SLIP OF A GAS IN A FIELD OF OPTICAL RADIATION

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A new mechanism of surface light-induced drift associated with the difference between the collision frequencies of excited and unexcited atoms is predicted.

The phenomenon of light-induced drift (LID) [1] consists of the fact that atoms or molecules absorbing radiation and being in a mixture with a buffer gas acquire a directional motion. Evidently [2] LID is possible in a purely resonance gas if the boundary surface scattering the excited and unexcited particles differently plays the part of a buffer gas. A number of strong assumptions is made in [2] and, consequently, the results are more often qualitative in nature.

The stationary motion of a monatomic gas along an interphasal boundary x = 0 due to resonance interaction of the gas with light directed along the Z axis is investigated in this paper. The absorbing particles are two-level particles (n and m are the ground and excited levels). The state of the gas interacting with the radiation is described by distribution functions f_i satisfying the kinetic equations [3].

If the probability of induced transitions is small (weak field), then the state of each component can be described by a distribution function insignificantly different from the Maxwellian f_{i0}:

$$f_i = f_{i0}[1 + h_i(x, \mathbf{v})], \quad i = n, m. \tag{1}$$

For not very low pressures the collision frequency between atoms is much greater than the radiation damping constants Γ_m, i.e.,

$$\Gamma_m/(\gamma_{nn} + \gamma_{nm}) = \Gamma_m^* \ll 1.$$

Then after linearization and reduction to dimensionless form, the kinetic equations [3] are transformed into equations for the perturbation functions

$$c_x \frac{\partial h_i^s}{\partial x'} = \frac{\varkappa}{2}\left(\frac{n_j - n_i}{n_i}\right) + \theta_i L(h_i^s), \quad i, j = n, m; \quad i \neq j;$$

$$h_i^s = \frac{h_i}{\Gamma_m^*}; \quad x' = x\left(\frac{m}{2kT}\right)^{1/2}(\gamma_{nn} + \gamma_{nm}); \quad \mathbf{c} = \left(\frac{m}{2kT}\right)^{1/2}\mathbf{v}; \tag{2}$$

$$\theta_i = \begin{cases} 1, & i = n, \\ (\gamma_{ii} + \gamma_{ij})/(\gamma_{jj} + \gamma_{ji}), & i = m; \end{cases} \qquad \varkappa(\mathbf{v}) = \frac{4|G|^2\Gamma}{\Gamma_m[\Gamma^2 + (\Omega - \mathbf{kv})^2]};$$

$$G = \frac{Ed_{mn}}{2\hbar}.$$

Here $\varkappa(v)$ characterizes the probability of induced transitions. The model representation [4] is used for the dimensionless collision integrals $L(h_i)$.

The model of specular-diffuse reflection is taken as boundary conditions, and with (1) taken into account has the form

$$h_i^s(0, c_x > 0) = (1 - \varepsilon_i)\, h_i^s(0, c_x < 0). \tag{3}$$

The coefficients ε_i characterizing the fraction of diffusely scattered excited and unexcited atoms are distinct in the general case.

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Taking account of (3) the equations (2) are transformed into a closed system of integral-moment equations for the gas velocity, the stress tensor, and the heat flux. This system is solved by the Bubnov–Galerkin method by analogy with [5].

Consequently, we obtain the following expression for the slip velocity

$$U_s = -\left(\frac{kT}{8\pi m}\right)^{1/2} \frac{\Gamma_m (n_n - n_m) \langle \varkappa \rangle \xi}{(\gamma_{nn} + \gamma_{nm})},$$

$$\xi = \frac{2(\varepsilon_m - \theta_m \varepsilon_n)(n_m + \theta_m n_n) + \varepsilon_n \varepsilon_m (n_n + \theta_m n_m)(1 - \theta_m)}{(n_n \varepsilon_n + n_m \varepsilon_m)(n_m + n_n \theta_m)\theta_m}, \tag{4}$$

$$\langle \varkappa \rangle = \int_{-\infty}^{+\infty} c_z \varkappa e^{-c_z^2} dc_z.$$

Thus, the light-induced slip is determined by quantities characterizing particle interaction with the surface, mutually, and with the radiation.

The direction of particle drift depends on the sign of the radiation frequency Ω-buildup from the center of the absorption line. For $\Omega \gtrless 0$ the gas as a whole moves in different directions. At strict resonance (Ω = 0) there is no drift.

If the atoms interact with the interphasal surface identically ($\varepsilon_i = \varepsilon$), then LID exists for a difference in the excited and unexcited particle collision frequencies ($\theta_m \neq 1$). This mechanics is predicted for the first time. Such a result could not be obtained in [2] since one average frequency of interatomic collisions was used there.

If $\theta_m = 1$ then $\xi = 2(\varepsilon_m - \varepsilon_n)/(n_n\varepsilon_n + n_m\varepsilon_m)$. In this case the LID is due to different atom accommodation which agrees qualitatively with the result in [2]. Let us note that the drift direction is determined by the relationship between the coefficients ε_n, ε_m.

A new kind of slip specifies new effects. Let us consider a system, say, consisting of two tanks connected by a capillary of radius r_0 and length L. A LID occurs under resonance action of the radiation on the gas. Consequently, a pressure drop is set up in the system. In the stationary state the LID is compensated completely by the Poiseuille flow so that the total flow through any channel cross-section will not exist.

Then the pressure gradient is determined as $|\nabla P| = \frac{8\eta}{r_0^2} U_s$, or integrating along the channel we obtain

$$\Delta P = P_2 - P_1 = \frac{8\eta L}{r_0^2 P'}(PU_s), \quad P' = \frac{1}{2}(P_1 + P_2),$$

where P_1, P_2 are the gas pressures in the tanks.

The analogy of the effect of a light-induced pressure difference (LPD) to the phenomenon of the thermomolecular pressure difference is obvious.

Let us estimate the magnitude of the LPD due to just the difference in the frequency of the interatomic collisions ($\varepsilon_i = 1$) for typical atomic characteristics $\Gamma \sim 10^9$ Hz, ($\gamma_{ii} + \gamma_{ij}$) $\sim 10^8$ Hz, $G \sim 10^8$ Hz, $\lambda \sim 10^7$ m, $v \sim 10^3$ m/sec. Then for $\Omega \sim \Gamma$ it follows from (4) that $U_S \approx 5$ m/sec. If $\eta \sim 10^{-5}$ Pa•sec, $L \sim 10^{-1}$ m, $r_0 \sim 10^{-3}$ m, then $\Delta P \sim 1$ mm Hg. Such a pressure drop can easily be measured. The LPD effect is detected experimentally in [6] in capillaries with mechanical surface treatment for which it is known $\varepsilon_i = 1$. The difference in the interatomic collision frequencies is apparently the fundamental mechanism clarifying the result [6].

The LPD effect is a reliable method of experimentally studying light-induced drift and can be utilized to study gas-surface interaction.

NOTATION

Γ_m, radiation damping constant; γ_{ij}, collision frequencies between atoms of the species i, j; $\kappa(v)$, saturation parameter; Γ, homogeneous absorption linewidth; E, amplitude of the

radiation electrical field; d_{mn}, dipole moment matrix element; k, wave vector of the light wave; Ω, retuning from resonance equal to the difference between the light frequency ω and transition frequency ω_{mn}; η, viscosity coefficient.

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HIGH REFLECTIVITY COATINGS USED IN CRYOVACUUM TECHNOLOGY

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A method is proposed for calculating the absorption capability of crysosystem reflective surfaces and reducing such absorption to the theoretical minimum.

In connection with developments in cryovacuum technology, a need has recently arisen for creation of metallic surfaces which are highly reflective at low temperatures.

The numerous experimental data collected in [1] permit the conclusion that vacuum deposition is one of the most promising methods for production of high reflectivity coatings. Encouraging results have already been obtained with this technique. Adsorption factor values of $6.5 \cdot 10^{-3}$ and $7.2 \cdot 10^{-3}$ for silver films deposited in a vacuum were announced in [2]. Values of $6 \cdot 10^{-3}$ for Al and $5.5 \cdot 10^{-3}$ for Cu were obtained in [3] for deposition in a helium flow.

To optimize the choice of metal and the conditions under which the reflective coating is prepared a strict analysis of the dependence of reflectivity on those electrophysical parameters of the film which determines its optical absorption is necessary. However the anomalous skin effect theory which is currently generally accepted for description of the optical properties of metals at low temperature is not very useful in practical applications because of the extreme cumbersomeness and complexity of the integrodifferential equations which form its mathematical base. Therefore in [4]* and later in [5-8] a relatively simple method was developed, sufficient for an exact analytical description of metal properties over a wide spectral and temperature range, including helium temperatures, based upon a physically clear piecewise-continuous approximation of the spectral dependence of absorption for various modifications of the skin effect.†

Such an approach allowed quantitative explanation of various absorption data [2, 3] for reflective coatings of cryovacuum systems without use of any empirical relationships as well as proposal of physically clear criteria for choice of metal and film preparation conditions. Moreover, limiting theoretical minimum absorption values were calculated for various metals and temperatures.

A comparison of experimental (in the given case, from [3]) and calculated absorption values (Table 1) shows satisfactory agreement.

*We will note that an arithmetical error was introduced into the calculations of [4], resulting in lowered values of absorption capability.

†Programs have been written which permit calculation of absorption for various metals and temperatures.

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