RADIATION FROM MIXTURE OF DIATOMIC VIBRATIONAL-NONEQUILIBRIUM GASES WITH NONOVERLAPPING BANDS

V. M. Strel'chenya and Yu. V. Khodyko

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The integral and spectral characteristics of steady-state nonequilibrium radiation from a two-component mixture of relaxing diatomic gases with nonoverlapping vibrational–rotational bands are calculated in the diffusion approximation.

In order to calculate the radiation characteristics of nonequilibrium molecular gases, it is necessary to solve a system of equations of the Boltzmann kind for molecules and photons [1], which is a quite difficult mathematical problem. The problem becomes much more simple, however, when local equilibrium within individual degrees of freedom for the molecules can be achieved. Specifically, calculation of the optical characteristics of a one-component diatomic gas with a vibrational temperature different than its translational and rotational temperatures reduces to solution of an integrodifferential equation for the density of its vibrational energy [2]. An analytical solution to this equation can generally not be obtained, but under certain assumptions in the spatially homogeneous case it is possible to reduce the integrodifferential equation to a much simpler differential equation of the diffusion kind [3] and solve the latter exactly [4].

In the case of a mixture of gases with a partial equilibrium, one can demonstrate that calculation of its optical characteristics reduces to solution of a system of integrodifferential equations for the density of vibrational energy in each component. Assuming that the additional requirements [3] are met, one can pass from this system of equations to a system of equations which describe the transfer of radiation energy in the diffusion approximation.

In this approximation we will determine the characteristics of nonequilibrium radiation from a two-component mixture of diatomic gases with nonoverlapping vibrational–rotational bands. We note that calculation of the radiation parameters of some polyatomic vibrational-nonequilibrium gases can also be reduced to this problem. The problem under consideration here is linked directly to calculation of the optical characteristics of a jet of hot molecular gases discharging into a rarefied space. Most important from the practical standpoint is the 1000-2000°K temperature range, where the effects of anharmonicity remain insignificant, but (unlike in problems encountered in laser physics) in this problem the radiation must be examined over the entire vibrational–rotational band, its characteristics being determined by radiative transitions as well as by vibration kinetics associated with intermolecular collisions.

Inasmuch as energy transfer occurs much faster within each group of degrees of freedom which molecules have than between different such groups, one can assume [5] that translational, rotational, and vibrational degrees of freedom are characterized by Boltzmann distributions with temperatures T, T_r, and T_{vi}, respectively. Since translational–rotational (T–R) relaxation occurs much faster than vibrational–translational (V–T) relaxation, moreover, one can let $T = T_r$. Assuming now that the gas density is sufficiently low and temperature T is sufficiently high, one can disregard the effect of radiative energy transfer on the temperature field in active degrees of freedom and regard them as given [4]. The radiation field distribution over the volume occupied by the gas will then be related only to the distribution of the vibrational energy of the mixture components, the latter distribution changing due to V–T relaxation and exchange of vibrational energy between molecules of different components (V–V' relaxation) as well as due to emission and absorption of radiation by molecules. Disregarding the anharmonicity of molecule vibrations, we can write the equations of the diffusion approximation for the given case as

$$\frac{\partial \varepsilon_1}{\partial t} = \frac{\varepsilon_1^0 - \varepsilon_1}{\tau_1^0} + \frac{N_2}{\tau^*} R_{VV'} - (N_1 h \nu_{01})^{-1} \nabla \int\limits_{(\Delta \nu_1)} \mathbf{S}_\nu d\nu, \tag{1}$$

V. I. Lenin Belorussian State University, Minsk. Institute of Physics, Academy of Sciences of the Belorussian SSR, Minsk. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 42, No. 2, pp. 296-302, February, 1982. Original article submitted December 23, 1980.

$$\frac{\partial \varepsilon_2}{\partial t} = \frac{\varepsilon_0^2 - \varepsilon_2}{\tau_2^0} - \frac{N_1}{\tau^*} R_{VV'} - (N_2 h\nu_{02})^{-1} \nabla \int\limits_{(\Delta\nu_2)} \mathbf{S}_\nu d\nu, \tag{2}$$

$$\mathbf{S}_\nu = -\frac{c}{4}(k_{\nu 1} + k_{\nu 2})^{-1} \nabla U_\nu, \tag{3}$$

$$\nabla \mathbf{S}_\nu = c\,[k_{\nu 1}(U_{\nu 1}^* - U_\nu) + k_{\nu 2}(U_{\nu 2}^* - U_\nu)], \tag{4}$$

where

$$R_{VV'} = \varepsilon_2 \exp(\theta_2 - \theta_1) - \varepsilon_1 + \varepsilon_1\varepsilon_2[\exp(\theta_2 - \theta_1) - 1] \tag{5}$$

describes the V–V' relaxation [5],

$$\varepsilon_i^0 = (\exp\theta_i - 1)^{-1}, \ \theta_i = h\nu_{0i}/kT, \ \tau^* = (ZQ)^{-1}.$$

Here and henceforth the indices are i, k = 1, 2; j = 3 − i, and l = 3 − k.

The nonlinearity due to radiation in the fundamental system of equations (1)-(4) vanishes in the "narrow band" approximation [4]. For the purpose of linearizing the exchange term $R_{VV'}$, we expand the product $\varepsilon_1\varepsilon_2$ into a power series in $\varepsilon_i - \varepsilon_i^0$ (i = 1, 2) and discard the last term, which quadratically decreases as the system approaches its equilibrium state. Inserting this series expansion into expression (5) yields

$$R_{VV'} = \sum_{i=1}^{2} (-1)^i \xi_i(\varepsilon_i - \varepsilon_i^0), \ \xi_1 = \frac{1+\varepsilon_2^0}{1+\varepsilon_1^0}, \ \xi_2 = \frac{\varepsilon_1^0}{\varepsilon_2^0}. \tag{6}$$

We now insert expression (6) into Eqs. (1)-(2) and, considering that in the "narrow band" approximation $U_{\nu i}^* \simeq 8\pi h\nu^3\varepsilon_i/c^3$ and the vibrational–rotational bands of molecules do not overlap, i.e., $k_{\nu i} = 0$ within the interval $\Delta\nu_j$, pass from the system of equations (1)-(4) to a system of two differential equations which in the spatially homogeneous case become

$$\nabla^2\left(\frac{\partial\varepsilon_i}{\partial t} + \frac{\varepsilon_i}{\tau_i^*} - \frac{\varepsilon_j}{\tau_{ij}}\right) = 4\varkappa_i^2\left(\frac{\partial\varepsilon_i}{\partial t} + \frac{\varepsilon_i}{\tau_i} - \frac{\varepsilon_j}{\tau_{ij}} - \frac{\varepsilon_i^0}{\tau_{i0}}\right). \tag{7}$$

Here

$$\begin{gathered}
\frac{1}{\tau_1} = \frac{1}{\tau_1^0} + \frac{\xi_1 N_2}{\tau^*}, \ \frac{1}{\tau_{10}} = \frac{1}{\tau_1^0} + \frac{N_2}{\tau^*}\left(\frac{\varepsilon_2^0 - \varepsilon_1^0}{1+\varepsilon_1^0}\right), \\
\frac{1}{\tau_2} = \frac{1}{\tau_2^0} + \frac{\xi_2 N_1}{\tau^*}, \ \frac{1}{\tau_{20}} = \frac{1}{\tau_2^0} + \frac{N_1}{\tau^*}\left(\frac{\varepsilon_1^0 - \varepsilon_2^0}{1+\varepsilon_1^0}\right), \\
\frac{1}{\tau_{12}} = \frac{\xi_2 N_2}{\tau^*}, \ \frac{1}{\tau_{21}} = \frac{\xi_1 N_1}{\tau^*}, \ \frac{1}{\tau_i^*} = \frac{1}{\tau_i} + A_i, \ \tau^* = (ZQ)^{-1}, \ A_i = \frac{8\pi\varkappa_i\nu_{0i}^2\Delta\nu_i}{c^2 N_i}
\end{gathered} \tag{8}$$

In order to make the system completely determinate, it is necessary to supplement Eqs. (7) with boundary conditions based on the two-stream approximation [6]

$$\mathbf{S}_\nu\Big|_\Gamma = \frac{1}{2} c U_\nu\Big|_\Gamma \mathbf{n} \tag{9}$$

and also initial conditions. With the aid of Eqs. (1)-(4), condition (9) can be reduced to the form

$$(\mathbf{n}\cdot\nabla + 2\varkappa_i)\left(\frac{\partial\varepsilon_i}{\partial t} + \frac{\varepsilon_i}{\tau_i^*} - \frac{\varepsilon_j}{\tau_{ij}}\right)\Bigg|_\Gamma = 2\varkappa_i\frac{\varepsilon_i^0}{\tau_{i0}} \tag{10}$$

containing only ε_i.

In this study we will consider only the steady-state problem for a volume of gas with a simple geometry. We will assume, for specificity, that the gas is contained in an infinitely long cylinder of radius R. For this case the solution to the system of equations (7)-(10) is

$$\varepsilon_i(\rho) = \varepsilon_i^0[1 - C_{i1}I_0(\lambda_1\rho) - C_{i2}I_0(\lambda_2\rho)], \ \rho = \frac{r}{\sqrt{\alpha_1}}. \tag{11}$$

Coefficients C_{ik} and α_1 are determined from the expressions

$$C_{ik} = \frac{1}{\varepsilon_i^0\alpha_1 G}\{(-1)^k 2\varkappa_1\varkappa_2\sqrt{\alpha_1}[\beta_i K_{ij} + (-1)^{i+k}\beta_j(\lambda_j^2 - K_{kk})]I_0(\lambda_l R^*) +$$

$$+(-1)^k \lambda_l [\gamma_i K_{ij} + (-1)^{i+k} \gamma j (\lambda_j^2 - K_{kk})] I_1(\lambda_l R^*)\},$$

$$G = 2\{\sqrt{D}[4\varkappa_1\varkappa_2(Y_1+Y_2) + (\varkappa_1+\varkappa_2)(F_1+F_2)] - \sigma(\varkappa_1-\varkappa_2)(F_1-F_2)\}.$$

$$\alpha_1 = \frac{1}{\tau_1^*\tau_2^*} - \frac{1}{\tau_{12}\tau_{21}} > 0,\quad \alpha_2 = \frac{1}{\tau_1\tau_2} - \frac{1}{\tau_{12}\tau_{21}},\quad R^* = \frac{R}{\sqrt{\alpha_1}}, \tag{12}$$

$$\beta_i = \frac{\varepsilon_i^0 A_i}{\tau_{ji}} + \frac{\varepsilon_j^0 A_j}{\tau_i^*},\quad \gamma_i = \frac{\varepsilon_i^0 A_i \varkappa_i}{\tau_{ji}} + \frac{\varepsilon_j^0 A_j \varkappa_j}{\tau_i^*},$$

$$\sigma = \varkappa_1^2\left(\frac{1}{\tau_1\tau_2^*} - \frac{1}{\tau_{12}\tau_{21}}\right) - \varkappa_2^2\left(\frac{1}{\tau_1^*\tau_2} - \frac{1}{\tau_{12}\tau_{21}}\right),$$

$$\lambda_{1,2}^2 = \frac{1}{2}(K_{11}+K_{22}) \pm 2\sqrt{D},\quad D = \sigma^2 + 4\varkappa_1^2\varkappa_2^2\frac{A_1A_2}{\tau_{12}\tau_{21}},$$

$$F_i = \lambda_i I_0(\lambda_j R^*) I_1(\lambda_i R^*),\quad Y_i = \sqrt{\alpha_i}\, I_{i-1}(\lambda_1 R^*) I_{i-1}(\lambda_2 R^*),$$

$$K_{ii} = 4\left(\frac{\varkappa_i^2}{\tau_i\tau_j^*} - \frac{\varkappa_j^2}{\tau_{12}\tau_{21}}\right),\quad K_{ij} = \frac{4}{\tau_{ij}}\left(\frac{\varkappa_i^2}{\tau_j^*} - \frac{\varkappa_j^2}{\tau_j}\right).$$

Knowing ε_i, one can easily calculate the integral densities of radiation energy in bands U_i from the equalities

$$\varkappa_i U_i = \int_{(\Delta\nu_i)} k_{\nu i} U_\nu d\nu.$$

For this we integrate Eq. (4) over the i-th band, taking into account that the bands do not overlap and using the approximate equality [4]

$$\int_{(\Delta\nu_i)} k_{\nu i} U_{\nu i}^* d\nu \simeq \frac{8\pi h \varkappa_i \nu_{0i}^3 \Delta\nu_i}{c^3} \varepsilon_i.$$

Inserting the result into Eqs. (1) and (2), we obtain

$$U_i = \frac{N_i h\nu_{0i}}{c\varkappa_i}\left(\frac{\partial\varepsilon_i}{\partial t} + \frac{\varepsilon_i}{\tau_i^*} - \frac{\varepsilon_j}{\tau_{ij}} - \frac{\varepsilon_i^0}{\tau_{i0}}\right). \tag{13}$$

This yields for the steady-state case

$$U_i(\rho) = U_i^0\{1 - [Q_{i1} I_0(\lambda_1\rho) + Q_{i2} I_0(\lambda_2\rho)]\}, \tag{14}$$

where $U_i^0 = 8\pi h\nu_{0i}^3 \Delta\nu_i \varepsilon_i^0 / c^3$ is the equilibrium value of U_i,

$$Q_{ik} = \frac{2\varkappa_i}{G}\left\{[\sqrt{D} + (-1)^{i+k}\sigma] q_{jl} + (-1)^k \frac{\varkappa_j}{\varkappa_i} b_i q_{il}\right\},$$

$$q_{il} = 2\varkappa_i\sqrt{\alpha_1}\, I_0(\lambda_l R^*) + \lambda_l I_1(\lambda_l R^*),\quad b_i = 2\varkappa_i^2 \frac{\varepsilon_j^0 A_j}{\varepsilon_i^0 \tau_{ij}}. \tag{15}$$

With the aid of the boundary conditions (9), we now determine the integral flux densities of energy within the vibrational–rotational bands of molecules radiated from the cylindrical surface

$$\mathbf{S}_i = \mathbf{n}\frac{cU_i^0}{2}\left\{1 - \frac{2\varkappa_i}{G}\left[\sqrt{D}(4\varkappa_j Y_1 + F_1 + F_2) + \left(\frac{\varkappa_j}{\varkappa_i} b_i + (-1)^i\sigma\right)(F_1 - F_2)\right]\right\}. \tag{16}$$

In order to determine the spectral characteristics of radiation, it is necessary first of all to solve the equation

$$\nabla^2 U_{\nu i} - 4k_{\nu i}^2 (U_{\nu i} - U_{\nu i}^*) = 0 \tag{17}$$

which follows from Eqs. (3)-(4) and has the corresponding boundary condition

$$(\mathbf{n}\cdot\nabla + 2k_{\nu i}) U_{\nu i}|_\Gamma = 0. \tag{18}$$

It is noteworthy that the parameters which characterize V–T and V–V' relaxation of gases appear in Eq. (17) expressed through the quantity $U_{\nu i}^* \sim \varepsilon_i(r)$.

Letting r = R in the solution to this equation and using the condition (9), we obtain the spectral density of the energy flux within the i-th band radiated from the cylinder surface

$$\mathbf{S}_{\nu i} = \mathbf{n}\,\frac{cU^0_{\nu i}}{2}\left\{\left[1+\frac{I_0(\tilde{R}_i)}{I_1(\tilde{R}_i)}\right]^{-1} - \sum_{k=1}^{2}\tilde{C}_{ik} I_0(\lambda_k R^*)\left[1-\frac{1+\mu_{ik}\dfrac{I_1(\lambda_k R^*)}{I_0(\lambda_k R^*)}}{1+\dfrac{I_1(\tilde{R}_i)}{I_0(\tilde{R}_i)}}\right]\right\}, \tag{19}$$

where $U^0_{\nu i} = 8\pi h\nu^3\varepsilon^0_i/c^3$; $\mu_{ik} = \lambda_k/2k_{\nu i}\sqrt{\alpha_1}$; $\tilde{R}_i = 2k_{\nu i}R$; $\tilde{C}_{ik} = C_{ik}(1-\mu^2_{ik})^{-1}$. The quantities $\Delta\nu_i$ and $\varkappa_i$ are determined according to the procedure in study [3].

Integral and spectral characteristics of radiating volumes in the shape of a plane layer or a sphere can be calculated in an analogous manner. It is easy to ascertain that the corresponding expressions for these cases can be derived from those for a cylinder by substitution of $I_0(z)$ with cosh z, $I_1(z)$ with sinh z, R with a in the case of a plane layer of thickness $2a$ or of $I_0(z)$ with $(\sin z)/z$ and $I_1(z)$ with $(z\cos z - \sin z)z^{-2}$ in the case of a sphere.

We will now discuss the results. First we note that the expressions for ε_i, U_i, $U_{\nu i}$, $\mathbf{S}_i$, and $\mathbf{S}_{\nu i}$ appear in the form of differences between two terms, the first one representing the value of a given quantity at thermodynamic equilibrium and the second one accounting for the deviation of the vibrational temperatures T_{vi} of both components from the translational–rotational temperature T of the gas due to finiteness of the relaxation rate and leakage of energy through the volume boundary. Upon introduction of the parameters $\psi_i(\rho) = 1 - U_i(\rho)/U^0_i$, which characterize the amount of deviation of radiation energy density within the bands from equilibrium, and with the use of equalities (14)-(15) one can demonstrate that $\psi_i > 0$ and $(d\psi_i/d\rho) > 0$, i.e., that the function $U_i(\rho) < U^0_i$ and decreases as ρ increases. It then follows from the equalities

$$\varepsilon_i = \varepsilon^0_i(1-\varphi_i),\quad \varphi_i = \frac{1}{\alpha_1}\left(\frac{A_i}{\tau^*_i}\psi_i + \frac{\varepsilon^0_j A_j}{\varepsilon^0_i \tau_{ij}}\psi_j\right),$$

based on expressions (11) and (13), that the mean vibrational energy of molecules in each component is also a decreasing function of ρ, with $\varepsilon_i(\rho) < \varepsilon^0_i$ at any ρ regardless of the values of the parameters which characterize V–T and V–V' relaxation. With increasing ρ, correspondingly also decreases the vibrational temperature of each component

$$T_{vi} = T\left[1+\frac{kT}{h\nu_{0i}}\ln\left(\frac{1-\varphi_i\exp(-\theta_i)}{1-\varphi_i}\right)\right]^{-1}.$$

Let us determine how addition of molecules of component 2 affects the spectral density S_1, assuming that N_1 = const and N_2 increases from zero, in the practically interesting case of an optically thin gas volume. We note that all time parameters τ defined according to expressions (8) depend on N_2, except τ_{21}, and so does $\varkappa_2(\varkappa_2 \sim N_2)$ [3]. For τ^0_i we use the expression [5]

$$\tau^0_i = (P_{i1}N_1 + P_{i2}N_2)^{-1},$$

where P_{ik} is proportional to the probability of one-quantum deactivation of a vibrationally excited molecule of component i by an inelastic collision with a molecule of component k. When $N_2 = 0$, then

$$S_1 = S^*_1 \equiv S^0_1 R\varkappa_1\left(1+\frac{A_1}{P_{11}N_1}\right)^{-1},\quad S^0_i = \frac{1}{2}cU^0_i.$$

Calculations reveal that in the case of the inequality

$$N_1\left(P_{12}\xi_2 + P_{12}P_{21}\tau^* + P_{21} - \frac{A_2}{A_1}P_{11}\right) + A_2P_{12}\tau^* > 0, \tag{20}$$

S_1 increases monotonically with increasing N_2 and tends to the limit $S^{**}_1 = R\varkappa_1 S^0_1$, independent of N_2. When $P_{21} + \xi_2P_{12} + P_{12}P_{21}\tau^* > P_{11}A_2/A_1$, then inequality (20) holds true for any N_1. In the opposite case this inequality holds true only at sufficiently low values of $N_1 < N^*_1$, where N^*_1 is the value of N_1 at which inequality (20) becomes an equality. When $N_1 > N^*_1$, however, then S_1, initially decreasing at N_2 equal to

$$N^*_2 = \frac{N_1\left\{\dfrac{A_2}{A_1}P_{11} - P_{21} - P_{12}\left[\xi_2 + \tau^*\left(\dfrac{A_2}{N_1} + P_{21}\right)\right]\right\}}{2P_{22}(1+P_{12}\tau^*)},$$

will now increase, tending to S^{**}_1 as N_2 increases further. We thus have $S^{**}_1/S^*_1 > 1$ when $\lambda_i R^* \ll 1$. Inequality (20) with a given N_1 indicates, as can be easily ascertained, that addition of the second component increases the radiation intensity of the first component in the cases of a slow V−V' exchange, a low emissivity of component 2 molecules, or a fast excitation of vibrations of component 1 molecules by component 2 molecules. In these cases addition of component 2 results first of all in a faster V−T relaxation in component 1, owing to an increase of the gas density, while transfer of vibrational energy from this component to molecules of component 2 and its subsequent luminescence play a relatively minor role so that the additional energy entering the vibrational degrees of freedom of component 1 molecules from its translational and rotational degrees of freedom is radiated out by molecules of this component.

We will now consider the special case where only one of the two diatomic gases, say gas 1, radiates and $A_2 = k_{\nu 2} = 0$. Then $\tau_2^* = \tau_2$, $\lambda_1 = 2\varkappa_1\sqrt{\alpha_1}$, $\lambda_2 = 0$ and relations (12) for the coefficients C_{ik} lead to the indeterminacy 0/0. This can be easily explained, if one considers that the last term in Eq. (2) vanishes when $k_{\nu 2} = 0$ and that this reduces the order of the system of Eqs. (17). As a consequence, one of the boundary conditions (10) (at $i = 2$) from which the coefficients C_{ik} are determined becomes simple corollaries of the fundamental system of equations. Instead of this boundary condition, therefore, it becomes necessary to use the equation

$$\frac{\varepsilon_2}{\tau_2} - \frac{\varepsilon_1}{\tau_{21}} - \frac{\varepsilon_2^0}{\tau_{20}} = 0, \tag{21}$$

which follows from Eq. (2). As a result, one can obtain $C_{i2} = 0$ and

$$C_{i1} = \frac{A_1\varepsilon_1^0}{8\varkappa_1^2\alpha_1\alpha_2}\left\{\left(\frac{1}{\tau_1} - \frac{1}{\tau_{12}}\right)\left[I_0(z^*) + \sqrt{\frac{\alpha_2}{\alpha_1}}\,I_1(z^*)\right]\right\}^{-1}, \tag{22}$$

where $z^* = 2\varkappa_1 R\sqrt{\alpha_2/\alpha_1}$. Then calculating ε_1 according to expression (11), we obtain

$$\varepsilon_1(r) = \varepsilon_1^0\left[1 - \left(1 - \frac{\alpha_2}{\alpha_1}\right)\frac{I_0\left(2\varkappa_1 r\sqrt{\frac{\alpha_2}{\alpha_1}}\right)}{I_0(z^*) + \sqrt{\frac{\alpha_2}{\alpha_1}}\,I_1(z^*)}\right], \tag{23}$$

while $\varepsilon_2(r)$ is calculated according to Eq. (21). The form of expression (23) is analogous to that of the $\varepsilon(r)$ relation for a one-component diatomic gas [4], but the coefficients in expression (23) account for the change in the rate of V−T relaxation in component 1 due to addition of component 2, for V−T relaxation in component 2, and for V−V' relaxation. It can be easily demonstrated that in the presence of a nonradiating component 2 the magnitude of $\varepsilon_1(r)$ at any r will exceed the corresponding magnitude attained in a one-component gas and that, moreover, $\varepsilon_1(r)$ will increase as N_2 increases (with N_1 = const).

In another special case, where V−V' exchange occurs much slower than V−T relaxation and vibrations are radiatively deactivated, expressions (11) and (12) for ε_i yield relations analogous to relation (23) with $\varkappa_i$ replacing $\varkappa_1$ and $1 + A_i\tau_i$ replacing the ratio α_1/α_2 (τ_i depending on the concentrations of both components).

It is noteworthy that the expressions obtained here for ε_i, U_i, $\mathbf{S}_i$, and $\mathbf{S}_{\nu i}$ retain their form also in the case of a mixture of gases containing alongside two radiating components also monatomic gases (He, Ar) or nonradiating diatomic gases (N_2, O_2, etc.). For the latter case, however, in the expressions for C_{ik} and Q_{ik} there appear additional terms which account for exchange of vibrational energy between radiating and nonradiating components.

NOTATION

t, time; T, temperature of translational and rotational degrees of freedom of molecules; T_{vi}, vibrational temperature (i = 1, 2 denotes the component number); N_i, concentration of respective molecules; ν_{0i}, frequency of vibrations; $\Delta\nu_i$, effective width of the respective vibrational−rotational band; ε_i and ε_i^0, mean number of vibrational quanta in a molecule and their mean number at equilibrium; $\theta_i = h\nu_{0i}/kT$; $k_{\nu i}$, respective absorption coefficient; $\varkappa_i$, respective effective band absorption coefficient; U_ν, $U_{\nu i}^*$, and $U_{\nu i}^0$, spectral density of radiation energy and its equilibrium values at temperatures T_{vi} and T, respectively; $\mathbf{S}_\nu$, spectral density of the radiation flux; U_i and U_i^0, integral density of radiation energy within the i-th band and its equilibrium value; $\mathbf{S}_i$, integral spectral density of the radiation flux in the respective band; τ_i^0, time of V− T relaxation; τ_i, τ_{ij}, τ_i^*, τ_{i0}, and A_i^{-1}, time parameters characterizing respectively the rate of relaxation, the rate of vibrational-energy exchange, and the rate of radiative deactivation; ZN_i, number of collisions between molecules of component j and molecules of component i per unit time; Q, probability of a quantum of vibrational-energy exchange; P_{ij}, a quantity proportional to the probability of one-quantum deactivation of a vibrationally excited molecule i upon collision with molecule j; λ_k, roots of the characteristic equation; I_n, modified Bessel function of order n; R, radius of a cylinder; r, radial coordinate; **n**, unit vector normal outward to the surface bounding the gas volume; and c, velocity of light.

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PIEZOELECTRIC PULSE TRANSDUCER WITH MATCHED AMPLIFIER FOR MEASUREMENT OF FAST VARYING PRESSURE

V. I. Zagorel'skii, N. N. Stolovich,
and N. A. Fomin

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A piezoelectric transducer with an electronic matching circuit has been built and tested for measuring the pressure behind a shock wave with a high time resolution. Here its construction is described and the test results are reported.

Intensive studies of shock waves have in recent years been stimulated by a tremendous interest in shock wave dynamics in liquids and gases as well as in hypersonic gasdynamics, high-temperature thermophysics, chemical kinetics, and magnetohydrodynamics. Many studies have dealt with the measurement of absolute pressure and of pressure variation profiles behind a shock wave. In most of those studies the authors used pressure gauges which they themselves had built. For such measurements one widely uses transducers where an electric signal is produced by deformation of an elastic element like a piezoceramic one [1-10]. Piezoelectric pressure transducers are wideband devices (with a high time resolution), inasmuch as deformations of a few microns are sufficient for polarizing the piezoelectric cell and, consequently, its inertia is not involved with large displacements of the center of mass but determined by the time in which its steady state of strain is reached.

These authors have developed and tested a pressure pulse transducer with a matching amplifier which ensures a microsecond time resolution in measurements of fast varying pressures. The piezoelectric transducer includes a matched acoustic absorbing rod (waveguide), as has been proposed [1-3], for eliminating the effect of the shock wave reflected by the faces of the piezoceramic cell. This transducer and the matching amplifier are simple in construction and ensure a high time resolution.

The construction of the pressure gauge is shown schematically in Fig. 1. Cylindrical specimens of grade TsTS-19 lead zirconate-titanate, 4 mm in diameter and 1 mm in wall thickness, were used here. One face of the piezoceramic cell 2 is soldered with Wood metal to the cylindrical zinc waveguide 3 and the other face is fastened with a thin conductor 8 to the brass case 1. With the aid of a rubber gasket 4 and a nut 5, waveguide 3 together with the piezoceramic cell 2 already soldered on and with conductors 6, 8 is inserted into and centered in the case. The clearance space inside the case is filled with beeswax so that vibrations of the case will not be recorded by the instrument. In order to minimize electric pickup, no window has been provided for soldering the conductor 6 to the coaxial connector 7. Conductor 6 is grade LÉShO enamelled single-silk 7 × 0.07mm Lietz wire.

A. V. Lykov Institute of Heat and Mass Transfer, Academy of Sciences of the Belorussian SSR, Minsk.
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