MEASUREMENT OF PARTIAL DENSITIES OF A TWO-COMPONENT LAMINAR GASEOUS FLOW BY THE METHOD OF RAYLEIGH SCATTERING

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In studies of processes of diffusion of gases, flow past obstacles, kinetics of reacting media, etc., it is necessary to determine partial densities (concentrations) of a multicomponent gaseous flow. In this work we show how to use the method of Rayleigh scattering of light in studying flows. This method has a high spatial (of the order of a few wavelengths of the probing radiation) and temporal (of the order of relaxation time of the molecules of the scatterer) resolution. We measured local values of concentrations of carbon dioxide and argon in an inundated jet freely flowing into the atmosphere.

The basic scheme of the measuring apparatus is shown in Fig. 1a, where we have a pulsed ruby laser ($\lambda = 0.69$ μm) 1, focusing lenses 2, a mirror 3, the investigated jet 4, an interference optical filter 5, photomultiplier FÉU-64 6, and a data registering unit 7. The flow comes from behind the plane of the figure toward the viewer.

In Fig. 1b we illustrate the method of obtaining the inundated jet of CO_2 in a stream of Ar. The laminar stream of Ar flows in the atmosphere from the nozzle 1 with semicubical generatrices and CO_2 leaks from a small inner nozzle 2. All flows are horizontal, their velocities are of the order of 2-3 cm/sec. The laminarity was verified by means of coloring the gases with tobacco smoke.

It is obvious that

$$I_r - I_s = kI_0(p_1\sigma_1 + p_2\sigma_2), \tag{1}$$

where I_r, I_s, and I_0 are intensities of the registered, stray, and incident radiation, respectively; k, proportionality constant to be easily found from the equation of state and the Loschmidt number; p_i, σ_i, partial pressure and scattering cross section of the particles of the i-th component of the mixture.

As the dissipation losses are small, for each point of a two-component inundated jet we have

$$p_1 + p_2 = p_0 \tag{2}$$

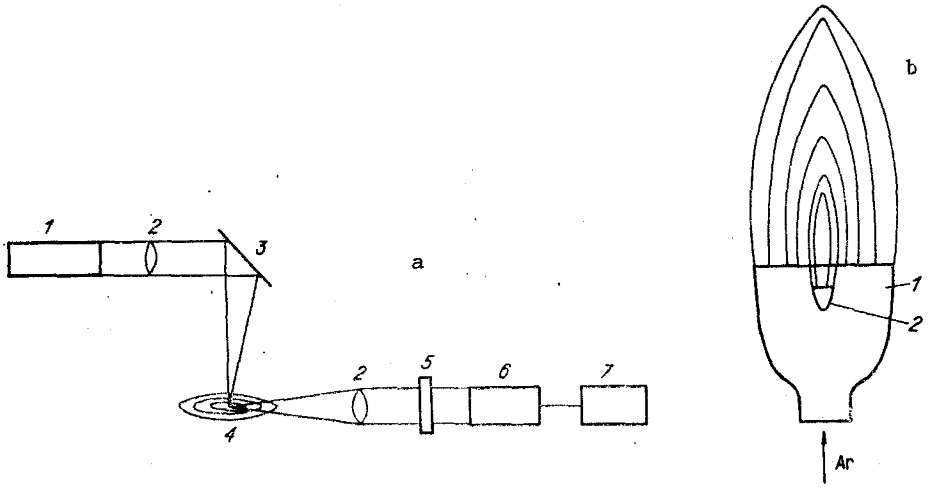

Fig. 1

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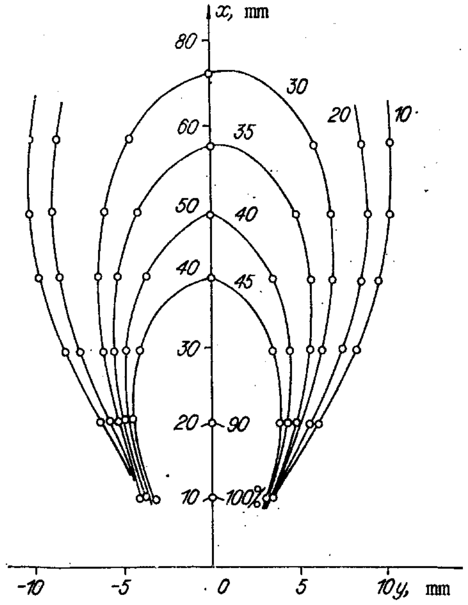

Fig. 2

TABLE 1

Gas	Scattering cross section		Gas	Scattering cross section	
	theory	experiment		theory	experiment
N_2	1,13	1,13±0,017	CO_2	2,53	2,68±0,15
He	0,015	0,021±0,03	Air	1,063	1,47

where p_0 is the atmospheric pressure. Similarly, for a one-component jet we have

$$I'_r - I_s = k p_0 \sigma_1 I_0. \tag{3}$$

The solution of the system (1)-(3) is

$$p_1 = \frac{p_0}{\sigma_1 - \sigma_2}\left\{\frac{(I_r - I_s)\,\sigma_1}{I'_r - I_s} - \sigma_2\right\}; \tag{4}$$

$$p_2 = p_0 - p_1 = p_0\left\{1 - \frac{1}{\sigma_1 - \sigma_2}\left[\frac{I_r - I_s}{I'_r - I_s} - \sigma_2\right]\right\}. \tag{5}$$

The value of I_r' is determined from the signal obtained for scattering from an inundated jet of CO_2. The magnitude of experimentally observed cross sections σ_1, σ_2 depends on the purity of the gases used, and for some gases also on the duration and energy density of the probing laser beam. Therefore, by using a vacuum chamber filled with the investigated gases at various (up to atmospheric) pressures, we carried out a preliminary study of relative values of scattering cross sections of gases. The cross section of Ar was assumed to be 1.

The intensity of the scattered radiation was measured at angle 90° to the direction of the incident ray. We used the same laser as for the measurements in gaseous jets. The pulse length was $2 \cdot 10^{-3}$ sec, energy 0.2 J, the dimension of the focal region 1 mm.

The studied gases were purified from suspensions by Petryanov filters and were allowed to settle in the receiver during 40-50 min. The cross sections were taken for the range of pressures 1-10 Pa with the step of 1 Pa.

The magnitude of the measured scattering signal was proportional to the pressure $I_r - I_s = k\sigma_i p_i I_0$ which indicated that the systematic errors were small. They would have been a result of the presence of suspended particles and nonlinear variation of the scattering cross section of the gases.

In Table 1 we show relative cross sections of the Rayleigh scattering for some gases as determined theoretically [1] and experimentally. The difference between experimental and theoretical values, especially remarkable for He and air, is perhaps due to admixtures beyond our control. The values for N_2 and CO_2 are within 5% of their theoretical predictions. The experimentally obtained relative cross section for CO_2 was multiplied by the cross section of Ar [2], yielding thus an absolute scattering cross section of CO_2.

The scattering cross sections of Ar and CO_2 and the experimental values of I_r, I_r' were substituted in (4) and (5). The magnitude of I_s for jets inundated in the atmosphere is negligibly small. This was concluded on the basis of proximity of the values of σ_i, obtained in the vacuum chamber and in the one-component CO_2 jet at atmospheric pressure. The injector nozzle was moving in the horizontal plane in two mutually perpendicular directions making possible scanning of the jet. The intensity of the scattered light was measured at the angle 90° to the incident ray.

In Fig. 2 we show the distribution of the concentration of CO_2 in the inundated two-component gaseous jet as found by means of the described method. The cut of the nozzle is in the plane x = 10 mm, the measurements were carried out in the central plane of the jet.

On the coordinate plane the circles indicate the points of measurement of partial concentrations of gases in the jet, the curves (isobars) are identified by the partial pressure of CO_2 in percentage of the atmospheric pressure.

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LAWS OF COLORING OF PHOTOCHROMIC SOLUTIONS USED IN EXPERIMENTAL HYDRODYNAMICS

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It is known that the introduction of small quantities of photochromic compounds into a liquid flow makes it possible to obtain colored tracks in the solution by directional irradiation at a certain wavelength. Recording the positions of the tracks at subsequent moments of time makes it possible to study the structure of the flow and the phenomenon of flow about bodies of different shapes [1-6].

In using the method of photochromic visualization of flows, it is very important to know the optical characteristics of the tracks in the solution. These properties depend on the type of photochromic compound used, its concentration in the liquid, the wavelength and intensity of the activating radiation, and other parameters.

Here we study the photochromic characteristics of an aqueous solution of spiropyran 11. We determined the length of the colored track in relation to the energy of the activating laser radiation and the concentration of photochromic substance in the solvent. We established the range of concentration of the photochromic substance and of other parameters necessary to reliably record a colored track.

1. Experimental Unit. Photochromic substances (PCS) may have molecules with different chemical structures and may be capable of changing color under the influence of laser radiation of a certain wavelength in different types of solvents, such as water, alcohol, acetone, benzene, etc. [7, 8]. Here we study the properties of an aqueous solution of spiropyran (one of the most promising photochromic compounds). The color of spiropyran in solution changed under the influence of laser radiation with a wavelength λ = 347.4 nm.

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