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Investigation of the absorption spectrum of a two-level system in intense nonmonochromatic radiation fields

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The change in the absorption line shape of weak radiation from two-level systems (Zeeman splitting levels of Cd^{113} atoms) under the action of Gaussian noise emission is investigated. Under strong nonresonance action, increase in the noise field power resulted in a shift of the absorption line peak and its broadening, and also in a strong growth in the fluctuations of the absorption index. In the region of low saturation, the line broadening is proportional to the square of the power, whereas it is proportional to the noise field power in the case of high saturation. A theory of the effect of nonresonance noise fields is developed. The results of the theory are in good agreement with the experimental results, and are used to predict the nature of the change in the atomic energy structure in nonresonance radiation fields of multimode lasers. An amplification of the weak radiation is observed in the action of a resonance or quasiresonance strong noise field. The maximum attainable value of the field decreases with increase in the spectral width of the noise field line.

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1. INTRODUCTION

We have communicated previously[1] on the observation of the change of the absorption spectrum of weak probing radiation of a two-level system (the levels of the Zeeman splitting of atoms of cadmium) under the action of an intense rotating monochromatic radiation field. For strongly nonresonant action, a shift of the frequency of the single phonon absorption line of atoms without change in its width is observed. In cases of the coincidence of the frequency of the strong field and the frequency of the atomic transition or of an insignificant difference between them, splitting of the absorption lines is observed, proportional to the field amplitude, and a reversal of the sign of the absorption index in some parts of the line, without creation of inversion of population levels. The width of the components of the splitting was close to the width of the initial absorption line. It was established that the usual course of observed changes in the shape of the absorption spectrum, the values of the line shift and splitting, and also the values of the absorption peaks agree with predictions of existing theory.

The investigation of the change in the absorption spectrum of a two-level system under the action of irregular nonmonochromatic radiation fields is of considerable interest. Such fields are as a rule generated by multimode lasers in regimes without mode locking. Since the instantaneous values of the shifts and splitting of the absorption line depend on the amplitude of the existing field, it follows that in the case of its irregular change with time, one can expect not only splitting and a shift of the absorption line, but also its broadening and the generation of significant fluctuations of the absorption index relative to its mean value. It is clear that the dynamics of these fluctuations and the shape of the absorption line will be determined in principle by the character of the statistics of the operating field.

The theoretical analysis of the excitation of the spectrum of even the simplest two-level system by an irregular intense radiation field presents a very complicated problem, general methods of the solution of which for an arbitrary statistics of the operating field do not exist at the present time. A more complete theoretical investigation of the dynamics of two-level systems has been carried out for the case in which the radiation field is a purely discontinuous random Markov process.[2,3] The use of such a type of radiation field enables us to write down a closed set of equations for the averaged density matrix elements and to compute the dynamics of the change in the mean level populations[2] and the spectrum of mean values of the absorption coefficient of of weak probing radiation.[3] The most important results of these researches lie in the prediction of the field broadening of the lines of atomic absorption and the possibility, as in the case of a monochromatic field, of reversal of the sign of the absorption coefficient without inversion of the average level population under the action of resonance radiation. The model of the operating field considered in these researches is realized in the case of monochromatic excitation of a atom that undergoes collisions in a rarefied gas, instantaneously changing the direction of motion of the atom. The applicability of such a model for the description of the perturbation of the spectrum of a two-level system by quasimonochromatic radiation of multimode lasers is far from obvious. The radiation of multimode lasers in regimes without mode locking represents a set of harmonics in a narrow spectral interval with randomly distributed phases. The statistical properties of such radiation are close to the properties of Gaussian noise emission.[4]

Quantitative investigations of the change in the spectrum of atoms in fields of radiation of multimode lasers are made very difficult at the present time by the absence of sufficiently powerful lasers with controlled degree of mode locking, with adjustable frequency, width of the spectral line, and duration of the radiation pulses. In this connection, we have carried out experimental studies of the change in the absorption spectrum of weak radiation from two-level systems under the action of a narrow-band Gaussian noise field of the radio-frequency range, generated from white noise by linear rectangular filters. In the case of a strongly nonresonant operating noise field, when one can neglect the changes in the level population, we succeeded in constructing a theory of the change in shape of the absorption line, the results of which are in excellent agreement with the experimental results. The results of the investigations have not only significance for two-level systems, but can also be used for the prediction of the character of the change in the energy structure of multilevel atomic systems under the action of strongly nonresonant radiation of multimode lasers without mode locking under conditions of the quadratic dynamic Stark effect. In the case of the effect of a resonant noise field, an amplification of the weak radiation was observed.

2. EXPERIMENT

As an object of study and a model for a two-level system, we chose the vapor of Cd^{113} atoms in a constant magnetic field. The Cd^{113} atoms have only the nuclear angular momentum $I=\frac{1}{2}$ in the ground state, which splits in a constant magnetic field into two Zeeman levels. Under the conditions of our experiment, the frequency of the Zeeman transition amounted to 4.5–5 kHz and was many orders of magnitude smaller than the frequency of transitions to the nearest level, which enables us to assume such a system to be purely two-level one. Predominant population of one of the Zeeman levels was created by the method of optical orientation of the Cd^{113} vapor by circularly polarized resonant radiation of 3261 Å of a tube with Cd^{114} (the scheme of the apparatus used is similar to that described in[1]). The vessel with Cd^{113} vapors, saturated at 220 °C in a buffer gas (xenon, 100 Torr) was placed at the center of a system of three pairs of Helmholtz coils, located mutually perpendicular to the magnetic field: the constant field H_z and two radio frequencies—the strong noise $H_x(t)=H_0(t)\cos\omega_0 t$ and the weak are $H_y(t)=H_1\cos\omega t$, the frequency of which was varied close to the frequency of the Zeeman transition ω_{21}.

The relative spatial inhomogeneity of all three fields in the volume of the vessel did not exceed $\Delta H/H=10^{-3}$. The strong noise field H_x was obtained with the help of filtration of broadband (practically white) shot noise by narrow rectangular filters. The damping in the attenuation band of the filter exceeded 60 dB, and the width of the pass band of the filters was much less than the band width of the spectrum of the white noise generator, which guaranteed Gaussian statistics of the noise emission acting on the atoms. The power of the noise field was controlled by measurement of the mean square voltage on the corresponding Helmholtz coils with a square-law detector. The light ray was directed onto the YOZ plane at an angle of 45° to the Y and Z axes. Transitions of the atoms as a result of the absorption of the weak probing radiation of frequency ω led to modulation with this frequency of the absorption of the optical beam. The percent modulation of the light beam with frequency ω, proportional to the absorption index of the test emission was measured. To obtain a sufficiently large ratio of signal to noise (greater than 10), filters with bandwidth 0.03 to 0.015 Hz were placed in the measurement circuit.

A. Action of the nonresonant ("weak") noise field

In these experiments, we aimed at the study of the change in the shape of the absorption line as the result of the change of the energy structure of the levels by the noise field only, without change in its population. The "weak" field is determined by this condition. It follows from analysis of the results of study of the absorption line shift in monochromatic nonresonant fields that the change of level populations is insignificant so long as the value of the absorption line shift remains small in comparison with the difference in frequencies of the effective radiation field ω_0 and that of the atomic transition ω_{21}.[1] Therefore, we have limited ourselves to such values of the powers of the operating noise emission for which the values of the shift and broadening of the absorption line remained much smaller than $\omega_0-\omega_{21}$. As will be shown later (see Sec. 3), under these conditions, the theoretical analysis of the change in shape of the absorption line is greatly simplified and the line shape can be expressed in analytic form in certain limiting asymptotic cases. This shape can be compared with the results of experiment.

We have observed the change in the absorption line shape of radiation with frequency ω near the frequency of the Zeeman resonance ω_{21} (~4.5 kHz) under the action of a noise field with central frequency ω_0 (~5 kHz) and spectral width Δ_n, is equal to 2, 6, 10 and 30 Hz at the half-power point. The sharp decrease in the spectral noise power outside the band Δ_n (by ~60 dB at distances of several Δ_n from the central frequency ω_0) produced a negligibly small change in the population of the Zeeman levels, which are resonant with the frequency of the Zeeman transition ω_{21}.

The general laws for the change in the line shape,

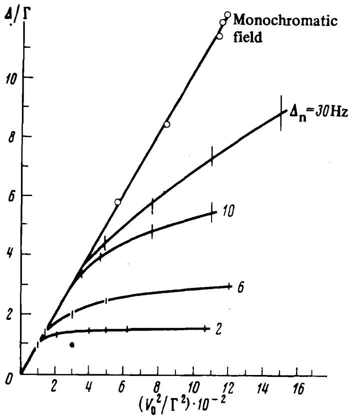

FIG. 1. Dependence of the shift in the absorption peak on the power of the noise field.

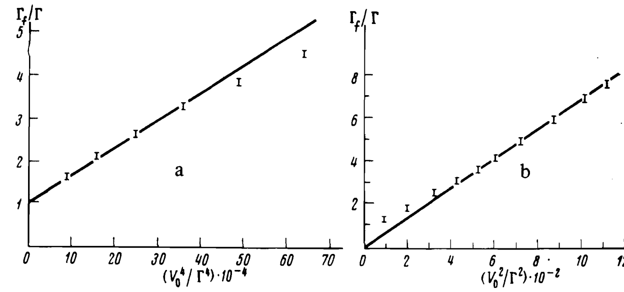

FIG. 3. Dependence of the absorption line width Γ_f on the power of the noise field: a) $\Delta_n = 30$ Hz, b) $\Delta_n = 2$ Hz.

established for all the noise fields used, are the following.

1. For small values of the noise field power, the value of the shift in the maximum of the absorption line Δ is identical with the value of its shift in a monochromatic field of the same power (Fig. 1)[1)].

2. The shift in the maximum of the absorption line Δ reveals a tendency toward saturation as the noise field power increases. With decrease in the width of the spectral line of the noise field Δ_n, the saturation of the maximum displacement is achieved for smaller powers of the noise field. In the saturation region Δ, at constant noise field power ($V_0^2 = \text{const}$), the shift of the maximum of the absorption line is greater, the greater the width of the spectral noise line Δ_n.

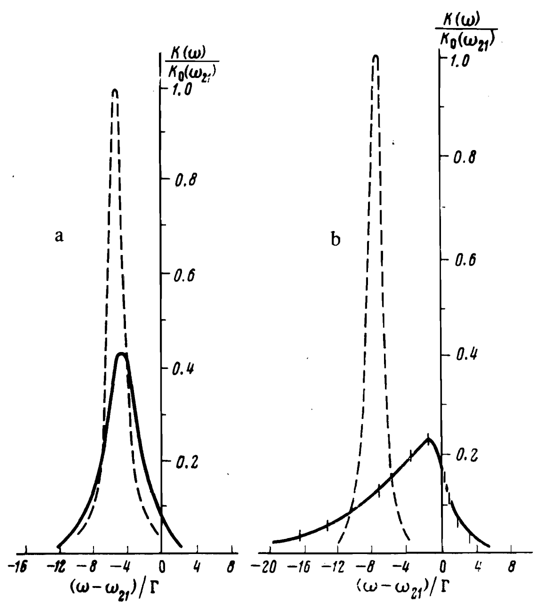

FIG. 2. Shape of the absorption line: a) continuous curve—experiment at $\omega_n = 30$ Hz, $V_0^2/\Gamma^2 = 5\times 10^2$; b) points—experiment at $\omega_n = 2$ Hz, $V_0^2/\Gamma^2 = 7\times 10^2$, continuous curve—calculation from Eq. (14) for these same values of ω_n and V_0^2/Γ^2. The dashed lines are the absorption lines in monochromatic fields of the same power; $K_0(\omega_{21})$ is the absorption index at the center of the line in the absence of a strong exciting field.

3. For low noise field powers, the shape of the absorption line is insignificantly different from Lorentzian (Fig. 2a). The width of the absorption line is proportional (Fig. 3a) and the value of the maximum of the absorption index is inversely proportional to the square of the noise field power.

4. In the region of high noise field powers, for the case of saturation of the shift of the absorption line maximum, its shape becomes very asymmetric (Fig. 2b). The dependence of the falloff of the line wing in the direction of the shift of its maximum is close to exponential. The absorption line width is proportional (Fig. 3b), and the value of the maximum of the absorption index is inversely proportional, to the noise field power.

5. Under the action of the noise field, the fluctuations of the absorption index increase significantly. For example, if under the action of a monochromatic powerful field, the ratio of the absorption signal to the noise at the maximum of the absorption line amounts to 10^3, then, for powers of the noise field corresponding to saturation of the shift of the absorption line maximum, this ratio amounts to 100–10 in a band of 0.03 Hz and 1–0.2 in a band ~1 kHz. It was verified that with the exception of the action of a weak probing field, the effect of strong noise field on the cadmium atoms does not lead to any appreciable increase in the noise in the 0.03 Hz band in the region of the atomic absorption line. This means that the increase in the fluctuations of the absorption index is a consequence of the fluctuations of the shift of the absorption line in the noise field.

B. Effect of resonant and quasiresonant noise fields

The study of the change in the absorption line shape under the action of powerful resonant noise fields is a much more difficult problem, because of the decrease in the difference of populations (and consequently, of the mean values of the absorption index) and because of the difficulty of eliminating the fluctuations of the light passing through the atomic vapor, with noise-field frequencies close to the frequency of the probing field. The presence of such strong fluctuations (which are present when the weak field of frequency ω is not applied to the vessel with atomic vapors of Cd) made unreliable the measurement of the absorption of weak probing radiation in the band of frequencies of the noise field. The degree of equalization of the level populations is proportional to the power of the noise field; as

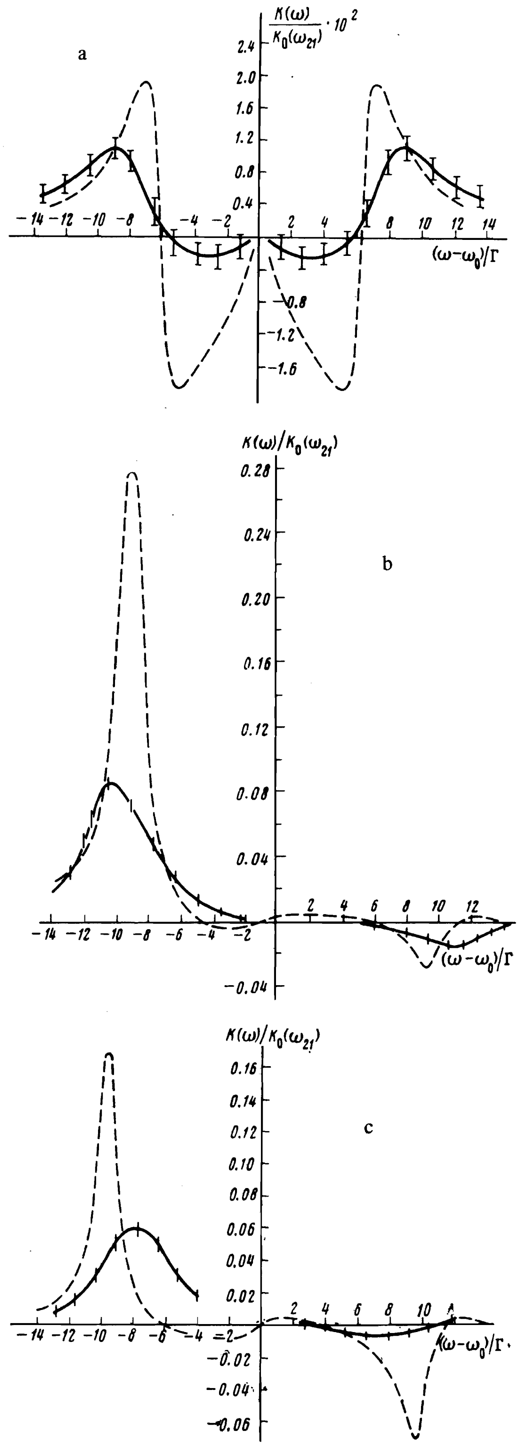

FIG. 4. Absorption spectra of a weak field: a) $\omega_0=\omega_{21}$, $\Delta_n=7$ Hz, $V_0^2/\Gamma^2=10$; b) $\omega_0-\omega_{21}=12$ Hz, $\Delta_n=7$ Hz, $V_0^2/\Gamma^2=16$; c) $\omega_0-\omega_{21}=9$ Hz, $\Delta_n=20$ Hz, $V_0^2/\Gamma^2=20$. The dashed lines indicate the calculated dependence of the line shape in a monochromatic field of the same power.

a result, the maximum powers of the noise emission for which reliable measurement of the absorption of the test radiation is possible are severely limited.

Figure 4 shows the absorption spectrum of the probing radiation in the case of the action of resonant (Fig. 4a) and quasiresonant (Figs. 4b, c) noise fields. The most important features of the change in the absorption line shape, established with the use of both resonant and quasiresonant noise fields consist in the following:

1. Under the action of a strong noise field the absorption line undergoes a splitting the value of which is proportional to the square root of the power of the noise field and is approximately equal to the value of the line splitting under the action of a monochromatic field of the same power.

2. As under the action of a strong monochromatic field, the effect of sign inversion of the absorption coefficient is observed (i.e., amplification) without inversion of the mean population of the levels. The maximum achievable value of the gain increases with decrease in the spectral line width of the noise field and is achieved for the case of quasiresonant action. Under conditions of resonant action, and also nonresonant action with the noise line width Δ_n, significantly greater than the width of the atomic line 2Γ, the maximum value of the absorption exponent is much less than in the action of the monochromatic field. For quasiresonant action of the noise field with spectral line width $\Delta_n \lesssim 2\Gamma$ the maximum achievable width of the absorption exponent is close to its value in the monochromatic field of the same power.

3. The resonant action of the noise field leads to strong fluctuations of the absorption exponent, the relative value of which (in relation to the mean value) increases with increase in the power and the resonance of the noise field. Thus, under conditions of quasiresonant action (Fig. 4b) the maximum ratio of signal to noise in the band 0.02 Hz was about 30. In the case of resonant action (Fig. 4a), it reaches ~10 in the band 0.02 Hz, and ~0.05 in the band ~1 Hz.

4. In the case of large widths of the spectral line of the resonant noise field Δ_n and not too large values of its power, when $V_0^2<\Delta_n^2$, only a broadening of the absorption line width is observed (approximately proportional to the power of the noise field) and a decrease in the maximum of the absorption index (approximately proportional to the square of the power of the noise field).

3. THEORY. DISCUSSION OF RESULTS

A. Action of the nonresonant ("weak") noise field

The change in the absorption line shape of the auxiliary probing field of a two-level system under the action of a strongly nonresonant noise field can be obtained from a solution of the equation for the matrix density in the rotating-field approximation:[2)]

$$i\dot f_{22}=V_{21}f_{12}-f_{21}V_{12}-i\gamma_1 f_{22},\quad i\dot f_{21}=V_{21}(f_{11}-f_{22})-i\gamma_2 f_{21},$$
$$f_{11}+f_{22}=1,\quad f_{12}=f_{21}^{*}. \tag{1}$$

Here $V_{21}=V_t\,e^{-i\tilde\omega_0 t}+v\,e^{-i\tilde\omega t}=V_{12}^{*}$, $V_t=-\pi_\gamma H_0(t)/2$, $v=-\pi_\gamma H_1/2$, γ_1 and γ_2 are the frequencies of longitudinal and transverse relaxation $\tilde\omega_0=\omega_0-\omega_{21}$, $\tilde\omega=\omega-\omega_{21}$; the states of the system are numbered in order of increasing energy. The amplitude of the field $H_0(t)$, in correspondence with the conditions of the discussed experiment, is assumed to be a random function of the time, having the statistics of a complex Gaussian process.

We used in the experiment linear fields the action of which differs from the action of a circular field only in the appearance of the Bloch–Siggert shift, equal to $V_0^2/2\omega_0$, which does not exceed 1 Hz for very powerful noise field and is much less than the observed shifts and broadenings of the absorption line.

Setting the moment of startup of the field to be $t=0$ ($V_{21}=V_{12}=0$ for $t<0$), we eliminate the quantities; f_{11} and f_{22} from the second equation of the system (1). The resultant equation for the quantity f_{21} is then represented in the form

$$\dot{f}_{21}(t)=-\gamma_2 f_{21}(t)+2V_{21}(t)\int_0^t e^{-\gamma_1(t-t')}\{V_{21}(t')f_{12}(t')-f_{21}(t')V_{12}(t')\}dt'-iV_{21}(t). \quad (2)$$

Upon satisfaction of the experimentally-realized condition of smallness of the change in the level populations in the noise field

$$V_0^2/(\omega_{21}-\omega_0)^2\ll 1, \quad (3)$$

$$\omega_0,\ \omega_{21}\gg|\omega_{21}-\omega_0|\gg\Delta_n \quad (4)$$

we can neglect in the integral term of Eq. (2) the components of order[3)] v and v^2. We represent the integral term of Eq. (2) obtained in such fashion in the form

$$2i\tilde{\omega}_0^{-1}V_t\exp[-i\tilde{\omega}_0 t-\gamma_1 t]\int_0^t \exp(\gamma_1 t')\{V_{t'}f_{12}(t')d\exp[-i\tilde{\omega}_0 t']\}+\text{c. c.} \quad (5)$$

and then integrate (5) by parts once. The result represents the sum of components of different order of smallness: the component which contains the integral is small in the measure of $\Delta_n/\tilde{\omega}_0$ since $\dot{V}_t\sim\Delta_n V_t$ or in the measure of $V_t^2/\tilde{\omega}_0^2$, since $\dot{f}_{12}$ and $\dot{f}_{21}$ are of the order of $V_0^2 f_{12}/\tilde{\omega}_0$ (and correspondingly $V_0^2 f_{21}/\tilde{\omega}_0$). The contribution to f_{21} from the rapidly oscillating components, which contain the factor $e^{-i\tilde{\omega}_0 t}$ or $e^{-i2\tilde{\omega}_0 t}$, is small in the measure of $V_0^2/\tilde{\omega}_0^2$.

Therefore, neglecting the rapidly oscillating and the integral components, we write down Eq. (2) in the abbreviated form

$$\dot{f}_{21}=-\gamma_2 f_{21}+2i\tilde{\omega}_0^{-1}|V_t|^2 f_{21}-i(V_t e^{-i\tilde{\omega}_0 t}+ve^{-i\tilde{\omega}t}). \quad (6)$$

The solution of Eq. (6), averaged over the ensemble of realizations of the random field, determines the averaged polarizability at the frequency ω of the weak field, the imaginary part of which is proportional to the absorption index $K(\omega)$ of the weak field:

$$K(\omega)\sim\text{Re}\int_0^\infty G(t)\exp(-\gamma_2 t+i\tilde{\omega}t)\,dt, \quad (7)$$

where

$$G(t)=\left\langle\exp\left\{2i\tilde{\omega}_0^{-1}\int_0^t|V_{t'}|^2dt'\right\}\right\rangle. \quad (8)$$

The quantity $G(t)$, in the case of complex Gaussian statistics of the perturbation V_t, can be represented in the form

$$G(t)=e^{\sigma(t)}, \quad (9)$$

where $\sigma(t)$ is determined by the infinite sum of irreducible contributions (ring diagrams):

$$\sigma(t)=i\int_0^t K_{11}\,dt_1+\frac{i^2}{2}\int_0^t\int_0^t K_{12}K_{21}\,dt_1\,dt_2+\frac{i^3}{3}\int_0^t\int_0^t\int_0^t K_{12}K_{23}K_{31}\,dt_1\,dt_2\,dt_3+\ldots \quad (10)$$

Here the correlator K_{jt} is defined as

$$K_{jl}\equiv K(t_j-t_l)=2\tilde{\omega}_0^{-1}\langle V_{t_j}V_{t_l}^*\rangle. \quad (11)$$

The expressions (9) and (10) can be obtained either by using the representation of the higher correlators in terms of the lower for the case of averaging the components of the expansion of the exponent (8) in a series, or by carrying out averaging of the exponent (12) with the help of a multidimensional normal distribution function, replacing the integral in the exponent of (8) by a Riemann sum.

The problem of the summation of the contributions (10) can be reduced to the problem of finding the solution of a certain linear integral equation. However, in connection with the fact that the method of solution of this equation is unknown in the general case, we shall not seek an exact solution of $\sigma(t)$ and shall limit ourselves to the study of the absorption line shape for two limiting cases.[4)]

The first case corresponds to the action of the noise field with the narrow spectrum:

$$K(0)=K_0=2V_0^2/\tilde{\omega}_0\gg\Delta_n.$$

In this case, it is sufficient to calculate the sum of the series (10) for $t\ll\Delta_n-1$[5]:

$$\sigma(t)\approx\sum_{n=1}^\infty\frac{i^n}{n}K_0^n t^n=-\ln(1-iK_0 t). \quad (12)$$

The absorption line shape in this case is determined by the expression

$$K(\omega)\sim\text{Re}\int_0^\infty\frac{\exp(-\gamma_2 t+i\tilde{\omega}t)\,dt}{1-iK_0 t}=\frac{\gamma_2}{2\pi}\int_0^\infty\frac{\exp(-\omega'/|K_0|)\,d\omega'}{(\tilde{\omega}-\omega'\,\text{sign}\,K_0)^2+\gamma_2^2}. \quad (13)$$

The expression (13) can be represented in the following approximate form when $\gamma_2\ll K_0$ (for $K_0>0$):

$$K(\omega)\sim\left(\frac{\pi}{2}+\arctan\frac{\omega_{21}-\omega}{\gamma_2}\right)\begin{cases}\exp[-(\omega-\omega_{21})/K_0], & \omega<\omega_{21}\\ 1 & \omega>\omega_{21}.\end{cases} \quad (14)$$

The $K(\omega)$ dependence, calculated according to Eq. (14)

for the values of $\gamma_2 = \Gamma$ and K_0 realized in the experiment, is shown in Fig. 2b. Since the equation (14) determines $K(\omega)$ with accuracy up to a constant factor, the matching is carried out at the maximum of the absorption line, where the experimental value of the absorption coefficient is more reliable (at this point, the experimental value of the absorption exponent is assumed equal to the theoretical).

As is seen from Fig. 2, the general form of the theoretical and experimental dependences is quite the same. It follows from (14) that for $K_0 \gg \gamma_2$ the shape of the absorption line is determined chiefly by the function $\exp\{(\omega - \omega_{21})/K_0\}$ and is proportional to K_0, i.e., to the power of the noise field, which is also in excellent agreement with the measured dependence (Fig. 3b). The picture of the change in the line shape, determined by the relation (13), can be interpreted in the following way. For $K_0 > \Delta_n$, the atomic system is located, as it were, in a quasimonochromatic field with an amplitude that is changing slowly in comparison with the value of the inverse of the mean line shift. In a time interval that significantly exceeds the correlation time $\tau_c = \Delta_n^{-1}$ of the exciting noise field, the field amplitude goes through nearly all possible values; the value of the line shift also takes on all possible values, which appears as its broadening. Upon satisfaction of conditions (3) and (4), the value of the line shift at each instant is proportional to the square of the field amplitude; therefore, the formula for the line, in the case of its initial width Γ is much less than the mean shift K_0, is close to the distribution of the density of probability of the square of the field amplitude.

For a complex Gaussian process, this distribution has the exponential form

$$W(|V|^2) = \frac{\pi}{2K_0} e^{|V|^2/K_0} \tag{15}$$

with a constant K_0 proportional to the noise field power in the exponent.

The absence of a limiting transition from the action of the noise field to monochromatic as the spectral width decreases is explained by their different statistics. In the case of the field obtained by narrow-band filtering of white noise, the amplitude of the effective field is variable, running through all its realizations during the time of recording. With decrease in the line width of the noise field, only the time necessary for realization of all values of the field amplitude increases. In the case of a monochromatic field, its amplitude remains constant over the time of recording.

The other limiting case corresponds to the action of the sound field with a wide spectrum: $K_0 \ll \Delta_n$. In this case, it suffices to keep only the first components in the sum of (10), considering them in the limit $t \gg \Delta_n^{-1}$.[5] The first component of the sum (10) corresponds to the line shift Δ, which is proportional to the total noise field power

$$\Delta = K_0 \tag{16}$$

and is equal to the value of the line shift in a monochromatic field of the same power. The result is in full agreement with the experimental results (see Fig. 1). The second component determines the value of the line width $\tilde{\gamma} = \Gamma_j - \Gamma$ of the noise field:

$$\tilde{\gamma} = \int_0^\infty K^2(t)\,dt \sim K_0^2/\Delta_n. \tag{17}$$

The quadratic dependence of this field broadening on the noise field power, predicted by the relation (17), is well confirmed experimentally (Fig. 3a). It follows from Eqs. (16) and (17) that in broad noise spectra, $\Delta_n \gg K_0$, the field broadening of the absorption line is less than its shift K_0 by the factor K_0/Δ_n. In the limiting case considered, the field amplitude changes rapidly in comparison with the frequency of the line shift and an averaging takes place of the instantaneous positions of the line relative to the mean shift K_0, which appears as a small broadening. The effective averaging time is the period of the frequency of the mean line shift K_0^{-1}—the time necessary to measure the value of the frequency with accuracy to within K_0. It is obvious that the degree of averaging of the instantaneous line shifts is determined by the ratio of the mean time of change in the field amplitude τ_0 to the averaging time, i.e., the ratio K_0/Δ_n.

The third component of the sum (10), in addition to the correction to the shift and to the broadening, contains in it information on the asymmetry of the absorption line. Its value is of the order of K_0^3/Δ_n^2 and, consequently, in the considered approximation $K_0 \ll \Delta_n$, the asymmetry of the line is less significant than its shift and broadening, which is also in agreement with the results of experiment (Fig. 2a). Each succeeding contribution to the sum (10) will contain the small factor K_0^3/Δ_n; therefore, the corrections associated with them are small.

Summing up all the results of the study of the change in the absorption line shape of a weak emission of a two-level system under the action of strongly nonresonant (weak) noise field with Gaussian statistics, we can conclude that the results of the theoretical analysis of the line shape on the basis of linear contraction of Eq. (6), are in excellent agreement with the experimental results. The basic initial position of the theory—the neglect of the change in population of the energy levels in the noise field, is the condition of the quadratic dynamic Stark effect in nonresonant fields of optical radiation. Since the statistics of emission of multimode lasers without mode synchronization are close to Gaussian, then analogous laws will be observed in the change in the energy structure of the atomic levels under conditions of the quadratic Stark effect in the radiation fields of such lasers, when the ionized level broadening is unimportant.[6] For low intensities of radiation of the laser, a shift in the levels should be observed that is equal to their shift in a monochromatic field of emission of the same intensity, and small in comparison with the shift in the level broadening that is absent in a monochromatic field. For level shifts (in frequency units) of the order of the width of the spectral line of the radiation, further increase in the radiation intensity will lead to the form of distribution of the density of energy levels shown in Fig. 2b. The shift in the maximum of the energy density will be quickly saturated, and the width of the level will increase in proportion with the intensity of the acting radiation, and will be equal in magnitude to the level displacement in a monochromatic field of the same intensity.

B. Action of resonant and quasiresonant noise fields

At the present time, there are no general methods for the calculation of the change in the absorption spectrum of weak probing radiation of a two-level system under the action of powerful resonant fields of radiation with Gaussian statistics, the results of which could be compared with the results of our experiment. The absorption spectrum that we have observed in a resonant noise field, with a spectral line shape that is close to rectangular (Fig. 4a), does not agree with the results of calculation of the absorption spectrum and the Lorentzian shape of the spectral line, where absence of sign inversion of the absorption exponent and splitting of the line into two components with width equal to the sum of the line widths of the atom and the interacting noise field had been predicted.[7] Comparison with the results of the calculation of the absorption spectrum in the case of the action of the resonant field, obtained as a result of modulation, of the phase, frequency and amplitude of the monochromatic wave in a purely discontinuous random Markov process[3] shows that the results of our experiment are very close to the results of the calculation for the case of phase modulation.

The absorption line shape predicted in this case is identical with the line shape under the action of a monochromatic field for an effective width of the atomic line equal to the sum of the widths of the initial line and the line of the active radiation.

We discussed in[1] the possibility of use of the effect of sign inversion of the absorption index for the creation of wavelength-tunable generators and amplifiers of stimulated emission with inversion of level population in the excitation of two-level atomic systems by resonance and quasiresonance monochromatic emission. The results of our experiments enable us to estimate the requirements for the degree of monochromaticity of the exciting radiation, when the latter is produced by multimode lasers without mode locking. In producing generators of stimulated emission, the line width of the laser emission should not exceed the homogeneous width of the atomic absorption line used. In the opposite case, the maximally achieved value of the gain is reduced and the width of the amplification line increased. Use of multimode lasers will lead to great fluctuations of the gain which can lead to serious obstacles in the creation of amplifiers of stimulated emission. Evidently, lasers with stable amplitude of emission should be used for such amplifiers and generators.

1)The power of the noise field is expressed in units of the ratio of the mean square matrix element of the interaction energy of the noise field $V_0^2=\pi^2\gamma^2\sqrt{H_0^2(t)}/4$ to the square of the half-width of the atomic absorption line Γ^2 ($\Gamma=2.7$ Hz $\gamma=942$ Hz/G is the gyromagnetic ratio). The method of measurement of Γ and the magnetic field intensity in the volume of the vessel with Cd is described in detail in[1].

2)Under the conditions of our experiment, when the shift in the levels under the action of the radiofrequency field is much smaller than the frequency of the Zeeman transition, the validity of the two-level approximation was shown experimentally in[1] by the identity of the conclusions of such a description with the experimental results. Departures from the predicted two-level approximation have been observed only when the frequency of the Zeeman transition was of the order of the shift of the Zeeman levels under the action of the radiofrequency field.

3)The smallness of v in comparison with V_t is not a sufficient condition for neglect of components proportional to v and v^2 in the integral term. These components determine the effect of the nonlinear interference on the weak field absorption.[3] The nonlinear interference effect is small if conditions (3) and (4) are satisfied.

4)A simplest problem for theoretical analysis is the calculation of the center of gravity of the line (first moment). However, the result of such a calculation is already well known: namely, the center of gravity is shifted in proportion to the power of the exciting field for strongly nonresonant perturbation. More informative characteristics—the location of the maximum of the absorption line and its shape—can be obtained only in limiting cases.

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