Parity nonconservation effects in nonlinear optics

M. G. Kozlov and S. P. Porsev

Leningrad Institute of Nuclear Physics, USSR Academy of Sciences
(Submitted 18 July 1989)
Zh. Eksp. Teor. Fiz. **97**, 154–161 (January 1990)

We discuss P-odd effects in light propagation in a longitudinal magnetic field. We show that the P-odd light-wave phase shift δ_p, which depends on the **H·k** correlation, reaches in an optimal magnetic field the same value as the P-odd polarization-plane rotation. In linear and nonlinear optics, the optimal fields H_0 and H'_0 differ by several orders of magnitude. For the $6p_{1/2}\to 6p_{3/2}$ transition in thallium $|\delta_p|\sim 10^{-7}$, $H_0\sim 10^3$ Oe, and $H'_0\sim 10^{-2}$ Oe.

The possible use of linear optics in an experimental search for breaking of fundamental smmetries connected with space inversion (P) and with time reversal (T) is being discussed of late.[1,2] We examine in the present paper, using a simple example, the influence of nonlinearities on a number of effects discussed in Refs. 3 and 4.[1)]

We consider to this end the transition between atomic level with total angular momenta $F=0$ and $F'=1$ in a plane-polarized laser beam directed along a constant magnetic field **H**. This model system was used to study the nonlinear Faraday effect.[9–12] It exhibits several effects connected with p-parity nonconservation and corresponding to correlations **s·k** and **H·k**, where **s** and **k** are the spin and propagation direction of the photon. A change to larger saturation parameters enhances, as in the case of the Faraday effect, the p-odd effects connected with the **H·k** correlation.

One can expect, from general considerations, similar effects to be produced also by P- and T-odd interactions when finite atomic-level widths are taken into account. It has been shown in Ref. 3, however, that this is not the case in linear optics. We prove below that no P- or T-odd effects arise when nonlinearity is taken into account.

To observe parity-nonconservation effects it is preferable to operate with magnetically induced (MI) transitions.[13] The reason is that it is difficult to have an optical length comparable with the absorption length simultaneously with a large saturation parameter. The former condition ensures an optimal signal/noise ratio and requires high gas densities, whereas the latter can be met only for small impact widths. A compromise situation occurs apparently for the $6p_{1/2}(F=0,1)\to 6p_{3/2}(F=1,2)$ transition in thallium.[13,14] The absorption length for this element is $L_0\sim 1$ m at a concentration $N\sim 10^{14}$ cm^{-3}. The impact width is $\Gamma_{\rm imp}\sim 10^4$ Hz (Ref. 13, §6.2), so that this transition can be saturated at a laser power ~ 10 mW.

INTERACTION OF AN ATOM WITH A LIGHT WAVE

We assume a quantization axis Z parallel to the magnetic field

$$\mathbf{E}=E(z)\mathbf{e}(z)\cos\chi,\ \chi=\omega t-kz. \tag{1}$$

As noted in Ref. 12, the influence of the medium on the field (1) can be described by a generalized polarization vector

$$\begin{aligned}\mathbf{\Pi}&=\mathbf{P}-[\mathbf{\nu M}]\\ &=(\Pi_1\cos\chi+\Pi_2\sin\chi)\mathbf{e}+(\Pi_3\cos\chi+\Pi_4\sin\chi)[\mathbf{\nu e}],\end{aligned} \tag{2}$$

where **P** and **M** are the electric and magnetic polarization vectors, and $\boldsymbol{\nu}=\mathbf{k}/|\mathbf{k}|$ is the wave-propagation direction. The four components of the polarization (2) determine the dispersion, absorption, dichroism, and optical rotation.

The operator of the interaction between the field (1) and the atom is expressed in terms of the electric and magnetic moment operators $\hat{\mathbf{D}}$ and $\hat{\boldsymbol{\mu}}$:

$$\hat{V}=-(\hat{\mathbf{D}}-[\boldsymbol{\nu}\hat{\boldsymbol{\mu}}])\mathbf{E}\equiv-\hat{\mathbf{\Pi}}\mathbf{E}. \tag{3}$$

The polarization (2) is also expressed in terms of the operator $\hat{\mathbf{\Pi}}$:

$$\mathbf{\Pi}=\langle \mathrm{Sp}(\hat{\mathbf{\Pi}}\rho)\rangle, \tag{4}$$

where the angle brackets denote averaging over the atom velocities and ρ is the density matrix.

We assume that the two states of the atom with $F=0$ and $F=1$ are connected by an MI transition whose amplitude, according to (3), is

$$A_\mu=-iq\nu\mu_q e_{-q}E, \tag{5}$$

where $q=\pm 1$ numbers the spherical components of the vectors $\boldsymbol{\mu}$ and **e**, and the magnetic field of the wave is expressed in terms of the electric field (1). The parity-nonconserving interactions lead to the onset of an electric-dipole amplitude[13]

$$A_D=(i\eta_P+\eta_{P,T})D_q e_{-q}E. \tag{5a}$$

Here η_P and $\eta_{P,T}$ are determined by admixture of opposite-parity states due to P-odd only and to P-odd plus T-odd interactions, respectively. As a result, the amplitude of the transition

$$|F=0,\ m=0\rangle\to|F'=1,\ m'=q\rangle$$

is equal to

$$A=-iq\nu(\mu_q+q\nu(-\eta_P+i\eta_{P,T})D_q)e_{-q}E. \tag{6}$$

Accurate to first order in η_P and $\eta_{P,T}$, a phase factor can be separated in this amplitude

$$A=\exp[iq\nu(\eta_{P,T}D_q/\mu_q-\pi/2)](\mu_q-q\nu\eta_P D_q)e_{-q}E. \tag{6a}$$

P-parity nonconservation leads thus to a difference between the absolute values of the amplitudes of the transitions $0\to+1$ and $0\to-1$, whereas simultaneous violation of P and T parities generates an additional phase.

Let us eliminate the phase factor in (6a) by a phase transformation. Then, directing the X axis along the wave-polarization vector, we obtain in the basis of the states $|+\rangle\equiv|1,1\rangle$, $|-\rangle\equiv|1,-1\rangle$, and $|0\rangle\equiv|0,0\rangle$ the following

 0038-5646/90/010085-05$03.00

expression for the system Hamiltonian:

$$H_0+V=\begin{vmatrix}\omega_0+\varepsilon & 0 & 0\\ 0 & \omega_0-\varepsilon & 0\\ 0 & 0 & 0\end{vmatrix}+\begin{vmatrix}0 & 0 & \alpha_+\\ 0 & 0 & \alpha_-\\ \alpha_+^* & \alpha_-^* & 0\end{vmatrix}\cos\chi, \quad (7)$$

where $\varepsilon=-\mu_0H_0$ is the Zeeman splitting, ω_0 the transition frequency, H_0 the external field,

$$\alpha_\pm=\alpha(1\pm\delta_P),\ \alpha=2^{-1/2}\mu_1E, \quad (8)$$

and

$$\delta_P=-\nu\eta_PD_1/\mu_1.$$

Obviously, in the new phase relation the factor $\eta_{P,T}$ is eliminated not only from the Hamiltonian (7) but also from the polarization (4) whose components can be expressed in terms of the amplitude (6a). We verify as a result that a *P, T*-odd interaction does not change the polarization Π induced by the electromagnetic field, and consequently does not affect the passage of light through the substance. This was demonstrated in Ref. 3 for the linear case.

EQUATIONS FOR THE ATOM DENSITY MATRIX

Examination of the Faraday effect[12] yielded significantly different results for the transitions $0\to1$ and $1\to0$ corresponding to the so-called V and Λ systems. The reason is that for the EI transition the width of the upper level is much larger than that of the lower. For the MI transition, on the contrary, the radiative width is small compared with the width determined by the time of interaction of the atom with the light wave. The widths of both levels are therefore of the same order in our case and the results for V and Λ systems do not differ in principle. To be specific, we consider a V system (Fig. 1).

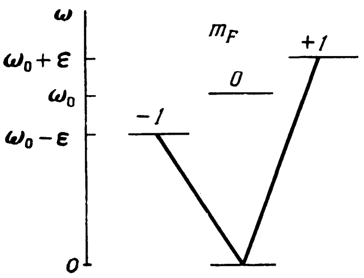

FIG. 1. The transition $F=0\to F'=1$ in a plane-parallel field of a wave propagating along a magnetic field. The lines join levels coupled by the wave field.

In the stationary regime the equations for the elements of the density matrix are[15]

$$\begin{aligned}
&\gamma_1\rho_{++}=-\mathrm{Im}(\alpha_+^*x_{+0})+\lambda_1,\\
&\gamma_1\rho_{--}=-\mathrm{Im}(\alpha_-^*x_{-0})+\lambda_1,\\
&\gamma_0\rho_{00}=\mathrm{Im}(\alpha_+^*x_{+0}+\alpha_-^*x_{-0})+\lambda_0,\\
&(\gamma+2i\varepsilon)\rho_{+-}={}^1/_2i(\alpha_-^*x_{+0}-\alpha_+x_{-0}^*),\\
&[\Gamma+i(\Delta+\varepsilon)]x_{+0}={}^1/_2i\alpha_+(\rho_{++}-\rho_{00})\\
&\qquad+{}^1/_2i\alpha_-\rho_{+-},\\
&[\Gamma+i(\Delta-\varepsilon)]x_{-0}={}^1/_2i\alpha_-(\rho_{--}-\rho_{00})\\
&\qquad+{}^1/_2i\alpha_+\rho_{+-}^*,\\
&x_{\pm0}=e^{i\omega t}\rho_{\pm0}.
\end{aligned} \quad (9)$$

In these equations λ_i and γ_i describe respectively incoherent pumping to the levels 0 and $\pm$ and their widths, γ and Γ are the widths of the transitions ($\gamma\geqslant\gamma_1$, $\Gamma\geqslant(\gamma_0+\gamma_1)/2$), while $\Delta=\omega_0-\omega$ is the detuning from resonance. The system (9) was obtained without allowance for the nonresonant part of the interaction (3).

To calculate the polarization (4) it suffices to know the matrix elements x_{+0} and x_{-0}. Introducing real variables a, b, c, and d defined by the relations

$$a+ib=x_{+0}+x_{-0},\ c+id=x_{+0}-x_{-0}, \quad (10)$$

we obtain in place of the system (9), accurate to terms linear in δ_P,

$$\left(\begin{vmatrix}-\Gamma & \Delta & 0 & \varepsilon\\ \Delta & \Gamma_2' & \varepsilon' & 0\\ 0 & \varepsilon' -\Gamma' & \Delta & \\ \varepsilon & 0 & \Delta & \Gamma_1\end{vmatrix}+\frac{\alpha^2}{2}\delta_P\begin{vmatrix}0 & L_2 & L_1 & 0\\ L_2 & 0 & 0 & L_3\\ L_1 & 0 & 0 & L_2\\ 0 & L_3 & L_2 & 0\end{vmatrix}\right)\begin{vmatrix}a\\ b\\ c\\ d\end{vmatrix}=\alpha N\begin{vmatrix}0\\ 1\\ 0\\ \delta_P\end{vmatrix}. \quad (11)$$

In this system

$$\begin{aligned}
&L_1+iL_2=\frac{\gamma+2i\varepsilon}{\gamma^2+4\varepsilon^2},\quad L_3=4\Gamma/\gamma_0\gamma_1-L_1,\\
&N=\lambda_1/\gamma_1-\lambda_0/\gamma_0,\ \varepsilon'=\varepsilon(1+\alpha^2L_2/2),\\
&\Gamma_1=\Gamma+\alpha^2/2\gamma_1,\ \Gamma'=\Gamma+\alpha^2L_1/2,\ \Gamma_2'=\Gamma'+\alpha^2/2\gamma_1+\alpha^2/\gamma_0.
\end{aligned} \quad (12)$$

P-ODD INTERACTION. LINEAR LIMIT

In the approximation linear in the laser-field strength, the parameter δ_P is contained only in the right-hand side of the system (11). In addition, the matrix A in the left-hand side acquires a high symmetry. In first order in δ_P the system (11) is transformed into

$$\begin{vmatrix}-\Gamma & \Delta & 0 & \varepsilon\\ \Delta & \Gamma & \varepsilon & 0\\ 0 & \varepsilon & -\Gamma & \Delta\\ \varepsilon & 0 & \Delta & \Gamma\end{vmatrix}\begin{vmatrix}a_P\\ b_P\\ c_P\\ d_P\end{vmatrix}=\alpha N\delta_P\begin{vmatrix}0\\ 0\\ 0\\ 1\end{vmatrix}. \quad (13)$$

Since the matrix in the left-hand side is symmetric, the solution of this system is expressed in terms of the system solution in zeroth order in δ_P

$$\begin{vmatrix}a_P\\ b_P\\ c_P\\ d_P\end{vmatrix}=\delta_P\begin{vmatrix}0 & 0 & 1 & 0\\ 0 & 0 & 0 & 1\\ 1 & 0 & 0 & 0\\ 0 & 1 & 0 & 0\end{vmatrix}\begin{vmatrix}a_0\\ b_0\\ c_0\\ d_0\end{vmatrix}, \quad (14)$$

or, in matrix form,

$$X_P=\delta_P\hat{U}_PX_0. \quad (14a)$$

Our problem is to find the components of the polarization Π. The connection between their *P*-odd parts and the solutions of the system (11) is, as can be discerned from (3)–(8).

$$\begin{aligned}
&\Pi_{1,P}=2^{1/2}\mu_1\langle a_P+\delta_Pc_0\rangle,\ \Pi_{4,P}=-2^{1/2}\mu_1\langle c_P+\delta_Pa_0\rangle,\\
&\Pi_{2,P}=2^{1/2}\mu_1\langle b_P+\delta_Pd_0\rangle,\ \Pi_{3,P}=2^{1/2}\mu_1\langle d_P+\delta_Pb_0\rangle.
\end{aligned} \quad (15)$$

In other words, the P-odd polarization is determined by the column

$$X_P'=X_P+\delta_P\bar{U}_P^{+}X_0. \tag{16}$$

By virtue of (14) we have

$$X_P'=2X_P. \tag{17}$$

The solution of the system (13) is easily seen to be:

$$X_P'=\frac{2\delta_P}{(\Gamma^2+(\Delta+\varepsilon)^2)(\Gamma^2+(\Delta-\varepsilon)^2)}\left|\begin{matrix}\varepsilon(\Gamma^2-\Delta^2+\varepsilon^2)\\ -2\Gamma\Delta\varepsilon\\ \Delta(\Gamma^2+\Delta^2-\varepsilon^2)\\ \Gamma(\Gamma^2+\Delta^2+\varepsilon^2)\end{matrix}\right|. \tag{18}$$

The two lower lines of this solution correspond to the well-known effects of optical activity and dichroism due to P-odd interactions.[13] The two upper lines correspond to corrections to the dispersion and absorption in an external magnetic field.[3,4] They are proportional to the product

$$\delta_P\varepsilon=\eta_P\frac{D_1}{\mu_1}\mu_0(\nu H_0).$$

It is seen from (18) that all the components of the vector X'_P are of the same order when $\varepsilon\sim\Gamma$, but have different dependences on the detuning Δ. Certain components Π_P of the polarization of the medium are therefore suppressed because the ratio Γ/Γ_D is small, where Γ_D is the width of the Doppler distribution. Indeed, if the function $f(\Delta)$ decreases rapidly enough, $f(\Delta)/\Delta\to 0$, we obtain after averaging over the Maxwellian distribution W

$$\langle f\rangle(\omega)=\int\limits_{-\infty}^{\infty}W(\omega-\omega_0-x)f(x)\,dx$$

$$=W(\omega-\omega_0)\int\limits_{-\infty}^{\infty}f(x)\,dx+O(\Delta_0/\Gamma_D), \tag{19}$$

where Δ_0 is the characteristic width of the function $f(\Delta)$:

$$\Delta_0=\max(\Gamma,\varepsilon). \tag{20}$$

The integral in (19) vanishes when $f(x)$ is equal to a'_P or b'_P. The polarization components $\Pi_{1,P}$ and $\Pi_{2,P}$ are therefore, in accordance with (15), (19), and (20), of order ε/Γ_D and not ε/Γ. Exactly the same suppression is obtained also for the Faraday effect.[9–12]

In sum, we can state that in the linear approximation in the saturation parameter the ratio of the P-odd corrections to the absorption and disperstion in P-odd rotation of the polarization plane is determined by the parameter ε/Γ_D. Under the best experimental conditions all the P-odd effects for $\varepsilon\sim\Gamma_D$ are of the order of δP.

P-ODD INTERACTION, ALLOWANCE FOR NONLINEARITY

The symmetry that leads to the solution (14) is missing if the terms linear in the laser field are retained in the system (11). Clearly, relation (17) does not hold in this case and we must use Eq. (16).

The expressions obtained by solving the system (11) of the terms nonlinear in the laser field do not contain the symmetry that has led to the solution (14). Clearly, (17) is not valid in this case and Eq. (16) must be used.

The expressions obtained by solving the system (11) are in general quite cumbersome. We confine ourselves below to a numerical solution, but advance first some qualitative arguments.

Let us show the cause of the P-odd correction to the dispersion. For plane-polarized light, the dispersion receives contributions from both transitions $0\leftrightarrow+$ and $0\leftrightarrow-$, to each of which corresponds a dispersion contour centered at the respective frequencies $\omega_0\pm\varepsilon$. The P-odd increments to the amplitudes of these transitions are of opposite sign, so that the corresponding increments to the dispersion correspond to profiles of opposite sign (Fig. 2a). The total P-odd correction is then a symmetric profile with a zero mean value. Let examine now the role played by a change in the level populations when a light wave is applied. Each of the transitions $0\leftrightarrow+$ and $0\leftrightarrow-$ is broadened. In addition, the transitions influence each other via the population of the zeroth level. Each of them alters this population near its resonance, and by the same token distorts the facing wing of the second profile (Fig. 2b). As a result, the central peak of the summary contour weakens and the integral over the frequencies becomes negative. Nonlinearity manifests itself in exactly the same manner in the Faraday effect.[12] In that case, however, there is one more nonlinear correction. We have considered up to now only the influences of nonlinearity on a P-odd correction to dispersion. On the other hand, P-odd corrections to absorption influence the populations of the left-hand level and by the same token influence also the value of the dispersion. Clearly, at the frequency ω_0 the corrections to the two amplitudes cancel each other, while corrections to one of the amplitudes predominate near the resonances $\omega_0\pm\varepsilon$, increasing or decreasing the corresponding peaks (Fig. 2c). The total P-odd correction is a sum of the two contributions shown in the third rows of Figs. 2b and 2c.

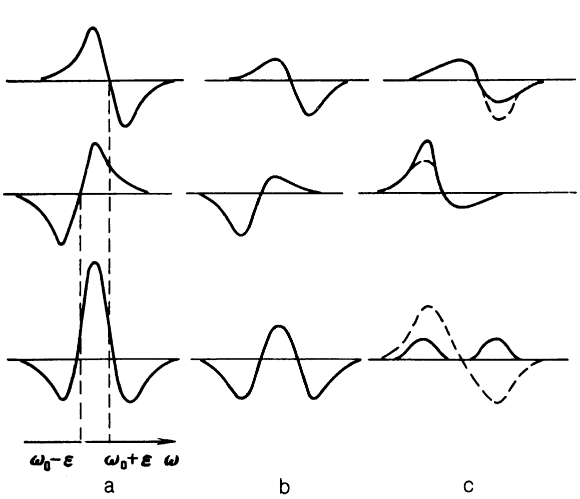

FIG. 2. P-odd correction to dispersion. The two upper rows show the contributions of the transitions $0\to+1$ and $0\to-1$, and the lower row shows the total correction to the dispersion. a) Linear case. b) Nonlinear case with allowance for only the P-odd corrections to the dispersion. c) Nonlinear case with allowance for P-odd absorption effects. The undistorted dispersion lines are shown dashed.

We have taken into account above only one of the nonlinear effects—the change of the populations. No less important are also the coherence effects.[15] Therefore the arguments above lead to a simplified picture of the phenomenon,

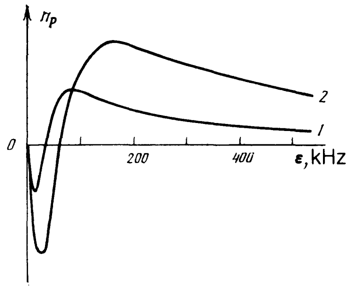

FIG. 3. Dependence of the P-odd correction to the dispersion n_p of magneto-chiral birefringence) on the Zeeman splitting. The saturation parameter $\alpha^2/\gamma_0\gamma_1$ is equal to 1 (curve 1) and to 10 (curve 2). The scale of curve 1 is magnified by a factor of two. $\gamma_0 = \gamma_1 = 50$ kHz.

but it is clear even from them that the dependences of the P-odd correction on the saturation parameter $\alpha^2/\gamma_0\gamma_1$ and on the splitting ε can be significantly more complicated than for the Faraday effect. It can be shown, in particular, that the corrections of first order in $\alpha^2/\gamma_0\gamma$ and a'_P cancel out and the expansion begins with a second-order term. The results of a numerical integration of a'_P over the frequencies are shown in Fig. 3. It shows that $\langle a'_P\rangle$ has, as a function of the Zeeman splitting ε, two peaks of opposite sign when $\varepsilon \sim \Gamma$. At large saturation parameters $\alpha^2/\gamma_0\gamma \gtrsim 1$ the amplitudes of both peaks are of order δ_P. This means that in observation of the P-odd correction and dispersion it is possible to obtain the maximum effect in magnetic fields $\mu_0 H_0 = \varepsilon \sim \Gamma \approx \gamma_0$. For the experiment of Ref. 11 we get $\gamma_0 \sim 10^4$ Hz and $H_0 \sim 10^{-2}$ Oe.

Let us discuss now the influence of nonlinearity on other P-odd corrections. According to (15), (18) and (19) the correction to absorption is also suppressed in the linear limit. The integral in (19) vanishes because the constant b'_P is an odd function of Δ. Obviously, this property is preserved in the general case, that the correction to the absorption is proportional to ε/Γ_D for any saturation.

Figure 4 shows the behavior of the component $\Pi_{3,P}$ that describes the dichroism. Its rapid decrease with increase of the saturation corresponds to the usual self-induced transparency of a medium in a strong field.

We proceed now to the optical rotation $\Pi_{4,P}$. Expansion (19) cannot be used for it because of the slow decrease of the function $c'_P(\Delta)$. Therefore, even though this function is odd, averaging over the velocities does not suppress the optical rotation.[13] It is clear that in this case the main contribution to the integral of the convolution with the Doppler

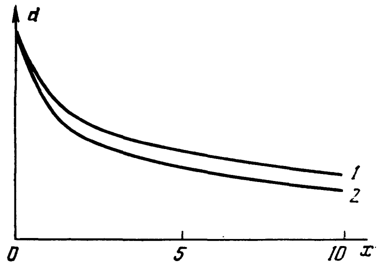

FIG. 4. Optical dichroism d vs the saturation parameter $x = \alpha^2/\gamma_0\gamma_1$. Zeeman splitting $\varepsilon = 0$ (curve 1) and $\varepsilon = 100$ kHz (curve 2). $\gamma_0 = \gamma_1 = 50$ kHz.

distribution (19) is made by the asymptotic tails of the function c'_P. Nonlinear effects, however, should alter the function c'_P in the region $|\Delta| \lesssim \alpha^2/\Gamma$ without affecting the asymptotic relation.

Indeed, analysis of the system (11) verifies that the nonlinear corrections to c'_P decreases like Δ^{-3}; we can therefore use for them an expansion of the convolution integral (19) with $O(\Gamma/\Gamma_D)$ replaced by $O(\alpha^2/\Gamma\Gamma_D)$. Since c'_P is odd, we have

$$\int c_P'(x)\,dx = 0,$$

and we conclude that the influence of the nonlinearity on P-odd optical rotation is determined by the saturation parameter $\alpha^2/\Gamma\Gamma_D$. This parameter is negligibly small in the fields used in experiment.

Summarizing the foregoing, we conclude that nonlinearity affects substantially the P-odd optical dichroism of a medium and the P-odd correction to dispersion (magneto-chiral birefringence). Whereas the former decreases when the wave field increases, the latter, on the contrary, increases by many orders.

CONSTANT MAGNETIZATION

We shall dwell in this section on one more P-odd effect. We have in mind the onset of stationary magnetization of the medium in the direction of propagation of the wave (1). This phenomon has the same nature as the energy splitting of a Zeemen doublet in the field of a plane-polarized wave.[2]

According to (9) and (10), the magnetization of the medium is equal to

$$M_z = \langle \mathrm{Sp}(\hat{\mu}_z\rho)\rangle = \mu_0\langle \rho_{++} - \rho_{--}\rangle$$

$$= \frac{\mu_0}{\gamma}\{\lambda_+ - \lambda_- - \alpha\langle d_0\rangle - \alpha\langle d_P'\rangle\} = M_1 + M_2 + M_3, \qquad (21)$$

where μ_0 is the magnetic moment of the atom.

We have taken into account here the difference between the pumps λ_+ and λ_- to the states $\langle\!\langle + \rangle\!\rangle$ and $\langle\!\langle - \rangle\!\rangle$, which leads to the appearance of the usual magnetization

$$M_1 = \mu_0 N(\mu_0 H_0/kT). \qquad (22)$$

The second term in (21) is due to optical pumping in a magnetic field, and the third to pumping and P-odd interaction. To lowest order in α we obtain from (14), (16), and (18)

$$d_0 + d_P' = [-2\Gamma\Delta\varepsilon + 2\delta_P\Gamma(\Gamma^2+\Delta^2+\varepsilon^2)]$$

$$\times [\Gamma^2 + (\Delta+\varepsilon)^2]^{-1}[\Gamma^2 + (\Delta-\varepsilon)^2]^{-1}. \qquad (23)$$

In the absence of a magnetic field there remains in this expression only the P-odd term

$$M_z = M_3 = 2\pi\frac{\alpha^2}{\gamma\Gamma}\mu_0 N\Gamma W(\omega-\omega_0)\delta_P. \qquad (24)$$

The meaning of this expression becomes clear if it is recognized that in the case of total polarization of the medium the magnetization is $M_{\max} = \mu_0 N$, and the fraction of the atoms interacting with the laser field is ΓW. Near the center of the Doppler contour we have $\Gamma W \sim \Gamma/\Gamma_D$. For larger saturation parameters we have

$$M_3 \sim 2\pi M_{max}(\Gamma/\Gamma_D)\delta_P. \tag{25}$$

This magnetization is directed along the wave vector $\mathbf{k}$.

CONCLUSION

When light interacts with vapor of an atomic gas in an external magnetic field, P-odd interaction generates a refractive-index correction proportional to $(\mathbf{H}\cdot\mathbf{k})$.[3,4] This correction to the dispersion has been named magneto-chiral birefringence.[8] In an optimal magnetic field its value is of the order of δ_P. A calculation in Ref. 14 yielded for thallium $|\delta_P| = 1.5\cdot 10^{-7}$.

An effect of this magnitude requires a magnetic field $H \sim \Gamma_D/\mu_0$ in the absence of saturation or $H \sim \Gamma/\mu_0$ in the nonlinear case. For typical experimental conditions these estimates correspond to fields 10^3 Oe and 10^{-2} Oe, respectively. Thus, magneto-chiral birefringence varies drastically in nonlinear optics. At the same time, nonlinear effect do not affect the P-odd optical activity.

The authors thank A. N. Moskalev for helpful discussions.

[1)]The very same effects were discussed earlier[5-8] for a medium consisting of chiral molecules. Such a medium is invariant to inversion of P provided the densities of isomers of opposite sign are different.

[1]L. M. Barkov, M. S. Zolotarev, and D. A. Melik-Pashaev, Pis'ma Zh. Eksp. Teor. Fiz. **48**, 134 (1988) [JETP Lett **48**, 144 (1988)].

[2]L. N. Labzovskiĭ and O. A. Mitrushchenkov, Zh. Eksp. Teor. Fiz. **94**, No. 9, 27 (1988) [Sov. Phys. JETP **67**, 1749 (1988)].

[3]A. N. Moskalev, Izv. AN SSSR Ser. Fiz. **50**, 1401 (1986).

[4]G. Wagniere, Z. Phys. D **8**, 229 (1988).

[5]N. B. Baranova, Yu. V. Bogdanov, and B. Ya. Zel'dovich, Opt. Commun. **22**, 243 (1977).

[6]N. B. Baranova and B. Ya. Zel'dovich, Mol. Phys. **38**, 1085 (1979).

[7]G. Wagniere and A. Meier, Chem. Phys. **93**, 78 (1982).

[8]L. D. Barron and J. Vrbancich, Mol. Phys. **51**, 715 (1984).

[9]I. O. Davies, P. E. G. Baird, and J. L. Nicol, J. Phys. B. **20**, 5371 (1987).

[10]F. Schuller, M. J. D. McPherson, and D. N. Stacey, Physica **147C**, 321 (1987).

[11]L. M. Barkov, D. A. Melik-Pashaev, and M. S. Zolotarev, INF Preprint N88-90 (1988).

[12]M. G. Kozlov, Leningrad Inst. Nucl. Phys. Preprint No. 1472, 1989.

[13]I. B. Khriplovich, *Pariton Nonconservation in Atomic Phenomena* [in Russian], Nauka, 1988.

[14]V. A. Dzuba, W. F. Flambaum, and P. G. Silvestrov, J. Phys. B. **20**, 3297 (1987).

[15]S. Stenholm, *Foundations of Laser Spectroscopy*, Wiley, 1984.

Translated by J. G. Adashko