The stopping power and straggling of strongly coupled electron fluids revisited

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Measuring energy losses of beams of charged particles is an important diagnostic tool in both modern condensed matter and plasma physics. If single-particle effects can be neglected, the general expression for polarization losses [1] simplifies as

$$\left(\frac{dE}{dx}\right)^{pol} = \frac{2}{\pi}\left(\frac{Z_p e}{v}\right)^2 \int_0^{\infty}\frac{dk}{k}\int_0^{kv} \omega^2 L\,(k,\omega)d\omega\,.$$

Here $Z_p e$ and v are the projectile charge and velocity, while $L(k,\omega) = -\mathrm{Im}\varepsilon^{-1}(k,\omega)/\omega$ is the target plasma loss function, $\varepsilon(k,\omega)$ being the system dielectric function (DF). Another important characteristic of energy loss by the beam of projectiles is the straggling:

$$\Omega^2 = \frac{2\hbar}{\pi}\left(\frac{Z_p e}{v}\right)^2 \int_0^{\infty}\frac{dk}{k}\int_0^{kv} \frac{\omega^3 L(k,\omega)d\omega}{tanh(\beta\hbar\omega/2)}.$$

Usually the polarizational stopping power and its straggling are calculated presuming the target plasma to be an electronic fluid and the DF of the latter has been evaluated within the random-phase approximation (RPA), the T-matrix approach, the method of effective potentials, or using the Mermin or more sophisticated DF models, see [2] for the references. It has been shown recently in [2] that all these perturbative DF models, except for the local-field corrected RPA do not satisfy the interaction-related sum rules and thus cannot be applied for the calculation of the stopping power and its straggling under the conditions of strong coupling. The approach we suggest here is based on the method of moments. It is not perturbative and the only limitation is that the electron fluid is presumed to be in the liquid phase. The moments are effectively the power frequency of the loss function,

$$C_\nu(k) = \frac{1}{\pi}\int_{-\infty}^{\infty} \omega^\nu L\,(k,\omega)d\omega,\ \ \nu = 0,2,4$$

and are the sum rules. The approach permits to apply the Nevanlinna formula of the classical method of moments and to model the system DF via the Nevanlinna parameter function (NPF) $q(k,z)$ [3]:

$$\varepsilon(k,\omega) = 1 + \frac{\omega_p^2(\omega+q)}{\omega(\omega^2-\omega_2^2+\omega_p^2)+q(\omega^2-\omega_1^2+\omega_p^2)},$$

where $\omega_1^2(k) = C_2/C_0$ and $\omega_2^2(k) = C_4/C_2$ and ω_p is the plasma frequency. We model the NPF here as $q(k,\omega) = q(k,0) = i\,\omega_2^2(k)/\sqrt{2}\,\omega_1(k)$, which is justified by the specific behavior of the one-component plasma (OCP) dynamic structure factor near the zero frequency [4]. Thus the calculation of the OCP plasma stopping power and starggling is reduced to the knowledge of the system static structure factor. The latter can be either calculated within a modified or local-field corrected RPA, or computed using the MD method with an adequate effective potential [5].

The results of our calculations are to be compared to the available experimental or simulation data.

References

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