Influence of Laser Field Polarization on Nonlinear Interference Effects

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The contour of the absorption line for the Ne $3s_2$—$2p_4$ transition is investigated experimentally in the presence of a strong laser field interacting with this transition. A strong polarization dependence of the shape and width of the absorption line is observed, the line being narrower for perpendicular than for parallel polarizations. An interpretation of the observed effects is proposed.

In the experiments described below we investigated the spectral dependence of the absorption coefficient of a weakly monochromatic field in the $3s_2 - 2p_4$ $(5s'[{}^1\!/_2]_1^0 - 3p'[{}^3\!/_2]_2)$ transition of neon in the presence of a strong field interacting with the same transitions. The two fields have the same propagation direction. The observed effect consists in a dependence of the shape and width of the weak-field absorption line on the polarization of the fields[1)]. The experimental setup is shown in Fig. 1.

The source of the strong field was a frequency-stabilized He-Ne laser 1 with mode selection by pressure[2]. The laser emission was modulated by a mechanical chopper 3 (modulation frequency 35 Hz) and directed to a neon-filled gas-discharge cell 4. To measure the absorption, weak radiation was introduced into the cell from a power-stabilized tunable-frequency He-Ne laser 2 with mode selection by means of an internal absorbing cell[3]. To separate this radiation, it was modulated at a frequency 3 kHz by chopper 5. The beam from laser 2 then entered the cell at an angle 3×10^{-3} rad to the propagation direction of the strong wave. This makes it possible to "cut off" the radiation of laser 1, thereby greatly improving the signal/noise ratio. Different wave polarizations were obtained from initially linearly polarized light with the aid of phase plates 12 and 13. In cell 4, the "low-frequency" (35 Hz) modulation due to the influence of the strong wave on the absorption coefficient of the medium, was superimposed on the "high-frequency" (3 kHz) modulation of the weak field. This doubly-modulated signal was received by photoreceiver 6. The recording system, consisting of a selective amplifier (f = 3 kHz) with diode detector 7 and an amplifier (f = 35 Hz) with synchronous detector 8, separated and detected the low-frequency component of the signal, which was then fed to one of the channels of a two-channel automatic plotter 9. The second channel recorded frequency "markers" comprising the laser-field beat signal produced at the photocathode of the photomultiplier 10 and passing through a system of receivers 11 tuned to fixed frequencies.

Thus, when the frequency of laser 2 is scanned, we obtain on the diagram of the plotter the contour of the increment to the absorption of the weak field as a result of the action of the strong field, and also a scale of markers indicating the frequency difference between the fields. The measurements were made at a neon pressure 1 Torr, a discharge current 80 mA, and a strong-field power 8 mW. The typical spectrograms shown in

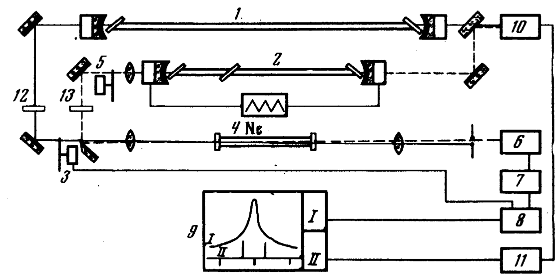

FIG. 1. Diagram of experimental setup: 1, 2—He-Ne laser; 3, 5—modulator; 4—gas-discharge cell; 6, 10—photomultiplier; 7, 8—selective amplifier with detector; 9—automatic recorder; 11—radio receivers; 12, 13—phase plates.

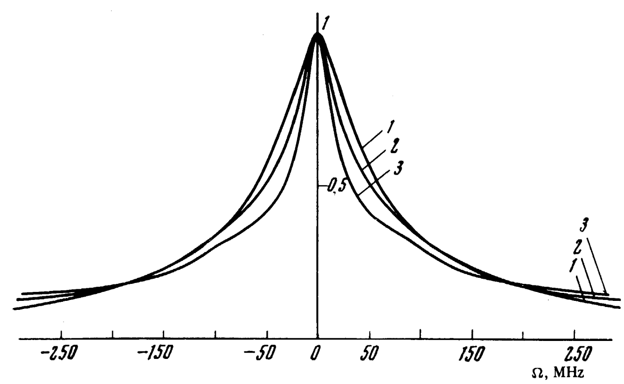

FIG. 2. Spectrograms of the absorption coefficient: 1—identical linear or circular polarizations, 2—perpendicular linear polarization, 3—opposing circular polarizations.

Fig. 2 demonstrate the observed effect. The broadest contour 1 corresponds to identical polarizations of both fields. At different polarizations, the contour becomes narrower; the narrowing is particularly strong in the case of opposing circular polarizations (curve 3).

The experimentally observed effects are qualitatively interpreted as follows. Let, for example, the weak and strong fields be waves with opposite circular polarizations. The transition scheme is given in this case by Fig. 3a. The quantization axis is chosen along the wave vectors. The strong field produces transitions with $\Delta M = 1$ (solid arrows), and the weak field transitions with $\Delta M = -1$ (wave arrows). In the transitions $0 \to 1$, and $1 \to 2$, only the upper Zeeman sublevels are perturbed by the strong field. But if the waves have the same circular polarization, then the transition scheme becomes different (Fig. 3b). The weak field acts here only on transitions in which both the upper and the lower

1)This effect was predicted theoretically by Dienes [1] for the spontaneous approximation.

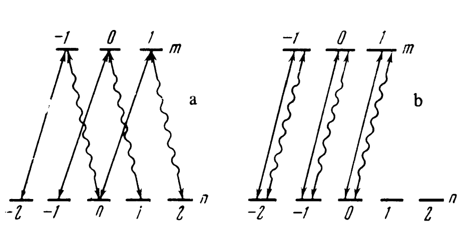

FIG. 3. Transitions for opposing (a) and identical (b) circular polarizations.

sublevels are perturbed by the strong field. On the other hand, it follows from earlier work[4,5] that the waveform of the absorption (emission) line depends strongly on whether one or both levels of the transition that resonates with the weak field are perturbed by the strong one. This indeed is the cause of the observed dependence of the line contour on the polarization of the fields.

Calculation shows that for waves having the same direction and arbitrary polarizations the change produced in the work of the weak field by the strong one is proportional to the expression

$$\operatorname{Re}\frac{\Gamma_m+\Gamma_n-i\varepsilon}{2\Gamma-i\varepsilon}\left\{\frac{C_m}{\Gamma_n(\Gamma_m-i\varepsilon)}+\frac{C_n}{\Gamma_m(\Gamma_n-i\varepsilon)}\right\}\exp\left[-\left(\frac{\Omega_\mu}{k\bar{v}}\right)^2\right];$$

$$C_m=A_0\sum_{\alpha=\pm1}\left(|G_\alpha G_\alpha{}^\mu|^2+A_1|G_\alpha G_{-\alpha}{}^\mu|^2+A_2G_\alpha G_{-\alpha}{}^*G_{-\alpha}{}^\mu G_\alpha{}^{\mu*}\right),$$

$$C_n=A_0\sum_{\alpha=\pm1}\left(|G_\alpha G_\alpha{}^\mu|^2+A_2|G_\alpha G_{-\alpha}{}^\mu|^2+A_1G_\alpha G_{-\alpha}{}^*G_{-\alpha}{}^\mu G_\alpha{}^{\mu*}\right),$$

$$G_\alpha=E_\alpha d_{mn}/2\hbar,\quad G_\alpha{}^\mu=E_\alpha{}^\mu d_{mn}/2\hbar,$$

$$A_0(J-1\to J)=\frac{2}{5}\,\frac{6J^2-1}{J(2J-1)(2J+1)},$$

$$A_1(J-1\to J)=\frac{(J-1)(2J-3)}{2(6J^2-1)},$$

$$A_2(J-1\to J)=\frac{(J+1)(2J+3)}{2(6J^2-1)},\quad A_1(J\to J-1)=A_2(J-1\to J),$$

$$A_2(J\to J-1)=A_1(J-1\to J),\quad A_0(J\to J)=\frac{2}{5}\,\frac{2J^2+2J+1}{J(J+1)(2J+1)},$$

$$A_1(J\to J)=A_2(J\to J)=\frac{(2J-1)(2J+3)}{2(2J^2+2J+1)}. \tag{1}$$

Here E_α and E_α^μ are the circular components of the weak and strong fields, Ω_μ and ϵ are the deviations of the weak-field frequency from the frequencies of the atomic transition and the strong field, respectively, Γ is the natural line width, and Γ_m and Γ_n are the damping constants of the levels m and n.

The total line contour, described by formula (1), consists of two parts of unequal widths (when the constants Γ_m and Γ_n differ). Their amplitudes are characterized by the coefficients C_m and C_n. In the spontaneous approximation ($2\Gamma = \Gamma_m + \Gamma_n$), each term describes a dispersion curve. For waves with identical polarizations, and also for $J \to J$ transitions with arbitrary wave polarizations, $C_m = C_n$. In the general case of arbitrary polarizations of the weak and strong fields we have

Polarization*	Expression for θ	θ			
		$J-1\to J$	$0\to1$	$^1/_2\to{}^3/_2$	$1\to2$
I	1	1	1	1	1
II	$\frac{1+A_1}{1+A_2}$	$\frac{14J^2-5J+1}{14J^2+5J+1}$	$^1/_2$	$^5/_8$	$^{47}/_{67}$
III	$\frac{1+A_1-A_2}{1-A_1+A_2}$	$\frac{(J-1)(6J+1)}{(J+1)(6J-1)}$	0	$^1/_4$	$^{13}/_{33}$
IV	$\frac{A_1}{A_2}$	$\frac{(J-1)(2J-3)}{(J+1)(2J+3)}$	0	0	$^1/_{21}$

*I—identical circular or identical linear polarizations,
II—one field linearly polarized, the other circularly,
III—linear perpendicular polarization,
IV—circular opposing polarizations.

$\theta = C_m/C_n \neq 1$, and the predominant term is the one corresponding to the level with the larger J. The difference between the polarizations of the two fields therefore causes the width of the summary contour to approach the width of the level with the larger J. The values of θ for several important particular cases are gathered in the table.

Under the conditions of our experiments, the amplitude of the Γ_n contour predominates for perpendicular linear polarizations ($\theta = 13/33$). Since $\Gamma_n < \Gamma_m$, the summary contour becomes narrower (see curves 1 and 2 of Fig. 2). An even greater narrowing occurs in the case of waves with opposite circular polarizations (curve 3 of Fig. 2), and is due to the fact that in this case the amplitude of the Γ_n contour is 21 times larger than the amplitude of the Γ_m contour, so that the latter can be neglected in practice.

An additional argument favoring the proposed interpretation is given by an experimental investigation by the procedure of[6]) of the spectrum of the spontaneous emission of neon in the $3s_2 - 2p_{10}$ transition in the presence of a strong field at the neighboring transition $3s_2 - 2p_4$. The line contour here is independent of the field polarizations (accurate to 1 MHz). Within the framework of the concepts developed here, this is due to the fact that the $2p_{10}$ level remains unperturbed by the strong field.

1)This effect was predicted theoretically by Dienes[1] for the spontaneous approximation.

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189