BINARY GAS MIXTURE MOTION IN A CYLINDRICAL CHANNEL

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Results of studies on motion of binary mixtures of rarefied gases in channels, obtained by solution of the kinetic equations and published in the last decade were analyzed briefly in [1]. Overall evaluation of these studies reveals two significant limitations.

In a number of these studies the results were obtained using lower order approximations of the moment method and are valid only at low values of the Knudsen number (Kn). Thus the treatment of the results in fact reduces to analysis of hydrodynamic or diffusion slip type equations. Moreover, the convergence of the moment method itself must be verified anew for each concrete problem. Individual attempts to describe isothermal motion of gas mixtures in channels at arbitrary Kn values have been based on solution of the model Bird–Hirschfedder–Curtis (BHC) equation with collision integral in Hamel form. However, it is known that this equation gives a false description of macroscopic characteristics upon transition to the diffusion approximation ($Kn \ll 1$). In fact, the Hamel model contains only three independent free parameters. But even in the simplest case of isothermal expansion of a binary gas mixture accurate (by Chapman–Enskog theory) values of five transfer coefficients are required: viscosity coefficients for each component and the mixture as a whole, and mutual diffusion and barodiffusion coefficients. In the case of inhomogeneous gas temperature the Hamel model is inapplicable in principle, since it does not describe the phenomenon of thermodiffusion. Thus, the results obtained are at best qualitative.

The goal of the present study is a description of motion of a binary gas mixture in a cylindrical capillary under the influence of gradients in total pressure, concentration, and temperature at arbitrary values of Kn. The calculation is based on a third-order approximate kinetic equation [2], ensuring exact description of the system in the diffusion approximation and permitting use of an arbitrary intermolecular interaction potential.

Formulation of the Problem. We will consider the stationary flow of a binary gas mixture in a cylindrical capillary of radius R under the influence of gradients in pressure, concentration, and temperature, directed along the z axis. Let the temperatures of the components be equal to each other at any point, but variable along the channel length. We assume that the capillary is sufficiently long, and that end effects may be neglected. Then the distribution functions for molecules of each type with weak inhomogeneity in total pressure p, temperature T, and molar concentration y_i can be written in the form

$$f_i = f_{i0}\left[1 + \frac{z}{p}\frac{dp}{dz} + \frac{z}{y_i}\frac{dy_i}{dz} + \left(c_i^2 - \frac{5}{2}\right)\frac{z}{T}\frac{dT}{dz} + h_i(\mathbf{r}, \mathbf{c}_i)\right], \tag{1}$$

where $f_{i0} = n_{i0}\left(\frac{m_i}{2\pi kT_0}\right)^{3/2}\exp\left(-c_i^2\right)$; $\mathbf{c}_i = \left(\frac{m_i}{2kT_0}\right)^{1/2}\mathbf{v}_i$; n_i, m_i are the numerical density and mass of molecules of the i-th sort; $\mathbf{v}_i$ is the velocity vector of the molecules; $\mathbf{r}$ is the two-dimensional radius vector in the capillary cross section.

Let the perturbation function h_i for molecules of the i-th component obey an approximate third order kinetic equation [2], which in dimensionless form appears as

$$\zeta_i\frac{\partial h_i}{\partial \mathbf{x}} + c_{iz}\left[\nu + \mu_i + \left(c_i^2 - 5/2\right)\tau\right] = R_i\left\{-h_i + 2c_{iz}\left[u_i - \varphi_{ij}^{(1)}\left(u_i - \left(\frac{m_i}{m_j}\right)^{1/2}u_j\right) - \varphi_{ij}^{(2)}\left(H_i - \left(\frac{m_i}{m_j}\right)^{3/2}H_j\right)\right] + \right. \tag{2}$$

$$\left. + 4c_{ir}c_{iz}\left[\left(\gamma_{ij}^{*} - \varphi_{ij}^{(3)}\right)p_{irz} + \varphi_{ij}^{(4)}p_{jrz}\right] + \frac{8}{5}c_{iz}\left(c_i^2 - \frac{5}{2}\right)\left[\left(1 - \varphi_{ii}^{(5)} + \varphi_{ii}^{(6)} - \varphi_{ij}^{(5)}\right)H_i + \varphi_{ij}^{(6)}H_j - \frac{5}{8}\varphi_{ij}^{(2)}\left(u_i - \left(\frac{m_i}{m_j}\right)^{1/2}u_j\right)\right]\right\},$$

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where

$$(i,\ j)=1,\ 2;\quad i\neq j,$$

$$\begin{gathered}
u_i=\left(\frac{m_i}{2kT_0}\right)^{1/2}U_i=\pi^{-3/2}\int c_{iz}\exp\left(-c_i^2\right)h_i d\mathbf{c}_i;\\
p_{irz}=\frac{P_{irz}}{2p_i}=\pi^{-3/2}\int c_{ir}c_{iz}\exp\left(-c_i^2\right)h_i d\mathbf{c}_i;\\
H_i=\left(\frac{m_i}{2kT_0}\right)^{1/2}\frac{1}{2p_i}\left(q_i-\frac{5}{2}\frac{kT_0}{m_i}J_i\right)=\frac{1}{2}\pi^{-3/2}\int c_{iz}\left(c_i^2-\frac{5}{2}\right)\exp(-c_i^2)h_i d\mathbf{c}_i;\\
\zeta_i^2=c_i^2-c_{iz}^2;\quad \mathbf{x}=\frac{\mathbf{r}}{R};\quad R_i=(\gamma_{ii}+\gamma_{ij})\left(\frac{m_i}{2kT_0}\right)^{1/2}R;\\
\nu=\frac{R}{p}\frac{dp}{dz};\quad \tau=\frac{R}{T}\frac{dT}{dz};\quad \mu_i=\frac{R}{y_i}\frac{dy_i}{dz};\\
\varphi_{ij}^{(n)}=\frac{\nu_{ij}^{(n)}}{\gamma_{ii}+\gamma_{ij}};\quad \varphi_{ii}^{(n)}=\frac{\nu_{ii}^{(n)}}{\gamma_{ii}+\gamma_{ij}};\quad \gamma_{ij}^{*}=\frac{\gamma_{ij}}{\gamma_{ii}+\gamma_{ij}};
\end{gathered}\tag{3}$$

U_i is the macroscopic velocity of molecules of type i, p_i and P_{irz} are the partial pressure and tangent stress tensor; q_i and J_i are the thermal and diffusion flows of component i; γ_{ii} and γ_{ij} are the collision frequencies for molecules of the same type and of differing types $(i \neq j)$; R_i is the gas rarefaction parameter, inversely proportional to the Knudsen number; $\nu_{ij}^{(n)}$ are quantities dependent on the molecular weights of the components, concentrations, and intermolecular interaction parameters [2].

We assume that at any point on the channel surface the molecules of each type are scattered completely diffusely by a Maxwall law with the local values of partial density and temperature. Then the boundary conditions for Eq. (1) can be written in the form

$$h_i(x=1,\ \mathbf{c}_i)=0,\ (\mathbf{c}_i\mathbf{n})>0,\tag{4}$$

where **n** is the normal to the channel wall.

Basic Equations. The problem of Eqs. (2)-(4) can be reduced to a closed system of integral-moment equations. To do this it is necessary to write Eq. (2) in integral form with consideration of boundary condition (4) and use the definitions of Eq. (3). As a result, we have

$$\begin{aligned}
u_i=&-\frac{1}{2\pi}\int\frac{d\mathbf{x}'}{|\mathbf{x}-\mathbf{x}'|}\left[(\nu+\mu_i)I_0+\tau(I_2-I_0)\right]+\\
&+\frac{R_i}{\pi}\int\frac{d\mathbf{x}'}{|\mathbf{x}-\mathbf{x}'|}\left\{\left[\left(1-\varphi_{ij}^{(1)}\right)I_0-\frac{1}{2}\varphi_{ij}^{(2)}\ (I_2-I_0)\right]u_i+\right.\\
&+\left(\frac{m_i}{m_j}\right)^{1/2}\left[\varphi_{ij}^{(1)}I_0+\frac{1}{2}\varphi_{ij}^{(2)}\ (I_2-I_0)\right]u_j+2\Omega_n\left[\left(\gamma_{ij}^{*}-\varphi_{ij}^{(3)}\right)p_{irz}+\right.\\
&\left.+\varphi_{ij}^{(4)}p_{jrz}\right]I_1+\left[-\varphi_{ij}^{(2)}I_0+\frac{4}{5}\left(1-\varphi_{ii}^{(5)}+\varphi_{ii}^{(6)}-\varphi_{ij}^{(5)}\right)\ (I_2-I_0)\right]H_i+\left.\left[\left(\frac{m_i}{m_j}\right)^{3/2}\varphi_{ij}^{(2)}I_0+\frac{4}{5}\varphi_{ij}^{(6)}\ (I_2-I_0)\right]H_j\right\},
\end{aligned}\tag{5}$$

$$\begin{aligned}
p_{irz}=&-\frac{1}{2\pi}\int\frac{\Omega_n d\mathbf{x}'}{|\mathbf{x}-\mathbf{x}'|}\left[(\nu+\mu_i)I_1+\tau(I_3-I_1)\right]+\frac{R_i}{\pi}\int\frac{\Omega_n d\mathbf{x}'}{|\mathbf{x}-\mathbf{x}'|}\left\{\left[\left(1-\varphi_{ij}^{(1)}\right)I_1-\frac{1}{2}\varphi_{ij}^{(2)}(I_3-I_1)\right]u_i+\right.\\
&+\left(\frac{m_i}{m_j}\right)^{1/2}\left[\varphi_{ij}^{(1)}I_1+\frac{1}{2}\varphi_{ij}^{(2)}(I_3-I_1)\right]u_j+2\Omega_n\left[\left(\gamma_{ij}^{*}-\varphi_{ij}^{(3)}\right)p_{irz}+\right.\\
&\left.+\varphi_{ij}^{(4)}p_{jrz}\right]I_2+\left[-\varphi_{ij}^{(2)}I_1+\frac{4}{5}\left(1-\varphi_{ii}^{(5)}+\varphi_{ii}^{(6)}-\varphi_{ij}^{(5)}\right)(I_3-I_1)\right]H_i+\left.\left[\left(\frac{m_i}{m_j}\right)^{3/2}\varphi_{ij}^{(2)}I_1+\frac{4}{5}\varphi_{ij}^{(6)}\ (I_3-I_1)\right]H_j\right\},
\end{aligned}$$

$$\begin{aligned}
H_i=&-\frac{1}{4\pi}\int\frac{d\mathbf{x}'}{|\mathbf{x}-\mathbf{x}'|}\left[(\nu+\mu_i)\ (I_2-I_0)+\tau\left(I_4-2I_2+\frac{5}{2}I_0\right)\right]+\\
&+\frac{R_i}{2\pi}\int\frac{d\mathbf{x}'}{|\mathbf{x}-\mathbf{x}'|}\left\{\left[\left(1-\varphi_{ij}^{(1)}\right)\ (I_2-I_0)-\frac{1}{2}\varphi_{ij}^{(2)}\left(I_4-2I_2+\frac{5}{2}I_0\right)\right]u_i+\right.\\
&+\left(\frac{m_i}{m_j}\right)^{1/2}\left[\varphi_{ij}^{(1)}\ (I_2-I_0)+\frac{1}{2}\varphi_{ij}^{(2)}\left(I_4-2I_2+\frac{5}{2}I_0\right)\right]u_j+2\Omega_n\left[\left(\gamma_{ij}^{*}-\varphi_{ij}^{(3)}\right)p_{irz}+\varphi_{ij}^{(4)}p_{jrz}\right]\ (I_3-I_1)+\left[-\varphi_{ij}^{(2)}(I_2-I_0)+\right.\\
&\left.+\frac{4}{5}\left(1-\varphi_{ii}^{(5)}+\varphi_{ii}^{(6)}-\varphi_{ij}^{(5)}\right)\left(I_4-2I_2+\frac{5}{2}I_0\right)\right]H_i+\left.\left[\left(\frac{m_i}{m_j}\right)^{3/2}\varphi_{ij}^{(2)}\ (I_2-I_0)+\frac{4}{5}\varphi_{ij}^{(6)}\left(I_4-2I_2+\frac{5}{2}I_0\right)\right]\ H_i\right\},
\end{aligned}$$

$$I_n(t)=\int\limits_0^\infty s^n\exp\left(-s^2-\frac{t}{s}\right)ds,\quad \Omega=\frac{\mathbf{x}-\mathbf{x}'}{|\mathbf{x}-\mathbf{x}'|},$$

with the argument of the function I_n being $(R_i|\mathbf{x}-\mathbf{x}'|)$, where Ω_n is the projection of the vector Ω on the normal to the channel surface.

From the structure of the free terms of the linear integral equations (5) it follows that the solution of the system has the form

$$u_i = u_i^{(p)}\nu + u_i^{(c)}\mu_i + u_i^{(T)}\tau, \tag{6}$$
$$p_{irz} = p_{irz}^{(p)}\nu + p_{irz}^{(c)}\mu_i + p_{irz}^{(T)}\tau, \quad H_i = H_i^{(p)}\nu + H_i^{(c)}\mu_i + H_i^{(T)}\tau.$$

Substitution of Eq. (6) in Eq. (5) and equating terms containing the same gradients leads to separation of Eq. (5) into three independent systems which describe local values of the quantities $u_i^{(k)}$, $p_{irz}^{(k)}$, $H_i^{(k)}$ $(k = p,\ c,\ T)$. However, in the final outcome, we are concerned with values averaged over the capillary section:

$$Q = p\left(\frac{2kT_0}{m_1}\right)^{1/2}\left(l_{11}\frac{d\ln T}{dz} + l_{12}\frac{dy}{dz} + l_{13}\frac{d\ln p}{dz}\right), \tag{7}$$
$$\langle U_1\rangle - \langle U_2\rangle = \left(\frac{2kT_0}{m_1}\right)^{1/2}\left(l_{21}\frac{d\ln T}{dz} + l_{22}\frac{dy}{dz} + l_{23}\frac{d\ln p}{dz}\right),$$
$$\omega = y\langle U_1\rangle + (1-y)\langle U_2\rangle = \left(\frac{2kT_0}{m_1}\right)^{1/2}\left(l_{31}\frac{d\ln T}{dz} + l_{32}\frac{dy}{dz} + l_{33}\frac{d\ln p}{dz}\right),$$

where

$$l_{11} = 2\left[y\langle H_1^{(T)}\rangle + (1-y)\left(\frac{m_1}{m_2}\right)^{1/2}\langle H_2^{(T)}\rangle\right]; \tag{8}$$
$$l_{12} = 2\left[\langle H_1^{(c)}\rangle - \left(\frac{m_1}{m_2}\right)^{1/2}\langle H_2^{(c)}\rangle\right];$$
$$l_{13} = 2\left[y\langle H_1^{(p)}\rangle + (1-y)\left(\frac{m_1}{m_2}\right)^{1/2}\langle H_2^{(p)}\rangle\right]; \quad l_{21} = \langle U_1^{(T)}\rangle - \left(\frac{m_1}{m_2}\right)^{1/2}\langle U_2^{(T)}\rangle;$$
$$l_{22} = \frac{1}{y}\langle U_1^{(c)}\rangle + \left(\frac{m_1}{m_2}\right)^{1/2}\frac{1}{1-y}\langle U_2^{(c)}\rangle; \quad l_{23} = \langle U_1^{(p)}\rangle - \left(\frac{m_1}{m_2}\right)^{1/2}\langle U_2^{(p)}\rangle;$$
$$l_{31} = y\langle U_1^{(T)}\rangle + (1-y)\left(\frac{m_1}{m_2}\right)^{1/2}\langle U_2^{(T)}\rangle; \quad l_{32} = \langle U_1^{(c)}\rangle - \left(\frac{m_1}{m_2}\right)^{1/2}\langle U_2^{(c)}\rangle;$$
$$l_{33} = y\langle U_1^{(p)}\rangle + (1-y)\left(\frac{m_1}{m_2}\right)^{1/2}\langle U_2^{(p)}\rangle; \quad y = y_1;$$

the angular brackets denoting averaging over the cross sectional area of the channel; the quantities l_{11}, l_{12}, l_{13} are related to the heat flux along the channel produced by the temperature, concentration, and pressure gradients; l_{21}, l_{22}, l_{23} characterize thermodiffusion, normal diffusion produced by inhomogeneity in component concentration, and barodiffusion; l_{31}, l_{32}, l_{33} characterizes thermal creep, mean numerical gas flow under the action of concentration gradients, and Poiseuille flow of the binary gas mixture.

In the general case all the quantities $l_{\alpha\beta}$ depend on the intermolecular interaction potential between molecules and with the boundary surface, the channel geometry, the concentrations, ratio of component molecular weights, and Knudsen number.

It should be noted that in the thermodynamics of irreversible processes for discontinuous systems [3] one finds expressions analogous to Eq. (7) and reciprocity relationships $l_{\alpha\beta} = l_{\beta\alpha} (\alpha \neq \beta)$ are postulated. It is of interest to verify these relationships on the basis of kinetic theory within the framework of the above assumptions for arbitrary Kn values.

Solution Method. In choosing one or the other approximate procedure for solution of system (5) two factors must be considered: First, Eq. (5) consists of linear Fredholm integral equations of the second sort; second, the quantities of interest are not the flow profiles of the moving gas, but the quantities averaged over capillary section, Eq. (8). From the latter fact it follows that the approximate method must converge with the mean. The Galerkin method satisfies these requirements, and has been proven effective in describing motion of a single-component gas in channels [4, 5]. To realize this method it is necessary to specify a system of base functions. From the symmetry of the problem it follows that in the N-approximation the following approximate expressions should be used:

$$u_i^{(N)} = \sum_{k=0}^{N} A_i^{(k)}x^{2k}, \quad p_{irz}^{(N)} = \sum_{k=1}^{N} B_i^{(k)}x^{2k-1}, \quad H_i^{(N)} = \sum_{k=1}^{N} C_i^{(k)}x^{2k-2} \tag{9}$$
$$i = 1, 2.$$

In order to determine the coefficients of the expansion, it is necessary to substitute Eq. (9) in Eq. (5) and require orthogonality of the expressions thus obtained to each of the base functions. The condition for orthogonality of two arbitrary functions f and g then has the form

$$(f, g) = \int_0^1 xf(x)\, g(x)\, dx = 0.$$

As a result, we obtain a system of 6N + 2 linear algebraic equations for determination of the coefficients $A^{(k)}$, $B^{(k)}$, $C^{(k)}$.

Solution of the problem of motion of a single-component gas in a channel [4, 5] has shown that with the approximations of Eq. (9) the Galerkin method converges very rapidly. Even in the first approximation (N = 1) the results obtained differ by not more than 1.5% from the reference solution for any values of Kn. Apparently the same convergence may be expected in the problem of gas mixture motion. In fact, the first approximation with Eq. (9) accurately describes the flow profiles for $Kn \ll 1$, while information on the flow value for almost free-molecular flow ($Kn \gg 1$) is contained completely in the free terms of the integral-moment equations (5). In the present study only the first approximation of Eq. (9) was used. The formalism of the Galerkin method for this case was described in great detail in [4]. Complete expressions for the kinetic coefficients have a cumbersome form and will not be presented here.

Evaluation. Asymptotic analysis of the results obtained is of interest. For the case of an almost free-molecular flow ($R_i \ll 1$) we have

$$l_{11} = -\frac{6}{\sqrt{\pi}}\left[y\left(1+\frac{5\sqrt{\pi}}{12}R_1\ln R_1\right)+(1-y)\left(\frac{m_1}{m_2}\right)^{1/2}\left(1+\frac{5\sqrt{\pi}}{12}R_2\ln R_2\right)\right],\quad l_{13}=l_{31}=\frac{4}{3\sqrt{\pi}}\left[y\left(1+\frac{3\sqrt{\pi}}{4}R_1\ln R_1\right)+\right. \tag{10}$$

$$\left.+\left(\frac{m_1}{m_2}\right)^{1/2}(1-y)\left(1+\frac{3\sqrt{\pi}}{4}R_3\ln R_2\right)\right],\qquad l_{12}=l_{21}=\frac{4}{3\sqrt{\pi}}\left[1+\frac{3\sqrt{\pi}}{4}R_1\ln R_1-\left(\frac{m_1}{m_2}\right)^{1/2}\left(1+\frac{3\sqrt{\pi}}{4}R_2\ln R_2\right)\right],$$

$$l_{22} = -\frac{8}{3\sqrt{\pi}}\left[\frac{1}{y}\left(1+\frac{3\sqrt{\pi}}{8}R_1\ln R_1\right)+\frac{1}{1-y}\left(\frac{m_1}{m_2}\right)^{1/2}\left(1+\frac{3\sqrt{\pi}}{8}R_2\ln R_2\right)\right],$$

$$l_{23} = l_{32} = -\frac{8}{3\sqrt{\pi}}\left[1+\frac{3\sqrt{\pi}}{8}R_1\ln R_1-\left(\frac{m_1}{m_2}\right)^{1/2}\left(1+\frac{3\sqrt{\pi}}{8}R_2\ln R_2\right)\right],$$

$$l_{33} = -\frac{8}{3\sqrt{\pi}}\left[y\left(1+\frac{3\sqrt{\pi}}{8}R_1\ln R_1\right)+(1-y)\left(\frac{m_1}{m_2}\right)^{1/2}\left(1+\frac{3\sqrt{\pi}}{8}R_2\ln R_2\right)\right].$$

In the so-called diffusion limit ($R_i \gg 1$) the results can be presented in the form of the ratio of eight-order determinants, in which each element depends on the parameters R_i, concentration, molecular weight of components, and reduced Chapman–Cowling integrals. Analysis of the behavior of the quantities $l_{\alpha\beta}$ at $R_i \gg 1$ shows that upon transition to the hydrodynamic limit the values of l_{33}, characterizing the value of the Poiseuille flow, increase in proportion to R_i, while the remaining kinetic coefficients decrease as R_i^{-1}.

Numerical calculations for intermediate R_i values were performed with a BÉSM-6 computer to an accuracy of at least 0.5%. Two gas combinations (helium–argon and helium–deuterium) were chosen for study because they represent limiting cases of greatly divergent and quite similar molecular weights. The intermolecular collision potential was specified in the Lennard–Jones form, with values of potential parameters for identical molecules taken from [6], while for molecules of opposite types they were calculated by the combination rule. Corresponding values of the reduced Chapman–Cowling integrals are given in [6]. Gas temperature was assumed equal to 295°K, with concentration of the lighter component being varied from zero to unity. Results of kinetic coefficient $l_{\alpha\beta}$ calculations for He–Ar (solid lines) and He–D_2 (dashed lines) as functions of rarefaction parameter R_1 and component concentration y are shown in Figs. 1-4 and Table 1 (y = 0.2, 0.5, 0.8 for curves 1-3, respectively).

It was established that at any values of the parameters varied and for any model of the intermolecular potential in the linear approximation (low gradients) reciprocity relationships are satisfied, i.e., $l_{\alpha\beta} = l_{\beta\alpha}$. This agrees with the basic conclusions of thermodynamics of irreversible processes for discrete systems [3]. In the present study diffuse scattering of molecules on the capillary surface was assumed. However, it can be shown that Onzager symmetry relationships for the kinetic coefficients will be valid for any "gas–surface" interaction law, since the scattering nucleus satisfies the detailed equilibrium principle.

It is known that the thermodiffusion phenomenon does not exist for Maxwellian molecules. The kinetic coefficient l_{21}, characterizing the diffusion flow under the action of a temperature gradient is nonzero in the case of Maxwellian molecules also. This is because the values of all the flows $l_{\alpha\beta}$, including l_{21} also, are

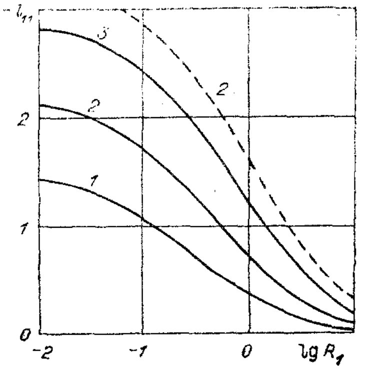

Fig. 1

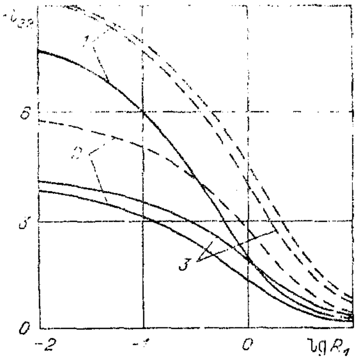

Fig. 2

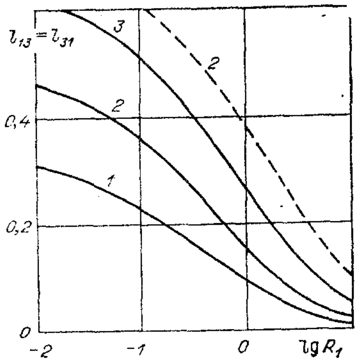

Fig. 3

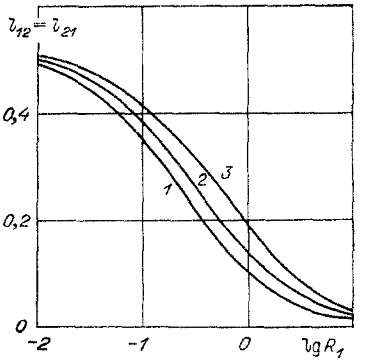

Fig. 4

TABLE 1

	$-l_{33}\cdot 10$ (He−Ar)			$l_{23}\cdot 10^2$ (He−D_2)		
y	0,2	0,5	0,8	0,2	0,5	0,8
0,01	9,95	10,0	10,0	−0,713	−0,890	−1,10
0,05	8,89	9,19	9,43	−0,836	−1,17	−1,56
0,1	7,90	8,43	8,88	−0,716	−1,07	−1,46
0,3	5,53	6,47	7,41	$5,18\cdot 10^{-2}$	−0,185	−0,428
0,5	4,25	5,27	6,44	0,696	0,544	0,399
0,7	3,44	4,44	5,70	1,17	1,06	0,957
1,0	2,66	3,58	4,86	1,64	1,55	1,46
3,0	1,04	1,51	2,38	2,10	1,92	1,73
5,0	0,644	0,954	1,55	,71	1,52	1,34
10,0	0,331	0,497	0,825	,04	0,905	0,776

defined not only by intermolecular collisions, but also by channel geometry and interaction of gas molecules with the boundary surface. The first factor proves dominant at $R_i \gg 1$, and the latter ones at $R_i \ll 1$.

Table 1 presents values of the kinetic coefficient $l_{23}=l_{32}$. A characteristic feature of the results obtained for the He−D_2 mixture is the inversion of the sign of l_{23} at $R_1 = (0.3\text{-}0.5)$. This means that the direction of the barodiffusion flow is determined by both the direction of the pressure gradient and the gas flow regime in the channel. A similar fact was established previously in [7] for the pair Ar−CO_2. Inversion of the sign of l_{23} can be explained by the fact that at $R_i \ll 1$, when intermolecular collisions are rare, the dominant role is played by the difference in effective collision sections. In the case of similar component molecular weights it develops that at $R_i \sim 1$ the dominant role begins to be played by the second factor. This is the cause of the change in sign of the barodiffusion flow.

Figure 5 compares theory (curves 1-3) with experimental data (points I-III) [8] for Poiseuille flow of an He−Ar mixture at various helium concentrations: y = 0.21, 0.50, 0.81. The value of l^*_{33} was determined from the ratio of the kinetic coefficient l_{33} to its free-molecular value, which follows from Eq. (10) at $R_i \to 0$. To calculate the experimental values of the parameter R_i the collision frequency between identical molecules was specified in analogy with the BHC expression $\gamma_{ii} = (8/5)n_i\Omega_{ii}^{(2,2)}$, while the frequency of collisions between different molecules was chosen after the recommendations of [2].

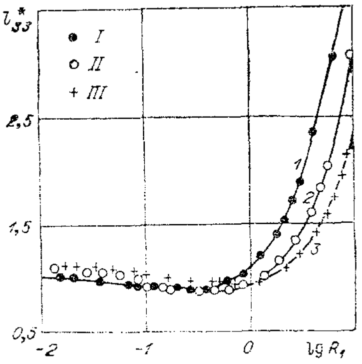

Fig. 5

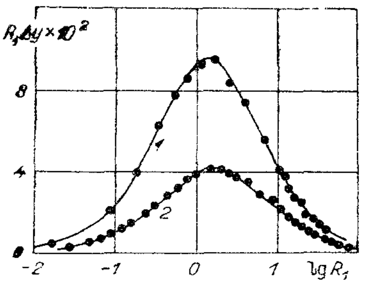

Fig. 6

Comparison for $R_1 > 1$ shows good (within the limits of experimental uncertainty) agreement of experimental and theoretical results. For $R_1 < 1$, where the dominant role is played by channel geometry and the character of molecular interaction with the surface, the theoretical curve lies below the experimental data. The maximum divergence reaches 5% at an He concentration $y = 0.21$, 7% at $y = 0.50$, and 10% at $y = 0.81$. This can be explained by the fact that in actual experiment, upon collision with the channel walls the molecules do not experience total accommodation of the tangential momentum component. The increase in divergence with increasing helium concentration is caused by the significantly lower accomodation of the helium molecules as compared to argon. Figure 6 shows a comparison of theory (curves 1, 2, $y = 0.50$, 0.93, respectively) with experiment [8] (points) for barodiffusion separation of an He–Ar mixture. The expression for calculating the concentration "shift" upon motion of the gas mixture through the channel under the influence of a pressure gradient has the form [8, 9]

$$\Delta y = y^1 - y^0 = y^0(1 - y^0)l_{23}/l_{33},$$

where y^1 and y^0 are the concentrations at the channel output and input, respectively. Divergence of the theoretical results from experiment does not exceed 5% at any values of the rarefaction parameter and concentration.

In conclusion, it should be noted that the results of the present study can be used to describe various effects in binary gas mixtures (baro- and thermodiffusion separation, diffusion baroeffect, thermomolecular pressure, mechanocaloric effect, etc.) for arbitrary Knudsen number and component concentration.

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