QUADRATIC MAGNETOOPTIC EFFECTS IN FERRO- AND ANTIFERROMAGNETS

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To describe magnetooptic effects in magnetically-ordered crystals it is convenient to introduce into consideration the polarizability tensor $\alpha_{jk}(a)$,[1] which depends on the spin $\vec{S}(a)$ of the paramagnetic ion a [1,2]:

$$a_{jk}(a) = a_{jkl}(a)S_l(a) + a_{jklm}(a)S_l(a)S_m(a) + \dots \quad (1)$$

However, as was shown by us earlier [2], this form is not sufficient, and to describe the symmetrical effects it is necessary to take into account the exchange interaction between the paramagnetic ions a and b:

$$a_{jk}(a,b) = c_{jk}(a,b)S(a)S(b). \quad (2)$$

The forms of the tensors in (1) and (2) are determined by the magnetic symmetry of the crystal.

Allowance for exchange causes the magnitude of the quadratic magnetooptic effects to be determined not by the spin-orbit interaction, which makes a contribution to the symmetrical effects in the second order of perturbation theory, but by the exchange interaction, which makes a contribution in the first order. The relative magnitude of the linear and quadratic effects in such an analysis depends mainly on the ratio of the parameter λ of the spin-orbit interaction to the parameter I of the exchange interaction.

In the present communication we present the results of an experimental investigation of the quadratic Cotton-Mouton effect (CME) in a number of crystals with different magnetic structures. The results confirm the correctness of the proposed mechanism of symmetrical magnetooptic effects and shows that the use of the CME in the investigation of magnetic crystals is promising.

The CME or magnetic birefringence is defined as the phase difference between two light waves propagating in a crystal perpendicular to the magnetization $\vec{M}$ (or the external field $\vec{H}$, and polarized $\vec{\mathcal{E}} \perp \vec{M}$ and $\vec{\mathcal{E}} \parallel \vec{M}$, where $\vec{\mathcal{E}}$ - electric vector of the light wave. In the experiment we determined the phase difference β_{C-M}

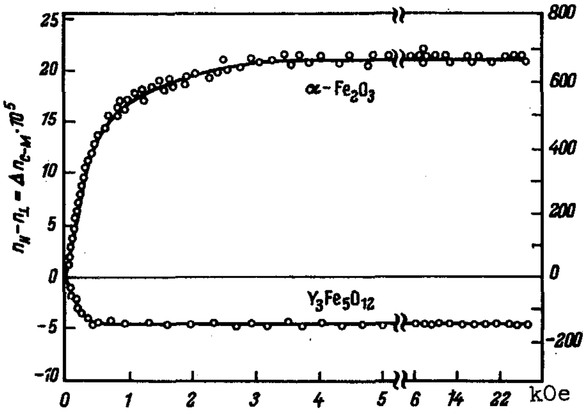

Fig. 1. Dependence of CME on the external magnetic field in $Y_3Fe_5O_{12}$ and in α-Fe_2O_3 at $\lambda = 1.15$ μ.

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[1] For simplicity we take into account in the equation for the polarizability only the contribution of the electric dipole transitions, and disregard the contribution of the magnetic dipole transitions.

Table

Quadratic CME (in a field H = 20 kOe) and linear FE in ferro- and antiferromagnets

Crystal	T_{C-M}, °K	T_{exp}	λ, μ	Δn_{C-M}	β_{C-M}, deg-cm	Δn_F	α_F, deg-cm
$Y_3Fe_5O_{12}$	550	295	1.15	4.5×10^{-5}	141	1.6×10^{-4}	260 [8]
α-Fe_2O_3	950	295	1.15	2.1×10^{-4}	657	-	-
$RbNiF_3$	139	77	0.555	2.2×10^{-5}	142	3×10^{-5}	95
$RbFeF_3$	102	77	0.556	2.5×10^{-4}	1600	2.2×10^{-4}	680 [6]

connected with the difference between the refractive indices Δn_{C-M} [2].

We investigated a cubic ferrimagnet $Y_3Fe_5O_{12}$, a hexagonal uniaxial ferrimagnet of the easy-plane type $RbNiF_3$ [3], a rhombohedral α-Fe_2O_3 crystal, which is a weak ferromagnet of the easy-plane type at 295°K [4], and an $RbFeF_3$ crystal, which is orthorhombic at 77°K and is apparently a weak ferromagnet [5]. To eliminate the effects of linear dichroism due to the light absorption, the measurements were made in the transparency region of the crystals.

The results of the investigation of the CME are listed in the table, which contains for comparison also the magnitude of the linear Faraday effect (FE). Attention is called to the exceedingly large value of the CME in all crystals, sometimes even exceeding the FE. The dependence of CME on the external magnetic field for $Y_3Fe_5O_{12}$ (field directed along one of the crystallographic axes) and for α-Fe_2O_3 (field lies in the basal plane) are shown in Fig. 1. In the absence of the field and in weak fields, the light at the output of the crystal was strongly depolarized in the CME and could not be measured. The depolarization was apparently due to spontaneous birefringence and light scattering by the domain.

It is important to note that the CME in $Y_3Fe_5O_{12}$ and α-Fe_2O_3 has different signs. The reason is that in the ferrimagnet $Y_3Fe_5O_{12}$ the magnetic moments of the two iron sublattices are parallel to the field, while in α-Fe_2O_3 it is the spontaneous moment which is directed along the field, while the magnetic moments of the sublattices, which determine the effect, are perpendicular to the field.

A decrease of the FE in iron garnets [7,8] was recently observed with increasing external magnetic field. We did not observe such a decrease for the CME, and this likewise indicates that the linear and quadratic effects have different microscopic natures.

The temperature investigation of the FE and the CME was made for the ferrimagnet $RbNiF_3$ (Fig. 2). A decrease linear in the magnetization is observed for the FE. On going over into the paramagnetic region, the exchange-dipole part of the polarizability (2) vanishes and the CME decreases rapidly.

From symmetry considerations it is possible to predict a number of new optical pheno-

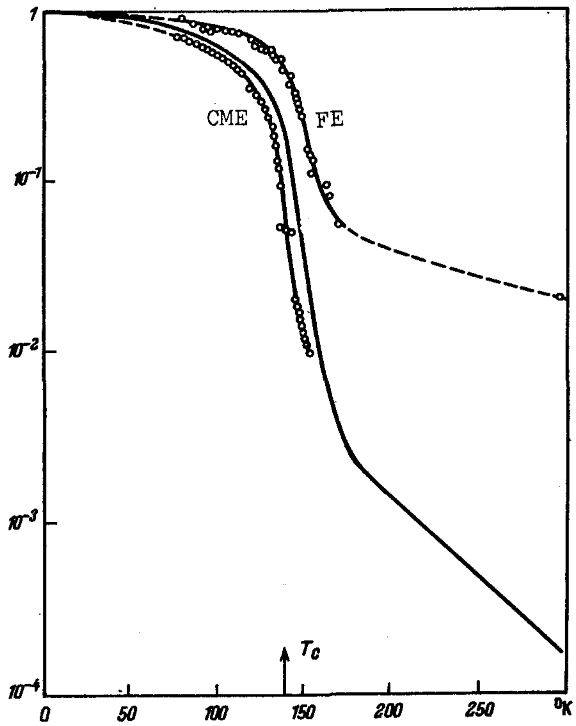

Fig. 2. Temperature dependence of the FE (H = 18 kOe, λ = 1.15 μ) and CME (H = 10 kOe, λ = 0.63 μ) in $RbNiF_3$. The central curve is obtained for the quadratic effects from the FE data. The values of the FE and the CME are given in relative units.

mena in magnetic crystals, due to the CME, such as the existence of the CME in uniaxial ferro- and antiferromagnets without application of an external magnetic field, and the presence of quadratic effects at the point of compensation of the magnetic moments (possibly with reversal of the sign), etc.

The observed large magnitude of the CME (e.g., $\Delta n_{C-M} = 2.1 \times 10^{-4}$ for α-Fe_2O_3 at 295°K) points to the possibility of using quadratic effects as an additional method of investigating magnetic structures and the magnetization of the sublattices. A joint investigation of linear and quadratic effects may be particularly effective. It is of interest to note the weak sensitivity of the CME to ferromagnetic impurities in antiferromagnets. The CME can be used to study the domain structure in the case when the domains are oriented perpendicular to the light propagation. The larger magnitude of the effect (thus, the CME effect in α-Fe_2O_3 greatly exceeds the FE in $Y_3Fe_5O_{12}$ at 295°K) shows that the utilization of quadratic effects in ferromagnets and antiferromagnets is practical for the creation of optical modulators, shutters, and other devices controlled by a magnetic field.

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