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CHARGED - PARTICLE STOPPING IN A CLASSICAL ELECTRON GAS

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Phenomena related to the interaction between beams of charged particles with condensed matter and plasmas have been widely studied using different methods of diagnostics. In addition, beams of heavy fast ions are considered as a perspective driver for the inertial fusion.

The plasma polarizational stopping power of heavy ions projectiles is described by the Lindhard formula /1/:

$$\left[-\frac{dE}{dx}\right]^{pol} = \frac{2(Z_p e)^2}{\pi\, v^2}\int_0^{\infty}\frac{dk}{k}\int_0^{kv}\omega^2\left(-\mathrm{Im}\frac{\varepsilon^{-1}(k,\omega)}{\omega}\right)d\omega, \qquad (1)$$

whose high-velocity asymptotic form was found by Bohr, Bethe, and Larkin /2-4/:

$$\left[-\frac{dE}{dx}\right]^{pol}_{v\to\infty} \cong \left(\frac{Z_p e\omega_p}{v}\right)^2 \mathrm{Ln}\,\frac{2m_e\, v^2}{\hbar\omega_p}. \qquad (2)$$

This expression is usually employed to diagnose the plasma /5,6/.
The plasma inverse dielectric function (IDF), $\varepsilon^{-1}(k,\omega)$, was determined in /7/ within the moment approach /8/ complemented by some physical observations which permitted to express it in terms of only two characteristic frequencies, which are the ratios of the frequency power moments of the IDF imaginary part:

$$\varepsilon^{-1}(k,\omega) = 1 + \frac{\omega_p^2(\sqrt{2}\,\omega_1\omega + i\omega_2^2)}{\sqrt{2}\omega_1\omega(\omega^2-\omega_2^2) + i\omega_2^2(\omega^2-\omega_1^2)}. \qquad (3)$$

The frequencies ω_1 and ω_2 in (3) can be calculated rigorously as soon as we know the static structure factor (SSF) of the system /7, 8/. Here we employ the following interpolation expressions /9, 10/:

$$\omega_1^2 = \omega_1^2(k) = \omega_p^2\left(1 + k^2k_D^{-2} + k^4k_q^{-4}\right), \qquad (4)$$

$$\omega_2^2 = \omega_2^2(k) = \omega_p^2\left(1 + \frac{\langle v_e^2\rangle k^2}{\omega_p^2} - \frac{v_{int}^2 k^2}{\omega_p^2}\right). \qquad (5)$$

The interpolation and fitting parameters introduced here are the following:

$$v_{int}^2 = -\frac{4}{15}\frac{\Gamma^{\frac{3}{2}}}{\beta m_e}\left(\frac{-0.9052}{\sqrt{0.6322+\Gamma}} + \frac{0.27243}{1+\Gamma}\right),$$

and k_D^{-1} is the Debye radius, $\Gamma = \frac{\beta e^2}{a}$, $k_q^4\, l^4 = 12 r_s \Gamma^4$, $r_S = \frac{a}{a_B}$, $l = e^2\beta$ is the Landau length, a and a_B are the Wigner-Seitz and Bohr radii, $\beta = 1/k_B T$, k_B is the Boltzmann constant, and T is the temperature. Under the thermodynamic conditions we deal with here, the system is practically a classical plasma so that all magnitudes can be expressed in terms of the plasma coupling parameter Γ, and we may use for the average electron thermal velocity the Vlasov classical form: $\langle v_e^2\rangle = k_B T/m_e$.

We have compared the polarizational losses of heavy projectiles in electron gas calculated within the simplified interpolation version of the modified method of moments /7/ to the results of the latter and to the PIC simulation data /11/ in classical systems, see Figure 1.

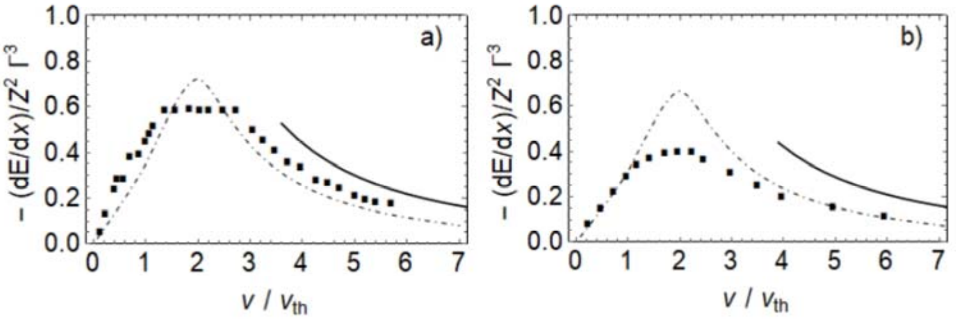

Figure 1: The stopping power (*-dE/dx*) in thermal units, i.e. divided by $3k_B T/l$, plotted vs the beam velocity $v_{\mathrm{th}} = \sqrt{k_B T/m_e}$. The dash-dotted line stands for the results of the interpolation model, the solid line represents the asymptotic form (2), the squares display the PIC simulation data /11/. The data describe an ion beam with a charge number of a) $Z = 5$ moving in an electron gas with $n = 1.1 \cdot 10^{20}\ \mathrm{cm}^{-3}$ and $T = 1.6 \cdot 10^5 K$ ($Z\Gamma^{3/2}$ =0.12), b) $n = 1.4 \cdot 10^{20}\ \mathrm{cm}^{-3}, T = 1.3 \cdot 10^5 K,\ \ Z = 10$ ($Z\Gamma^{3/2}$ =0.354).

Under the above conditions the interaction contribution |*U(q)*| to the frequency

ω_2 is at least an order of magnitude smaller than the kinetic one, $K(q)$, so that the simplified random-phase interpolation form for the frequency $\omega_1(q)$ is perfectly applicable /12/.

We observe that the suggested simplified interpolation approach based on the modified method of moments is capable of describing the energy losses of a charged particle in warm dense effectively classical electron plasmas with a fairly satisfactory precision. Notice that no adjustable parameters were used, and the interpolation-model calculation is practically algebraic. Last year the same interpolation approach was applied to describe the stopping power of two-component plasmas, and we are planning to carry out a comparative study. Our results imply the physical applicability both of the interpolation and the complete modified moment approach.

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