KINETIC COEFFICIENTS OF A MULTICOMPONENT NONISOTHERMAL PLASMA

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The effect of polarization on the kinetic coefficients in a two-component completely-ionized nonisothermal plasma was considered in [1-4]. The "corrections" obtained in [1] to the Coulomb logarithm in the viscosity and thermal conductivity coefficients are of the order

$$\frac{T_e}{T_i}\frac{1}{2}\left|\frac{e_i}{e}\right|\left[\ln\frac{e_i^2 m_i T_e^3}{e^2 m_e T_i^3}\right]^{-1} \tag{1}$$

and are much greater than the corresponding correction to the Coulomb logarithm in the coefficient of friction for electrons and ions which is of order

$$\frac{T_e}{T_i}\left[\ln\frac{e_i^2 m_i T_e^3}{e^2 m_e T_i^3}\right]^{-2}. \tag{2}$$

Correction (1) results from the interaction of electrons with ion-sound oscillations in a nonisothermal plasma; these oscillations have phase velocities less than the electron thermal velocity v_{Te} and greater than the ion thermal velocity v_{Ti}, whereas correction (2) is due to electron and ion interaction with the same sound oscillations; in this case, the number of "resonant" ions with velocities greater than v_{Ti} is small. This also explains the presence of the higher power of the logarithm in the denominator of (2).

In the considered case of a three-component nonisothermal plasma with two types of ions i and I and with conditions

$$v_{Te} \gg v_{Ti} \gg v_{TI}, \qquad r_{DI}^{-2} \gg r_{De}^{-2} + r_{Di}^{-2}, \tag{3}$$

there exist sound waves with phase velocities $v_{Ti} \ll v(k) \ll v_{Ti}$ and spectrum:

$$v(k) \equiv \frac{\omega(k)}{k} = \left(\frac{\omega_{LI}^2}{r_{De}^{-2}+r_{Di}^{-2}}\right)^{1/2}\left(1+\frac{k^2}{r_{De}^{-2}+r_{Di}^{-2}}\right)^{-1/2}; \tag{4}$$

$$\gamma(k) = \frac{\sqrt{\pi}}{2}\omega(k)\frac{v^3(k)}{\omega_{LI}^2}\left\{\frac{1}{v_{Te} r_{De}^2} + \right.$$

$$\left. + \frac{1}{v_{Ti} r_{Di}^2} + \frac{1}{v_{TI} r_{DI}^2}\exp\left[-\frac{v^2(k)}{v_{TI}^2}\right]\right\}; \tag{5}$$

$$v_{T\alpha}^2 = \frac{2T_\alpha}{m_\alpha}, \quad r_{D\alpha}^2 = \frac{T_\alpha}{4\pi n_\alpha e_\alpha^2}, \quad \omega_{L\alpha}^2 = \frac{4\pi n_\alpha e_\alpha^2}{m_\alpha}$$

From (3) and (5) it is not difficult to see that when

$$\frac{v_{Ti}^2}{v_{TI}^2}, \quad \frac{r_{DI}^{-2}}{r_{De}^{-2}+r_{Di}^{-2}} \gg \ln X \gg 1,$$

$$X = \frac{1/v_{TI} r_{DI}^2}{1/v_{Te} r_{De}^2 + 1/v_{Ti} r_{Di}^2}, \tag{6}$$

attenuation, i.e., particle interaction with waves, is determined by electrons and "fast" ions for wave phase velocities $v_{Ti} \gg v(k) > v_{TI}\ln^{1/2} X$ here the number of such resonant ions with velocities $|v| < v_{Ti}$ is a significant quantity. Allowance for such interaction leads to the following expression for the friction forces R_{ei} of electrons and fast ions:

$$\mathbf{R}_{ei} = -n_e m_e(\mathbf{u}_e - \mathbf{u}_i)\frac{4\sqrt{2\pi}e^2 e_i^2 n_i}{3 m_e^{1/2} T_e^{3/2}}\left\{\ln\frac{r_D}{r_{min}} + \right.$$

$$+ \frac{1}{4}\frac{1}{1+\theta^{-1}}\frac{r_{Di}^2}{r_{DI}^2}\left(1+\frac{1}{1+\theta}\frac{T_e-T_i}{T_i}\right)\frac{1}{\ln X} +$$

$$\left. + \frac{1}{4\ln^2\theta}\left(1+\frac{\omega_{LI}^2}{\omega_{Li}^2}\right)\frac{T_e}{T_i}\right\} +$$

$$+ n_e m_e(\mathbf{u}_i - \mathbf{u}_I)\frac{4\sqrt{2\pi}e^2 e_I^2 n_I}{3 m_e^{1/2} T_e^{3/2}}\left\{\frac{1}{4}\frac{1}{1+\theta^{-1}}\frac{T_e-T_i}{T_I}\frac{1}{\ln^2 X}\right\},$$

$$\theta = \frac{v_{Te} r_{De}^2}{r_{Ti} r_{Di}^2}. \tag{7}$$

Here X is given by (6).

As in (2), the correction, which is on the order of the square of the logarithm in the denominator, is only important [1,2] when $\theta \gg 1$, $T_e/T_i > 10^3$. The second term in the friction force R_{ei}, which is proportional to $u_i - u_I$, is due to particle interaction with sound waves of spectrum (4) and (5), where the corresponding "cross" terms, which have order $\ln^2 X$ in the denominators, also appear in the friction forces R_{ei} and R_{iI}.

Of greatest interest is the reciprocal of the logarithmic correction in (7) which, when isothermal conditions do not prevail and $T_e/T_i \gtrsim 5$ and $T_i/T_I \geqslant 10$ can exceed the Coulomb logarithm. Using (7) for the static conductivity we have

$$\sigma = \frac{n_e e^2}{m_e \nu},$$

$$\nu = \frac{4\sqrt{2\pi}e^2(e_i^2 n_i + e_I^2 n_I)}{3 m_e^{1/2} T_e^{3/2}}\left\{\ln\frac{r_D}{r_{min}} + \right.$$

$$\left. + \frac{e_I^2 n_I}{e_i^2 n_i + e_I^2 n_I}\frac{1}{4}\frac{1}{1+\theta^{-1}}\frac{T_i}{T_I}\left(1+\frac{1}{1+\theta}\frac{T_e-T_i}{T_i}\right)\frac{1}{\ln X}\right\}, \tag{8}$$

in which we ignore terms on the order of the square of the logarithm in the denominator.

From (8) it is not difficult to see that when isothermal conditions do not hold ($T_e/T_i \gg 10^2$) and fast ions have a low density $n_i/n_e \sim (m_e^{1/2} T_i^{3/2}/m_i^{1/2} T_e^{3/2})$, the conductivity in a three-component plasma can be completely determined not by particle collisions but by the "exchange" of sound waves with spectrum (4) and (5) between e electrons and fast ions, i.e., by plasma polarization effects.

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