T_1 is the initial gas temperature, m_a is the mass of the atom, n_e and n_a are respectively the electron and atom densities per cm^3, $\xi = n_e/(n_a + n_e)$ is the degree of ionization, J is the ionization potential, and T_a is the atomic temperature, with

$$T_a = T_1\left\{1 - \xi\left(\frac{T_e}{T_1}\right) - \frac{2}{5}\xi\left(\frac{J}{kT_1}\right) + \frac{M^2}{3}\left[1 - \left(\frac{\rho_1}{\rho_2}\right)^2\right]\right\}, \quad (8)$$

where M is the Mach number of the shock wave.

In the general case the derivative $(dn_e/dt)_i$ in Eq. (7) is determined by the aggregate of the collision and radiative excitation and deactivation processes, ionization, and recombination. In an exact determination of the ionization rate it is necessary to consider the system of kinetic equations that determine the populations of all the levels of the atom. However, an analysis carried out by Bates et al.[11] has shown that the populations of the upper excited states reach quasi-equilibrium values very rapidly, so it can be assumed that at any point behind the front of the shock wave the populations of the excited states are connected with the electron density by a modified Saha equation. We shall assume that this holds true for all the excited levels down to the first excited one. At the same time, the population of the ground state will differ from the equilibrium population corresponding to the electron temperature. Thus, the relative population of the ground and first-excited levels will differ from the Boltzmann value.

We note also that the absolute magnitudes of the populations of the excited levels for inert gases are very small, so that it can be assumed that the rate of change of the population of the ground state is equal to the rate of change of the electron density.

Under our conditions $n_e \sim 5 \times 10^{16}$ cm^3. Therefore, in accordance with the Griem criterion[12], the contribution of the radiated transition to the value of $(dn_e/dt)_i$ can be neglected and we can confine ourselves to collision processes. Then

$$(dn_e/dt)_i = \alpha n_e n_a - \beta n_e^3, \quad (9)$$

where α and β are the constants of the ionization and recombination rates, and are connected with one another by the detailed-balancing principle

$$\alpha/\beta = K(T_e), \quad (10)$$

while

$$K(T_e) = \frac{g_+}{g_0}\frac{2(2\pi m_e kT_e)^{3/2}}{h}\exp\left(-\frac{J}{kT_e}\right)$$

is the Saha formula (the symbols here are standard). From (9) and (10) we can obtain for α the following expression:

$$\alpha = \frac{dn_e/dt}{(m_a D^2/5kT_a)n_a n_e\,[1 - n_e^2/n_a K(T_e)]}. \quad (11)$$

It should be borne in mind that the ionization rate constant determined from (11) is actually the rate constant of the excitation from the ground state in electron-atom collisions, since it is precisely this process which determines the ionization rate. Approximating, as usual, the dependence of the excitation cross section of the level E* on the electron energy near the threshold of excitation, by the straight line $\sigma = C_e(E - E^*)$, we can obtain the following expression for the effective excita-

tion cross section C_e, corresponding to an electron energy exceeding E* by 1 eV:

$$C_e = \frac{5kT_a}{2m_a D^2}\sqrt{\frac{\pi m_e}{2kT_e}}\frac{\exp(E^*/kT_e)}{(E^* + 2kT_e)[1 - n_e^2/n_a K(T_c)]n_a n_e}\frac{dn_e}{dt}. \quad (12)$$

From this relation we can determine C_e, if E* is known. The value of E* can be determined experimentally from our data, if the plot of $\ln(\alpha/T_e^{3/2})$ against $1/T_e$ is constructed for a sufficiently wide temperature interval.

It should be noted that the quantity dn_e/dt in formulas (7), (9), (11), and (12) is defined in a system connected with a particle, whereas experiment yields the derivative dn_e/dt_L in the laboratory frame, with dt $= (\rho_2/\rho_1)di_L$.

4. RESULTS AND THEIR DISCUSSION

The experiments were performed at an initial xenon pressure of 3 mm Hg. The results of the experiments are shown in Fig. 2 for the two most characteristic regimes, with M equal to 11.2 and 12.7. The time intervals between the margins on the oscillograms are 67 μsec of laboratory time. The method described above was used to determine from these oscillograms the profiles of the electronic and atomic temperatures and the distribution of the electron density in the shock waves. The atomic temperature was determined from formula (8). The results of such a reduction are shown in Figs. 3 and 4. It is easy to see that the atomic temperature decreases quite sharply in the ionization process, while the electronic temperature increases insignificantly, approaching the atomic temperature in the equilibrium region. This is in agreement with the theoretical calculations of[7], where it is indicated that the electron temperature in a xenon plasma behind the front of the shock wave is equal to the equilibrium atomic temperature. It follows from Fig. 3 that actually at M < 12.7 the electron temperature is practically always equal to the equilibrium atomic temperature. With increasing intensity of the shock waves, the changes of the temperatures T_e and T_a increase. After the equilibrium state of the gas is reached, its temperature (now $T_e = T_a$) begins to decrease, owing to the cooling of the plasma as a result of radiation losses. This cooling reaches its largest value at M = 12.7, where the temperature of the plasma drops by 600°K within 50 μsec of laboratory time. We note that at M = 11.2, during the same time interval, the plasma cools only by 200°K.

The distribution of the electron density in the shock
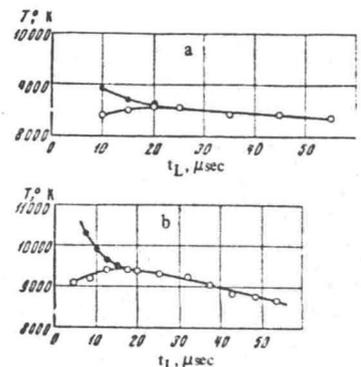
FIG. 3. Distribution of the electronic temperature T_e(●) and of the atomic temperature T_a(○) behind the front of a shock wave in xenon. $p_1 = 3$ mm Hg (laboratory time); a—M = 11.2, b—M = 12.7.