Electron Distribution Function In A Nonequipartition Plasma

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ELECTRON DISTRIBUTION FUNCTION IN A NONEQUIPARTITION PLASMA

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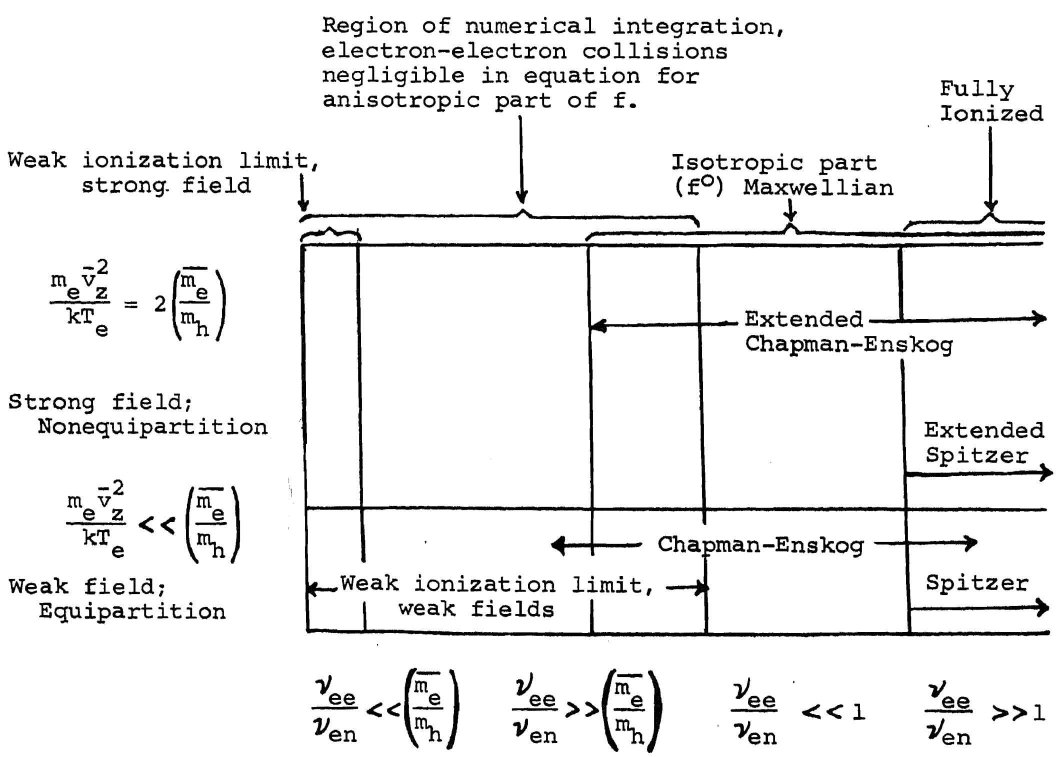
Abstract

The accurate prediction of the electron temperature, electrical conductivity, and other properties in a partially ionized nonequipartition plasma rests on a knowledge of the electron distribution function. Of particular interest are the conditions under which departures occur from a Maxwellian form for the isotropic part f^o of the distribution. To this end the electron Boltzmann equation has been formulated for a spatially uniform, steady-state plasma in a strong electric field, employing an expansion in spherical harmonics and the simplifications consistent with the small electron mass. Boltzmann collision operators were used for electron-neutral and electron-ion collisions, and the Fokker-Planck operator for electron-lectron encounters. The heavy-particle .stribution functions were assumed to : Maxwellian at the temperature T_h.

The conditions studied and qualitative ɜsults can be discussed in terms of the ɔllowing diagram:

Here the ordinate, the square of the ratio of the electron drift velocity $\bar{v}_z$ to the mean electron thermal speed, is approximately equal to the ratio of the average energy gained by an electron between collisions in an electric field to the electron thermal energy. Hence the ordinate is a measure of the strength of the electric field. The abscissa is the ratio of the electron-electron collision frequency to the total electron-neutral collision frequency and is a measure of the degree of ionization. The upper limit on the diagram corresponds to the static instability referred to by Kerrebrock.[1]

Values of the ordinate very much less than the mean electron-to-heavy-particle mass ratio $(\overline{m_e/m_h})$ correspond to weak electric fields and thus to equal electron and heavy particle temperatures. In this region, the electrical conductivity σ can be calculated accurately by means of the Chapman-Enskog expansion.



Spitzer and Härm's[2] results for fully ionized plasmas apply when $\nu_{ee}/\nu_{en} >> 1$, the weak ionization (Lorentz) limit occurs when $\nu_{ee}/\nu_{en} << 1$.

In the nonequipartition case, when $\overline{v_z^2} \Big/ \frac{kT_e}{m_e} \not\ll (\overline{m_e/m_h})$, the electron temperature $T_e \equiv m_e \overline{v^2}/3k$ can be found from the expression

$$\frac{j_z^2}{\sigma} = \int_0^\infty m_e v^2 \left(\sum_h \frac{m_e}{m_h} n_h Q_{Mh} v \right) \left[f^o + \frac{T_h}{T_e} \left(\frac{kT_e}{m_e v} \frac{df^o}{dv} \right) \right] 4\pi v^2 dv$$

where $Q_{Mh}(v)$ is the cross section for momentum transfer between electrons and the heavy species h, n_h the number density of species h, and j the current density.

It can be shown from an analysis of the kinetic equations that whenever $\nu_{ee}/\nu_{en} >> (m_e/m_h)$, the isotropic part of the distribution function is Maxwellian, although at an elevated temperature. When this holds the equation for the anisotropic part of the distribution function becomes independent of the heavy-particle temperature. In this limit the Chapman-Enskog solution for the electrical conductivity can be accurately extended to nonequipartition plasmas. That is, in the fully ionized limit Spitzer and Härm's results apply with the electron temperature replacing the gas temperature. Between $\nu_{ee}/\nu_{en} >> (m_e/m_h)$ and the fully ionized limit the results of Schweitzer and Mitchner,[3] which compare the mixture rule of Frost to the Chapman-Enskog solution, can be extended to the strong-field region by the use of T_e in place of T_h.

The transition between the weak-ionization (Lorentz) and Maxwellian forms for f^o has been studied by numerical integration of the kinetic equations in the region $\nu_{ee}/\nu_{en} << 1$. As indicated in the diagram, this region overlaps the region where f^o is Maxwellian. Accordingly, it has been possible to demonstrate numerically the transition to an elevated-temperature Maxwellian. When $\nu_{ee}/\nu_{en} << 1$ the electron-electron collision terms can be neglected in the equation for the anisotropic part of the distribution function and the electrical conductivity is given by

$$\sigma = \frac{4\pi e^2}{3m_e} \int_0^\infty \frac{v^2}{\sum_h n_h Q_{Mh}} \left(\frac{-df^o}{dv} \right) dv$$

Here, in general, f^o must be obtained numerically. It has been found, however, that accurate values for σ can be obtained from this equation by the use of a Maxwellian f^o based on the actual electron temperature from the numerical solution.

Calculated electrical conductivities have been compared with the experimental results of Kerrebrock and Hoffman[4] and Cool and Zukoski,[5] with good agreement. Under the conditions of these experiments, no significant departures from a Maxwellian f^o are predicted by the numerical solutions.

Results from the numerical evaluation of f^o show in some cases an interesting depression of the high energy "tail" of the distribution function in an argon plasma, resulting from the Ramsauer minimum in the noble-gas cross section and the energy variation of the electron-electron cross section. The effect of non-elastic collisions on this depression of the tail of the distribution function is presently under investigation.

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