REPLY TO COMMENT

Reply to Comment on ‘Formation of bound states of electrons in spherically symmetric oscillations of plasma’

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Abstract
I reply here to the comment of Dr Shmatov on my recent work (Dvornikov 2010 Phys. Scr. 81 055502), and demonstrate the invalidity of his criticism of the classical physics description of the formation of bound states of electrons participating in spherically symmetric oscillations of plasma.

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Nowadays there is a lack of a universally recognized theoretical model for stable natural plasma structures existing in the atmosphere [1]. An approach to the description of such a plasmoid based on radial oscillations of electron gas was recently put forward in [2–4]. Oscillations of electrons were treated in both quantum and classical frameworks [2] within the proposed model. Various important phenomena, such as the emission of high-energy radiation, which arise in spherically symmetric plasma oscillations, were predicted in [3]. Note that other theoretical descriptions of natural plasmoids, including very exotic ones, were reviewed in [5].

In [4], I examined the possibility of formation of bound states of electrons participating in spherically symmetric oscillations due to the exchange of ion acoustic waves. Note that in [4] the dynamics of electron oscillations was treated in the framework of classical electrodynamics. In the comment of Dr Shmadov [6] on my recent work, it was claimed that the classical physics description adopted in [4] is inconsistent with the numerical estimates presented in my paper, since the typical energy of an electron participating in oscillations is below the minimal kinetic energy $E_q$ (see [6]) resulting from the Heisenberg uncertainty principle.

I disagree with the statement in [6] that classical electrodynamics is invalid for the description of the bound state formation. Indeed, to form a bound state the energy of the effective attraction should be greater than the kinetic energy of electrons (see e.g. [7]). As in [4], we can discuss singly ionized nitrogen plasma with the background electron density $n_0 = 10^{15} \text{ cm}^{-3}$ and electron temperature $T = 10^5 \text{ K}$, which corresponds to the typical plasma of a gas discharge [8]. Note that this value of $T$ is different from that used in [4].

Taking the amplitude of electron oscillations $a \sim 10^2 k_e^{-1}$, where $k_e$ is the Debye wave number, and the distance between oscillating electrons $d \sim 10a$, as well as using equation (16) from [4], we find that effective attraction takes place if $|\omega_i - \Omega_1| \leq 10^{-4} \omega_i$, where $\omega_i$ is the ion Langmuir frequency and $\Omega$ is the frequency of electron motion. Note that in this case the kinetic energy of electrons prevails over both the energy of their thermal motion, which approximately equals several electron volts, and $E_q \sim 10^{-18} \text{ eV}$.

Thus, I have demonstrated that the classical electrodynamics description of the bound state formation of electrons participating in radial oscillations is still valid although one should choose the values of the parameters of the system, such as $T$, $d$ and $a$, different from those in [4]. Nevertheless, I thank Dr Shmatov for pointing out in his comment [6] the unsuccessful choice of the parameters in my work [4].

Finally, I mention that electron harmonic motion at frequency $\Omega < \omega_i$ should not necessarily be treated as forced oscillations as in [4]. It was demonstrated in [9] that a plasma oscillation has to be considered as a wave packet where both
rapid and slow motions are present since a monochromatic Langmuir wave is likely to be unstable [10]. Thus, the results of [4] can be applied to those electrons that participate in slow oscillations.

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