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Collisional Radiative Forces in Fully-Ionized Plasmas

A. Tahraoui, A. Bendib and K. Bendib
Laboratoire d'Electronique Quantique, Faculté de Physique, USTHB, El Alia BP 32,
Bab Ezzouar 16111, Algiers, Algeria
G. Matthieussent
LPGP, URA 73, CNRS, Université Paris XI, 91405 Orsay Cedex, France

I. Introduction

The transport coefficients can be used as closure relations for the fluid equations resulting in a model, which is equivalent to the kinetic description. In laser-heated-plasmas, these fluid equations are particularly useful to study the parametric instabilities, which can constitute a major problem for inertial confinement fusion. Since, if the laser beam smoothing techniques open efficient ways for control the fluctuations, the high intensity laser speckles could be also a source of potentially enhanced level of these fluctuations. For a complete description of the heated plasmas, the effects of the laser field have to be included into the transport coefficients, in addition to the usual temperature gradient terms. The contribution of the high-electric field can be taken into account through two mechanisms: the inverse bremsstarhlung heating (IBH) and the ponderomotive effects. This paper deals with such contributions to the transport coefficients by taking into account the electron-electron interactions up to the second anisotropy.

II. Equations of the model

The basic equation of our model is the electron Fokker-Planck equation that includes both ponderomotive and inverse bremsstrahlung heating contributions. In planar geometry (the inhomogeneity is along the x-axis) and steady-state approximation, its expression in the rest frame of ions reads,

$$\mathrm{v}_x \frac{\partial}{\partial x} f - \frac{e}{m} E \frac{\partial f}{\partial \mathrm{v}_x} = C_{ee}(f) + C_{ei}(f) + C_{IBH}(f) + C_{pond}(f), \qquad (1)$$

where in the right hand side of Eq. (1), the respective terms are the Landau electron-electron collision operator[1], the electron-ion collision operator[1], the heating term[2,3] due to the IBH and the last term accounts for the ponderomotive effects[2,3]. The other variables have their usual meaning. We assume that the magnitude of the electric field and the gradients in the plasma is weak and therefore the plasma can be modelled by a global equilibrium defined by a Maxwellian $f_M(\mathrm{v},n,T)$ and a perturbed state defined by the distribution function $\delta f << f_M$. Furthermore, if we assume that the perturbed quantities have a spatial harmonic dependence $\delta X \sim \exp(ikx)$ and if we expand the distribution function on the Legendre polynomials basis, $\delta f(\vec{\mathrm{v}}) = \sum_{n=0}^{\infty} P_n(\mu)\delta f_n(\mathrm{v})$, Eq. (1) becomes

$$ik\frac{\mathrm{v}}{\sqrt{3}}\delta f_1 = C_{ee}^0(\delta f_0, f_M) + C_{ee}^0(f_M, \delta f_0) + C_{IBH}^0(\delta f_0) \tag{2}$$

$$\frac{1}{\sqrt{3}}ik\mathrm{v}\,\delta f_0 + ik\mathrm{v}\frac{2}{\sqrt{15}}\delta f_2 - \frac{1}{\sqrt{3}}\frac{e}{m}\delta E\frac{\partial f_M}{\partial \mathrm{v}} = C_{ei}(\delta f_1) + C_{ee}^1(f_M, \delta f_1) + C_{pond}(\delta f_1) \tag{3}$$

$$\frac{2}{\sqrt{15}}ik\mathrm{v}\,\delta f_1 = C_{ei}(\delta f_2) + C_{IBH}^2(\delta f_2) \tag{4}$$

where $\delta \mathrm{v}_0 = \left| e\delta E_0 / m\omega_0 \right|$, is the quiver velocity in the laser field and δE_0 is the amplitude of the electric field with a frequency ω_0. Equations (2)-(4) constitute the basic equations of this work. They correspond, to three integro-differential equations, which describe the evolution of δf_0, δf_1 and δf_2 in the velocity space. These equations, obviously, do not admit analytic solutions and they have to be solved numerically.

III. Numerical solution and transport coefficients

Equations (2)-(4) have been solved numerically with a method which involves a finite difference representation. By finite differencing these equations in velocity space, it results a matrix equation, which is solved by standard numerical techniques.

The heat flux and the force due to the laser electric field are deduced in current free plasmas. The semicollisional results with respect to the collisionality parameter $k\lambda_{ei}$ have being already reported in Refs 2 and 3, we present in this work the collisional values of the transport coefficients with respect to the atomic number Z, in order to display the effects of the electron-electron collisions.

We give in Fig. 1 the normalized conductivity $\xi_q^{coll} = \delta q / \left(ik\lambda_{ei} mn \mathrm{v}_t (\delta \mathrm{v}_0)^2 \right)$ as a function of the atomic number Z, where δq is the heat flux. The comparison of the present model (*pm*) result with the one derived in Ref. 3 for high *Z*, [the electron-electron collisions are kept only in Eq. (2)] has shown an important discrepancy, since for $Z=8$, $\xi_q^{pm} \approx 0.67 \xi_q^{BBTR}$. For practical purposes, we have calculated a numerical fit with a precision of 5% valid for arbitrary atomic number, $\xi_q^{coll} = \dfrac{69.62 Z^2}{Z+4.76}$.

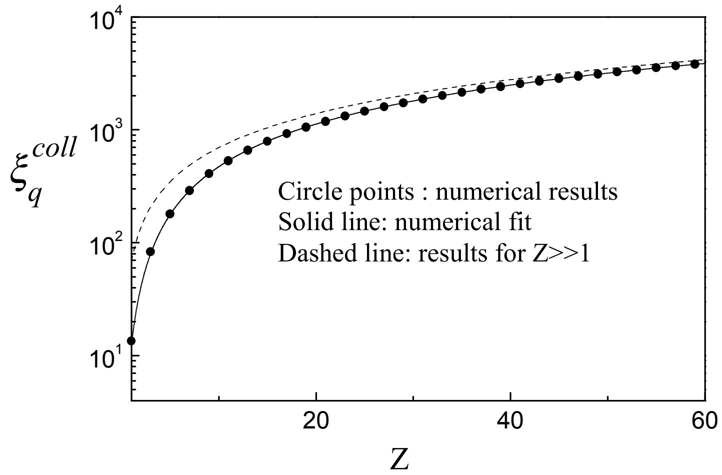

Fig. 1

Normalized collisional conductivity ξ_q^{coll} due to the laser electric field as a function of the atomic number Z.

In Fig. 2, we have also represented the normalized radiative force $\xi_F^{coll} = \delta F / \left(-ikmn (\delta \mathrm{v}_0)^2 \right)$. For $Z \gg 1$, the classical value[2,3] $\xi_F^{coll} = 16/45$ is recovered and we note that the disagreement with respect to the asymptotic value is significant only for very low Z-values. A simple numerical fit of this force (with a precision better than 5%) is also proposed and its expression is given by $\xi_F^{coll} = \dfrac{16}{45} Z / (Z + 0.66)$.

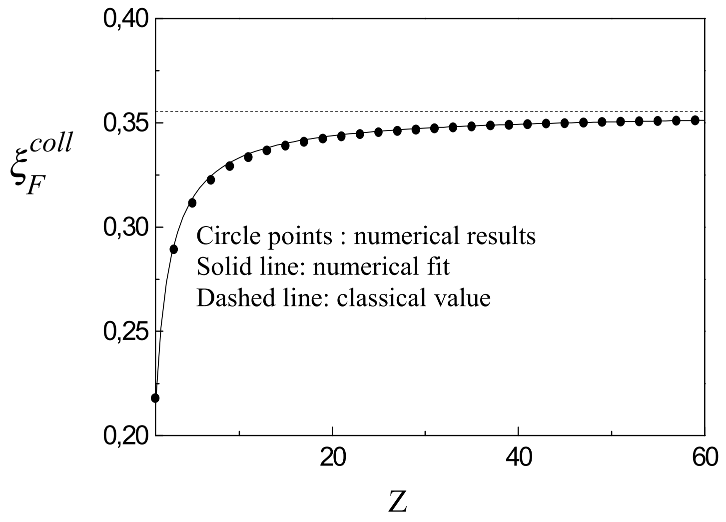

Fig. 2

Normalized collisional radiative force ξ_F^{coll} due to the laser electric field as a function of the atomic number Z.

IV. Summary

In this work we have presented the numerical computation of the linear Fokker-Planck equation to calculating transport coefficients for arbitrary atomic numbers Z. Our results improve all previous calculations performed only for $Z>>1$. Simple numerical fits for the conductivity and the radiative force with a precision better than 5% are proposed.

V. Acknowledgments

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VI. References

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