frequency and the wave vector of the photons, as indicated by the observed unique dependence of the intensities of the minima on the magnetic field.

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GAS LASER FREQUENCY FLUCTUATIONS

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Equations for the spectral densities of the natural intensity and frequency fluctuations of the emission of a continuously-operating single-mode laser were derived in [1]. An experimental verification of the intensity fluctuation was performed earlier [2]. We report here the result of an experimental investigation of the frequency fluctuations of a helium-neon laser at wavelength 0.62 μ and the determination of the natural width of its spectral emission line.

According to the theory [1], the fluctuations of the frequency ν of a laser whose cavity is tuned to the center of the active-medium transition has an approximate spectral density

$$w_\nu = \frac{(\Delta\nu)^2 h\nu}{P} \alpha\tilde{\beta}\frac{\kappa^\circ_2}{\kappa^\circ_2} \quad (\mathrm{Hz}^2/\mathrm{Hz}) \tag{1}$$

where $\Delta\nu$ is the resonator bandwidth and P the power generated by the active medium. It follows from the earlier experiments [2] that for our purpose we can assume $\alpha\tilde{\beta}\kappa_2^0/\kappa_2 \simeq 2$.

If we put by way of an example in (1) P = 1 mW and $\Delta\nu$ = 6 MHz, we get $w_\nu \simeq 0.02$ Hz^2/Hz. The natural emission line width is π times larger, i.e., $\simeq 0.06$ Hz in our example. It is well known that the real (technical) instability of a laser frequency is larger than this quantity by many orders of magnitude. This discrepancy is due to a number of different technical factors, that lead to variations of the laser parameters, and hence to considerable spreading of the emission frequency. The possibility of separating the natural fluctuations is based on the fact that the value of w_ν does not depend theoretically on the observation frequency F, and the spectrum of the frequency fluctuations due to technical factors decreases rapidly with increasing values of F. A similar problem was encountered also in investigations of the frequency fluctuations of radio oscillators, and was also solved by studying the frequency-fluctuation spectrum (see [3-5]). The methods used there, however, are not convenient for our purpose, since estimates have shown that, for many reasons, the signal/noise ratio will not be sufficient for a reliable determination of the values of w_ν of the laser emission.

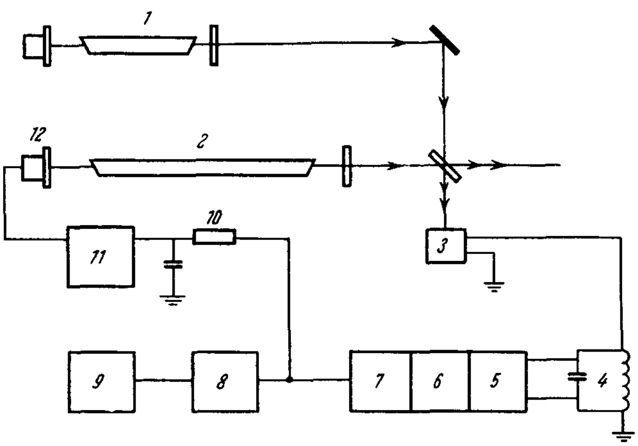

Fig. 1

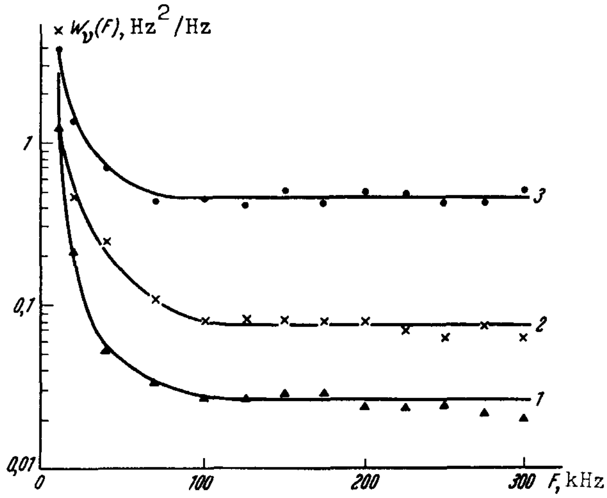

Fig. 2

Following a suggestion by I. L. Bershtein, we used a setup whose schematic diagram is shown in Fig. 1. The emission from the investigated laser 1 interferes with the emission from an auxiliary laser 2 (heterodyne) and is fed to a photodiode 3 whose load is the LC network 4, tuned to 8.4 MHz. This is followed by an amplifier 5, an amplitude limiter 6, and a frequency discriminator 7. The output voltage of the latter, which is thus determined only by the fluctuations of the 8.4-MHz difference frequency, goes through amplifier 8 to the spectrum analyzer 9, and is also fed through RC network 10, which has a time constant ~ 0.3 sec, to amplifier 11 and then to the piezoelectric element 12 that controls the heterodyne frequency. Such a system maintains the mean value of the difference frequency (8.4 MHz) constant automatically without exerting any influence on the frequency fluctuations in the investigated band (F = 10 - 300 kHz).*

The heterodyne parameters were chosen such (higher power and lower cavity bandwidth) as to make its frequency fluctuations much lower than the fluctuations of the frequency of the investigated laser; it can be assumed here that the fluctuations of the difference frequency 8.4 MHz are due only to the fluctuations of the frequency of the investigated laser.

We shall show that the method used to observe the natural frequency fluctuations of the laser has sufficient sensitivity. The useful effect is the sought value of w_ν. The harmful effect is the noise voltage at the input of the radio circuitry, whose spectral density is approximately

$$w_u \simeq 4zkT + 2ez^2(I_h + I_\ell), \qquad (2)$$

where z is the circuit impedance at 8.4 MHz, k is Boltzmann's constant, T ≃ 290°, e is the electron charge, and I_h and I_ℓ are the dc components of the photocurrents from the heterodyne and the laser. The difference-frequency voltage at the input to the circuit is $U \simeq \sqrt{I_h I_\ell}\, z$.

The presence of noise voltage (2) together with U produces a random frequency deviation whose spectral density at the observation frequency F is equal to

$$w_b\ (F) = \frac{F^2}{U^2}\ w_u \quad .$$

For the ratio of the useful and harmful effects we get

$$\frac{S}{N} = \frac{w_\nu}{w_b\ (F)} = \frac{w_\nu\ I_h\ I_\ell}{F^2[\frac{4kT}{z} + 2e(I_h + I_\ell)]} \quad . \tag{3}$$

Substituting $w_\nu = 0.02\ Hz^2/Hz$, $z = 2 \times 10^3$ ohm, $I_h = 30\ \mu A$, and $I_\ell = 15\ \mu A$, we get $S/N \simeq 4000$, 160, and 4.5 respectively for F = 10, 50, and 300 kHz.

To determine the experimental values of the spectral frequency density $w_\nu(F)$, we used a method of calibrating the apparatus such that the observation data could be processed reliably and simply.

We investigated a single-frequency laser with dc supply to the discharge and with a resonator length ~23 cm; the lasing frequency was set in the center of the optical transition. Numerous measurements of $w_\nu(F)$ have shown that the technical component of the spectrum, which is primarily due to mechanical and acoustical noise, can be reliably separated; this section of the spectrum was in the region 40 - 60 kHz of the frequency F. ** The spectral density $w_\nu(F)$, starting with 60 - 100 kHz, was practically independent of F and remained constant (within the limits of measurement accuracy) at different noise levels. This section of the spectrum can be ascribed to fluctuations due to natural causes. The experiments were made in the evening, when the technical noise level was the lowest attainable under laboratory conditions.

Typical results of the measurements of $w_\nu(F)$, for three values of the power P, are shown in Fig. 2, where curves 1, 2, and 3 correspond to P = 1060, 296, and 82 μW, respectively.*** We note that the laser output power was ~ 20% of P.

Let us compare the values of w_ν obtained by means of formula (1) with the experimental values (averaged in the range of F from 100 to 300 kHz).

T a b l e

P, μW	82	148	296	555	1060
Experiment w_ν, Hz^2/Hz	0.456	0.186	0.076	0.057	0.026
Theory w_ν, Hz^2/Hz	0.379	0.206	0.098	0.048	0.021

The discrepancy between the experimental data and the theoretical ones does not exceed the measurement errors.

Summarizing, we can state that we have developed a procedure and performed measurements of the natural frequency fluctuations (and of the natural line width) of a gas laser.

A comparison shows that the experimental data are in satisfactory agreement with the results of the theoretical analysis.

The authors are grateful to I. L. Bershtein, under whose guidance the work was performed.

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* The authors are grateful to L. A. Khurtin for help in constructing the radio apparatus.

** Frequency fluctuations due to noise of the gas discharge were observed in the frequency band up to 100 - 150 kHz. This effect was eliminated by proper choice of the discharge conditions.

*** We note that in some cases narrow peaks were observed in the values of $w_\nu(F)$, corresponding to mechanical resonances of the laser system; they were eliminated by taking appropriate measures.

RADIO-FREQUENCY SIZE EFFECT IN MOLYBDENUM

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The progress made in recent years in the production of pure transition metals (Cr, W, Mo) have made it possible to perform a number of experiments [1-4] on the Fermi surfaces of these metals.

Comparison of the experimental data with the Fermi-surface model proposed by Lomer [5,6] for metals of the chromium group yielded good agreement.

It must be noted, however, that the comparison was only semiquantitative [4]. The method proposed by Gantmakher [7]for the investigation of the electron spectrum of metals - the size-effect method - greatly expanded the experimental possibilities of investigating Fermi surfaces and has made possible a more detailed com parison with the existing theoretical models.

However, owing to the regired high purity of the investigated materials ($l > d$), such measurements were made with a very small group of metals [7-10].

We present here results obtained by observing the size effect in molybdenum.

The molybdenum samples investigated had a resistance ratio $R_{300°K}/R_{4.2°K} = 12\,000$ and were in the form of discs 6 mm in diameter and 0.142 mm thick. They were placed in the coil of the generator tank circuit and were cooled together with the coil to helium temperatures. The experiment consisted of measuring $\partial R/\partial H$ as a function of H.

Since the intensities of the size-effect lines depend on the electric-field polarization, the apparatus was operated at maximum sensitivity in all the experiments by making E perpendicular to the constant magnetic field H.