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ACOUSTIC FLOWS AND ACOUSTOOPTIC INTERACTION IN A GASEOUS MEDIUM

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The formation of secondary flows generated when intensive ultrasonic waves are propagated and absorbed in a gaseous medium is investigated experimentally. The effect of acoustic flows and sound absorption on acoutooptic interaction for diffraction of light on acoustic waves in a gas is investigated.

The propagation with absorption of large-amplitude acoustic waves results in the formation of intensive secondary flows (acoustic wind) in the region of the acoustic beam [1]. The investigation of such flows in a gas is of independent interest and is also of interest in connection with the need to study the effect of the acoustic wind on different processes coinciding with it in space and time. Thus, in realizing diffraction of light on ultrasonic waves in a gaseous medium for the purpose of active influence on the light radiation one needs high-frequency, high-intensity acoustic fields [2]. In this case the frequency and intensity of the sound are large enough to result in its absorption and the development of secondary acoustic flows in the medium. The existing theories of diffraction of light on acoustic waves [3, 4] do not allow one to take account of the acoustic wind, because they are oriented toward condensed acoustooptic media in which such flows are either negligibly small or do not arise at all.

In the present work the development of the acoustic wind arising when ultrasonic waves with frequency equal to 1 MHz are absorbed and the effect of secondary flows on acoustooptic interaction in the Bragg regime are investigated experimentally. Air and xenon at atmospheric pressure are used as a working medium. The sound was radiated into the gas by pulses of duration up to 1 sec and intensity up to 140 dB. Dissipative phenomena that arise in the propagation of acoustic waves were investigated by shadow methods on the IAB-451 apparatus. Since a variation in the velocity of the medium in the propagation of sound is spatially related to a variation in its temperature, the intensity of the flows was estimated from the angle of deflection of light in a shadow device ε measured directly in the experiment.

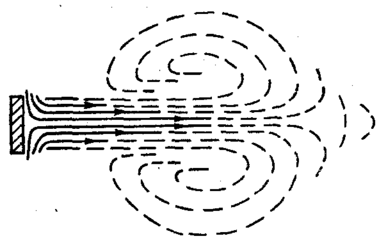

Fig. 1. Secondary acoustic flows near the acoustic radiator.

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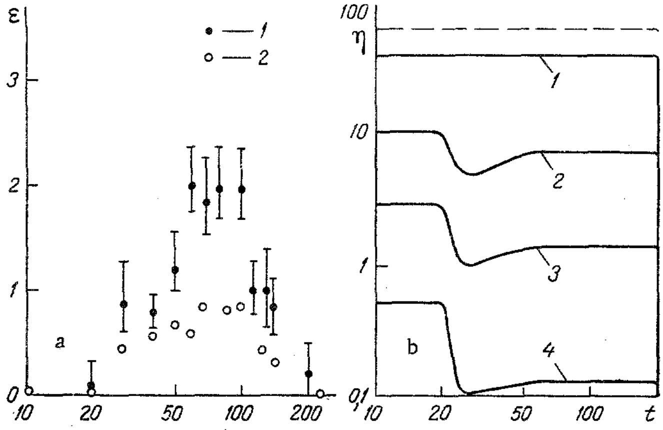

Fig. 2. Time dependences: a) of the angle of deviation of the light in a shadow device under the action of dissipation processes (1 – in xenon; 2 – in air); b) of the diffraction efficiency at different distances from the acoustic radiator to the diffraction zone. 1) 1 mm; 2) 10; 3) 20; 4) 35. ε, rad·10^5; t, msec; η, %.

TABLE 1. Effect of the Acoustic Dissipation on Bragg Diffraction in a Gas

Dissipation coeffs., cm^{-1}	Air	Xenon
α_{10} (t=10 msec)	0,28	0,62
α_{100} (t=100 msec)	0,32	0,84
$\alpha_W=\alpha_{100}-\alpha_{10}$	0,08	0,44

As a result of visualization it was found that vortex flows of square type arise in the acoustic flow (in the region of the acoustooptic interaction) [1]. In the direction of propagation of the acoustic beam a jet is developed which at some distance from the light emitter splits into an eddy "cap" (Fig. 1). As follows from the time dependences of the intensities of the observed phenomena (Fig. 2a), an intensive development of flows starts 10-20 msec after initiation of the sound radiation into the gas and continues for an additional 50-100 msec after the sound has been shut off. In Fig. 2b, a change in the diffraction efficiency is represented by the first diffraction maximum η during the acoustic pulse for different distances x from the acoustic radiator to the zone of acoustooptic interaction. With increasing distance from the emitter the diffraction pulse loses its rectangular shape, and the diffraction starts varying with time, in spite of the fact that the intensity of sound remains constant during the acoustic pulse (the shape of the acoustic pulse is shown in Fig. 2b by a dashed line). The diffraction efficiency is reduced considerably for time durations longer than 20 msec.

A comparison of plots in Figs. 2a and b allows one to suggest that secondary convective flows in the diffraction zone cause a decrease in the diffraction efficiency, the beginning of which coincides with the beginning of the development of the acoustic wind. With the development of the acoustic flow (50-70 msec after the beginning of the sound radiation), one can observe stabilization of the diffraction. If one compares dependences of the diffraction efficiency on distance from the radiator to the diffraction zone η(x) at times when acoustic flows have not yet arisen (10 msec) with the times when they are already shaped (100 msec), Fig. 3, then one can notice that the influence of the acoustic wind on diffraction is approximately exponential in nature and formally is similar to the influence of the sound absorption which is described by the exponential law and is in good agreement with experimental dependences for t = 10 msec. Therefore, in this case the effect of the acoustic wind on acoustooptic interaction can be quantitatively characterized by "the coefficient of acoustic wind" (see Table 1).

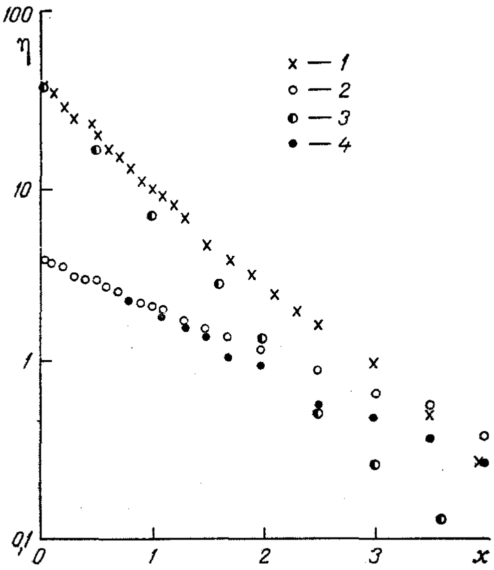

Fig. 3. Dependence of the diffraction efficiency on the distance between the acoustic radiator and the diffraction zone for short-duration acoustic pulses ($\tau \leq 20$ msec) (1 – in xenon; 2 – in air); for long-duration acoustic pulses ($\tau \geq 100$ msec) (3 – in xenon; 4 – in air). x, cm.

A decrease in the diffraction efficiency under the action of the acoustic wind is apparently due to the distortion of the acoustic wave front which results in the violation of diffraction angles and, consequently, in the reduction of its efficiency. Such a mechanism is confirmed indirectly by the fact that, firstly, the effect is cumulative with the distance (the degree of distortion of the wave front increases with the distance) and, secondly, the quantity α_B in xenon is much larger than in air, and diffraction in xenon is more sensitive to the violation of angles in comparison with air [5].

An analysis of the results obtained allows one to make the following conclusions: acoustooptic interaction in a gas is feasible, but in contrast to condensing media it is subject to the effect of dissipative processes; in computing diffraction in gases, the effect of sound absorption as well as secondary convective processes can be quantitatively taken into account for different durations of acoustooptic interaction; a diffraction method allows one to indirectly control the variation of the acoustic wave front during its propagation.

NOTATION

η, diffraction efficiency (the ratio of light intensity in the diffraction maximum to the incident radiation intensity); ε, angle of deviation of the light in the shadow device; x, distance from the acoustic radiator to the acoustooptic interaction zone; t, time; α_{10}, α_{100}, empirical absorption coefficients calculated from the dependences; α_W, empirical coefficient of the acoustic wind.

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FUNDAMENTAL REGULARITIES IN THE MOTION OF AN ARBITRARY GAS

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The problem of the derivation of the equation of state for real, dissociating, and ionizing gases expressed in terms of the similarity numbers for gaseous flows and the determination of the most general connections among heterogeneous variables are given.

We write the equation of state in the most general form

$$pu = Z_{ef} \frac{R}{\mu} T, \quad Z_{ef} = Z\varepsilon. \tag{1}$$

Here Z designates the coefficient of compressibility, and ε is the reduced number of moles obtained as a result of dissociation. For example, for dissociating nitrogen tetroxide

$$\varepsilon = 1 + \alpha_{10} + \alpha_{10}\alpha_{20},$$

where α_{10} and α_{20} are the degrees of dissociation of the first and second stages of the reaction in the reactive system $N_2O_4 \rightleftarrows 2NO_2 \rightleftarrows 2NO + O_2$. Below, we will operate with the effective coefficient (Z_{ef}), which takes account of the dissociation of molecules as well as the nonideality of gas.

When considering a real gas in the absence of dissociation $\varepsilon = 1$ and $Z_{ef} = Z$, i.e., everywhere when applied to a real gas, we will treat Z_{ef} as a coefficient of compressibility.

If we consider, as an arbitrary gas, a diatomic gas with account for dissociation and ionization, then

$$Z_{ef} = 1 + \alpha + 2\alpha_e,$$

where α is the degree of dissociation and α_e is the degree of ionization.

The velocity of sound in an arbitrary gas can be represented as

$$a = y a_{id}, \tag{2}$$

where y is a correcting coefficient, and a_{id} is the velocity of sound in an ideal gas:

$$a_{id} = \sqrt{k \frac{R}{\mu} T}. \tag{3}$$

In order to derive an analytic expression for the correcting coefficient y, we perform the following transformations. We use the differential equations of thermodynamics in the form

$$C_p - C_v = -T \frac{\left[\left(\frac{\partial v}{\partial T}\right)_p\right]^2}{\left(\frac{\partial v}{\partial p}\right)_T}, \tag{4}$$

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