BOUND STATES OF COULOMB SYSTEM IN SUPERSTRONG LASER FIELDS IN PLASMAS

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In spite of known quantum restrictions, the classical approach to the research of interaction of intense radiation with an atom demonstrates good opportunities to study stochastic ionization [1,2], harmonic emission at tunnel ionization [3], atom stabilization [4] and other problems. The classical approach is even more appropriate obviously in the study of continuum processes, connected with infinite trajectories. Electro-optically, Coulomb potential is focusing. It deflects a particle towards a stronger field area, which amplifies electron-ion interaction. The paper analyzes the influence of that effect on the efficiency of induced radiation due to electron scattering by a Coulomb center in a strong electromagnetic field.

In our paper we analyze and numerically demonstrate an area of initial parameter where "duration" effects (such as recombination, atom stabilization, laser induced bound state and others) can appear. The simplest laser induced bound state is constructed and found numerically. And at the end, we demonstrate atom stabilization in super strong field.

We solve numerically the classical equation of an electron motion in a Coulomb field of an ion and homogeneous alternating electrical field $\boldsymbol{E}$ varying on harmonic law. The equation can be written in dimensionless variables [5]

$$\ddot{\boldsymbol{R}} = -\boldsymbol{R}/R^3 + \boldsymbol{n}\cos(\Omega t), \tag{1}$$

that is convenient for consideration of strong fields. The following notation are introduced here (Z is the ion charge, ω is the laser field frequency)

$$r_E = \sqrt{eZ/E},\quad \omega_E = \sqrt[4]{eE^3/m^2 Z},\quad \upsilon_E = \sqrt[4]{Ze^3E/m^2},\quad \Omega = \omega/\omega_E \tag{2}$$

It is important to note that the considered problem is described by one dimensionless parameter Ω. It depends on the frequency and intensity of a field in a combination $\Omega \sim \omega^4/E^3$. It means, that a limiting case of quasistatic field ($\Omega \to 0$) is equal a case of superstrong field.

The value of r_E characterizes the distance from the ion, where Coulomb field is stronger than external electric field. Another important parameter is the electron's oscillating radius

$r_{\sim}=eE/m\omega$. In the case, when electron oscillations can lie inside the interaction area ($r_{\sim}<r_E$), the initial phase of the electron motion is unimportant and we can use some averaging model: average potential [6], approach of small angle collision [7] and so on. In other case ($r_{\sim}>r_E$) the initial phase (or more exactly the collision phase) is important and as a result we cannot use averaging models for particles in the interaction area! In this case the time of passing the interaction area is essentially important due to repeatedly returns of a rapidly oscillating electron to the ion and increase electron attraction to the ion. In other words, when electron drift velocity smaller than $r_E\omega$ we should expect many new dependent effects such as recombination, atom stabilisation, great increasing of propagation time and more other.

Really, in the process of numerical simulations we have found most of these effects. One of the most prevalent effects is represented in Figure 1. An electron with small drift velocity moves on keplerian-like trajectory, collides and moves again on another keplerian-like trajectory. This sequence may repeat many times.

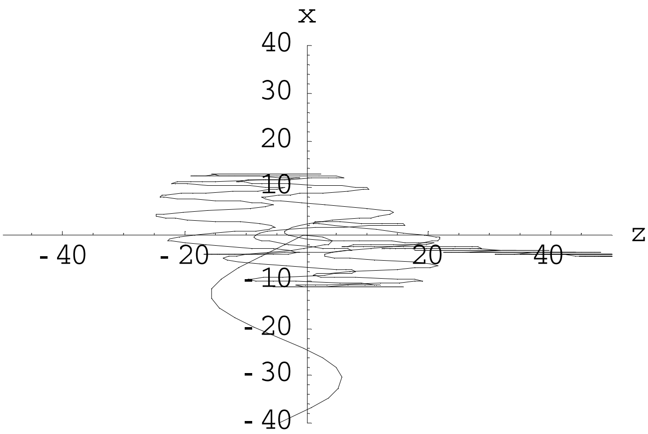

Fig. 1. Example of trajectory with durable propagation time (quasitrapping). *Ω=0.32, υ=0.1.*

Another interesting effect is the laser-induced bound states of electron. It can be described analytically in the simplest case. Electron begins motion with small drift velocity at $r_{\sim}$ before an ion, moves and slightly collides passing the ion and come to the point at $r_{\sim}$ after the ion with drift velocity opposite to the initial. Motion repeats backward. As a result we construct a plain laser induced bound state. A corresponding mapping in dimensionless variable can be written as:

$$\upsilon_{n+1}=\upsilon_n-\frac{\Omega^2}{\upsilon_n}\frac{\Omega^2-2\upsilon_n^2}{\Omega^2-\upsilon_n^2}. \qquad (3)$$

It's easy to find a stationary point $\upsilon^*=\Omega/\sqrt{2}$ ($\omega r_E/\sqrt{2}$ in dimension variable). Numerically this trajectory is represented in Figure 2. Note that transverse size is equal to r_E, the size of the interaction area.

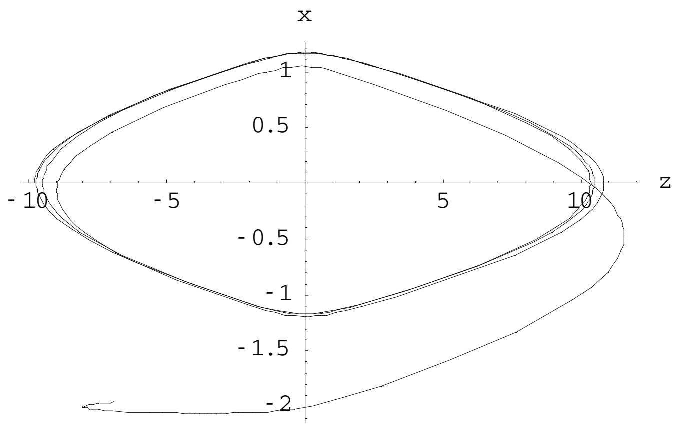

Fig. 2. Simplest trajectory of the laser induced bound state for $\Omega=0.32$ (plain motion).

Unfortunately, this trajectory is unstable for small variations of initial parameters. Some modification of mapping (3) for 3D motion shows a possibility of existence of stationary point that's stable for variations of initial parameters. But real trajectories found numerically differ from assumptive trajectory (Fig. 2 and 3).

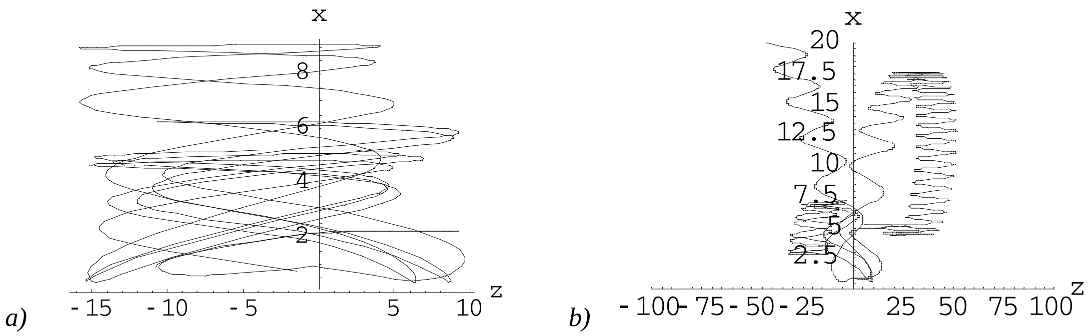

Fig. 3. Examples of quasistable trajectories for $\Omega=0.32$ (3D case).

Fortunately, the quasistable trajectories have been found in huge area of initial parameters with "ionization" time much longer than the field's period (in 20…30 times, Fig. 3). All of these trajectories can be divided in two types: (i) stochastic modification of "romb" trajectory (Fig. 2 and 3a); (ii) quasikeplerian trajectories with periodical returns to the ion (Fig. 3b). The last case, apparently, can be described in terms of motion in the average potential.

The third type of quasistable trajectories can be found analytically in the simple approximation (monopole and dipole expansion) of the average potential – "two centers" potential:

$$V_{2c} = \frac{1}{2}\left(\frac{1}{\sqrt{x^2 + (z - r_\sim)^2}} + \frac{1}{\sqrt{x^2 + (z + r_\sim)^2}} \right). \tag{4}$$

This potential differs from the exact average potential, but in the first approximation it takes into account the extent of the average potential along the external field and has true dependence on long distance. Two centers potential has been investigated in more detail in work [8]. It was found that a group of infinite trajectories could move near the ion very very long (Fig. 4). A radiation loss decreases a particle energy and, as a result, electron's trajectory become stabilize (transfer to finite motion) or the electron drop to the ion.

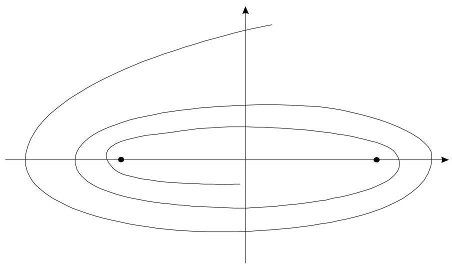

Fig. 4. Example of quasistable trajectory in two centers potential.

At the end we should note that the result presented in this paper facilitate development of understanding of electron's dynamics with small drift velocities, recombination, atom stabilisation and so on. In the future we will construct mapping describing all types of trajectories, analyse a quantum system, formation hollow atom and calculate some recombination and atom's stabilisation characteristics…

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