

Zhang *et al.* Reply: In our Letter [1] the evolution of the shape of an initially isotropic nonequilibrium energy distribution function (DF) is investigated experimentally and theoretically for actual atomic gases. We solved the linear Boltzmann equation (LBE) and determined the evolution of DF of energetic atoms and the average translational energy (ATE), $\langle E(t) \rangle$. In the preceding Comment [2], Shizgal fitted ATE using the long-time asymptotic expansion, and concluded that the two-stage relaxation reported in [1] does not exist. Our statement, that the long-range interaction produces a two-stage relaxation both in the Lorentz and Rayleigh gases, contrary to the hard sphere model where the preservation of the Maxwellian DF occurs only for the Rayleigh gas, was misrepresented in [2].

The shape relaxation of a DF is essential in thermalization. The time-dependent DF is obtained by propagating the LBE [1] or, equivalently, from the *discrete* and *continuous* eigenspectrum of the collision operator L . The exact expansion may be truncated to the first term $f(v, t) \approx f_m(v, T_b) + a_1 e^{-\lambda_1 t} \phi_1(v)$ only when the system is *close to equilibrium* [3]. It requires a sufficient separation of the smallest nonzero eigenvalue λ_1 from the others and a long enough time, $\theta = t(\lambda_2 - \lambda_1) \gg 1$, so that the single exponential decay dominates. In our study only one of nine experimental points was measured after 400 ns at which $\theta \approx 0.96$. Truncation to the first term, as in [2], is not valid. An additional approximation that the DF is Maxwellian at all times was introduced in [2]. With these assumptions, Shizgal fitted the nine experimental points with a single exponential function. There are significant deviations in the first two points from the experimental data, indicating a nonsingle exponential decay. The initial DF influences the ATE evolution as shown in the example of electron thermalization [4]. The explicit expression of the non-Maxwellian initial DF in our experiments was given in Ref. [5]. Further evidence of nonsingle exponential decay can be found in [2]: the energy relaxation time, $k_E^{-1}(t)$, is time-dependent, varying from 123 to 231 ns. The ATE variation cannot always define a relaxation time scale: the relaxation of ATE and of the shape of the DF are not uniquely connected [6]. An instructive example is the relaxation of an initial monoenergetic ensemble of particles with energy of $3/2kT_b$, for which the shape of the DF relaxes to Maxwellian with little variation in the ATE.

The total relaxation time τ in [1] was defined as the time required for the initial energy to relax to the value that is within 1% to thermal energy. It is commonly used in electron thermalization [4]. τ is an order of magnitude longer than the time τ_g of the formation of a Maxwellian-like DF. At 600, 1200, and 2000 ns, the ATEs for N atoms ($E(0) = 0.93$ eV) thermalized in the He bath gas are 3.32, 1.71, and 1.53 in units of kT_b , consistent with the limiting theoretical value of the order of 3000 ns.

For the determination of the short time τ_g , the shape of the calculated DF was numerically compared using a least square procedure with an exact Maxwellian characterized

by an effective temperature $T_{\text{eff}}(t) = \frac{2}{3} \langle E(t) \rangle / k$ and also compared with the experimental Doppler profiles (DPs). The theoretical DP at relaxation times $t > \tau_g$ is Gaussian (see Fig. 8 of [5]). The close agreement of the DPs from theory and from experiments confirms the two-stage relaxation. The strong forward scattering modifies significantly the kernel of the LBE (see Fig. 5 of [5]) and established the necessary conditions for the formation and preservation of a Maxwellian-like DF. Fitting of the limited data on ATE decay carried out in [2] does not allow the details of the shape relaxation of the DF to be determined, or specifically, the fast stage of the formation of a Maxwellian-like DF to be recognized.

The relaxation of a gas with an interaction potential $V(r)$ varying as r^{-4} is discussed in [2]. The analytical solution to the asymptotic form of the LBE, the Fokker-Planck equation, confirms the fast formation and preservation of a Maxwellian-like DF [7]. This is consistent with the two-stage relaxation mechanism we reported. The nonsingle exponential decay of the electron energy at early relaxation times and the strong dependence on the initial DF were directly demonstrated in [4], and they contradict the single exponential decay asserted in [2]. The Comment does not consider the shape relaxation investigated in our experimental and theoretical research. Although the evolution of the DF determines the development of the ATE, it is not possible to infer the DF shape evolution from the relaxation of the ATE.

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