Magnetoelectric effect in terbium molybdate

S. A. Ivanov, V. N. Kurlov, B. K. Ponomarev, and B. S. Red'kin
Institute of Solid State Physics, Academy of Sciences of the USSR

(Submitted 16 July 1990)
Pis'ma Zh. Eksp. Teor. Fiz. **52**, No. 7, 1003–1005 (10 October 1990)

The effect of magnetic fields up to 110 kOe on the electric polarization of a single crystal of the ferroelectric $Tb_2(MoO_4)_3$ has been studied at 77 K and 290 K. A magnetoelectric effect occurs at 77 K: A magnetic field creates an electric polarization of the sample.

The terbium molybdate single crystal was grown by the Czochralski method in an apparatus with induction heating, fitted with a system for automatically controlling the weight of the growing crystal. The starting material was terbium molybdate of stoichiometric composition prepared by the SVS method. The crystals were grown from platinum crucibles in air in the [001] direction at a pulling velocity of 3–8 mm/h and at a rotation velocity of 100 rpm. Terbium molybdate single crystals 90 mm long with a cross section of 25×25 mm were obtained.

We measured the potential difference which arose between the surfaces of the sample oriented perpendicular to the [010] axis during the imposition of a pulsed magnetic field along the [100] axis. The experimental layout is shown in Fig. 1.

The test sample *1* was a plate with dimensions of $1 \times 9 \times 15$ mm. The [001] axis ran perpendicular to the long side of the plate, while the [010] axis was directed along the normal to the plane of the plate. Rectangular pieces of copper foil *2*, with dimensions of $0.05 \times 9 \times 15$ mm, were cemented to the two surfaces of the sample oriented perpendicular to the [010] axis.

The capacitor formed as a result was used as a capacitive polarization detector. This detector was placed inside a pulsed solenoid *3*. A pulsed magnetic field was produced by discharging a capacitor bank into the solenoid. The length of the pulse was 13 ms, and the maximum field was 110 kOe. The field was uniform within 1% over the length of the sample. The field was directed along the long dimension of the sample (the [100] axis).

The voltage from the detector was fed to the input of an electrometer cascade *5*, with an input impedance of $10^9\ \Omega$, and then to the Y plates of a digital storage oscilloscope *6*. The capacitance of the detector was $C_d = 60$ pF, and the capacitance of the cable was $C_c = 520$ pF. A capacitance $C_p = 2000$ pF was connected in parallel with the polarization detector in order to reduce the signal amplitude. The time constant of the input circuit of the detector was 2.58 s, which was considerably longer than the field pulse. In this manner, the voltage pulse from the detector was reproduced essentially perfectly. A signal proportional to the magnetic field of the solenoid was fed to the X plates of the oscilloscope. This signal was created by a field measurement coil *4* and an integrator *7*.

A plot of the voltage across the plates of the polarization detector versus the

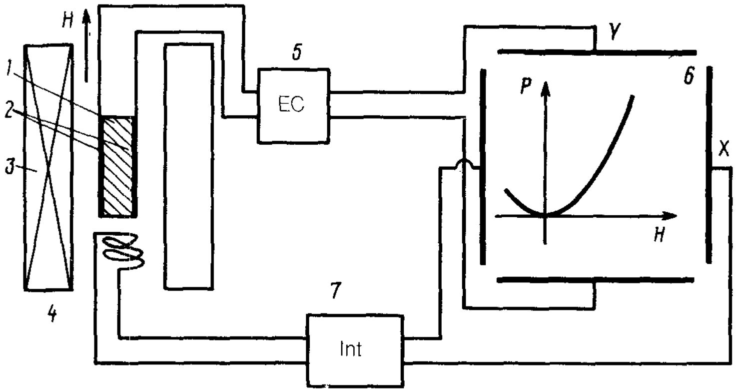

FIG. 1. Experimental layout. 1—Sample; 2—plates of capacitive detector; 3—solenoid; 4—field measurement coil; 5—electrometer cascade; 6—oscilloscope; 7—integrator.

magnetic field was displayed on the oscilloscope screen. This plot was fed from the oscilloscope to a computer. The polarization P of the sample was calculated from the detector output voltage.

Figure 2 shows the sample polarization P along the [010] axis as a function of the magnetic field H, directed along the [100] axis, at $T = 77$ K (curve 1). Curve 2 was

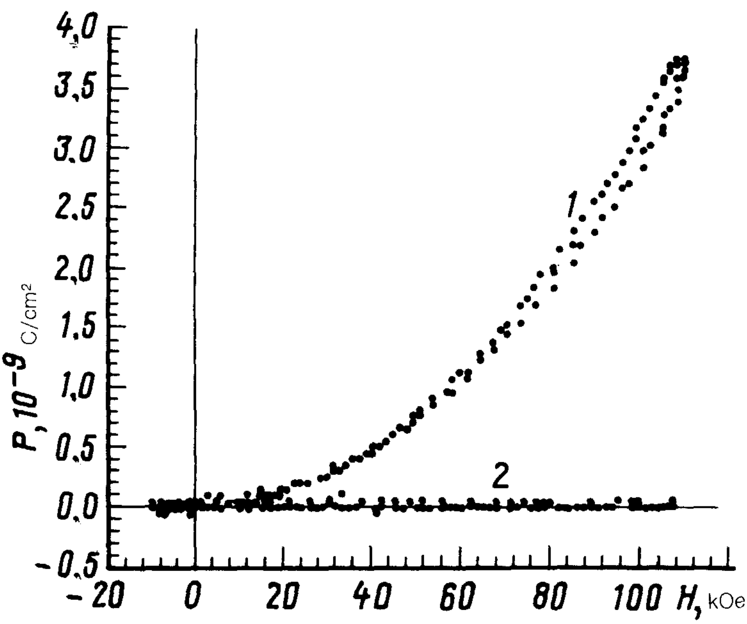

FIG. 2. 1—Polarization of $Tb_2(MoO_4)_3$ along the [010] axis versus the magnetic field, applied along the [100] axis, at $T = 77$ K; 2—null signal.

found from the detector without the sample. We see that the electric polarization P depends on the magnetic field H. At $H = 110$ kOe, the polarization is $P = 3.7 \times 10^{-9}$ C/cm^2, or about 2% of the spontaneous polarization at 298 K, which is $P_s = 0.18 \times 10^{-6}$ C/cm^2 (Ref. 1). The plot of $P(H)$ is approximately quadratic, without any tendency toward saturation up to 110 kOe. The effect does not change sign when the magnetic field is reversed. At $T = 290$ K, the measurements were carried out to values $H \simeq 40$ kOe. Within the experimental error, the polarization was zero ($P < 2 \times 10^{-11}$C/cm^2).

The observed magnetoelectric effect can be explained on the basis that terbium molybdate has ferroelectric properties[1] and also contains paramagnetic terbium ions with a nonzero orbital angular momentum. We know that rare-earth ions with a nonzero orbital angular momentum can be a source of giant magnetostriction deformations,[2,3] which might create an electric polarization in the case at hand by virtue of the effect which is the inverse of electrostriction. This explanation is only a suggestion and requires further research. Preparations for such research are in progress.

We wish to thank E. G. Ponyatovskiĭ, A. V. Serebryakov, and V. M. Teplinskiĭ for useful discussions.

[1] H. J. Borchardt and P. E. Bierstedt, J. Appl. Phys. **38**, 2057 (1967).

[2] K. P. Belov, R. Z. Levitin, and B. K. Ponomarev, Zh. Eksp. Teor. Fiz. **49**, 1733 (1965) [Sov. Phys. JETP **22**, 1185 (1965)].

[3] K. P. Belov, R. Z. Livitin, B. K. Ponomarev, and Yu. F. Popov, Pis'ma Zh. Eksp. Teor. Fiz. **10**, 13 (1969) [JETP Lett. **65**, 108 (1969)].

Translated by D. Parsons