Interaction of Relativistic and non-Relativistic Laser Pulse With a Plasma

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Introduction

- Plasma is a quasineutral gas of charged and nuetral particles which exhibits collective behaviour.
- If an electron in plasma is displaced from its equilibrium position, it will start oscillating around its equilibrium position. The frequency of oscillation is characteristics of the plasma parameters and is called plasma frequency.
- A plasma is underdense for an electromagnetic wave if its frequency is less than the frequency of the em wave. On the other hand, a plasma is overdense if its frequency is greater than the frequency of the em wave.

PIC Algorithm

Particle in Cell (PIC) is a numerical approach that simulates a collection of particles that interact via external and self-induced electromagnetic fields.

- Replace a system of charges with a macro particle having the same charge to mass ratio.
- Decretise the space by drawing line parallel to the boundaries of the system.
- Replace the continuous electric and magnetic by values on the descete mesh.
- Interpolate the charge on the grid to update the fields.
- Update **E** from step n to $n+1$ is done via central differencing using **B** at $n+1/2$.
- Update **B** from step $n-1/2$ to $n+1/2$ is done via central differencing using **E** and the current density (**J**) at step n.
- The updated electric and magnetic fields are used to forward velocity for step $n-1/2$ to $n+1/2$

- Velocity at step $n+1/2$ is used to forward position for step n to $n+1$.

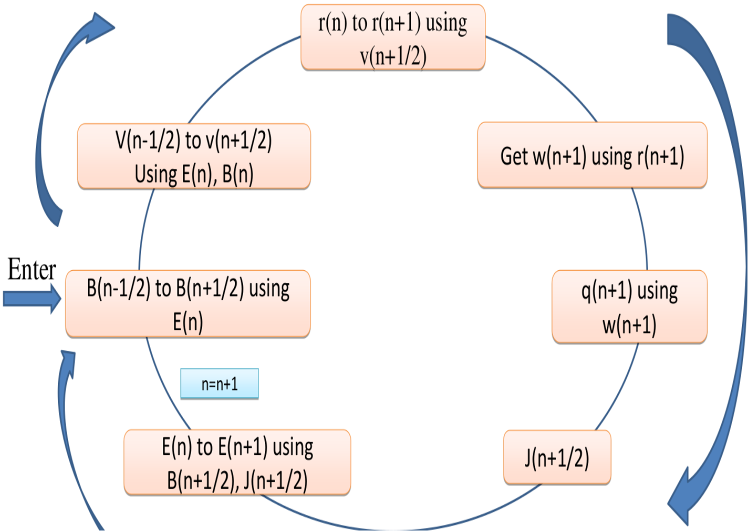


Figure: The PIC Cycle

Simulation Parameters

For a laser of frequency ω_l and electric field amplitude E_0, the laser vector potential is defined as $a_0 = \frac{eE_0}{mw_l c}$. A laser is called relativistic if $a_0 \geq 1$.

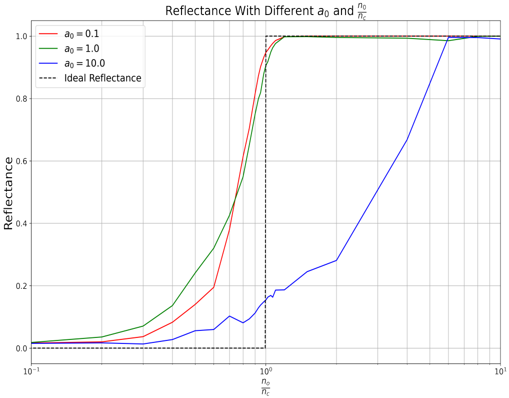
- The simulation box extends for $20\lambda_l$ (from $-10\lambda_l$ to $10\lambda_l$), where λ_l is the laser wavelength and has total 1000 cells.
- The plasma is placed at $x = 0$ and with a thickess of λ_l.
- Number of particles per cell are 100.
- The plasma density n_p is defined in terms of the critical density n_c and is varied from 0.1 to 10.
- The vector potential a_0 is used as 0.1, 1.0 and 10.0.

The envelope of the incident laser field varies according to

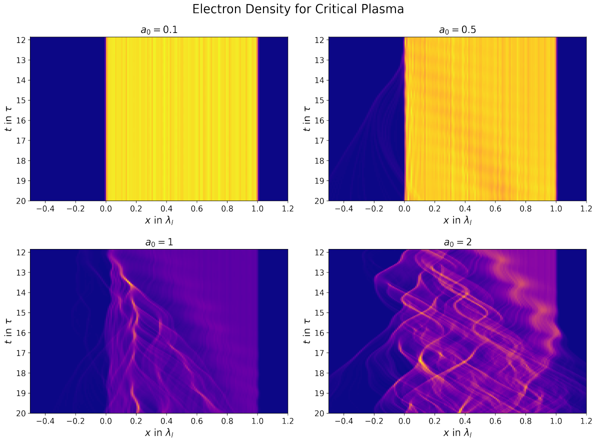
$$P(t) = \begin{cases} \sin^2(\pi t/T) \text{ for } 0 \leq t \leq T \\ 0 \text{ otherwise} \end{cases} \tag{1}$$

Where T is the pulse duration here taken as $T = 10\tau$ with $\tau = 2\pi/\omega_l$ is the time of one laser cycle. The simulation is performed for $t = 20\tau$.

We define a term
$R = \frac{E_{300}^2 - E_{600}^2}{E_{300}^2}$
The plot of R with different ratio of n_c and n_0 is shown in the figure 1 for different values of vector potential a_0.
We find a shifting of the critical density for relativistic laser pulse.



The electron density with time is plotted for different a_0. The plot shows that the oscillation of electrons increases with increasing vector potential.



Conclusion

- When the laser becomes relativistic for $a_0 \geq 1$, the particles inside plasma starts to oscillate with relativistic velocity, gaining mass. This results in change in the plasma frequency and hence the laser does not get reflected even for density greater than the critical density corresponding to the non-relativistic case.
- The laser pulse, after interacting with electrons, makes them oscillate. If the pulse becomes relativistic, the oscillations becomes strong and hence the plasma surface oscillates with relativistic velocity.

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