

Electron capture by the excited hydrogen atom in the dense semiclassical partially ionized plasma

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Introduction. The elementary processes [1-7, 9-11] in plasma are of great interest since that processes immensely influence on the transport properties of plasma. Electron-ion and electron-atom collisions in plasmas have been widely investigated on the basis of the various interaction potentials depending on the characteristics of the surrounding plasma. In the dense semiclassical plasma it is necessary to take into account the screening and quantum-mechanical effects such as the diffraction effect. In the electron-atom interaction, the atom can be polarized by the projectile electron and then their interaction has polarization character.

The electron capture process can be investigated on the consideration of the motion trajectories of the projectile electron near the target atom. These trajectories were calculated on the basis of the motion equations [10-11]. Electron, passing near the atom, is attracted to the atom due to polarization effect on the distance close to the capture radius. This radius is usually determined as the distance where the kinetic energy of moving electron and the interaction energy between the electron and the atom are equal. In works [10-11], we considered the electron capture by the hydrogen atom in the ground state.

In this paper the electron capture by the excited hydrogen atom in various states, like 2s and 2p, was explored. The interaction between the electron and the excited hydrogen atom was investigated on the basis of the effective potential, taking into account the quantum-mechanical effect of diffraction and plasma screening effect. The applied potential (see [4-6, 9, 10]) can be written as:

$$\Phi_{ea}(r) = -\frac{e^2 \alpha_p}{2r^4 C_{ea}^2} \left[e^{-B_{ea}r} (1 + B_{ea}r) - e^{-A_{ea}r} (1 + A_{ea}r) \right]^2, \quad (1)$$

where $A_{ea}^2 = (1 + C_{ea}) / (2\lambda_{ea}^2)$, $B_{ea}^2 = (1 - C_{ea}) / (2\lambda_{ea}^2)$, $C_{ea}^2 = (1 - 4\lambda_{ea}^2 / r_D^2)$, $r_D = \sqrt{\frac{k_B T}{4\pi e^2 n_e}}$ is the Debye length. Also, n_e is the numerical density of electrons; T is the plasma temperature; k_B is the Boltzmann constant. $\lambda_{ea} = h / \sqrt{2\pi\mu_{ea} k_B T}$ is the de Broglie thermal wavelength;

$\mu_{ea} = m_e m_a / (m_e + m_a)$ is the reduced mass of the ion and the atom, $\bar{\alpha}_p(n, l) [\equiv \alpha_p / a_B^3 = n^6 + (7/4)n^4(l^2 + l + 2)]$ is the dipole polarizability of the hydrogen atom [8] for the nl -state, n and l are the principal and orbital quantum numbers. In this work the following dimensionless parameters were used: $\Gamma = e^2 / a k_B T$ is the coupling parameter, the average distance between particles is $a = (3/4\pi n)^{1/3}$, n is the density of the charged particles. The density (Brückner) parameter $r_s = a/a_B$ ($a_B = \hbar^2 / m_e e^2$ is the Bohr radius of the hydrogen atom, \hbar is the reduced Plank constant). The degeneracy parameter for electron component is $\theta = k_B T / E_F$. Here, E_F is the Fermi energy.

For complete research of the electron behavior in the field of the excited hydrogen atom, the capture time was stated as the time of electron location in the capture region determined by the capture radius. Furthermore, the electron capture probability was calculated on the basis of the expression used in [10-11]. Eventually, using electron capture probability, the electron capture cross section was defined by the following formula:

$$\sigma_{cap} = 2\pi \int db b P_{cap}(b), \quad (2)$$

where $P_{cap}(b)$ is the electron capture probability, b is the impact parameter.

Results. Figure 1 shows the trajectories of the electron near the excited hydrogen atom in 2s (panel a) and 2p (panel b) states for various values of the impact parameter. In this figure the excited hydrogen atom is located at $x=0$ and $y=0$. One can see that the trajectories of the electron are more curled when the atom is in 2p state then those corresponding to the atom in 2s state. This distinction is due to the relatively high dipole polarizability of atom in 2p state based on the high orbital distance.

The electron capture time as function of impact parameter was represented in figure 2 for the different values of kinetic energy of the moving electron (panels a and b). Furthermore, both panels illustrate the comparison of capture times corresponding to 2s state and to 2p. It can be seen that with an increase in kinetic energy the capture time reduces, as electrons with high velocity leave capture region very quickly. Also, the calculated capture time for the case 2p lays over data corresponding to 2s state.

Figure 3 shows the differential cross sections of the electron capture for the different values of the velocity of the moving electron and the density parameter. In this figure, one can see that the electron capture cross section increases with growing of the density parameter, since the influence of the screening effect weakens.

Figure 4 reveals the comparison of the total cross sections for the 2s and 2p states of excited hydrogen atom and dependence the total cross sections on the energy of electron.

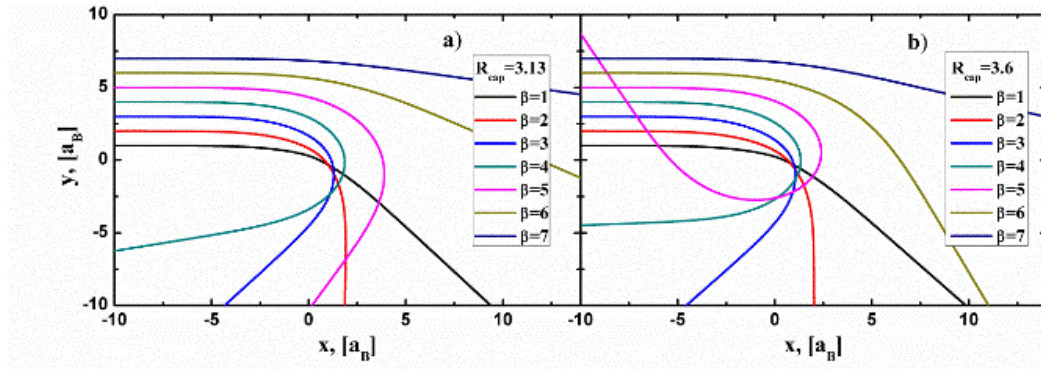


Figure 1. The trajectories of an electron near the excited hydrogen atom obtained for the various impact parameters ($\beta = b/a_B$) and initial relative velocity $\delta = v/v_{Th} = 2$ by calculating the equations of motion, $\theta = 2$, $r_s = 10$: a) excited hydrogen atom in 2s state; b) excited hydrogen atom in 2p state.

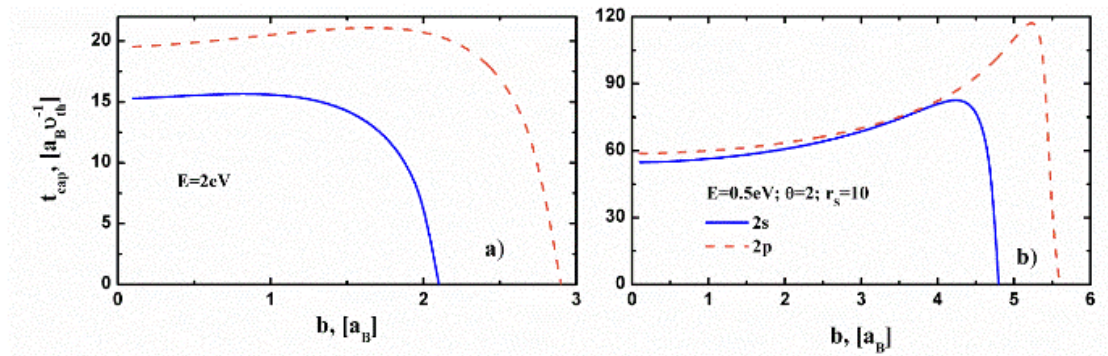


Figure 2. The dependence of the electron capture time on the impact parameter for different values of kinetic energy of the moving electron, $\theta = 2$, $r_s = 10$: a) $E = 2\text{ eV}$; b) $E = 0.5\text{ eV}$.

Conclusion. In this paper, the process of the electron capture by the excited hydrogen atoms in the states 2s and 2p was investigated. The trajectories of the moving electron near the atom were calculated on the basis of the interaction potential, taking into account quantum-mechanical effect and screening effect. The time of the capture, differential and total capture cross sections were calculated for various values of plasma parameter, energy of moving electron and excited states of atom. Respectively, obtained dates of research were compared, and analysis was carried out.

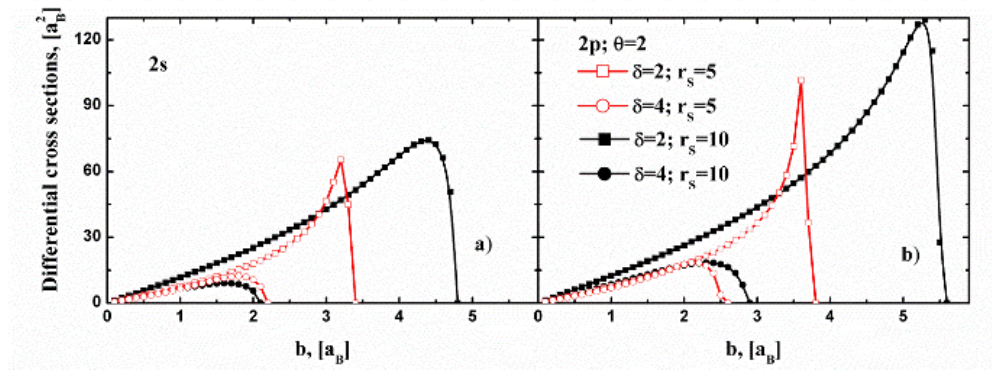


Figure 3. Differential capture cross sections for different values of the velocity of the moving electron and density parameters, $\theta = 2$: a) 2s state, $r_s = 10$ (black color) and $r_s = 5$ (red color); b) 2p state, $r_s = 10$ (black color) and $r_s = 5$ (red color).

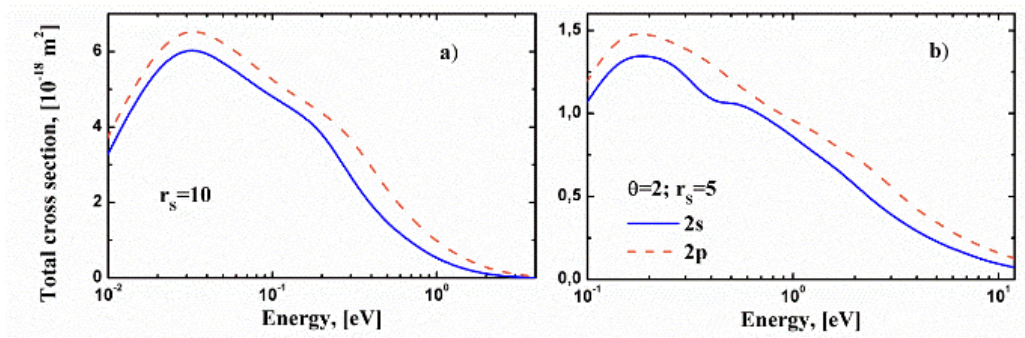


Figure 4. Total cross sections of the electron capture for different values of the energy of projectile electron, density parameters and states of excited hydrogen atom, $\theta = 2$. a) $r_s = 10$; b) $r_s = 5$.

Acknowledgments. The authors acknowledge support within the Grant AP05132665 of the Ministry of Education and Science of the Republic of Kazakhstan.

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