magnetic field, increases up to 150 Oe, and then decreases abruptly to a low value.

The observed $\Delta\sigma(H)$ plots indicate the existence of two processes that exert opposing influences on the magnetoplastic effect. It can be assumed that an increase of the magnetic field would give rise, on the one hand, to a mechanism of unblocking of the dislocations stopped by the domain walls and to an increase of their mean free paths, owing to the displacement and removal of the magnetic domain walls. This mechanism contributes to the appearance and growth of the magnetoplastic effect. On the other hand, when a high-intensity field is turned on, magnetostriction effects come into play. In addition, the initial stage of reorientation and change of the domain structure prior to the unification of the domains may be accompanied by a break-up of the domains and therefore by an increase in the length of the domain walls [4]. These processes should lead to a strengthening of the crystal [5] and to a reduction of the magnetoplastic effect. With increasing alternating-field intensity, however, the processes that suppress the magnetoplastic effect are less effective than the weakening due to the application of the magnetic field. On the other hand, in a constant magnetic field of high intensity, the contribution of the latter predominates over the weakening, and a maximum is therefore observed on the $\Delta\sigma(H)$ plots. Further investigations will make it possible to determine more definitely the nature of the observed differences between the effect of the constant and alternating magnetic high-intensity field on the magnitude of the magnetoplastic effect.

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ANOMALOUS DECREASE OF THE SHIFT OF THE CENTER OF THE LAMB DIP IN LOW-PRESSURE MOLECULAR GASES

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1. We report here, for the first time, observation of a nonlinear dependence of the shift of the center of the Lamb dip on the pressure in molecular gases. The nonlinear character of the shift is due to the influence of the elastic scattering of molecules in the region of widths and pressures when the Doppler frequency shift in scattering is comparable with the impact broadening [1]. The observed features uncover in principle new possibilities for the use of laser spectroscopy to measure elastic-scattering cross sections and to study of the interaction potential of colliding molecules. Our spectroscopic investigations, with relative accuracy 10^{-13}, have been made possible by the appreciable progress in frequency-stabilization methods, proposed in [2 - 4] and based on the use of nonlinear absorption of molecules. We report also that we obtained a reproducibility 3×10^{-14} and high values of short- and long-period frequency stability, 5×10^{-15}. The sharp decrease of the shift of the Lamb dip

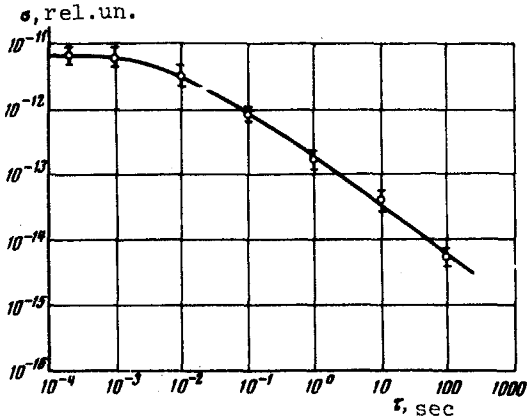

Fig. 1

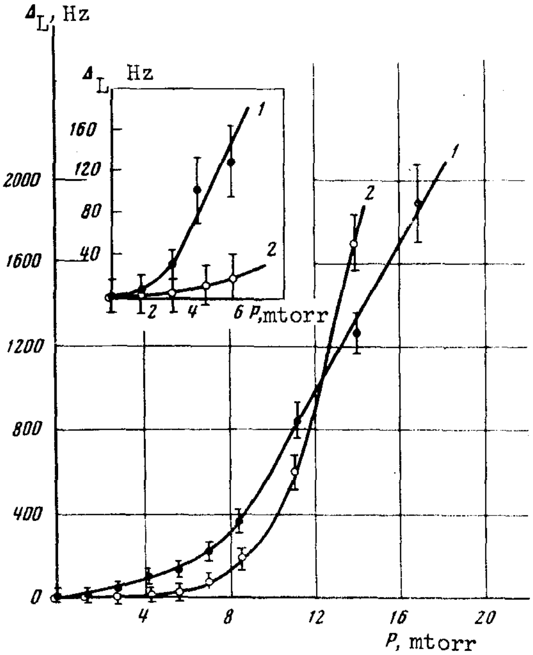

Fig. 2

Fig. 1. Root-mean-square frequency deviation vs. the averaging time τ. The data were obtained with the aid of an electronic-counting frequency meter.

Fig. 2. Shift of generation frequency of a laser stabilized against the power peak, as a function of the pressure of helium (curve 1) and xenon (curve 2) in the absorption cell. The methane pressure in the cells is ∿1 millitoor.

at low pressures[1)] practically eliminates one of the main obstacles to the attainment of frequency reproducibility on the order of 10^{-13} - 10^{-15}, and consequently uncovers new prospects for optical frequency standards.

2. The impact shifts of the center of the Lamb dip were determined by measuring the shift of the frequency of an He-Ne laser, stabilized against the peak of the generation power [3, 5], with a nonlinear methane absorber (λ = 3.39 μ). This system, which was proposed in [2, 3], turned out to be convenient for spectroscopic investigations. Narrow resonances and generation-frequency stabilization in it were first obtained in [6]. Dependending on the averaging time τ, a long-period stability 10^{-11} - 10^{-13} was attained in [7 - 9]. Mode competition in a laser with nonlinear absorption leads to a narrowing of the resonance and an increase of its contrast [10]. This has made it possible to obtain a long-period frequency stability 5×10^{-14} at τ = 10 sec [11]. In spite of attaining high long-period stability, there are practically no data on the investigation of the collisions, which are the most important factor limiting the frequency reproducibility. The investigations of frequency reproducibility were limited to a value $\sim 10^{-11}$.

Preliminary experiments have shown that to measure the line shifts in the pressure region of 1 millitorr it is necessary to tune to the center of the Lamb dip with accuracy to ∿10 Hz. When the width and amplitude of the peak

[1)]The possibility of decreasing the impact shift of the Lamb dip at low pressure was indicated in [1].

change at different gas pressures, at different values of the field, etc., changes take place in the gain and in the static error of the automatic frequency control. An inaccuracy in the setting to the peak center, which is of no importance when it comes to obtaining long-period stability, can produce, as a result of the static error, large but false "impact" and "field" frequency shifts. Our efforts were therefore aimed at improving greatly the resonance parameters in comparison with our earlier experiments [9]. In this study the peak amplitude was 3 - 5 mW (peak contrast 50 - 90%), and the width was $\sim 5 \times 10^4$ Hz at a CH_4 pressure less than 1 millitorr. Measures taken to prevent vibration have ensured a high short-period stability compared with the known results (Fig. 1).

3. The nonlinear dependence of the shift of the Lamb-dip center on the He and Xe pressures, shown in Fig. 2, indicates that at low pressures, $\sim$1 millitorr, the shift is very small. With increasing pressure, the shift increases sharply, and the slope of the curve at pressures higher than 10 millitorr becomes commensurate with the impact shift of the Doppler contour, obtained in [12] at pressures 10 - 100 Torr. This dependence is not explained in the theory[2]. The theory of the Lamb-dip shift in collisions can be constructed on the basis of the quantum kinetic equations of [13], generalized to include problems that are nonlinear in the field. We confine ourselves here only to a qualitative estimate. We have for the line shift (cf. [14])

$$\Delta = Nv\sigma'', \qquad \sigma'' = 2\pi \int_0^\infty d\rho\, \rho \sin \eta(\rho), \tag{1}$$

where N is the density of the scattering centers, v is the average velocity of the molecule, and $\eta(\rho)$ is the difference between the phase shifts at the upper and lower levels for flight with an impact parameter ρ. The change of velocity upon collision is neglected in the derivation of (1). To calculate the shift Δ_L of a narrow Lamb dip it is impossible to neglect the change of the trajectory, since the atoms scattered through angles $\theta > \theta_L = \gamma/kv$ (γ is the width of the dip and k is the wave number) make no contribution to the shift of the dip. Integrating in (1) not from zero but from ρ_L (ρ_L corresponds to θ_L and is obtained by solving the classical scattering problem), we obtain

$$\Delta_L = 2\pi N v \int_{\rho_L}^\infty d\rho\, \rho \sin \eta(\rho). \tag{2}$$

The high-frequency shift of the methane line corresponds to a major role of the repulsion forces in the interaction between CH_4 and the He and Xe atoms. If the repulsion forces are described by a potential c/r^{12}, then we obtain from (2) for $\Delta_L \ll \Delta$ and for strongly differing constants c for the upper and lower levels

$$\Delta_L \approx 0.1 [q\sqrt{\sigma''} (\gamma/kv)]^{3/4} \Delta, \tag{3}$$

where $q = Mv/\hbar$ and M is the mass of the molecule. An estimate based on (3) is in qualitative agreement with the experimental results. For a pressure of 1 millitorr we have $\gamma/kv \sim 5 \times 10^{-4}$ and $\Delta \sim 500$ Hz [12], which yields $\Delta_L \sim 1$ Hz.

[2]The features of the broadening in a low-pressure molecular gas were noted in a preprint (No. 15, IFP SO AN SSSR, 1970), which we co-authored with L.S. Vasilenko. The nonlinear dependence of the line broadening on the pressure at low collision frequencies was considered theoretically in our preprint No. 22, IFP SO AN SSSR, 1972.

For a Lenard-Jones potential, which is used to describe molecule scattering, the attraction part of the potential influences mainly the scattering of the molecule as a whole, and makes no noticeable contribution to the line shift. The short-range part of the potential c/r^{12} is significant at distances on the order of the molecule dimension and is different for the upper and lower levels, thus leading to the appearance of the shift. With decreasing pressure and line width, the role of the collisions with large ρ increases. Analyzing (2), we can note two physical causes of the sharp decrease of the shift at low pressures: the decrease of the number of scattered atoms in the interaction, and the increased role of attraction forces, and as a consequence the decrease of the shift.

4. The small line shifts in methane, less than 10 Hz/millitorr in the region of $\sim$1 millitorr, have contributed to the high values of frequency reproducibility. At equal methane pressures in the laser cells, the measured mean values of the frequency differed by less than 3 Hz in the reduction of the results of 50 independent tunings of two lasers. Measurements of the shift and direct investigations of the laser frequency reproducibility indicate that gas lasers are the most stable electromagnetic-radiation generators and uncover possibilities for the performance of fundamental physical experiments. The development of generators with long-period frequency stability $\sim 10^{-17}$ and reproducibility $\sim 10^{-15}$ becomes realistic.

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