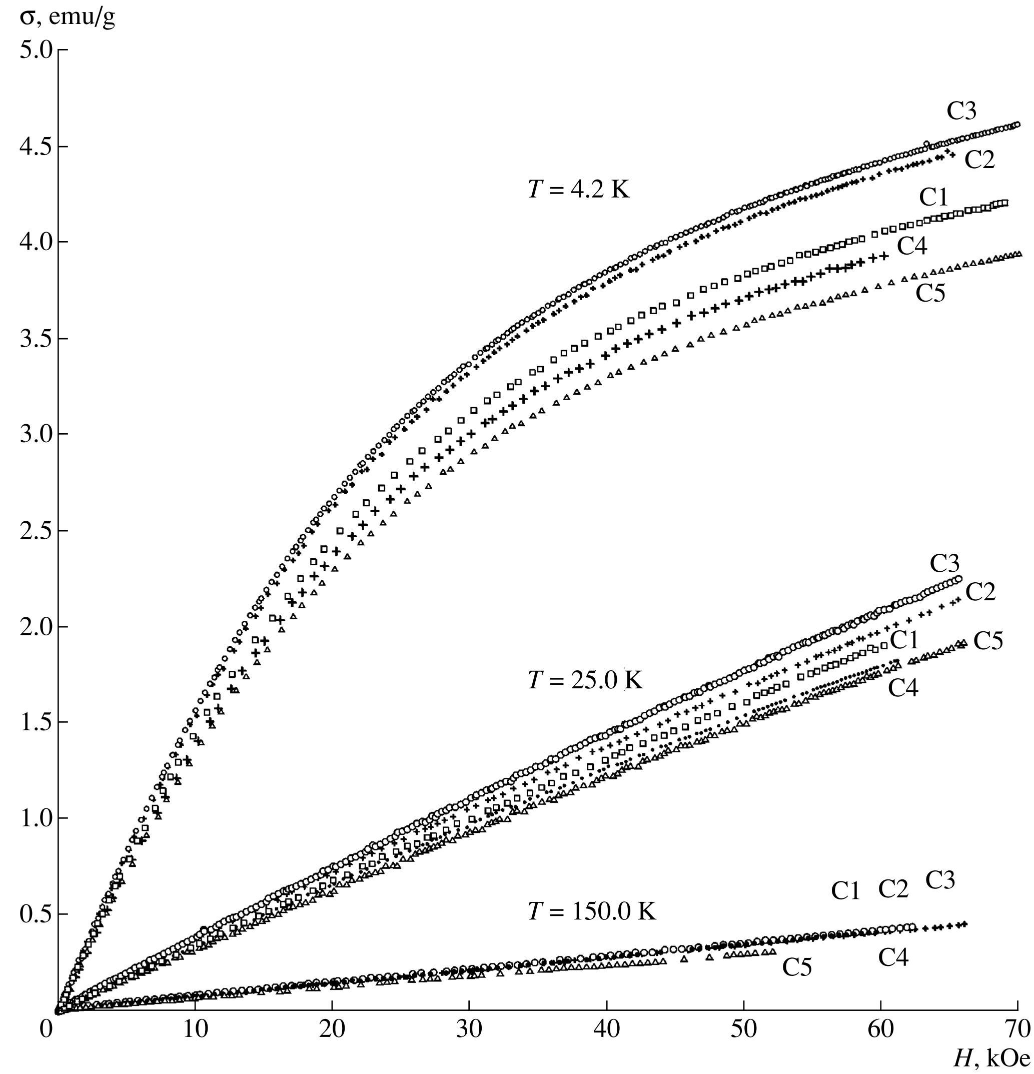

Fig. 3. Isotherms of the magnetization curves of samples C1–C5.

4.12 emu/g and $\chi = 1.52 \times 10^{-4}$ cm^3/g. These results are in good agreement with σ(C1) = 4.06 emu/g and χ(C1) = 1.50×10^{-4} cm^3/g. The additivity is retained for other temperatures and magnetic fields.

The possible errors can arise from aggregation of particles in the process of magnetic separation, from errors of weighing the samples, and from the relative error of magnetic measurements. One can conclude that

Main parameters of the magnetic properties of samples C1–C5

	$B \cdot \mathrm{grad}B$, kG^2/cm	σ(4.2 K; 60 kOe), emu/g	σ(4.2 K; 6 kOe), emu/g	χ, 10^{-4}, cm^3/g	σ(78 K; 6 kOe), emu/g	θ_a, K ± 7 K
C1	–	4.06	0.923	1.50	0.079	–175
C2	750	4.36	0.980	1.60	0.089	–180
C3	900	4.42	0.992	1.61	0.100	–140
C4	1560	3.93	0.880	1.46	0.081	–115
C5	2900	3.78	0.855	1.40	0.074	–135

no monotonic behavior is observed for θ_a; on the other hand, all of them have a negative sign.

Thus, the temperature and magnetic-field dependences of the magnetization for C1–C5 samples have been measured. With a negligible difference in the magnetic properties, all the samples are paramagnetic, manifesting a close range of antiferromagnetic arrangement. A monotonic reduction of the magnetic properties of fractions C2–C5 with increasing magnetic "force" during separation is observed.

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