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Scattering of low-energy electrons by noble gas atoms in partially ionized plasma

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Abstract

Within the polarization model, elastic scattering processes between electrons and atoms in partially ionized plasmas are investigated using the method of phase functions. Total cross sections for the scattering of electrons on noble gas atoms were calculated and compared with experimental and other theoretical data.

Introduction

Elastic scattering of electrons on atoms is a fundamental process that continuously attracts the attention of researchers. A large number of various theoretical and experimental studies of elementary processes is devoted to the elastic scattering of electrons on noble gas atoms. Reaction cross sections are valuable since they provide information on how particles collide and interact. They are needed to describe transfer processes within partially ionized plasmas.

As it was already mentioned, studies of elastic scattering processes make it possible to describe the interaction of particles involved in the transport process. In Refs. [1, 2] we proposed a pseudopotential model developed on the basis of the dielectric response method. This model takes into account the polarization of the atom in an external field and can be applied for the description of particle interactions in partially ionized plasma. Collective and quantum effects in dense plasma are also considered within this model.

Within the pseudopotential model, the electron-atom interaction as function of the distance r is given by

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

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

In the previous works [3, 4] we applied the pseudopotential (1) to the investigation of scattering processes in hydrogen plasmas. Comparison of results obtained there with experimental data showed the applicability of this model to the description of the interaction between electrons and hydrogen atoms. In the present work we will report new investigations of elastic scattering of electrons on noble gas atoms, which have been performed employing this model.

Phase functions method

The method of phase functions is used for the investigation of scattering processes, see Ref. [4]. The mathematical background of this method is given by the following fact which is well known in the theory of differential equations: A linear homogeneous equation of the second order (the Schrödinger equation, in our case) can be reduced to a non-linear equation of the first order, i.e. to the Ricatti equation, in our case. The monograph [5] provides a detailed description of this method. Thus, within this approach we solve a first-order differential equation for the scattering phase, i.e. the Calogero equation:

$$\frac{d\delta_l^{\alpha\beta}(k,r)}{dr} = -\frac{1}{k}U(r)\left[\cos\delta_l^{\alpha\beta}(k,r)\cdot J_l(kr) - \sin\delta_l^{\alpha\beta}(k,r)\cdot n_l(kr)\right]^2 \qquad (2)$$

with the initial condition $\delta_l^{\alpha\beta}(k,0) = 0$, the subscripts α,β denote the species of the particles under consideration. In Eq. (2), $n_l(kr)$ and $J_l(kr)$ are Ricatti-Bessel functions, $U(r) = (2\mu_{\alpha\beta}/\hbar^2)\Psi_{\alpha\beta}(r)$, where $\Psi_{\alpha\beta}(r)$ is the particle interaction potential (1), $\mu_{\alpha\beta}$ denotes the reduced mass of the particles. $\delta_l^{\alpha\beta}(k)$ is defined as $\delta_l^{\alpha\beta}(k) = \lim_{r\to\infty}\delta_l^{\alpha\beta}(k,r)$. Note that in the Calogero equation there is an obvious relation between the interaction potential and the scattering phase shift. Besides, it is quite easy to solve this equation numerically. In the present work we employed the Runge-Kutta method of fourth order.

If the scattering phase shifts are known, we can calculate the total cross section for the elastic scattering of plasma particles according to [6]:

$$Q^{\alpha\beta}(k) = \frac{4\pi}{k^2}\sum_l (2l+1)\sin^2\delta_l^{\alpha\beta}, \qquad (3)$$

where k denotes the wave number, l the angular momentum. The wave number k is given by the energy of the incident particle, $k^2 = 2\mu_{ea}E/\hbar^2$.

Transport scattering cross sections for the scattering of electrons by atoms are calculated using the relation [7]

$$Q_t^{ea}(k) = \frac{4\pi}{k^2}\sum_{l=0}^{\infty}(l+1)\sin^2(\delta_l^{ea}(k) - \delta_{l+1}^{ea}(k)). \qquad (4)$$

Results

Calculations have been performed for helium, neon, argon, and xenon atoms. The results are presented in the Figs. 1 - 4. As seen from Fig.1 showing the elastic transport cross section for scattering of electrons on helium atoms, our results are in good agreement with experimental data from Ref. [8]. Figs. 2, 3, and 4 present the total cross sections for the scattering of electrons on neutral Ne, Ar, Xe, respectively. The comparison of our results with the data obtained in experimental and other theoretical works shows that the effective potential used in the present work describes adequately the interaction of electrons with atoms.

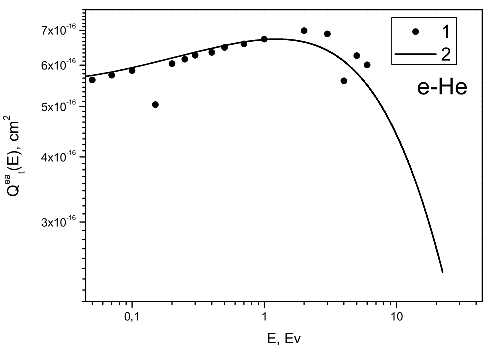

Figure 1: Transport cross section for scattering of electrons on helium atoms; 1-Ref. [8], 2-our calculations.

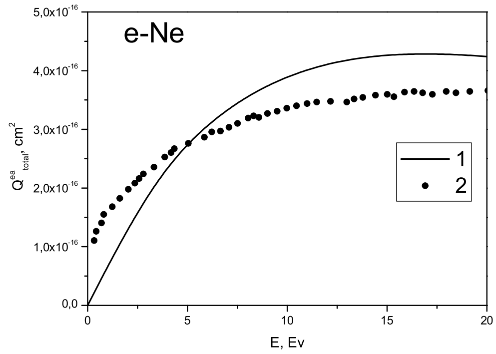

Figure 2: Total cross section for scattering of electrons on neon atoms; 1- our calculations, 2- Ref. [9]

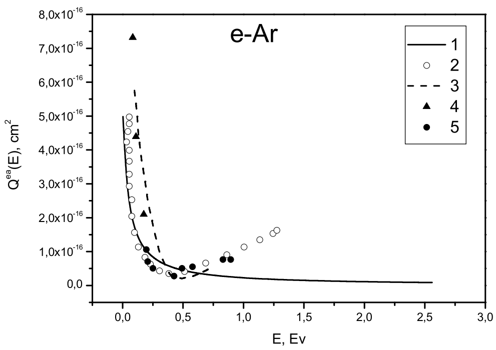

Figure 3: Total cross section for scattering of electrons on argon atoms; 1- our calculations, 2- Ref. [10], 3- Ref. [12], 4-Ref. [13], 5-Ref. [11]

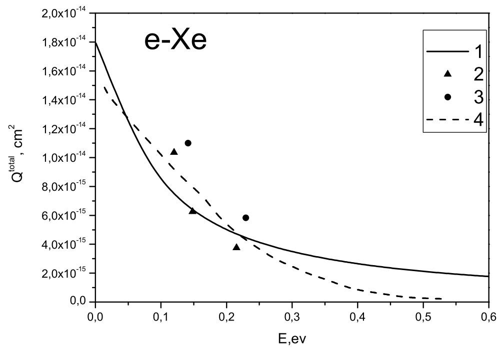

Figure 4: Total cross section for scattering of electrons on xenon atoms; 1- our calculations, 2- Ref. [14], 3- Ref. [15], 4-Ref. [12]

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