A method for measuring collison broadening of spectral lines

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An investigation of homogeneous broadening of the 0.63 μm γ_{ab} transition line from a He-Ne laser is carried out by measuring the dependence of the Verdet "constant" of the laser medium on the pressure of the mixture. At a temperature T = 365° K the measured dependence $d\gamma_{ab}/dp$ = (63 ± 5) MHz/mm Hg is in satisfactory agreement with the results obtained by other methods.

The effects of pressure in gas lasers have by now become the subject of a large number of investigations (see the bibliography in[1]). Some of the studies are devoted to specific investigation of the homogeneous broadening of the laser transition line γ_{ab}. The parameter γ_{ab} strongly influences the characteristics of the emission of gas lasers, and the behavior of γ_{ab} in measurements of the temperature and pressure of an active plasma makes it possible to assess the line-broadening mechanism. We have previously observed experimentally[2] the effect of pressure on the value of the Verdet "constant" of an active medium, thereby uncovering the possibility of quantitatively investigating the collision broadening with the aid of a ring laser.

For an experimental verification of the reliability of the method, we chose the well-investigated neon laser transition $2S_2 - 3P_4$. The obtained[3] empirical formula connecting the collision width with the concentration and with the absolute temperature of the gas

$$\gamma_{coll} = 3.37\cdot 10^{-20} nT^{0.33\pm0.04}$$

permits a quantitative comparison of our results with the results of that reference. We know of no other measurements of collision broadening where the temperature was monitored.

As shown by one of us[4], the beat frequency of the opposing waves of a ring laser with circularly anisotropic resonator, following application of a longitudinal magnetic field to the active medium, can be expressed by the formula

$$f = \Delta\nu \frac{\mathfrak{R}}{2\mathfrak{R}_0} \operatorname{Im}[Z(\xi - \mu + i\gamma_{ab}) - Z(\xi + \mu + i\gamma_{ab})], \qquad (1)$$

where $\Delta\nu$ is the optical-resonator band, $\mathfrak{R}$ is the relative excess of the gain over the losses, Z(x) is the plasma dispersion function[5], and $\mathfrak{R}_0 = \operatorname{Re} Z(i\gamma_{ab})$ is a normalization factor that characterizes the gain at the center of the Doppler curve. The resonator detuning ξ relative to the center of the gain curve, the Zeeman splitting μ of the line, and the homogeneous width of the line were normalized to the parameter ku, which characterizes the Doppler broadening of the line.

Using the smallness of the quantities ξ, μ, and γ_{ab}, we can easily obtain an approximate expression for the frequency of the Zeeman beats:

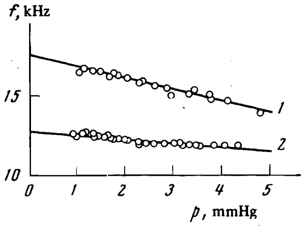
$$f \approx \frac{2}{\pi^{1/2}} \mathfrak{R}\mu\Delta\nu\left[1 - \left(\pi^{1/2} - \frac{2}{\pi^{1/2}}\right)\gamma_{ab} + \left(1 + \frac{4}{\pi}\right)\gamma_{ab}^2 - 2\xi^2 - \frac{2}{3}\mu^2\right]. \qquad (2)$$

It is seen from this formula that by measuring the dependence of the frequency of the Zeeman beats on the pressure and on the temperature of the active medium it is possible to obtain information on the change of the homogeneous line width. In the case when the active medium is a mixture of equal amounts of two isotopes (50% mixture), formula (1) can be generalized in obvious fashion. The approximate expression for the beat frequency differs from expression (2), roughly speaking, by a factor $(1 - \sigma^2/2)(1 - \sigma^2/4)^{-1}$, where σ is the isotopic shift normalized to ku. This circumstance enables us to determine the value of the parameter ku and consequently the plasma temperature, for which purpose it suffices to compare the Verdet "constant" of the active plasma with different isotopic contents of active atoms. The presence of an intrinsic possibility of determining the temperature of the plasma makes it possible in this manner, in investigations of the homogeneous line broadening, to separate the temperature and pressure effects, an important factor in the determination of the broadening mechanism. Usually, on the other hand, the plasma temperature is determined from the temperature of the outer wall of the gas-discharge tube, with allowance for the calculated correction for the temperature drop between walls[3].

The experiment was performed with a ring He-Ne laser with circularly anisotropic optical resonator operating at a wavelength 0.63 μ. The calculated ellipticity of the emission is not less than 0.95. The investigated ring laser was connected to a vacuum system, with which it was possible to vary the pressure and the isotopic composition of the working gas. The ballast volume of the vacuum system exceeds the volume of the gas-discharge tubes by at least two orders of magnitude. After each change of the isotopic composition of the neon, the active elements were refilled many times and conditioned for a long time, thereby ensuring stability of the composition of the active medium during the measurements. The ratio of helium to neon in the working mixture was maintained at 6.5 : 1.

The active medium was excited with a discharge. A 3.9 Oe longitudinal magnetic field was applied to the gas-discharge tubes with the aid of solenoids. The resonator was tuned relative to the center of the gain curve manually against the beat amplitude, using piezoceramic elements to move the resonator reflectors. The stability of the optical frequency in this case was not worse than 50 MHz. The relative excess was chosen minimal in each case, so that the beat signal level was sufficient for reliable measurement of the frequency with a digital frequency meter ($\mathfrak{R} < 0.14$). The value of the excess was monitored against the width of the generation region. The stability of the excess could easily be maintained with accuracy 1.5%, by maintaining the width of the resonator detuning region, within which lasing could be produced, with accuracy 20%. The single-mode lasing regime was monitored with a scanning interferometer.

The figure shows the results of measurements of the dependence of the beat frequency on the pressure at two different isotopic compositions of the neon atoms. The



Frequency of Zeeman beats against the pressure of the working mixture: 1 – n(Ne^{20}) = 99.7%; 2 – n(Ne^{20}) = 46.6%.

spread of the experimental points is due to the instability of the detuning of the resonator ξ and the gain $\mathfrak{N}$ on which earlier experiments[7] had shown the Zeeman beat frequency to be strongly dependent. The best straight lines were drawn through the experimental points by least squares. The computer "Mir-1" was then used to determine, with the aid of formula (1), values of ku and $d\gamma_{ab}/dp$ such that the theoretical relations coincided with the experimental ones. It is easy to see that in this method of measuring and reducing the results, the lack of information on the optical-resonator bandwidth $\Delta\nu$ and inaccurate knowledge of the magnetic field and also its inhomogeneity do not influence the measurement accuracy. The calculations yielded for the plasma temperature a value 356° K and for the collision broadening $d\gamma_{ab}/dp = 63 \pm 5$ MHz/mm Hg. The measurement error was estimated by comparing the theoretical and experimental curves plotted for other isotopic compositions of the neon.

The collision broadening measured by us at the indicated plasma temperature is in good agreement with the value 62.5 MHz/mm Hg obtained from the empirical formula of Mikhnenko et al.[3].

We note that in a ring laser the frequency of the Zeeman beats at zero detuning of the resonator is due to a purely linear effect, and consequently the accuracy with which the homogeneous line width is determined does not depend on the correctness of the description by the theory of nonlinear wave interaction. This, as well as the simplicity of the experiment, makes the described procedure superior to the best-known laser methods of determining γ_{ab} from the width of the Lamb dip[3] and from the width of the absorption peak[6].

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