CONTRIBUTION TO THE THEORY OF PHOTOPHORESIS OF LARGE STRONGLY ABSORBING DROPS

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A theory of motion of large absorbing drops in an optical radiation field, when the evaporation from the surface is by diffusion or by convection (regimes 1 and 3 in accord with the classification in the book [3]) was constructed earlier in [1] and [2]. In the present paper we obtain a general expression for the photophoretic force acting on an absorbing drop. This equation is valid for both diffusion and convective evaporation.

The photophoretic force is due to the thermal and diffuse sliding of the gas molecules along an inhomogeneously heated surface, as well as to reactive and thermocapillary effects.

Estimates have shown that for drops of radius $R = 10$ μm at a radiation intensity up to $5 \cdot 10^2$ W/cm² the principal role is played by the thermocapillary force, and at higher intensities the reactive force predominates.

In an advanced convective evaporation regime, the expressions for the photophoretic force and for the viscous resistance force are

$$\vec{F}_{\varphi} = -\frac{\pi R^2 \rho \vec{I}\,|I|\,K_a J_1(1)}{3(\rho L)^2} \tag{1}$$

$$\vec{F}_u = -\frac{32\pi \eta^2 L}{I \cdot K_a} \vec{u} \tag{2}$$

Here ρ, η are the density and viscosity of the gas mixture, $\vec{I}$ is the radiation intensity, $J_1(1)$ is the asymmetry factor of the surface temperature, K_a is the absorption coefficient, L is the heat of evaporation, $\vec{u}$ is the particle velocity, and $R = R(t)$ is the drop radius.

In the particular case when the optical properties of the particle are close to the properties of an absolutely blackbody, integration of the equations of motion of the drop leads to the following dependence of the drop velocity on the time:

$$u = \exp\left[-\frac{48\pi\eta^2 L^2}{(I \cdot K_a)^2 (R_0 - \beta t)^2}\right] \cdot \int_0^{R_0 - \beta t} \frac{I^2}{8\rho L^2 \gamma} \exp\left[\frac{48\pi\eta^2 L^2}{(I \cdot K_a)^2 (R_0 - \beta t)^2}\right] \frac{dt}{R_0 - \beta t} \tag{3}$$

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where $R_0 = R(0)$, $\beta = I/4L\gamma$, γ is the density of the drop material.

An analysis of Eq. (4) shows that the particle velocity has a nonmonotonic dependence on the time.

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EXPERIMENT ON THE ACTION OF INTENSE RADIATION OF A CO_2 LASER (λ = 10.6 μm) ON FROZEN WATER DROPS

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There are few known experimental studies of the action of powerful continuous CO_2 laser radiation at λ = 10.6 μm on single ice particles [1, 3, 4, 5]. Crystalline clouds encountered in nature contain also frozen drops of diameter less than a hundred microns, especially during the cloud-formation stage [7].

We present here the results of experiments on the action of cw CO_2 laser radiation at λ = 10.6 μm on frozen water drops moving in a stream of air cooled in the temperature interval from 273 to 213°K at a radiation intensity $(0.7\text{-}3.7)\cdot 10^4$ W/cm^2. We used in the experiment an improved version of the setup whose main parameters were described in [2]. The CO_2 laser action on the drops was recorded with an LV-04 "time magnifier." The measurement errors are ± 3 μm in the drop diameter, 20% in the radiatio intensity, and ± 3°C in the temperature of the air stream.

The photographs in Fig. 1 show the growth of the vapor bubble around a frozen water drop of initial radius R_0 = 25 μm. The radiation intensity has a Gaussian distribution with dispersion σ = 150 and maximum $I_0 = 2.4 \cdot 10^4$ W/cm^2 at the center of the frame. The temperature of the air stream in which the drop moves is < 123°K.

The radiation started to act on the drop 50 μsec before the start of the exposure of the first frame, and the radiation intensity increased linearly from zero to maximum within 50 μsec. Frames 6-7 show pulsations of the drop surface. On frame 12 one can see the nucleation of the vapor bubble which surrounds the entire drop surface and increases at a rate of the order of ∿ 5 m/sec. The bubble growth terminates by a burst of its shell (frame 14) and

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