Dynamics and net energy gain of electron in a plane wave

Ghasemi S. A.[1*], Faghih S.[2]

[1]Plasma and Nuclear Fusion Research School, Nuclear Science and Technology Research Institute, P.O. Box: 14399-51113, Tehran, Iran
[2] University of Damghan, Physics Department, P.O. Box: 41167-36716 Damghan-Iran
* *Email: abo.ghasemi@gmail.com*

Abstract
One of the most important issues in laser-plasma interaction is the net energy gain of the electrons under the physical interaction conditions. In this paper, by investigating the interaction of electrons with laser pulse and their dynamic changes, the effect of electromagnetic wave scattering and dephasing electrons in achieving a net energy gain and the dependence of electron dynamics on laser wavelength under these conditions is investigated.
Keywords: laser-plasma interaction, dephasing, direct laser acceleration, magnetic field.

Introduction
Due to the importance of producing energetic electrons in laser-plasma interaction and the fact that it underlies many different aspects of laser-plasma interaction [1], in this paper its achievement has been investigated using the direct laser acceleration (DLA) mechanism [2]. In other words, the effect of the nature of scattering of electromagnetic waves in plasma and its wavelength on the motion of electrons in a strong and relativistic electromagnetic wave and thus on the direct laser acceleration of electrons in the interaction of high-intensity laser pulses with low-density plasma [1,2] is investigated.
In reference.[3], it is shown that pure energy can occur if the electron is already under strong and relativistic fluctuations in an external electric field when the laser pulse arrives. In reference.[4], it has been shown that the longitudinal component of a coherent bipolar radiation pulse can deliver pure energy to an electron. In reference.[1,2], the effect of electromagnetic scattering on the motion of an electron in a strong relativistic surface wave is investigated. The solution shows that even a relatively small difference between the phase velocity of the wave and the speed of light can significantly change the electron dynamics.

Electron interaction with plane wave
When a relativistic intensity laser pulse interacts with electrons, electrons can gain energy while oscillating in the laser electric and magnetic fields [5]. The laser pulse interacts with electrons in two stages: the first reduction of the phase rate of the electrons occurs and then the electrons are accelerated by the laser with the Lorentz force [6].
This dephasing is expressed by Equation $R=\gamma\, d\tau/dt$ where γ is a relativistic factor and τ is defined as $\tau=t-x/c$. This dephasing rate depends on the velocity of the electrons in the laser direction and the phase velocity of the laser. To study the dynamics of the motion of a charged particle under an external magnetic field, a position is considered in which the applied external magnet is parallel to the electric field of the laser pulse. The electric field of the laser is in the direction of y and $E_{wave,y}=-d\tau/dt$, the magnetic field of the laser is $B_{wave,z}=(1/V_p)\,d\tau/dt$, and the applied magnetic field is $\mathbf{B}=B_0\hat{y}$. The energy equation of a single electron moving in this plane wave is $d\gamma/dt=(eV_y/m_ec^2)d\tau/dt$ and The equations of motion of the electron that need to be considered are:

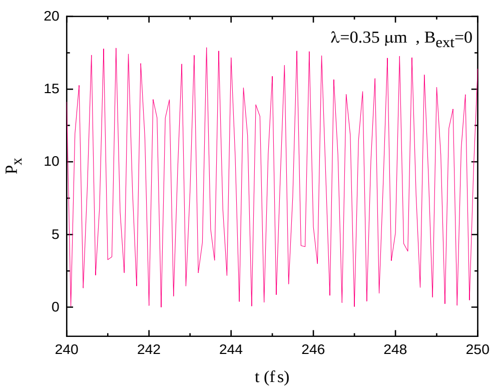
(1) $$d\mathbf{P}_x/dt=\alpha\left[(V_y/c)d\tau/dt-V_zB_0\right]$$

(2) $$d\mathbf{P}_y/dt=\alpha\left[-d\tau/dt-(V_x/c)d\tau/dt\right]$$

(3) $$d\mathbf{P}_z/dt=\alpha\left[V_xB_0\right]$$

Where α is $\alpha=q/m_e$. Using two Eqs.1,2 can be obtained $\gamma-(V_p/c)(P_x/m_ec)=1$ where V_p is the phase velocity. According to the definition of laser vector potential as $A(\tau)=a_0\cos\omega_L\tau$, in the absence of an external magnetic field, the transverse and longitudinal momentum of the electron is obtained as $\tilde{p}_y=a$ and $\tilde{p}_x=a^2/2$, respectively.

The diagrams in Figures.1,2 show the longitudinal and transverse momentum dependence of the electron on the laser wavelength changes.



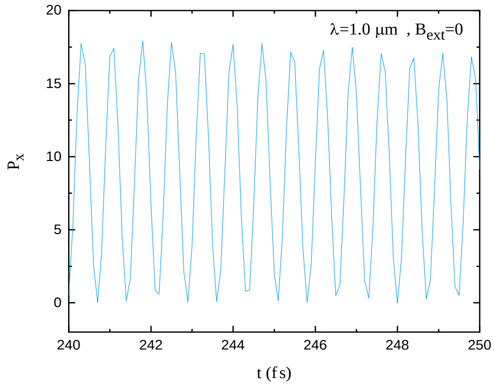


Figure 1. Momentum electrons in the x-direction in the absence of an external magnetic field for a) $\lambda = 0.35\ \mu m$, b) $\lambda = 1\ \mu m$.

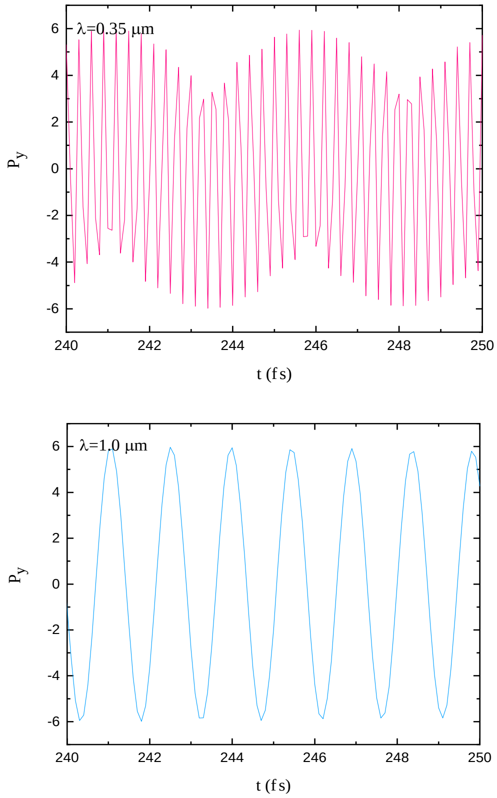


Figure 2. Momentum electrons in the y-direction in the absence of an external magnetic field for a) $\lambda = 0.35\ \mu m$, b) $\lambda = 1\ \mu m$.

Conclusions

In this paper, the dynamics of electron motion interacting with an electromagnetic wave are investigated. The resulting graphs for different wavelengths show that as the pulsed laser wavelength decreases, the direction of movement of the electrons in the x-direction is more convergent. As expected, py is set by the vector potential of the laser pulse and returns to zero once the laser pulse overtakes the electron [2].

Based on reference 2, initially this roughly follows the pure plane wave solution ($\tilde{P}_x = a^2/2$), and p_x also acquires a much more slowly varying component that manifests after the pulse overtakes the electron. During the interaction, p_x is positive. Therefore, the net energy gain occurs in this erea.

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