MAGNETIC VISCOSITY IN RARE-EARTH FERROMAGNETS

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It is found that terbium, dysprosium, and alloys containing terbium possess in the ferromagnetic region in fields up to 100 Oe, a high magnetic viscosity with a relaxation time of the order of tens or hundreds of seconds. In contrast to these metals, gadolinium has a vanishingly small viscosity. Estimates show that the activation energy of the magnetic relaxation process in terbium and dysprosium is of the order of 10^{-1} eV.

THE magnetic properties of rare-earth ferromagnets in strong and moderate magnetic fields (greater than 1 kOe) has been intensively studied lately in connection with the helicoidal magnetic structures found in them. In the region of weak fields these substances have not been well studied, although here one expects peculiarities of magnetic behavior compared to ferromagnets of the iron group.

In this paper we take up the study of the magnetic properties of certain rare-earth ferromagnets in magnetic fields of tens to hundreds of oersteds. We observed the existence in these fields of a high-magnetic viscosity with relaxation times of the order of tens to hundreds of seconds for polycrystalline samples of terbium, dysprosium, and yttrium-terbium alloys, as well as for a single crystal of dysprosium.

The apparatus for measuring the magnetic viscosity effect was as follows. The viscous change of magnetization induced an EMF in differential coils, one of which contained the sample. This EMF was integrated and amplified by a microwebermeter, the output of which was connected to a pen recorder.

Figure 1 shows the temperature dependence of the relaxation time $\tau_{0.8}$ for polycrystalline dysprosium. The relaxation time was defined as the time in which the effect of viscous change of magnetization attained 80% of its limiting value. It should be pointed out that in all our samples the viscous change of magnetization can only approximately be described by an exponential dependence on time. The appearance of a high magnetic viscosity in dysprosium is observed close to and below the temperature of the helicoidal antiferromagnetism to ferromagnetism transition ($\Theta_1 = 85°K$), and the relaxation time $\tau_{0.8}$ grows particularly strongly near Θ_1 and remains rather high in the ferromagnetic region (below Θ_1). Magnetic viscosity is absent in the state with helicoidal magnetic structure. Some preliminary measurements we made also indicated a high magnetic viscosity in a single crystal of dysprosium below Θ_1' of the same character as in the polycrystalline sample. Anisotropy of the viscosity effect was observed.

In terbium (Fig. 2) one also observes a high magnetic viscosity in the ferromagnetic state and in the region of the helicoidal antiferromagnetism to ferromagnetism transition ($\Theta_1 = 219°K$). Near Θ_1 is observed a sharp increase in the relaxation time, and

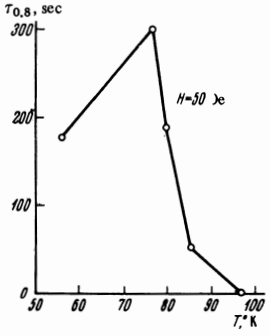

FIG. 1. Temperature dependence of the relaxation time for polycrystalline dysprosium (measurements were made at H = 50 Oe). The relaxation time $\tau_{0.8}$ was determined as the time in which the effect of viscous change of magnetization attained 80% of its limiting value.

then, below Θ_1, the relaxation time decreases strongly, but nonetheless remains large. In addition, a small increase in $\tau_{0.8}$ is observed in cooling in the vicinity of 150°K.

In the alloy 83.5 at.% Tb + 16.5 at.% Y, where Θ_1 lies near 130°K, the relaxation time strongly increases with approach to this temperature, but then, below Θ_1, it remains constant. The terbium-yttrium alloys were obtained in the form of bars and wires from the laboratory of E. M. Savitskiĭ. The temperature dependence of the magnitude of the magnetic viscosity effect and of the relaxation time, as well as the temperature dependence of magnetization, in the terbium-yttrium alloy have a similar behavior in a given field. A similar conclusion can be drawn for dysprosium and terbium.

We also investigated gadolinium; however, in this case we did not observe any magnetic viscosity with relaxation times of seconds to hundreds of seconds. This agrees with the results of Telesnin et al.,[1] who studied the viscosity of gadolinium by a method which could measure relaxation times of the order of a hundred microseconds.

We attempted to estimate the activation energy ϵ of the magnetic relaxation process for terbium and

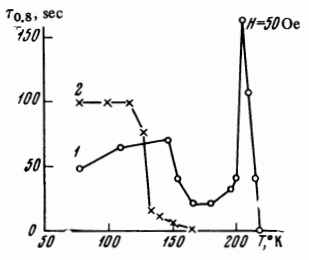

FIG. 2. Temperature dependence of the relaxation time $\tau_{0.8}$ for polycrystalline terbium (Curve 1) and the alloy 83.5 at.% Tb + 16.5 at.% Y (Curve 2).

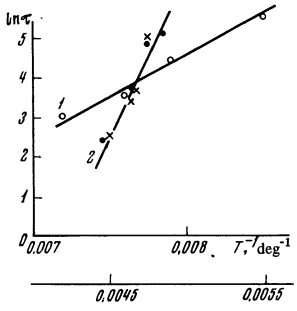

FIG. 3. Dependence of $\tau_{0.8}$ on the inverse of the absolute temperature for polycrystalline terbium (Curve 2, lower scale) and the alloy 83.5 at.% Tb + 16.5 at.% Y (Curve 1, upper scale).

dysprosium. To describe the temperature dependence of the relaxation time τ we used the well-known relation $\tau = \tau_\infty \exp(\epsilon/kT)$, where k is the Boltzmann constant and τ_∞ is a constant. We found that this equation satisfactorily describes the portions of the $\tau(T)$ curves corresponding to the increase of τ upon cooling near Θ_1.

From Fig. 3 it is seen that the dependence of ln τ on 1/T is linear to a first approximation. The following activation energies were found from the slopes of the straight lines: for Dy, $\epsilon \approx 0.2$ eV, for Tb, $\epsilon \approx 0.6$ eV, for the alloy 83.5 at.% Tb + 16.5 at.% Y, $\epsilon \approx 0.2$ eV.

In considering the processes that cause a high magnetic viscosity in these substances, it is necessary first of all to consider the mechanism which associates the viscosity with processes of diffusion of impurity atoms during magnetization. The rare earth metals investigated in our work have a purity of 99.5%, and the principal impurities are rare earth metals and yttrium; the remaining impurities are not greater than 0.1% and consist of iron, copper, and calcium.

The existence of magnetic superviscosity in terbium, dysprosium, and alloys of terbium with relaxation times of the order of tens to hundreds of seconds can obviously not be attributed to the diffusion of impurity atoms, since the temperatures at which this effect is observed are too low. High magnetic relaxation is observed even at 57°K, and there is no tendency for the effect to disappear upon cooling in the interval 57–100°K.

In addition, the activation energies we calculate (of the order of 0.1 eV) are too small for impurity diffusion; they are more characteristic of electronic diffusion.[2] At the present time it is difficult to say anything definite about what mechanism pertains to the appearance of high magnetic viscosity in terbium, dysprosium, and their alloys. We propose that the gigantic magnetostriction characterizing these materials in the region below Θ_1 ($\lambda \sim 10^{-2}$)[3] plays a large part in this mechanism.

Since magnetization causes magnetostrictive tensions in the lattice, directions along the magnetization are preferred. As a result of the creation of these new, equilibrium directions in the crystal a redistribution of the electron density occurs with a certain relaxation time. And this brings about the magnetic viscosity. In gadolinium this mechanism should be much less important, since the magnetostriction of gadolinium[4] is two orders of magnitude less than that of terbium and dysprosium.

In conclusion, the authors express their thanks to V. F. Terekhova and I. A. Markova, who prepared the samples of rare earth alloys, and to K. M. Bol'shova for participating in a discussion of the results.

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