

# ON THE STATISTICAL THEORY OF RELAXATION PROCESSES AND MASS TRANSFER PHENOMENA IN ASYMMETRIC LIQUIDS

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The dynamic process of mass transfer in liquid systems consisting of identical rigid molecules, which have an arbitrary form and possess translational and rotational degrees of freedom, has been studied. General analytical expressions for the dynamic coefficients of diffusion, thermo-diffusion, and convection, as well as for the corresponding dynamic moduli of elasticity, which make allowance for the features of the molecular structure of a liquid, have been obtained.

Under the practical conditions of operation, liquid systems undergo the action of external factors of various kinds, including periodic ones. In turn, the character of the dynamic nonequilibrium properties of liquids is closely connected with the origin of internal relaxational processes occurring in them.

Transport phenomena in liquids, in general, and diffusion processes, in particular, can be investigated on the basis of the known conservation laws of mass, momentum, and energy. However, the equations of those laws cannot be applied in their general forms to studying specific systems, because the relevant system of equations is not closed, and the fluxes that are included into these equations remain unknown. If we define those fluxes on the basis of the known phenomenological relations of Fick, Fourier, and Newton and thus close the system comprising the equations of conservation laws, we shall obtain the system of equations of ordinary hydrodynamics, suitable for the description of slow and stationary processes. But the transport coefficients, which are included into those equations, will remain indefinite.

Provided that the equations of generalized hydrodynamics are formulated on the basis of rigorous methods of the statistical theory of nonequilibrium processes, we become able to describe the dynamic transport processes in liquids in wide ranges of variations of the external perturbation frequency and the parameters of state with regard for the contribution of internal relaxational processes occurring in liquids. When considering simple liquids, such problems are resolved on the basis of the method of kinetic equations

[1]. However, the task of formulation and solution of such kinetic equations for complex asymmetric liquid systems meets difficulties.

Recently, the method of nonequilibrium statistical operator has been applied successfully to the description of nonequilibrium processes in various condensed systems [2]. In the present work, we made an attempt to generalize this method with the purpose to describe the dynamic process of mass transfer and relaxational phenomena in asymmetric liquids. The generalization consists in a significant enlarging of the number of dynamic variables describing a nonequilibrium state of the system and taking the angular characteristics of non-spherical molecules into account.

Consider a system made up of  $N$  rigid identical molecules of an arbitrary form, with the mass  $m$  and the moment of inertia  $I_{\alpha\beta}$  each. The state of the system of such molecules, possessing translational and rotational degrees of freedom, can be described by the laws of classical physics.

The position of each non-spherical molecule in the phase space will be described making use of three Cartesian coordinates  $\vec{X}_i = \{x_i, y_i, z_i\}$  which determine the position of the center of inertia of the  $i$ -th molecule; three values of the angular coordinates  $\vec{\theta}_i = \{\theta_i, \varphi_i, \psi_i\}$  which determine an orientation of this molecule in the coordinate space; and the relevant components of the momentum  $\vec{P}_i = \{p_{xi}, p_{yi}, p_{zi}\}$  and the torque  $\vec{M}_i = \{M_{xi}, M_{yi}, M_{zi}\}$ .

A microscopic model of the system is defined with the help of the Hamiltonian

$$H(\vec{X}_i, \vec{\theta}_i, \vec{P}_i, \vec{M}_i) = \sum_{i=1}^N \left( \frac{P_i^2}{2m} + \frac{M_i^\alpha M_i^\beta}{2I_{\alpha\beta}} + \frac{1}{2} \sum_{i \neq j=1}^N \Phi_{ij}(\vec{X}_{ij}, \vec{\theta}_i, \vec{\theta}_j) \right), \quad (1)$$

where  $\Phi_{ij}$  is the noncentral potential of the intermolecular pairwise interaction in the liquid. The

equations of molecular motion are presented in the Hamiltonian form.

Similarly to work [2], the dynamic concentration of particles  $\hat{n}(\vec{X}, \vec{\theta})$  and the energy of the system  $\hat{H}(\vec{X}, \vec{\theta})$  were used as the dynamic variables describing a nonequilibrium state of the liquid system. We extended the number of those variables by adding the dynamic densities of components of the vectors of diffusion fluxes  $\hat{J}_t^\alpha(\vec{X}, \vec{\theta})$  and  $\hat{J}_r^\alpha(\vec{X}, \vec{\theta})$ , the stress tensors  $\hat{P}_t^{\alpha\beta}(\vec{X}, \vec{\theta})$ ,  $\hat{P}_r^{\alpha\beta}(\vec{X}, \vec{\theta})$ , and  $\hat{P}_{tr}^{\alpha\beta}(\vec{X}, \vec{\theta})$ , and the vectors of heat fluxes  $\hat{S}_t^\alpha(\vec{X}, \vec{\theta})$  and  $\hat{S}_r^\alpha(\vec{X}, \vec{\theta})$  conditioned by the translational (subscript  $t$ ) and rotational (subscript  $r$ ) degrees of freedom of non-spherical molecules, as well as by the interaction of those degrees of freedom (subscript  $tr$ ). Following work [2], we constructed the nonequilibrium statistical distribution function. In a linear approximation with respect to deviations of the parameters of the system state from their equilibrium values, this function can be written as [3]

$$f(t) = f_L(1 + \Delta f) \approx f_L + f_0 \Delta f, \quad (2)$$

where  $f_L$  is the locally equilibrium distribution function defined by the expression

$$f_L \approx f_0 \{1 + \dots - d_t^\alpha(\vec{X}, t) \bar{J}_t^\alpha(t) - d_r^\alpha(\vec{X}, t) \bar{J}_r^\alpha(t) - \dots +\}, \quad (3)$$

$$f_0 = \frac{\exp\{-\beta(\vec{X}, t)(\bar{H} - \mu(\vec{X}, t)N)\}}{\int \dots \int \exp\{-\beta(\vec{X}, t)(\bar{H} - \mu(\vec{X}, t)N)\} d\Gamma} \quad (4)$$

is the Gibbs grand canonical distribution, and

$$\begin{aligned} \Delta f = & - \int_{-\infty}^0 e^{\varepsilon t_1} dt_1 [A_t^\alpha(\vec{X}, t + t_1) \tilde{J}_t^\alpha(t_1) + \\ & + A_r^\alpha(\vec{X}, t + t_1) \tilde{J}_r^\alpha(t_1) + d_t^\alpha(\vec{X}, t + t_1) \frac{\tilde{F}^\alpha(t_1)}{m} + \\ & + d_r^\alpha(\vec{X}, t + t_1) I_{\alpha\beta}^{-1} \tilde{N}^\beta(t_1) + \dots]. \end{aligned} \quad (5)$$

The unknown macroscopical parameters  $\beta$ ,  $\mu$ ,  $d$ ,  $\dots$  were determined from the condition

$$\langle \hat{P}_b(\vec{X}, \vec{\theta}) \rangle = \langle \hat{P}_b(\vec{X}, \vec{\theta}) \rangle_L, \quad (6)$$

where  $\hat{P}_i(\vec{X}, \vec{\theta})$  is the density of the corresponding dynamic quantity which characterizes a nonequilibrium state of the liquid, and  $\langle \dots \rangle$  means averaging over the corresponding statistical ensemble.

Expressions (2)–(5) exhibit only those terms which make contributions to the dynamic process of mass transfer. The full expressions of these distribution

functions can be found in work [3]. Distribution functions (2)–(5) can be used to study nonequilibrium properties of asymmetric liquids. In particular, averaging the equations, which describe time variations of the dynamic densities of components of the vectors of diffusion fluxes, over those functions, we obtained the system of equations [4, 5]

$$\begin{aligned} & \frac{\partial J_t^\alpha(\vec{X}, \vec{\theta}, t)}{\partial t} + n(\vec{X}, \vec{\theta}, t) \frac{\partial u^\alpha(\vec{X}, t)}{\partial t} + \\ & \frac{1}{m} \frac{\partial P_t(\vec{X}, \vec{\theta}, t)}{\partial X^\alpha} = \frac{\langle \hat{F}^\alpha(\vec{X}, \vec{\theta}) \rangle_t}{m}, \\ & \frac{\partial J_r^\alpha(\vec{X}, \vec{\theta}, t)}{\partial t} + n(\vec{X}, \vec{\theta}, t) \frac{\partial \omega^\alpha(\vec{X}, t)}{\partial t} + \\ & + I_{\alpha\beta}^{-1} \frac{\partial}{\partial \theta^\gamma} (a^{\gamma\beta} P_r(\vec{X}, \vec{\theta}, t)) = I_{\alpha\lambda}^{-1} \langle \hat{N}^\lambda(\vec{X}, \vec{\theta}) \rangle_t, \end{aligned} \quad (7)$$

where

$$\begin{aligned} J_t^\alpha(\vec{X}, \vec{\theta}, t) &= \left\langle \sum_{i=1}^N \frac{\tilde{P}_i^\alpha}{m} \delta(\vec{X}_i(t) - \vec{X}) \delta(\vec{\theta}_i(t) - \vec{\theta}) \right\rangle, \\ J_r^\alpha(\vec{X}, \vec{\theta}, t) &= \left\langle \sum_{i=1}^N I_{\alpha\beta}^{-1} \tilde{M}_i^\beta \delta(\vec{X}_i(t) - \vec{X}) \delta(\vec{\theta}_i(t) - \vec{\theta}) \right\rangle \end{aligned} \quad (8)$$

are the dynamic values of components of the densities of the particle flux vectors;  $\tilde{P}_i = \vec{P}_i - m\vec{u}(\vec{X}, t)$  and  $\tilde{M}_i = \vec{M}_i - I\vec{\omega}(\vec{X}, t)$  are the momentum and the torque of the  $i$ -th molecule, respectively, in the coordinate system linked to the liquid;  $\vec{u}(\vec{X}, t)$  and  $\vec{\omega}(\vec{X}, t)$  are the macroscopical velocities of translational and rotational motions of the liquid, respectively;

$$\begin{aligned} \langle \hat{F}^\alpha(\vec{X}, \vec{\theta}) \rangle_t &= -\beta_{tt}^{\alpha\beta} J_t^\beta(\vec{X}, \vec{\theta}, t) - \beta_{tr}^{\alpha\beta} J_r^\beta(\vec{X}, \vec{\theta}, t), \\ \langle \hat{N}^\alpha(\vec{X}, \vec{\theta}) \rangle_t &= -\beta_{rt}^{\alpha\beta} J_t^\beta(\vec{X}, \vec{\theta}, t) - \beta_{rr}^{\alpha\beta} J_r^\beta(\vec{X}, \vec{\theta}, t) \end{aligned} \quad (9)$$

are the nonequilibrium parts of the averaged intermolecular forces and their averaged moments, respectively, which are responsible for the dissipation and irreversibility in the system;

$$\begin{aligned} \beta_{tt}^{\alpha\beta} &= \frac{1}{3nkT} \int_0^\infty dt \langle \hat{F}^\alpha(\vec{X}, \vec{\theta}) \tilde{F}^\beta(t) \rangle_0, \\ \beta_{tr}^{\alpha\beta} &= \frac{1}{3nkT} \int_0^\infty dt \langle \hat{F}^\alpha(\vec{X}, \vec{\theta}) \tilde{N}^\beta(t) \rangle_0, \end{aligned}$$

and

$$\beta_{rt}^{\alpha\beta} = \frac{1}{3nkT} \int_0^{\infty} dt \langle \hat{N}^{\alpha}(\vec{X}, \vec{\theta}) \tilde{F}^{\beta}(t) \rangle_0,$$

$$\beta_{rr}^{\alpha\beta} = \frac{1}{3nkT} \int_0^{\infty} dt \langle \hat{N}^{\alpha}(\vec{X}, \vec{\theta}) \tilde{N}^{\beta}(t) \rangle_0 \quad (10)$$

are the corresponding friction coefficients; and  $P_t$  and  $P_r$  are the components of hydrostatic pressure which are caused by the translational and rotational degrees of freedom of molecules.

In work [7] on the basis of macroscopical relations like Eq. (9), the nonequilibrium properties of liquids containing complex helical Brownian particles were studied, including the corresponding diffusion coefficients. Following this work, we resolved the system of equations (9) with respect to the components of the vectors  $\hat{J}_t^{\alpha}(\vec{X}, \vec{\theta})$  and  $\hat{J}_r^{\alpha}(\vec{X}, \vec{\theta})$  and obtained the corresponding expressions for the coefficients of mobility and diffusion of molecules. For example, for the diffusion coefficients, we get

$$D_{tt}^{\alpha\beta} = \frac{kT}{m} \frac{\beta_{rr}^{\alpha\beta}}{\det[D]}, \quad D_{rt}^{\alpha\beta} = \frac{kT}{m} \frac{\beta_{rt}^{\alpha\beta}}{\det[D]},$$

$$D_{tr}^{\alpha\beta} = \frac{kT}{I_{\alpha\gamma}} \frac{\beta_{tr}^{\beta\gamma}}{\det[D]}, \quad D_{rr}^{\alpha\beta} = \frac{kT}{I_{\alpha\gamma}} \frac{\beta_{tt}^{\beta\lambda}}{\det[D]}, \quad (11)$$

$$\det[D] = \beta_{tt}^{\alpha\beta} \beta_{rr}^{\alpha\beta} - \beta_{tr}^{\alpha\beta} \beta_{rt}^{\alpha\beta} > 0.$$

Neglecting the interference effects, i.e. supposing that  $\beta_{tr}^{\alpha\beta}$  and  $\beta_{rt}^{\alpha\beta}$  equal zero, we obtained the known relations connecting the diffusion coefficients and the coefficients of internal friction in the liquid:

$$D_{tt}^{\alpha\beta} = \frac{kT}{m\beta_{tt}^{\alpha\beta}}, \quad D_{rr}^{\alpha\beta} = \frac{kT}{I_{\alpha\gamma}\beta_{rr}^{\beta\gamma}}. \quad (12)$$

The expressions obtained in this work are more general than those obtained in work [7], because the coefficients  $\beta^{\alpha\beta}$  in our formulae are expressed, according to Eq. (10), in terms of the molecular-structural characteristics of a liquid. The molecular-structural features of a liquid system were taken into account in Eq. (10) by introducing the locally equilibrium correlators force-force  $\langle \hat{F}^{\alpha}(\vec{X}, \vec{\theta}) \tilde{F}^{\beta}(t) \rangle_0$ , force-torque  $\langle \hat{F}^{\alpha}(\vec{X}, \vec{\theta}) \tilde{N}^{\beta}(t) \rangle_0$ , torque-force  $\langle \hat{N}^{\alpha}(\vec{X}, \vec{\theta}) \tilde{F}^{\beta}(t) \rangle_0$ , and torque-torque  $\langle \hat{N}^{\alpha}(\vec{X}, \vec{\theta}) \tilde{N}^{\beta}(t) \rangle_0$ . The existence of non-zero values

of such correlators even for liquids made up of comparatively simple non-spherical molecules was demonstrated in work [8].

The diffusion coefficients (11) allow the diffusion properties of liquids to be described only at slow and stationary processes. In order to describe the dynamic diffusion processes, one should deal not only with the expressions for the diffusion fluxes, but take into account the evolution of these currents in time [5, 6]. In a linear approximation, without making allowance for the contributions of viscoelastic and thermoelastic processes, it is possible to start from the system of equations (7), (9) which includes the relaxational equations for components of the vectors of diffusion fluxes  $J_t^{\alpha}(\vec{X}, \vec{\theta}, t)$  and  $J_r^{\alpha}(\vec{X}, \vec{\theta}, t)$  with characteristic relaxation times

$$\tau_{tt}^{\alpha\beta} = \frac{m}{\beta_{tt}^{\alpha\beta}}, \quad \tau_{tr}^{\alpha\beta} = \frac{m}{\beta_{tr}^{\alpha\beta}}, \quad \tau_{rt}^{\alpha\beta} = \frac{I_{\alpha\gamma}}{\beta_{rt}^{\beta\gamma}}, \quad \tau_{rr}^{\alpha\beta} = \frac{I_{\alpha\gamma}}{\beta_{rr}^{\beta\gamma}}. \quad (13)$$

According to these equations, the dynamics of time variation of each component of the vector of diffusion flux is affected by the relaxation of not only this component but also by that of the other components of this vector and all components of the other vector of diffusion flux.

Fourier-transforming the system of equations (7) in time and resolving the resulting system with respect to  $J_t^{\alpha}(\vec{X}, \vec{\theta}, \nu)$  and  $J_r^{\alpha}(\vec{X}, \vec{\theta}, \nu)$ , we obtained the following expressions for the generalized complex coefficients of diffusion  $\tilde{D}(i\nu)$  and convection  $\tilde{K}(i\nu)$ :

$$\tilde{D}_{tt}^{\alpha\beta}(i\nu) = \frac{1}{m} \left( \frac{\partial P_t(n, T)}{\partial n} \right) {}_T R_{tt}^{\alpha\beta}(i\nu),$$

$$\tilde{D}_{rr}^{\alpha\beta}(i\nu) = \frac{1}{I_{\alpha\gamma}} \left( \frac{\partial P_r(n, T)}{\partial n} \right) {}_T R_{rr}^{\alpha\beta}(i\nu),$$

$$\tilde{D}_{rt}^{\alpha\beta}(i\nu) = \frac{1}{m} \left( \frac{\partial P_t(n, T)}{\partial n} \right) {}_T R_{rt}^{\alpha\beta}(i\nu),$$

$$\tilde{D}_{tr}^{\alpha\beta}(i\nu) = \frac{1}{I_{\alpha\gamma}} \left( \frac{\partial P_r(n, T)}{\partial n} \right) {}_T R_{tr}^{\alpha\beta}(i\nu),$$

$$\tilde{K}_{tt}^{\alpha\beta}(i\nu) = i\nu n R_{tt}^{\alpha\beta}(i\nu), \quad \tilde{K}_{rt}^{\alpha\beta}(i\nu) = i\nu n R_{rt}^{\alpha\beta}(i\nu),$$

$$\tilde{K}_{tr}^{\alpha\beta}(i\nu) = i\nu n R_{tr}^{\alpha\beta}(i\nu), \quad \tilde{K}_{rr}^{\alpha\beta}(i\nu) = i\nu n R_{rr}^{\alpha\beta}(i\nu); \quad (14)$$

$$R_{tt}^{\alpha\beta}(i\nu) = \frac{\tau_{tt}^{\gamma\sigma} (\delta^{\gamma\sigma} + i\nu \tau_{rr}^{\gamma\sigma})}{\Delta^{\alpha\beta}},$$

$$R_{rr}^{\alpha\beta}(i\nu) = \frac{\tau_{rr}^{\gamma\sigma}(\delta^{\gamma\sigma} + i\nu\tau_{tt}^{\gamma\sigma})}{\Delta^{\alpha\beta}},$$

$$R_{tr}^{\alpha\beta}(i\nu) = \frac{\tau_{tt}^{\gamma\sigma}\tau_{rr}^{\gamma\sigma}}{\tau_{tr}^{\alpha\gamma}\Delta^{\gamma\beta}}, \quad R_{rt}^{\alpha\beta}(i\nu) = \frac{\tau_{tt}^{\gamma\sigma}\tau_{rr}^{\gamma\sigma}}{\tau_{rt}^{\alpha\gamma}\Delta^{\gamma\beta}};$$

$$\Delta^{\alpha\beta} = \delta^{\alpha\beta}(\delta^{\gamma\sigma} + i\nu\tau_{tt}^{\gamma\sigma})(\delta^{\gamma\sigma} + i\nu\tau_{rr}^{\gamma\sigma}) - \frac{\tau_{tt}^{\gamma\sigma}\tau_{rr}^{\gamma\sigma}}{\tau_{tr}^{\alpha\gamma}\tau_{rt}^{\gamma\beta}}.$$

Here,  $\nu$  is the external action frequency and  $\delta^{\alpha\beta}$  is the Kronecker symbol. The expressions for the generalized coefficients of thermal diffusion  $\tilde{T}(i\nu)$  are the same as those for the coefficients of ordinary diffusion  $\tilde{D}(i\nu)$  where the derivatives  $(\frac{\partial P}{\partial n})_T$  are replaced by  $(\frac{\partial P}{\partial T})_n$ . Under the term ‘‘coefficients of ordinary or thermal diffusion’’ we mean the coefficients that connect the vectors of diffusion fluxes with the coordinate and angular gradients of the density of particle number  $n(\nu)$ . The coefficients of thermal diffusion connect the fluxes with analogous gradients of the temperature  $T(\nu)$ , while the convection coefficients establish the interrelation between fluxes and velocities of a macroscopical motion of the liquid.

It is evident that the analytical expressions obtained for the generalized coefficients of the dynamic process of mass transfer are awkward complex-valued expressions, difficult for investigation in this form. Therefore, we made some simplifying assumptions: (i) assuming  $\alpha = \beta$ , we neglected the interference between noncoincident components of the particle number gradient and the vectors of diffusion fluxes; (ii) assuming  $\gamma = \sigma$ , we neglected the relaxational dependence of various components of the same vector of diffusion flux of particles; (iii) assuming  $(\tau_{tt}, \tau_{rr}) \ll (\tau_{rt}, \tau_{tr})$ , we asserted that the energy exchange among various degrees of freedom is impeded considerably in comparison with that among identical degrees of freedom. The last assumption is valid for liquids consisting of molecules, whose form is simple, and it is possible to neglect the interference of the rotational and translational degrees of freedom of molecules.

With these assumptions in view, expressions (14) became considerably simpler. Determining the real and imaginary parts of the simplified expressions, for example, for the dynamic coefficients of thermal diffusion  $T(\nu)$  and the corresponding dynamic moduli of thermodiffusion elasticity  $M^T(\nu)$  of asymmetric liquids, we obtained

$$T_{tt}(\nu) = \frac{1}{m} \left( \frac{\partial P_t(n, T)}{\partial T} \right)_n \frac{\tau_{tt}}{1 + (\nu\tau_{tt})^2},$$

$$T_{rr}(\nu) = \frac{1}{I} \left( \frac{\partial P_r(n, T)}{\partial T} \right)_n \frac{\tau_{rr}}{1 + (\nu\tau_{rr})^2}, \quad (15)$$

$$M_{tt}^T(\nu) = \frac{1}{m} \left( \frac{\partial P_t(n, T)}{\partial T} \right)_n \frac{(\nu\tau_{tt})^2}{1 + (\nu\tau_{tt})^2},$$

$$M_{rr}^T(\nu) = \frac{1}{I} \left( \frac{\partial P_r(n, T)}{\partial T} \right)_n \frac{(\nu\tau_{rr})^2}{1 + (\nu\tau_{rr})^2}.$$

So, in this simplified case, the translational diffusion in the configuration space of coordinates and the rotational diffusion in the configuration space of angles occur independently. Expressions (15) made it possible to describe the dynamic diffusion processes in asymmetric liquids in a wide range of external perturbation frequencies taking into account the contribution of the rotational and translational relaxational processes in the liquid.

Similarly to the case of ordinary diffusion coefficients [5], one can analyze the asymptotic behavior of the dynamic coefficients of thermal diffusion in the limiting cases of high- and low-frequency dynamic processes starting from Eqs. (15). It is easy to demonstrate that the thermo-diffusion properties of the liquid are described by the static values of the thermal diffusion coefficients  $T_{tt}(0) = \frac{1}{m} \left( \frac{\partial P_t(n, T)}{\partial T} \right)_n \tau_{tt}$ ,  $T_{rr}(0) = \frac{1}{I} \left( \frac{\partial P_r(n, T)}{\partial T} \right)_n \tau_{rr}$  for low-frequency processes, i.e. when  $\nu \rightarrow 0$ , and by the high-frequency values of the thermo-diffusion elastic moduli  $M_{tt}^T(\infty) = \frac{1}{m} \left( \frac{\partial P_t(n, T)}{\partial T} \right)_n$ ,  $M_{rr}^T(\infty) = \frac{1}{I} \left( \frac{\partial P_r(n, T)}{\partial T} \right)_n$  in the region of high frequencies ( $\nu \rightarrow \infty$ ). These results are in a quite good agreement with the statement that the transport properties of liquid systems in the low-frequency region are described by the static values of kinetic coefficients (diffusion, viscosity, heat conductivity, electroconductivity, etc.), and by the high-frequency asymptotical values of the corresponding elastic moduli in the high-frequency region [1]. We note that, in the framework of the locally equilibrium distribution function (5), the kinetic parts of the pressures  $P_t(n, T)$  and  $P_r(n, T)$  are identical. Provided that the equation of state of the ideal gas is used, the expressions obtained for low-frequency values of the diffusion coefficients coincide with the known results of the Einstein theory for translational and rotational diffusion [5].

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## ДО СТАТИСТИЧНОЇ ТЕОРІЇ РЕЛАКСАЦІЙНИХ ПРОЦЕСІВ ТА ЯВИЩ МАСОПЕРЕНОСУ В АСИМЕТРИЧНИХ РІДИНАХ

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### Р е з ю м е

На основі методу нерівноважного статистичного оператора досліджено динамічний процес масоперенесення в рідинних системах, що складаються з однакових жорстких молекул довільної форми, що мають поступальні та обертальні ступені вільності. Одержано загальні аналітичні вирази для коефіцієнтів дифузії, термодифузії, конвекції і для відповідних їм динамічних модулів пружності, які дозволяють враховувати особливості молекулярної структури рідини.