Stopping of relativistic ions in multicomponent plasmas

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Investigation of the processes of stopping of charged particles moving in different media is of significant interest for many realms of Physics, such that Nuclear Physics, Condensed Matter Physics, Plasma Physics, etc.

The problem of evaluation of energy losses of relativistic protons has acquired special importance recently [1] and, due to the experimental conditions, it is necessary to estimate relativistic corrections to the asymptotic form of energy losses in non-ideal multicomponent plasmas.

Thus, we have studied corrections to the modified asymptotic Bethe-Larkin expression for the stopping power taking into account those related to the target ions, described in [2], and different components of ions in the nonrelativistic target plasma.

The polarizational formalism, which becomes more precise for faster projectiles, has been used in the present work to calculate the energy losses of a fast particle penetrating the Coulomb system. In 1959 Lindhard obtained an expression relating the plasma polarizational stopping power to the system dielectric function, which can be generalized using the Fermi golden rule [3]:

$$-\frac{dE}{dx}=\frac{2(Ze)^2}{\pi\upsilon^2}\int_0^\infty\frac{dk}{k}\int_{\alpha_-(k)}^{\alpha_+(k)}\omega n_B(\omega)\left(-Im\varepsilon^{-1}(k,\omega)\right)d\omega,$$

$\alpha_\pm(k)=\pm k\upsilon+\hbar k^2/2M$, Ze, υ, M are the projectile charge, speed, and mass, while $n_B(\omega)=\left(1-\exp(-\beta\hbar\omega)\right)^{-1}$, where β^{-1} is the system temperature in energy units.

The dielectric formalism we employ is based on the method of moments [4], which permits to determine the dielectric function in terms of the first known converging sum rules:

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

where

$\omega_1^2=\omega_1^2(k)=C_2/C_0$, $\omega_2^2=\omega_2^2(k)=C_4/C_2$, for any $q=q(k,z)$, analytic in the upper half-plane $Imz>0$, where its imaginary part is positive, and such that $\lim_{z\to\infty} q(z)/z=0$ there .

Under the sum rules we understand the power-frequency moments of the plasma loss function, defined as:

$\mathcal{L}(k,\omega)=-\omega^{-1}Im\varepsilon^{-1}(k,\omega)$ and

$C_\nu(k)=\pi^{-1}\int_{-\infty}^{\infty}\omega^\nu\mathcal{L}(k,\omega)d\omega, \nu=0,1,\ldots.$

Relativistic corrections to the Linhard formula were studied in [5]. Using the dielectric formalism of the method of moments, we can write the estimating formula for the energy losses of relativistic particles as:

$$\left.\frac{-dE}{dx}\right|_{v\to c}\simeq\left(\frac{Ze\omega_p}{\upsilon}\right)^2\ln\frac{2mv^2}{\hbar\omega_p\sqrt{1+H}}+$$

$$+\left(\frac{Ze\omega_p}{c^2}\right)^2\int_{\frac{\omega_p\sqrt{1+H}}{\upsilon}}^{\frac{2m\upsilon}{\hbar}}\frac{dk}{k^3}\frac{\omega_2^2(k)\left(1-\frac{\omega_2^2(k)}{k^2\upsilon^2}\right)(\omega_2^2(k)-\omega_1^2(k))^2}{\Omega^4(k)+\left(\frac{\omega_p^2\omega_2(k)Imq(k,\omega_2(k))}{\left|q(k,\omega_2(k))\right|^2}\right)^2},$$

where

$$\Omega^2(k)=\omega_p^2+\left(\omega_2^2(k)-\omega_1^2(k)\right)\left(1-\frac{\omega_2^2(k)}{k^2c^2}\right)+$$

$$+\frac{\omega_p^2\omega_2(k)Req(k,\omega_2(k))}{\left|q(k,\omega_2(k))\right|^2}.$$

In the multicomponent plasmas, we can calculate the power moments with taking into account all types of ions, as was done in [4], but for the model of "averaged" hydrogen-like atom [5].

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