# Coulomb logarithm and stopping power of ions in a partially ionized hydrogen plasma

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By using the Coulomb logarithm the stopping power of ions in a partially ionized hydrogen dense plasma are investigated. The Coulomb logarithm is derived on the basis of strongly screened effective potential, which accounts short range quantum effects and long-range many-particle screening effects.

## 1. Introduction

The stopping power of ions in plasma is an important parameter in the physics of inertial confinement fusion, the interaction of highly charged ions with dense plasmas. There exist several experimental investigations of the beam–plasma interaction [1–4]. To interpret these experiments study of the energy loss of charged particles travelling through plasmas is needed. Stopping power calculations were done in many theoretical works using various approaches, theory and computational simulations [5-6]. It was found that, in general, the stopping power is increased in two cases, namely because the effective charge of a projectile becomes higher and because the value of the Coulomb logarithm is increased.

In this paper we investigate the stopping power of heavy particles in a partially ionized hydrogen plasma with a density higher $10^{19}$ cm$^{-3}$. At an initial pressure of the target plasma the density of free electrons in the plasma is determined by using the Saha equation, which takes into account the lowering of the ionization potential of atoms due to the particle interaction.

Dimensionless variables are the coupling parameter $\Gamma = e^2/ak_BT$, the average distance between the particles $a = (3/4\pi n)^{1/3}$, the density parameter $r_s = a/a_B$.

## 2. The Coulomb logarithm on the basis of effective potentials

Coulomb logarithm is most accurately determined by the center-of mass scattering angle of particles [7]

$$\lambda = \frac{1}{b_\perp^2}\int_0^\infty \sin^2\left(\frac{\theta_c}{2}\right) b\,db, \qquad (1)$$

where $\theta_c$ is the center-of-mass scattering angle for a collision between two plasma particles and $b_\perp = Z_\alpha Z_\beta e^2/(2E_c)$, $E_c = \frac{1}{2}m_r u^2$ - is the center of mass energy.

The center-of-mass scattering angle for a binary collision

$$\theta_c = \pi - 2b\int_{r_0}^\infty \frac{dr}{r^2}\left(1 - \frac{\Phi(r)}{E_c} - \frac{b^2}{r^2}\right)^{-1/2}, \qquad (2)$$

where $\Phi(r)$ is the interaction potential and $r_0$ is the distance of closest approach for a given impact parameter b.

We used the effective pseudopotential taking into consideration quantum-mechanical and screening effects for description of the interaction of charged particles in semiclassical dense partially ionized plasma [8]:

$$\Phi_{\alpha\beta}(r) = \frac{Z_\alpha Z_\beta}{\sqrt{1-4\lambda_{\alpha\beta}^2/r_D^2}}\left(\frac{e^{-Br}}{r} - \frac{e^{-Ar}}{r}\right), \qquad (3)$$

where $A^2 = \frac{1}{2\lambda_{\alpha\beta}^2}\left(1+\sqrt{1-\lambda_{\alpha\beta}^2/r_D^2}\right)$, $B^2 = \frac{1}{2\lambda_{\alpha\beta}^2}\left(1-\sqrt{1-\lambda_{\alpha\beta}^2/r_D^2}\right)$,

$Z_\alpha e, Z_\beta e$ - is the electric charges of $\alpha$ and $\beta$ of particles, $\lambda_{\alpha\beta}$ is the thermal de Broglie wave length, $m_{\alpha\beta}$ is reduced mass of $\alpha-\beta$ pair, $r_D$ is the Debye radius.

Numerical results for the center-of-mass scattering angle as the dependence on impact parameter are plotted in fig.1 for a different proton beam particle velocity.

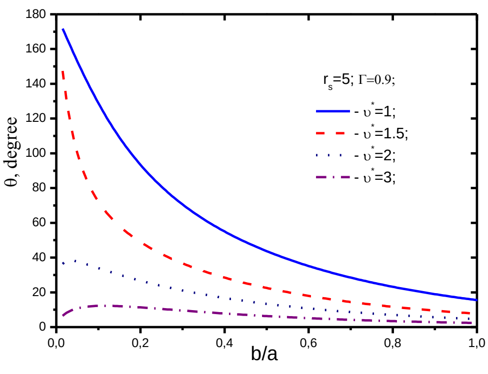


Fig.1. The center-of-mass scattering angle as the dependence on impact parameter for a different proton beam particle velocity $\upsilon^* = \upsilon_p/\upsilon_{th}$.

It is shown that at low energies of projectile particle the scattering angle rapidly rises with the decrease in impact parameter and at high energies of projectile particle the scattering angle at head-on collision can be less then angle equaled $180^0$. It can be explained by rising of the role of quantum mechanical effects of diffraction with increase in the projectile particle velocities. So, the possible diffraction of projectile on the target particle at small impact parameter relates with the finite values of the interaction effective potential at small inter particles distances.

We have obtained the Coulomb logarithm and stopping power of ion for various plasma potentials. The fig. 2 shows that the Coulomb logarithm on the basis of potentials which take into account diffraction effects is almost twice less than the level of the Coulomb logarithms obtained on the basis of Coulomb and Debye potentials.

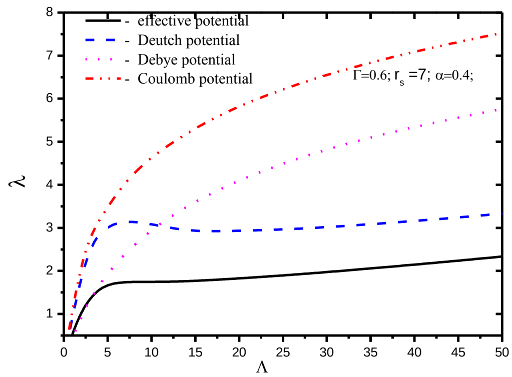


Fig.2. The Coulomb logarithm for different interaction potentials as a function of $\Lambda$ at $r_s = 5; \Gamma = 0.6$.

Therefore, we can make the following conclusion: the Coulomb logarithm calculated by the center-of mass scattering angle of particles may describe more properly the collisions in plasma in comparison with conventional formula of Coulomb logarithm.

## 3. Stopping power

The stopping power for ions in a partially ionized plasma can be represented as the sum of contributions due to bound electrons (be) and free plasma electrons (fe) [2]

$$-\frac{dE}{dx} = \frac{4\pi e^4 n_e Z_{eff}^2}{m_e \upsilon_p^2}\left(\lambda_{fe} + \lambda_{be}\right), \qquad (4)$$

where $\upsilon_p$ and $Z_{eff}$ - are the velocity and the effective charge of the fast ion, $\lambda_{fe}$ and $\lambda_{be}$ are the Coulomb logarithms, respectively.

In fig.3. there is a graph which shows that the stopping power on the basis of the effective potential is less than the one on the basis of the Coulomb, Debye or Deutch potentials due to taking into account both effects: screening and diffraction. As the graphs show, the energy losses are less due to the collective effects of charge screening.

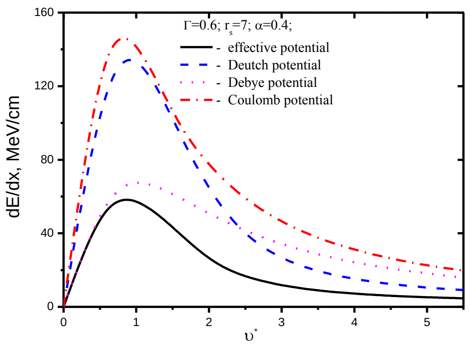


Fig.3. Stopping power of a partially ionized hydrogen plasma for different interaction potentials as a function of proton beam particle velocity at $r_s = 5; \Gamma = 0.6$.

## 4. Conclusion

Center-of-mass scattering angle versus impact parameter as a function of proton beam velocity was calculated. It was shown that the quantum effects should be taken into account at the high projectile velocity. The Coulomb logarithms on the basis of the effective potential in partially ionized plasma for various plasma potentials were obtained. It is shown that the stopping power on the basis of the effective potential is less then one on the basis of the Coulomb, Debye, Deutch potentials.

## 5. References

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