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EXPERIMENTAL INVESTIGATION OF STIMULATED EMISSION FROM A GAS MIXTURE

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The change in the spectrum of light passing through a medium with negative absorption coefficient is investigated. Narrowing of the 6362 Å line of Zn is observed.

In earlier work[1] a medium was prepared having a negative absorption coefficient for the 6362 Å line ($4^1P_1^0 - 4^1D_2$) of zinc. The present paper reports the change in the spectrum of light passing through the same medium. The spectrum was analyzed with conventional interference apparatus including a Fabry-Perot etalon and with a Michelson two-beam interferometer.[2,3]

The true width of a line extremely narrowed by amplification cannot easily be determined with a Fabry-Perot interferometer, since the instrumental width becomes greater than the width of the investigated spectral distribution. It is especially difficult to determine the effect of mirror imperfections,[4] so that relative measurements were used to determine the narrowing of the line.

Two lamps were investigated, having Hg-Zn electrodes similar to those used in [1]. The frequency dependence of the amplification factor of Zn 6362 Å was studied. The positioning of the lamps before the apparatus permitted a study of the line from each lamp separately, and also when the light from one lamp passed through the other lamp. The line intensity of the first lamp is denoted by $I_1(\nu)$, that of the second lamp by $I_2(\nu)$, and that for light from the first lamp passing through the second lamp by $I_{12}(\nu)$. The amplification factor is then given by

$$K(\nu) = [I_{12}(\nu) - I_2(\nu)]/I_1(\nu). \qquad (1)$$

The different curves in Fig. 1 represent $K(\nu)$ for different orders of interference. Curve 1 corresponds to the interference fringes formed by an interfering beam having the direction of the optical axis. Curves 2 and 3 correspond to successively increased angles. Curve 1 exhibits a clear peak, which is absent from the other curves.

In order to study the narrowing of the amplified line a special lamp was constructed, consisting of a cylinder 20 mm in diameter and 110 mm long sealed at its ends by glass windows. The electrodes, having somewhat different mercury and zinc contents, were positioned so that emission both parallel and perpendicular to the tube axis could be studied.

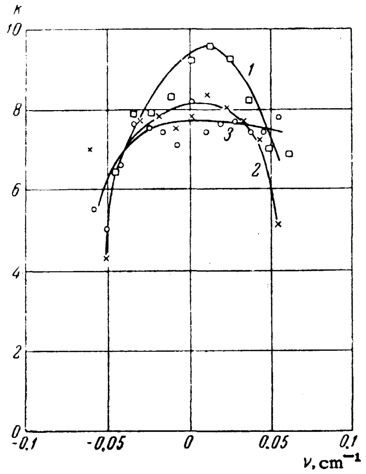

FIG. 1. Frequency dependence of the amplification factor for Zn 6362 Å in three different interference orders. Curve 1 corresponds to the direction of the optical axis of the system. Curves 2 and 3 correspond to different angles.

Figure 2 shows the observed shapes of the 6362 Å and 4680 Å lines of zinc; the second line is not amplified in two interference orders. Curves a

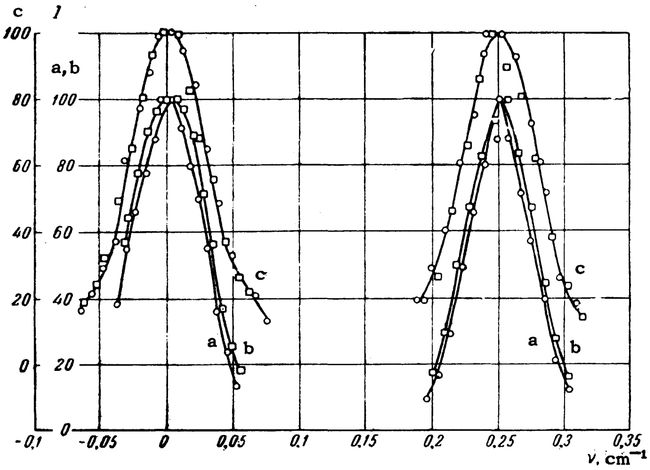

FIG. 2. Observed intensity distributions of the zinc lines 6362 Å (curves a and b) and 4680 Å (curve c) in two orders of interference along two directions, perpendicular (□) and parallel (○) to the discharge lamp.

Path difference between the two interfering beams for identical visibility of the interference pattern

t/2 parallel to discharge tube, mm	72	60	60	59.5	49	50	54	56	43	46	45	51.5	54.5
t/2 perpendicular to discharge tube, mm	67	44	47	49.5	40	38	46	46	37	38	38	45	45
Temperature of water coolant, °C	17	6	6	16	16	7	10	10	20	18	18	25	36
$\Delta\nu(l_\parallel)/\Delta\nu(l_\perp)$	0.93	0,735	0.785	0,83	0.82	0.76	0,85	0.82	0,86	0,83	0.845	0.875	0.827

represent emission parallel to the lamp axis; curves b represent emission perpendicular to the axis. Line narrowing is clearly observed in the figure. The curves c show that the line shape remains practically unchanged.

The intensity ratio of emission parallel to the lamp axis ($I_\parallel$) and perpendicular to the axis ($I_\perp$) was measured. For the 6362 Å line $I_\parallel/I_\perp = 14$—20, depending on the discharge conditions; for 4680 Å, $I_\parallel/I_\perp = 3.5$. The ratio of the geometric dimensions of the luminous positive column was $l_\parallel/l_\perp \approx 5$.

The ratio of the half-widths of $I_\parallel(\nu)$ and $I_\perp(\nu)$ was estimated from the visibility of interference fringes produced by the Michelson interferometer. According to Michelson,[3] fringe visibility is given by

$$V = (I_{max} - I_{min}) / (I_{max} + I_{min}), \qquad (2)$$

where I_{max} and I_{min} are maximum and minimum intensities in the interference pattern. For Lorentzian and Gaussian line shapes the visibility is given by

$$V_L = \exp\left\{-\frac{2\pi\Delta\nu_0}{[\Delta\nu]}\right\}; \quad V_G = \exp\left\{-\left(\frac{\pi\Delta\nu_0}{[\Delta\nu]}\right)^2 \frac{1}{\ln 2}\right\}, \qquad (3)$$

where $2\Delta\nu_0$ is the half-width, $[\Delta\nu] = 1/t$ is the dispersion, and t is the path difference of the two interfering beams. We observed identical visibility of the interference pattern produced by light emitted parallel and perpendiuclar to the lamp axis with several path differences t. Therefore, for both the Lorentzian and Gaussian line shapes we obtain

$$\Delta\nu_\parallel / \Delta\nu_\perp = [\Delta\nu_\parallel] / [\Delta\nu_\perp] = t_\perp / t_\parallel. \qquad (4)$$

The intensity distribution represented by the Voigt function is more complicated and will not be considered here.[5]

The table gives the values of $t_\perp/t_\parallel$ for different electrode temperatures. Let the line and the absorption coefficient as a function of frequency have either a purely Lorentzian or a purely Gaussian shape. Using $e^x \approx (2+x)/(2-x)$, we obtain the ratio of the half-widths $\Delta\nu(l)$ of emission from the source to the half-width $\Delta\nu_0$ of spontaneous emission:

$$\left(\frac{\Delta\nu(l)}{\Delta\nu_0}\right)_L = \sqrt{\frac{2-k_0 l}{2}}; \quad \left(\frac{\Delta\nu(l)}{\Delta\nu_0}\right)_G = \sqrt{\ln\frac{4-k_0 l}{2} / \ln 2}, \qquad (5)$$

where k_0 is the absorption coefficient and l is the length of the luminous volume. In deriving these formulas $k_0 l < 1$ was assumed. From the range 0.73—0.93 of the ratio $\Delta\nu(l_\parallel)/\Delta\nu(l_\perp)$ we obtain the range 0.03—0.095 cm^{-1} for k_L and 0.041—0.113 cm^{-1} for k_G. The intensity ratio

$$I_\parallel(\nu) / I_\perp(\nu) = (e^{kl_\parallel} - 1) / (e^{kl_\perp} - 1) \qquad (6)$$

varies from 7 to 10. Taking into account the nonuniform cross-sectional distribution of zinc in the tube, which effectively reduces $l_\perp$, the results are found to agree satisfactorily with the direct measurement of $I_\parallel(\nu)/I_\perp(\nu)$.

In conclusion I wish to thank I. L. Fabelinskiĭ for valuable discussions of the results.

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