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Scattering processes in partially ionized plasma on the basis of the effective polarization potential

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Abstract

Elastic cross sections of electrons on atoms were investigated in a framework of pseudopotential interaction model. The partial wave expansion scattering method was used. Total and differential cross sections were obtained. The bremsstrahlung cross section for electrons collision with neutral atoms is considered.

Introduction

A partially ionized hydrogen plasma is considered with the following parameters $T = 10^3 \div 10^6 K$, $n_e = n_i = 10^{21} \div 10^{24} cm^{-3}$. The average distance between particles is $a = (3/4\pi n)^{1/3}$, where $n = n_e + n_i$. It is well known that the state of the plasma depends essentially on the coupling parameter $\Gamma = e^2/ak_BT$, which describes the ratio of potential energy of charged particles interaction at the average distance to their thermal energy. The plasma becomes non-ideal at $\Gamma > 1$. Furthermore, we introduce the density parameter $r_S = a/a_B$ (a_B is the Bohr radius), which decreases with increasing of densities.

Interaction models

This paper considers the scattering processes in partially ionized hydrogen plasma. In electron scattering, the elastic scattering of electrons on hydrogen atoms at low energies is of great interest. In our previous works [1,2] we proposed an effective polarization potential for partially ionized dense plasma; the potential takes into account the quantum-mechanical and screening effects. This pseudopotential for the interaction between charged particles and atoms considers polarization of an atom in external field:

$$\Psi(r) = -\frac{e^2\alpha}{2r^4(1-4\lambda^2/r_D^2)}\left(e^{-Br}(1+Br) - e^{-Ar}(1+Ar)\right)^2, \qquad (1)$$

where $A^2 = (1+\sqrt{1-4\lambda^2/r_D^2})/(2\lambda^2)$, $B^2 = (1-\sqrt{1-4\lambda^2/r_D^2})/(2\lambda^2)$ are coefficients, $\lambda_{ab} = \hbar/(2\pi\mu_{ab}k_BT)^{1/2}$ is the thermal de Broglie wave-length of electrons, $r_D = \sqrt{k_BT/(4\pi ne^2)}$ is the Debye radius.

In [3] the Buckingham screened potential model was used for investigation of hydrogen plasma properties. It considers polarization of hydrogen atoms in external field. This model is usually used in the form:

$$\Psi(r) = -\frac{e^2\alpha}{2(r^2+r_0^2)^2}\exp\left(-\frac{2r}{r_D}\right)(1+\frac{r}{r_D})^2, \tag{2}$$

where α is polarizability of an atom and $r_0 = (\alpha a_B/2)^{1/4}$ is a cutoff radius of hydrogen.

Scattering cross section

Partial and total elastic cross sections for plasma particles are defined by phase shifts $\delta_l^{\alpha\beta}$ [4]:

$$Q_l^{\alpha\beta}(k) = \frac{4\pi}{k^2}(2l+1)\sin^2\delta_l^{\alpha\beta} \tag{3}$$

$$Q^{\alpha\beta}(k) = \frac{4\pi}{k^2}\sum_l (2l+1)\sin^2\delta_l^{\alpha\beta}, \tag{4}$$

where k is a wave number, l are orbital quantum numbers, α,β are sorts of particles. To calculate phase shifts in the present paper we use the partial wave expansion method [5,6] and solve Calogero equation. Differential cross sections are defined as:

$$\frac{d\sigma(\theta)}{d\Omega} = \left|\frac{1}{2ik}\sum_l (2l+1)[\exp(2i\delta_l^{\alpha\beta})-1]P_l(\cos\theta)\right|^2, \tag{5}$$

where $P_l(\cos\theta)$ are the Legendre polynomials.

It is well known that the bremsstrahlung cross section for electrons collision with neutral atoms is expressed in terms of the cross section for elastic scattering of electrons on atoms [7]:

$$\frac{d\sigma}{d\omega} = \frac{4}{3\pi}\frac{e^2\upsilon^2}{c^3\hbar\omega}Q_{ea}^T(\upsilon), \tag{6}$$

where $Q_{ea}^T(\upsilon)$is a transport cross section, υ is velocity of incident electrons, c is speed of light, ω is photon frequency.

Results

Figure 1 presents phase shift as a function of distance and wave number of incident electrons. The phase shifts are obtained on the basis of the effective polarization potential (1) by numerical solving of Calogero's equation for electron scattering on atomic hydrogen. It is shown that the phase shifts decrease at increase of incident electron's energy. Figure 2 presents the comparison of calculated differential cross section with experimental data [8].

It is shown that the results of this paper have a good agreement with experimental data. Figure 3 shows total cross sections for potentials (1) and (2). One can see that cross section

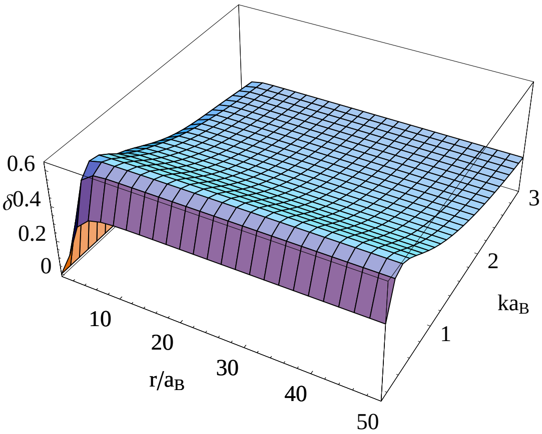

Figure 1: Phase shift as function of wave number and distance at $\Gamma = 0.5, r_S = 10$ and $l = 0$.

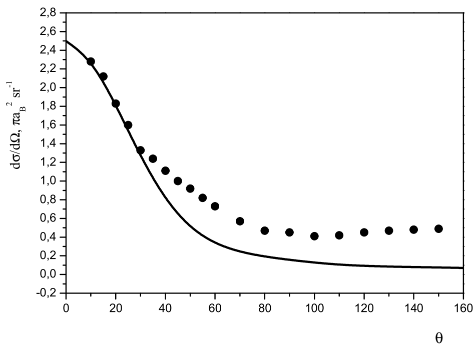

Figure 2: Differential cross sections; solid line denotes the present results, circles show the experimental results [8] at $k = 0.8a_B^{-1}$.

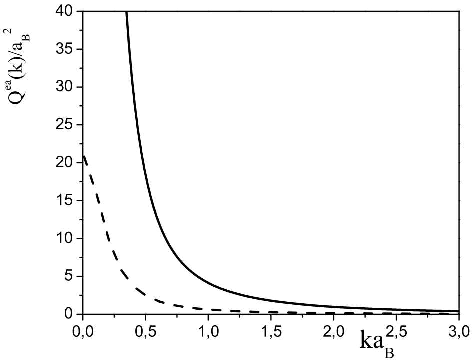

Figure 3: Total cross sections for scattering of electrons on atomic hydrogen on the basis of pseudopotentials, solid line is for the pseudopetential (1) and dash line is for Buckingham potential (2) at $\Gamma = 0.5, r_S = 10$.

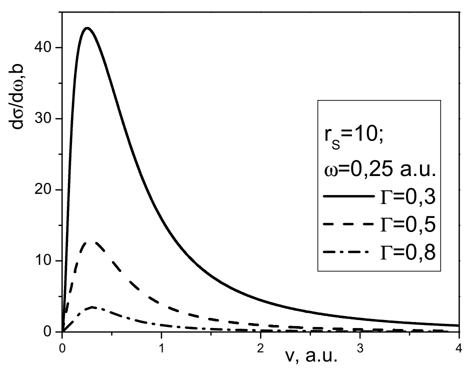

Figure 4: Bremsstrahlung cross section as a function of incident electron's velocity, $b = \frac{1}{137^3 a_B^2 \omega_0}$.

for potential (1) is more than the same for Buckingham potential. It is explained by taking into account quantum mechanical effects. The next figure presents bremsstrahlung cross section as a function of incident electron's velocity and coupling parameter. It is shown that bremsstrahlung cross section decrease with increasing of the coupling parameters. It should be to note that the results of bremsstrahlung cross section are presented in atomic units.

Conclusions

Based on the results of this work one can make the following conclusions:

1. Consideration of quantum mechanical effects in the effective polarization potential leads to increasing of elastic cross section;
2. From comparison of our results with experimental data we can conclude that the potential (1) gives the adequate description of some elementary processes.

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