Quantum jumps of magneto-optical effects and the magnetization in rare-earth compounds in ultrastrong magnetic fields

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The processes leading to reorientation of the orbital and spin magnetic moments of light rare-earth ions in ultrastrong magnetic fields are investigated theoretically. It is shown that at low temperatures they involve a series of quantum jumps, which are smoothed as the temperature increases, so that the transitions from the ferrimagnetic phase to the canted phase and then to the ferromagnetic phase approximate the classical picture. The features of the behavior of the magnetization, the Faraday effect, and the magnetic linear birefringence of Sm^{3+} and Eu^{3+} ions associated with these quantum reorientation processes in ultrastrong fields are studied.
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1. INTRODUCTION

Methods for generating magnetic fields in the super-megagauss range (1 to 10–15 MG) and measurement techniques for that range have been developed in recent years. They include methods based on the use of low-inductance (single-turn) solenoids[1,2] for fields up to 1–3 MG and magnetoimplosive generators,[3–5] which make it possible to generate a 10–15 MG magnetic field in a fairly large volume. Magnetoimplosive generators designed for even stronger fields are being developed.

One of the most important areas of application of ultrastrong magnetic fields is the investigation of magnetostructural transformations in magnetically ordered materials. Measurements of the dependence of the Faraday effect on the magnetic field strength in ferrimagnets and antiferromagnets have been performed,[1,6–9] and the critical fields for the phase transitions in these materials have been measured. In all these phenomena the phase transitions are usually attributed to the competition between the external magnetic field and the exchange coupling between spins belonging to different ions in the crystal.

Ultrastrong fields make it possible to investigate phenomena in which a magnetic field competes with intra-atomic interactions, primarily with spin–orbit coupling. Such competition is naturally examined in rare-earth compounds, in which, as is widely known, the f subshell of the rare-earth ions maintains the features characteristic of the free ions to a satisfactory extent.

Light rare-earth ions are especially interesting in this respect, since the spin–orbit coupling constant in them is positive, i.e., the spin and orbital magnetic moments have an antiparallel alignment, and therefore a sufficiently strong magnetic field can induce their transition to a parallel alignment.

From this standpoint light rare-earth ions resemble ferrimagnetic systems, in which an external field causes a sequence of transitions from ferromagnetic ordering to a canted structure and then to ferromagnetic ordering of the magnetic moments. Also, in the canted phase there is continuous turning of the sublattices, which is characterized by a constant susceptibility equal to $1/\Lambda$, where Λ is the exchange coupling constant between the sublattices. If this analogy is used, in our case for a single ion we have $\Lambda=(1/2)\mu_B^{-2}\lambda$, where λ is the spin–orbit coupling constant. We see that in an f ion the reorientation of the spin and orbital magnetic moments does, in fact, have some features inherent to the classical reorientation in ferrimagnets and, at the same time, differs qualitatively from the classical process. It takes place at low temperatures as a series of quantum jumps, which are smoothed as the temperature increases, and the process as a whole approximates the classical process just cited. In particular, the critical fields for the transition to the canted structure and the mean "susceptibility" in the canted phase can be described approximately by the same equations as the analogous quantities in the theory of classical spin-reorientation transitions in ferrimagnets and antiferromagnets.

In the present work we investigated the magnetic-field-induced quantum reorientation of the spin and orbital magnetic moments in the Sm^{3+} and Eu^{3+} ions and the field dependences of the Faraday effect, the magnetic linear birefringence, and the magnetization, which are associated with this process, in appropriate rare-earth compounds.

Before proceeding to an analysis of the behavior of the wave functions and the energy spectrum of rare-earth ions in ultrastrong fields, let us briefly examine the relationship between the magneto-optical effects in rare-earth compounds and the quantum characteristics of the f subshell of these ions.

2. ORBITAL AND QUADRUPOLE MOMENTS OF AN *f* ION AND MAGNETO-OPTICAL EFFECTS

The most interesting magneto-optical phenomenon for experiments in ultrastrong fields is the Faraday effect.

The contribution of the magnetic subsystem to the Faraday effect in the near-infrared, optical, and ultraviolet wavelength ranges is usually described by the equation[10]

$$\alpha_F=\frac{\omega^2}{\omega_0^2-\omega^2}\left[2\frac{\omega^2}{\hbar(\omega_0^2-\omega^2)}AH+BH-CM\right], \qquad (1)$$

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where ω_0 is the mean frequency of the actual optical transitions, ω is the frequency of the light, M is the magnetization of the magnetic subsystem, and A, B, and C are coefficients which determine the contributions of the individual microscopic mechanisms. The diamagnetic contribution (the A term) for ions having a nonzero orbital magnetic moment is usually vanishingly small. The main contribution to α_F is made by the paramagnetic C term. The contribution of the mixing (the B term) is quite small at $T \leqslant 300$ K in most cases.

An analysis of the experimental data based on (1) made it possible to account for several aspects of the behavior of the magneto-optical effects in rare-earth compounds (see, for example, Refs. 11–13).

However, Eq. (1), which served as the basis for interpreting the experimental data, was obtained using relatively weak magnetic fields. In fields comparable in magnitude to the spin–orbit splitting of the terms the behavior of the magneto-optical effects should be expected to differ sharply from that described by Eq. (1), as is graphically evinced by the results in Ref. 6, in which the Faraday effect caused by Sm^{3+} ions was investigated experimentally in fields up to 10^7 G.

It should, however, be noted that Pavlovskiĭ[6] used laser radiation with $\lambda = 0.63$ μm, which is very close to the absorption line in this ion.[14] This situation complicates the interpretation of the experimental results, since the resonant contribution to the Faraday effect must then be taken into account. Measurements in the near-infrared region would be more informative.

In the near-infrared, visible, and ultraviolet regions of the spectrum, the magneto-optical effects are described by the corrections $\delta\varepsilon_{ij}$ to the dielectric tensor, which depend on the magnetic field. The contribution of the rare-earth ions to $\delta\varepsilon_{ij}$ is determined by the components of the polarizability tensor of the ions

$$\alpha_{ij} = \sum_{eg} \rho_g \left\{ \frac{\langle g|d_i|e\rangle\langle e|d_j|g\rangle}{\hbar\omega + (E_e - E_g)} - \frac{\langle g|d_j|e\rangle\langle e|d_i|g\rangle}{\hbar\omega - (E_e - E_g)} \right\}, \tag{2}$$

where d_i is a component of the dipole moment of the ion, $|g\rangle$, E_g, $|e\rangle$, and E_e are, respectively, the wave functions and energy levels of the ground (thermally populated) and excited states of the ion, and ρ_g is the population of the level.

The main contribution to (2) is made by the $4f^N - 4f^{N-1}5d$ electric-dipole transitions. The actual states $|g\rangle$ are states of the ground L_0S_0 term. The LS terms can serve as the unperturbed states of the $4f^{N-1}5d$ configuration. This also applies to crystalline samples and corresponds to the mean-field approximation.[15] In this case it can be shown that the tensor components α_{ij} (2) take the form[16–20]

$$\alpha_{ij} = d_1 i e_{ijk}\langle L_k\rangle + d_2 i e_{ijk} H_k + \delta\langle Q_{ij}\rangle, \tag{3}$$

where $\langle L_k\rangle$ is the mean value of the respective component of the orbital angular momentum of the $4f$ subshell of the ion, $\langle Q_{ij}\rangle$ is the mean quadrupole moment of the rare-earth ion, and d_1, d_2, and δ are coefficients which depend on the frequency of the light. It follows from (3) that for the Faraday effect, instead of (1), we have (in a coordinate system with $\mathbf{H}\|z$)

$$\alpha_F = C\langle L_z\rangle + V_D H. \tag{4}$$

The first term in (4) is a combination of the paramagnetic contribution and the mixing contribution to α_F, and the second term is the diamagnetic contribution. In fields up to 10^8 G it can be assumed that V_D does not depend on the magnetic field.[6] For most compounds $V_D \sim 3\times10^{-4}$ to 8×10^{-4} deg/cm·G, and in fields $H \gtrsim 10^7$ G the diamagnetic term can be predominant.

Great importance is attached to the fact that α_F [see (4)] is determined by the mean value of the orbital angular momentum $\langle L_z\rangle$, which permits the direct use of measurements of the Faraday effect to study processes involving the reorientation of atomic angular momenta in ultrastrong fields.

Another important characteristic, which is very sensitive to the reorientation of $\mathbf{S}$ and $\mathbf{L}$, is the magnetic linear birefringence. This effect is specified by the last term in Eq. (3) for the polarizability α_{ij}.

Using (3), we can show that the magnetic-field-dependent difference Δn between the refractive indices of the ordinary and extraordinary waves propagating perpendicularly to a magnetic field $\mathbf{H}$ equals[16–20]

$$\Delta n = A(\langle O_{20}(\mathbf{L})\rangle_H - \langle O_{20}(\mathbf{L})\rangle_{H=0}), \tag{5}$$

where $O_{20}(\mathbf{L})$ is the quadrupole moment operator of the rare-earth ion and A is a function of the frequency.

3. FIELD DEPENDENCE OF THE ENERGY SPECTRUM. CASCADE OF GROUND-STATE LEVEL CROSSINGS

To study the behavior of the magnetization, the Faraday effect, and the magnetic linear birefringence in ultrastrong fields, the wave functions and the energy levels of the rare-earth ions must be determined. The actual Hamiltonian of the problem is

$$\mathcal{H} = \mu_B(\mathbf{L}+2\mathbf{S})\cdot\mathbf{H} + \lambda\mathbf{L}\cdot\mathbf{S} + \mathcal{H}_{cr}, \tag{6}$$

where $\mathcal{H}_{cr}$ is the crystal-field Hamiltonian.

Setting $\mathbf{M}_1 = \mu_B\mathbf{L}$, $\mathbf{M}_2 = 2\mu_B\mathbf{S}$, and $\Lambda = \lambda/2\mu_B^2$, we can easily see the aforementioned analogy to the Hamiltonian of the birefringence of a ferrimagnet. Here the term $\mathcal{H}_{cr}$ plays a role similar to the magnetic anisotropy in the case of a ferrimagnet.

At first we neglect the influence of the crystal field.

In this case the matrix

$$\mathcal{H}_{so} + \mathcal{H}_Z,$$

where

$$\mathcal{H}_{so} = \lambda\mathbf{L}\cdot\mathbf{S}, \quad \mathcal{H}_Z = \mu_B(\mathbf{L}+2\mathbf{S})\cdot\mathbf{H},$$

in the space of the functions $|JM\rangle$ ($J = |L-S|, \ldots, L+S$) is divided into blocks representing three-diagonal (Jacobian) matrices, whose order is specified by the value of M.

The nonzero matrix elements of the Hamiltonian (6) have the form

TABLE I. Magnetic field strength and wave functions of the Sm^{3+} ion at the crossing points of the lowest levels.

$h=2.14$	$\Psi_{0-5/2}=0.603\|5/2-5/2\rangle+0.713\|7/2-5/2\rangle+$ $+0.347\|9/2-5/2\rangle+0.090\|11/2-5/2\rangle+$ $+0.013\|13/2-5/2\rangle+0.001\|15/2-5/2\rangle$, $\Psi_{0-7/2}=0.836\|7/2-7/2\rangle+0.525\|9/2-7/2\rangle+$ $+0.156\|11/2-7/2\rangle+0.025\|13/2-7/2\rangle+$ $+0.002\|15/2-7/2\rangle$.
$h=2.91$	$\Psi_{0-7/2}=0.723\|7/2-7/2\rangle+0.639\|9/2-7/2\rangle+$ $+0.262\|11/2-7/2\rangle+0.058\|13/2-7/2\rangle+$ $+0.007\|15/2-7/2\rangle$, $\Psi_{0-9/2}=0.869\|9/2-9/2\rangle+0.477\|11/2-9/2\rangle+$ $+0.124\|13/2-9/2\rangle+0.015\|15/2-9/2\rangle$.
$h=3.62$	$\Psi_{0-9/2}=0.808\|9/2-9/2\rangle+0.559\|11/2-9/2\rangle+$ $+0.182\|13/2-9/2\rangle+0.028\|15/2-9/2\rangle$, $\Psi_{0-11/2}=0.913\|11/2-11/2\rangle+0.401\|13/2-11/2\rangle+$ $+0.074\|15/2-11/2\rangle$.
$h=4.32$	$\Psi_{0-11/2}=0.880\|11/2-11/2\rangle+0.463\|13/2-11/2\rangle+$ $+0.104\|15/2-11/2\rangle$, $\Psi_{0-13/2}=0.957\|13/2-13/2\rangle+0.291\|15/2-13/2\rangle$.
$h=5.00$	$\Psi_{0-13/2}=0.943\|13/2-13/2\rangle+0.333\|15/2-13/2\rangle$, $\Psi_{0-15/2}=\|15/2-15/2\rangle$.

TABLE II. Magnetic field strength and wave functions of the Eu^{3+} ion at the crossing points of the lowest levels.

$h=1.7$	$\Psi_{00}=0.636\|00\rangle+0.683\|10\rangle+0.344\|20\rangle+$ $+0.102\|30\rangle+0.019\|40\rangle+0.002\|50\rangle$, $\Psi_{0-1}=0.748\|1-1\rangle+0.616\|2-1\rangle+0.241\|3-1\rangle+$ $+0.053\|4-1\rangle+0.007\|5-1\rangle$.
$h=2.18$	$\Psi_{0-1}=0.699\|1-1\rangle+0.647\|2-1\rangle+0.295\|3-1\rangle+$ $+0.078\|4-1\rangle+0.012\|5-1\rangle+0.001\|6-1\rangle$, $\Psi_{0-2}=0.815\|2-2\rangle+0.550\|3-2\rangle+0.181\|4-2\rangle+$ $+0.032\|5-2\rangle+0.003\|6-2\rangle$.
$h=2.72$	$\Psi_{0-2}=0.769\|2-2\rangle+0.594\|3-2\rangle+0.229\|4-2\rangle+$ $+0.050\|5-2\rangle+0.005\|6-2\rangle$, $\Psi_{0-3}=0.869\|3-3\rangle+0.479\|4-3\rangle+0.126\|5-3\rangle+$ $+0.016\|6-3\rangle$.
$h=3.29$	$\Psi_{0-3}=0.834\|3-3\rangle+0.526\|4-3\rangle+0.161\|5-3\rangle+$ $+0.025\|6-3\rangle$, $\Psi_{0-4}=0.916\|4-4\rangle+0.394\|5-4\rangle+0.073\|6-4\rangle$.
$h=3.89$	$\Psi_{0-4}=0.893\|4-4\rangle+0.438\|5-4\rangle+0.093\|6-4\rangle$, $\Psi_{0-5}=0.959\|5-5\rangle+0.284\|6-5\rangle$.
$h=4.5$	$\Psi_{0-5}=0.949\|5-5\rangle+0.316\|6-5\rangle$, $\Psi_{0-6}=\|6-6\rangle$.

$$\langle J,M|\mathcal{H}|J,M\rangle=\frac{\lambda}{2}(J(J+1)-L(L+1)-S(S+1))+\mu_B g_J HM, \tag{7}$$

$$\langle J+1,M|\mathcal{H}|J,M\rangle=\langle J,M|\mathcal{H}|J+1,M\rangle=S^J_M\mu_B H,$$

where g_J is the Landé factor,

$$S^J_M=g'_J[(J+1)^2-M^2]^{1/2},$$

$$g'_J=-\left\{\frac{(L+S+J+2)(L+S-J)(L-S+J+1)(S-L+J+1)}{4(2J+1)(2J+3)(J+1)^2}\right\}^{1/2}.$$

One characteristic feature of the quantum system under consideration is the fact that when $H=0$ the energies of the levels increase with the quantum number J. Since the energies of the levels with large J decrease more rapidly as the field H increases than do the energies of the levels with small J, there is a sequence of field strength values at which the two lowest levels cross and the ground state subsequently changes from $J=|L-S|$ to $J=|L+S|$. From this standpoint there is interest in the analogy between the system under consideration and high-spin molecular clusters with antiferromagnetic interactions between the spins (for example, $Mn_{12}Ac$, Fe_{10}, etc.[21,22]).

In the present work we determined the energy levels E_{iM} and the eigenfunctions Ψ_{iM}, which have the form

$$\Psi_{iM}=\sum_J C_{iMJ}(H)|J,M\rangle,$$

where $i=0,\dots,L+S-|M|$, for the Sm^{3+} ($L=5$, $S=5/2$) and Eu^{3+} ($L=S=3$) ions in fields up to H_{crit}, where

$$H_{crit}=\left(\frac{\lambda}{\mu_B}\right)\times\frac{(L+S)^3 g_{L+S}}{(L+S)^2[g^2_{L+S}+(L+S-1)g_{L+S}(g_{L+S}-g_{L+S-1})]-LS} \tag{8}$$

is, as can easily be seen, the value of the field intensity at which the last crossing of the lowest levels occurs and the sequence of changes in the ground state of the ion ends. In (8) g_J is the Landé factor of the corresponding multiplet. The relative values of the fields $h=\mu_B H/\lambda$ at which crossings of the lowest levels occur and the corresponding wave functions Ψ_{0m} at the crossing points are presented in Tables I and II. Then the formulas

$$\langle f\rangle=\sum_{iM}\langle\Psi_{iM}|f|\Psi_{iM}\rangle\rho_{iM},$$

$$\rho_{iM}=Z^{-1}\exp(-E_{iM}/kT),\quad Z=\sum_{iM}\exp(-E_{iM}/kT)$$

were used to calculate the mean values $\langle L_z\rangle$, $\langle 2S_z\rangle$, $\langle L_z+2S_z\rangle$, and $\langle O_{20}(\mathbf{L})\rangle$ as functions of the magnetic field strength at various temperatures. We also analyzed the influence of a crystal field of the very simple form

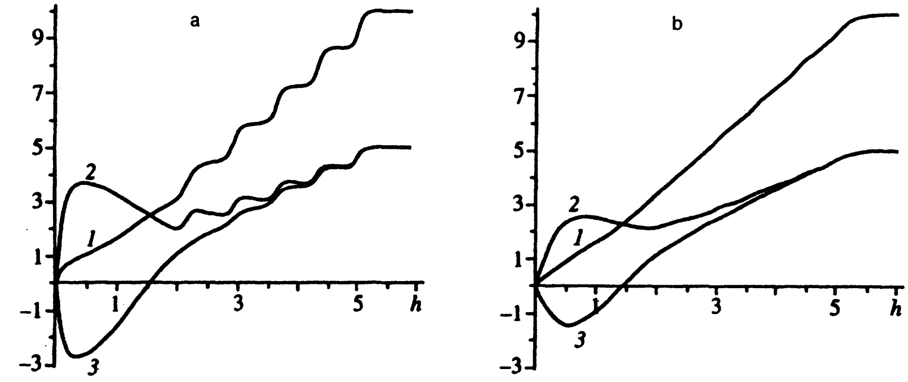

FIG. 1. Dependence of the total magnetic moment (*1*), the orbital magnetic moment (2), and the spin magnetic moment (*3*) of the Sm^{3+} ion on the magnetic field strength $h=\mu_B H/\lambda$; the magnetic moments are measured in units of μ_B; $\tau \equiv kT/\lambda = 0.05$ (a), 0.19 (b).

$$\mathcal{H}_{cr}=BO_{20}(\mathbf{L}) \qquad (9)$$

on the behavior of the orbital, spin, and quadrupole moments in ultrastrong magnetic fields.

The results are presented in Figs. 1–4 (in relative units of $h=\mu_B H/\lambda$ and $\tau=kT/\lambda$).

4. DISCUSSION

4.1. The Sm^{3+} ion

The field and temperature dependences of the orbital magnetic moment, the spin magnetic moment, the magnetization, and the quadrupole moment are presented in Figs. 1 and 2. The scale values of the field strength and the temperature for Sm^{3+} are: $\lambda/\mu_B \approx 6$ MG and $\lambda/k \approx 400$ K. In the analogy between classical spin-reorientation transitions and the reorientation of **S** and **L** in an ion considered in the Introduction, the Sm^{3+} ion ($L=5$, $S=5/2$) is similar to an antiferromagnet. From the classical standpoint its orbital magnetic moment $M_o=\mu_B L=5\mu_B$ is equal in magnitude to the spin magnetic moment $M_s=2\mu_B S$; therefore, in the absence of anisotropy (i.e., $\mathcal{H}_{cr}$) the appearance of a quantum analog of spin flop (overturning of the sublattices) might be expected in a zero field (M_o and M_s are almost perpendicular to **H**, and their projections onto **H** are positive). However, as is seen from Fig. 1a, this does not occur. The projections of the orbital ($\langle L_z \rangle$) and spin ($\langle 2S_z \rangle$) magnetic moments onto the direction of the field are opposite in sign up to fields $h \sim 1.5$. This behavior can be interpreted as a consequence of quantum fluctuations or, in other words, as the presence of longitudinal spin and orbital susceptibilities. The values of $\langle L_z \rangle$ and $\langle 2S_z \rangle$ become equal to one another when $h \gtrsim 4$. This value is very close to the critical field for collapse of the magnetic moments, which is given by (8) and whose relative value for Sm^{3+} equals $h_{crit}=5$. The corresponding "classical" expression for the critical field $H_{crit}=2\Lambda M_o$ [$\Lambda=(1/2)\mu_B^{-2}\lambda$] also leads to $h_{crit}=5$.

The quantum jumps of the orbital magnetic moment, the spin magnetic moment, and the quadrupole moment caused by the crossing of the lowest levels of Sm^{3+} ions in a field are clearly displayed at low temperatures (Figs. 1a and 2). At relatively high temperatures (see, for example Fig. 1b) the calculated magnetization is described with a sufficient degree of accuracy by the constant susceptibility $\chi=2\mu_B^2/\lambda$, in agreement with the classical models ($\chi=1/\Lambda$). It is noteworthy that for both $B<0$ (an easy axis) and $B>0$ (an easy plane) the influence of the crystal field (9) (we investigated the simplest case of $\mathbf{H}\|\mathbf{Z}$) does not qualitatively alter the picture of the reorientation of the magnetic moments in fields $h<2$, while the picture of the behavior of the quadrupole moment in weak fields is altered significantly (Fig. 2a). In some cases the crystal field causes the two crossings of the lowest levels to coincide and, accordingly, causes the jumps of the angular momenta and the quadrupole moment to coincide. A nonmonotonic character of the variation of the con-

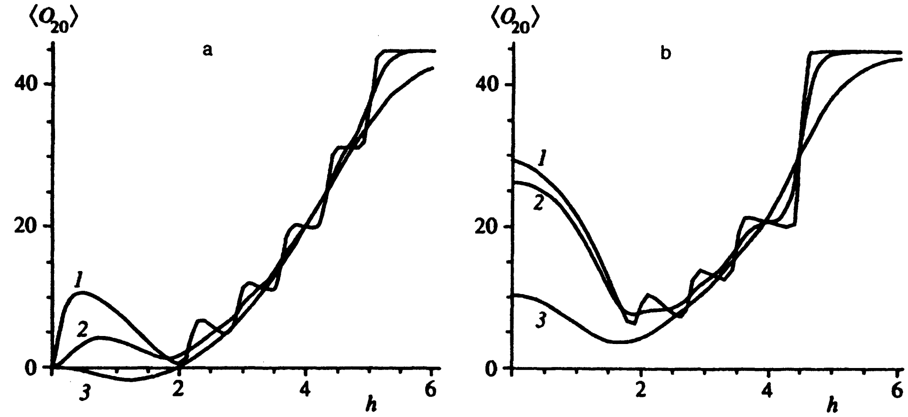

FIG. 2. Dependence of the quadrupole moment $\langle O_{20}(\mathbf{L}) \rangle$ of the Sm^{3+} ion on the magnetic field strength $h=\mu_B H/\lambda$; $\tau \equiv kT/\lambda = 0.05$ (*1*), 0.19 (*2*), 0.73 (*3*); a — without consideration of the crystal field ($B=0$), b — when $B/\lambda=-0.0145$.

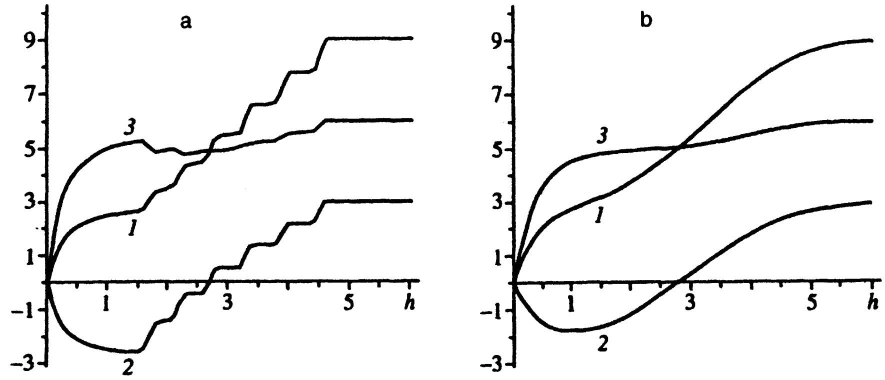

FIG. 3. Dependence of the total magnetic moment (*1*), the orbital magnetic moment (*2*), and the spin magnetic moment (*3*) of the Eu^{3+} ion on the magnetic field strength $h=\mu_B H/\lambda$; the magnetic moments are measured in units of μ_B; $\tau \equiv kT/\lambda = 0.035$ (a), 0.67 (b).

tribution of Sm^{3+} ions to the Faraday effect and to the magnetic linear birefringence as the field increases follows from Figs. 1 and 2 and Eqs. (4) and (5).

4.2. The Eu^{3+} ion

The principal dependences are presented in Figs. 3 and 4. The scale values of the field strength and the temperature for Eu^{3+} are $\lambda/\mu_B \approx 8$ MG and $\lambda/k \approx 530$ K.

From the classical standpoint, the Eu^{3+} ion ($L=3$, $S=3$) is an analog of a ferrimagnet, despite the fact that its ground state is a singlet with a zero total angular momentum. Its spin magnetic moment $M_s = 2\mu_B S$ is twice the orbital magnetic moment $M_o = \mu_B L$. The picture of the reorientation of the orbital and spin magnetic moments in a magnetic field is presented in Fig. 3. It is seen from Fig. 3 that the transition from the ferrimagnetic phase to the canted phase occurs at $h_1 \simeq 1.5$ and that the transition from the canted phase to the ferromagnetic phase occurs at $h_{\text{crit}} = \mu_B H_{\text{crit}}/\lambda = 4.5$ [see Eq. (8)]. The values of h_1 and h_{crit} correspond completely to the classical values of the fields for the transitions from the ferrimagnetic phase to the canted phase $[H_1 = \Lambda(M_s - M_o)]$ and from the canted phase to the ferromagnetic phase $[H_2 = \Lambda(M_s - M_o)]$. At low temperatures the reorientation process involves a series of quantum jumps (Fig. 3a), which are smoothed as the temperature increases (Fig. 3b); when $\tau \gtrsim 0.17$ (this condition corresponds to $T \gtrsim 87$ K) the behavior of the magnetization for $h > h_1$ corresponds completely to the classical behavior [for $h_1 < h < h_2$ the magnetization is described using a constant magnetic susceptibility equal to $2\mu_B^2/\lambda(l/\Lambda)$]. We also note the pronounced nonmonotonic character of the field variation of the magnetic linear birefringence ($\langle O_{20} \rangle$, Fig. 4) and the Faraday effect ($\langle L_z \rangle$, Fig. 3) in ultrastrong fields.

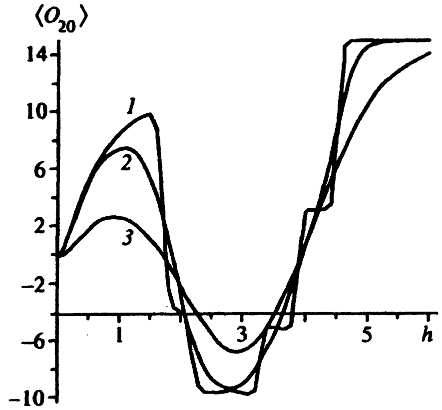

FIG. 4. Dependence of the quadrupole moment $\langle O_{20}(\mathrm{L}) \rangle$ of the Eu^{3+} ion on the magnetic field strength $h=\mu_B H/\lambda$; $\tau \equiv kT/\lambda = 0.035$ (*1*), 0.17 (*2*), 0.67 (*3*).

5. CONCLUSIONS

It has been shown in this paper that an external magnetic field, competing with the spin–orbit coupling in light rare-earth ions, induces reorientation of the spin and orbital magnetic moments of an ion, which is analogous to some extent to the process occurring in ferrimagnets. Unlike the latter process, which is continuous and takes place with a constant susceptibility in the canted phase in the isotropic case, the quantum reorientation of the spin and orbital magnetic moments has a discrete character and takes place as a series of quantum jumps. The relationship between these jumps and the crossings of the ground-state levels appearing in the magnetic field has been revealed. Discrete reorientation induced by a magnetic field has also been observed in ferrimagnets (see, for example, Ref. 23 and the literature cited therein), but it is caused in them by the influence of effects due to the strong crystal field. In the situation considered here the discrete nature of the magnetization process is observed in the isotropic case and has a fundamentally quantum character. In light rare-earth ions quantum reorientation takes place in 1–50 MG fields. The initial stage of this process is accessible to experimental study using existing magnetoimplosive generators.[4,5] The Faraday effect is of greatest interest for investigating the quantum reorientation of the spin and orbital magnetic moments, since in the case of ions with $L \neq 0$ it responds only to the orbital magnetic moment of the ion and not to its total magnetic moment.

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