$$\mathrm{Nu} = \frac{\alpha\rho_0}{\lambda}; \qquad K_1 = \frac{q\rho_0^2 r\rho''}{\sigma\lambda T_s};$$

$$K_2 = \frac{\rho'\sigma T_s C_p}{(r\rho'')^2\rho_0}; \qquad \mathrm{Re}^* = \frac{\sqrt{P(v''-v')}\,\rho_0}{\nu};$$

$$\mathrm{Re} = \frac{4qx}{r\rho'\nu}; \qquad Z = x\left(\frac{g}{\nu^2}\right)^{1/3}\frac{\lambda\Delta T}{r\rho'\nu}.$$

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EFFECT OF THERMAL DIFFUSION ON PHOTOPHORETIC MOTION OF AEROSOL PARTICLES

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Expressions for the strength and velocity of photophoresis of moderately large and large nonvolatile aerosol particles in binary gas mixtures are obtained. The effect of thermal diffusion on the photophoretic motion of aerosol particles is taken into account.

The papers on photophoresis that have been published so far (see [1-2], for instance) have ignored the effect of thermal diffusion on the photophoretic motion of aerosol particles, although it is known that thermal diffusion can greatly affect the nature of the motion of aerosol particles in gas mixtures that are inhomogeneous in temperature and concentration [3]. In the present paper we take into account the effect of thermal diffusion on the photophoresis of moderately large and large aerosol particles in binary gas mixtures.

In the construction of the theory we took into account all kinds of slipping of the gas over the particle surface [4], temperature discontinuities [5], and bulk thermal diffusion [6].

As in the other studies of photophoresis, the theory is constructed for spherical particles. The distributions of temperature T, concentration c_j of the gas mixture components, pressure p, and mass velocity $\vec{U}$ of the gas mixture were found by solution of the linearized system of equations (1)-(6). The solution of this system was obtained in a spherical coordinate system (r, Θ) with the origin at the center of the particle and the polar axis directed along the flux of electromagnetic radiation (Θ = 0). With this choice of coordinate system the velocity of the gas flow at infinity is equal, but opposite in sign, to the velocity of photophoretic motion of the particle:

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$$\eta \Delta \vec{U} = \Delta p, \tag{1}$$

$$\operatorname{div} \vec{U} = 0, \tag{2}$$

$$\Delta T_e = 0, \tag{3}$$

$$\varkappa_i \Delta T_i + q(r, \theta) = 0, \tag{4}$$

$$\Delta c_1 = 0, \tag{5}$$

$$p_e = nkT_e, \tag{6}$$

where $c_j = n_j/n$, $j = 1, 2$; n_j is the number density of molecules of the j-th component; $n = n_1 + n_2$; k is the Boltzmann constant; T_e, T_i and $\varkappa_e$, $\varkappa_i$ are the temperatures and thermal conductivities of the gas mixture and particle, respectively; $q(r, \Theta)$ is the density of heat sources within the particle.

The system of equations (1)-(6) was obtained by linearization of the equations of hydrodynamics [7], convective thermal conductivity [7], and diffusion [6]. We regarded the temperature and concentration drops in the gas–particle system as much less than unity.

To find the distribution of mass velocity, pressure, temperature, and concentration, we used the following system of boundary equations (7)-(16):

$$U_\theta = C_m \left[\frac{1}{r} \frac{\partial}{\partial r} \left(\frac{U_\theta}{r} \right) + \frac{1}{r} \frac{\partial U_r}{\partial \theta} \right] \Bigg|_{r=R} + \frac{K_{TS}}{R} \frac{\partial \ln T_e}{\partial \theta} \Bigg|_{r=R} + \frac{K_{DS}}{R} \frac{\partial c_1}{\partial \theta} \Bigg|_{r=R}, \tag{7}$$

$$U_r|_{r=R} = 0, \tag{8}$$

$$\left(\frac{\partial c_1}{\partial r} + K_{\text{т}} \frac{\partial \ln T_e}{\partial r} \right) \Bigg|_{r=R} = 0, \tag{9}$$

$$-\varkappa_i \frac{\partial T_i}{\partial r} \Bigg|_{r=R} = -\varkappa_e \frac{\partial T_e}{\partial r} \Bigg|_{r=R}, \tag{10}$$

$$(T_e - T_i)|_{r=R} = C_T \frac{\partial T_e}{\partial r} \Bigg|_{r=R}, \tag{11}$$

$$U_r|_{r \to \infty} = U_\infty \cos \theta, \tag{12}$$

$$U_\theta|_{r \to \infty} = -U_\infty \sin \theta, \tag{13}$$

$$p|_{r \to \infty} = p_0, \tag{14}$$

$$T_e|_{r \to \infty} = T_{e0}, \tag{15}$$

$$c_1|_{r \to \infty} = c_{10}, \tag{16}$$

where U_r and U_θ are the radial and polar components of the mass velocity of the gas mixture; U_∞ is the gas velocity at a large distance from the particle; R is the particle radius; C_m, K_{TS}, and K_{DS} are the coefficients of isothermal, thermal, and diffusional slip [4]; C_T is the temperature-discontinuity coefficient [5]; K_T is the thermal-diffusion ratio [6].

Substituting the expressions obtained for the gas velocity $\vec{U}$ and pressure p in the stress tensor [7] and integrating this tensor over the particle surface we find the following expression for the total force acting on the particle:

$$\vec{F} = 4\pi R \eta \frac{-\frac{3}{2} \left(1 + 2C_m \frac{1}{R} \right) \vec{U} + [K_{TS} - K_{DS} K_{\text{т}}] \vec{a}}{\left(1 + 3C_m \frac{1}{R} \right)}, \tag{17}$$

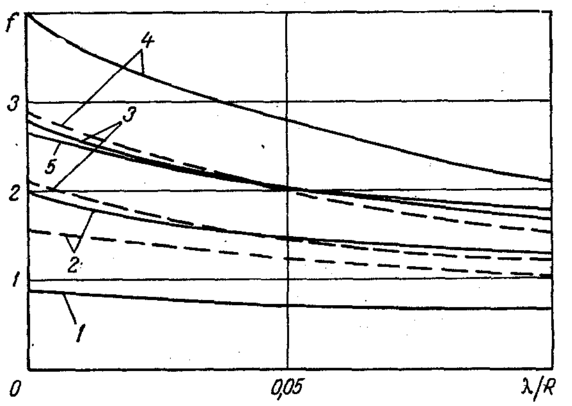

Fig. 1. Plots of f [see (19)] against variable λ/R for pure gases with $c_1 = 0$ (curve 1), $c_1 = 0.33$ (2), $c_1 = 0.5$ (3), $c_1 = 0.71$ (4), and $c_1 = 1$ (5). The dashed lines are obtained when thermal diffusion is ignored.

$$\vec{a} = \vec{n}_{\mathrm{I}} \frac{R}{T_{e0}} \int_0^1 dx x^3 \int_{-1}^{+1} dy y q(x, y) \frac{1}{\left[\varkappa_i\left(1+2C_T\frac{1}{R}\right)+2\varkappa_e\right]},$$

where $x = r/R$; $y = \cos\theta$; $\vec{n}_{\mathrm{I}}$ is the unit vector in the direction of the radiation flux.

Equating (17) to zero, we obtain an equation for the velocity of photophoresis

$$\vec{U}_p = -\frac{2}{3}\frac{R}{T_{e0}}\frac{(K_{TS}-K_{DS}K_{\mathrm{T}})}{\left(1+2C_m\frac{1}{R}\right)\left[\varkappa_i\left(1+2C_T\frac{1}{R}\right)+2\varkappa_e\right]}\vec{n}_{\mathrm{I}}\int_0^1 dxx^3\int_{-1}^{+1} dyyq. \tag{18}$$

Using (18) we evaluated the effect of thermal diffusion on the photophoretic motion of large and moderately large aerosol particles. Figure 1 shows plots of f against the parameter λ/R (λ is the mean free path of the gas-mixture molecules) for different concentrations c_1. All the calculations were made from the equation

$$f = \frac{K_{TS}-K_{DS}K_{\mathrm{T}}}{\left(1+2C_m\frac{1}{R}\right)\left[1+2C_T\frac{1}{R}+2\frac{\varkappa_e}{\varkappa_i}\right]\nu_0}, \tag{19}$$

where ν_0 is the kinematic viscosity of the medium at $c_1 = 0$. The expressions for the slip and temperature-discontinuity coefficients were taken from [4-5]. The evaluations were made for a petroleum jelly aerosol in a helium–air mixture at $T_{e0} = 293$°K and pressure $p_0 = 760$ mm Hg.

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