The study of waves in plasma and laser interaction with plasma

Mehrniya Habib alah

Department of plasma Physics,Scince and Research Branch, Islamic Azad university, Tehran, Iran
Address: no 145 -Kiyanpars West 6 street- Ahvaz-Iran;Phone number: 00989163010368
Email: mehrniya.habib@yahoo.com

Abstract: Continuous progresses in base of short Laser plasmas have attracted the researchers to this point within the interaction of these lasers with materials. One of the most important interactions of laser with substances is the plasma or laser interaction which today, this is attracted by everyone.The present study, as a case study, has studied the waves in plasma in which the laser interaction with plasma is the main purpose of this research.

[Mehrniya Habib alah. **The study of waves in plasma and laser interaction with plasma.** *Rep Opinion* 2013;5(1):7-19]. (ISSN:1553-9873). http://www.sciencepub.net/report. 2

Keywords: plasma, laser, interaction

Introduction

The basic laser operation

We consider two energy balances such as 1 and 2 balances from a substance, and also we assume that a mass of these two balances are respectively like N_1 and N_2. If a flat wave in a relevant intensity involving photon flux, F, passes from the substance along with Z axis, then the minor change of this flux, due to the Stimulated emission and absorption, would be obtained as the following equation in which the σ is the Transient area, and this fact has been shown in fig 1:

$$dF = \sigma F(N_2 - N_1)dz$$

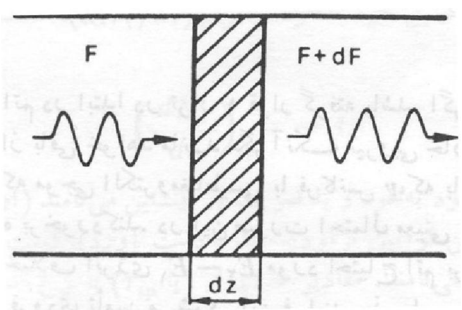

Fig1-shows the transient area

The above equation shows that if $N_2 > N_1$, then the substance would be behaved as a amplifier, and if it would be as $\frac{dF}{dz} > 0$, in which while $N_2 < N_1$, then the substance's behavior would be as an absorber.

Laser, not only for visible light frequencies, but also for other frequencies which are in the far or close Infrared area would be applied, and also would be applied for Ultraviolet, and even the x-ray .in order to make an Oscillator from an amplifier, it is needed to utilize an appropriate feedback. The feedback generally would be provided within putting an active substance between two Reflective mirrors. In this case, the flat wave of electromagnetism would be passed perpendicularly along with the surface of two mirrors, and it would be amplified while passing from the active substance .if one of two mirrors be Semitransparent, the laser beam would be exited from mirror. The laser is required the particular requirement. While the optimal of active substance overcomes the wastage , so that, the fluctuation would be started. Optimal means the ratio of output photon flux to input photon flux in each passage from the active substance which is equal to $\exp[\sigma(N_2 - N_1)L]$, in which L is the length of active substance. However, the westage in quack is only due to the transmission, and the following would be resulted:

$$R_1 R_1 \exp[2\sigma(N_2 - N_1)L] = 1$$

In which R1 and R_2' are the reflective potential of two mirrors. Based on the above equation, while the Population inversion be as $\sigma(N_2 - N_1)_c$, in this case it could be named the critical inversion and would be obtained in Threshold barrier. This critical amount would be obtained as following ,and these points have been shown in fig2, the whole plot of laser :

$$(N_2 - N_1)_c = -\frac{Ln(R_1R_2)}{2\sigma L}$$

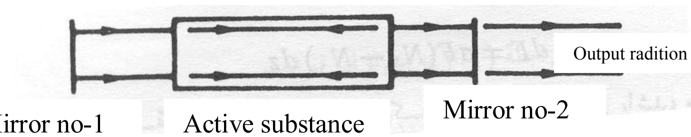

Fig2- th[illegible] se

As shown in above figure, while the critical inversion obtains, the oscillation would be obtained from the emission, and in this case the photons which spontaneously emit along with quack axis, in fact the amplification process would be started in this situation; and this would be the base of laser oscillator.

How the Population inversion is created in active substance? it seems that the creation of population inversion be possible through the substance interaction and the intense electromagnetic field in ν frequency .in thermal balance , while the first balance population be more than the second balance population ,so that , the absorption would overcome to stimulated emission.

Compression and stretching could be obtained from the prism or paired networks. Paired networks could be categorized within separating the pulse spectra from oscillators, in a way that the difference between wavelengths could cause the difference in optical system. The less output of Nano joul is compressed with 10^4 , and it could be amplified it in a smaller and bigger system respectively with 10^6. After a short while, the laser pulse would be compressed as the first time, and the laser system could be obtained in higher amounts of 10^{10} .within focal the lasers off, the potential flux would be $10^{20}\ {cm^2}/{w}$. The laser systems expanded most of the academic branches and industrial facilities, and unity of the lasers would be possible through the research in plasma physics, which previously these were not possible in laboratory.

Existence of Plasma in nature

It has been said that 99 percent of available materials in the nature is plasma, meaning that it has the shape of an electrical gas that it's atoms are ionized to positive ions and negative electrons. We have seen some plasma samples in the flashes of lightening, trapped gases in a fluorescent lamp or in shining aurora lighting.

Saha equation shows the portion of a gas's ionization in the position of the thermal equality as following:

$$\frac{n_i}{n_n} \approx 2/4 \times 10^{21} \frac{T^{\frac{3}{2}}}{n_i} e^{\frac{-ui}{KT}}$$

n_i Stands for density of ionized atoms (number of square meter), n_n for density of neutral atoms. T is gas temperature in Kelvin, K stands for Boltzmann constant and u_i for energy of gas ionization.

While u_i is more than KT , within the increase of temperature, ionization temperature would not increase, then, $\frac{n_i}{n_n}$ would immediately increase , and gas would find the shape of plasma. The more increase in temperature makes n_n less than n_i , and then plasma gets ionized completely.

Plasma as a fluid

This is a relation between a normal plasma and plasma physics:

$$\nabla . D = \sigma$$
$$\nabla \times H = J + \dot{D}$$

σ and J, stand for charge density and (free) current. Charge density and (bound) current are the results of polarization and magnetization of environment in H and D quantities, in terms of ϵ and μ . Ions and available electrons in a plasma equals charges and (bound) currents.

In plasma physics, most of the work is done with Maxwell's equations in vacuum, in which σ And J includes all internal and external currents and charges.

$$\nabla . E = \frac{\sigma}{\varepsilon_\circ}$$
$$\nabla \times B = \mu_\circ (J + \varepsilon_\circ \dot{E})$$

Classical discussion of magnetic substance

Since all orbital particles have magnetic moments, it seems that plasma as a magnetic substance, has $\mu_m$permeability

The below linear relation stands for a magnetic substance:

$$B = \mu_\circ(1+\chi_m)H$$

In plasma within magnetic field, each particle has a magnetic moment μ_α and the quantity M is the collection of μ_α in one square centimeter, then:

$$\mu_\alpha = \frac{mV_\perp^2}{2B} \propto \frac{1}{B} \qquad M \propto \frac{1}{B}$$

The relation of M and B or H is not linear any more, and then assumption of the plasma as a magnetic field is not true.

Di -electric constant in plasma

In a polarized dielectric, P $and\ \epsilon$ has a linear relation with E as following:

$$P = \varepsilon_\circ \chi_e E$$

$$\varepsilon = (1+\chi_e)\varepsilon_\circ$$

In the plasma E field within time interval, j_p *would be the* polarized current as following:

$$\nabla \times B = \mu_\circ(J_F + J_P + \varepsilon_\circ \dot{E})$$

This equation could be written as following as well, in which this equation could be used $\varepsilon = \varepsilon_\circ + \frac{J_P}{\dot{E}}$:

$$\nabla \times B = \mu_\circ(J_F + \varepsilon_\circ \dot{E})$$

Di-electric of plasma with low frequency for horizontal motions is defined as following, in which $\epsilon_{R,p\to\circ}$:

$$\varepsilon_R = \frac{\varepsilon}{\varepsilon_\circ} = 1 + \frac{\mu_\circ \rho c^2}{B^2}$$

In the normal experimental plasma, comparing with other units, $\mu_\circ\rho c^2/B^2$ would be large; Meaning that electric fields resulted of the plasma particles have much diversity with external applied fields. The plasma would be within large ε protective orbits in front of alternative fields; and it would be like the plasma with small λ_D which this makes it protective against dc field.

Main body

The properties of laser beam

The property of laser beam within high degree could be specified respectively as monochromatic, coherence, directional, and radiance.

The monochromatic

Laser light is mono-chromatic, meaning that the light energy is concentrated in a very tight spectral (wavelength) band. Since water, and by extension, tissue interacts with different light wavelengths differently; a specific laser wavelength is chosen to achieve certain clinical results. For example, if tissue ablation is desired, selecting a laser wavelength that is highly absorbed by water creates the required ablation effect.

Coherent

Laser light is also directional and coherent, which means that it can be targeted accurately and with very high intensity. Temporal coherence is the measure of the average correlation between the value of a wave and itself delayed by τ, at any pair of times. Temporal coherence tells us how monochromatic a source is. In other words, it characterizes how well a wave can interfere with itself at a different time. The delay over which the phase or amplitude wanders by a significant amount is defined as the coherence time τ_c. At τ=0 the degree of coherence is perfect whereas it drops significantly by delay τ_c. lasers emit light that is highly directional; laser light is emitted as a relatively narrow beam in a specific direction. Ordinary light, such as coming from the sun, a light bulb, or a candle, is emitted in many directions away from the source. Spatial coherence typically is expressed through the output being a narrow beam which is diffraction-limited. Laser beams can be focused to very tiny spots, achieving a very high irradiance, or they can be launched into beams of very low divergence in order to concentrate their power at a large distance. The diffraction phenomenon is described as the apparent bending of waves around small obstacles and the spreading out of waves past small openings. Similar effects occur when light waves travel through a medium with a varying refractive index or a sound wave through one with varying acoustic impedance.

Gas lasers

He-Ne lasers are usually used for mapping subjects and co- linearization, Kr and Ar lasers are used in optical displays, and both types of lasers are the samples of Dc gas lasers. Co2 is a powerful laser which has a commercial usage as a cutting device.

Waves in plasma

The waves display

Any periodic motion of a fluid can be decomposed by Fourier analysis into a superposition of sinusoidal oscillations with different frequencies ω and wave length λ. A simple wave is any one of these components. When the oscillation amplitude is small, the wave form is generally sinusoidal. We shall consider sinusoidal waves under the small signal approximation. The sinusoidal oscillating quantity-say the density n-can be represented as following in which $\tilde{n}$ $and\ \vec{k}$ are respectively constant defining the amplitude of the wave and propagation constant .

$$n = \bar{n}\ \exp[i(k.r - \omega t)]$$

If the wave propagates in the x direction, $\vec{k}$ has only an x component and following Equation Would be resulted :

$$n = \bar{n}e^{i(kx - \omega t)}$$

A point of constant phase on the wave moves so that ;

$$\frac{dx}{dt} = \frac{\omega}{K} = V_{\phi}$$

Group velocity

The phase velocity of a wave in a plasma exceeds the velocity of light c. An infinitely long wave train of constant amplitude cannot carry information unless it is modulated. The modulation information does not travel at the phase velocity but at the group velocity, which is always less than c. Let us consider a modulated wave formed by adding (*beating*) two waves of nearly equal frequencies.

Let these waves be

$$E_1 = E_0\ \mathrm{COS}\ [(k + \Delta k)x - (\omega + \Delta\omega)t]$$

$$E_2 = E_0\ \mathrm{COS}\ [(k - \Delta k)x - (\omega - \Delta\omega)t]$$

E_1 and E_2 differ in frequency by $2\Delta\omega$.

Since each wave must have the phase velocity (ω / k) appropriate to the medium in which they propagate one must allow for a difference $2\delta k$ in propagation constant. we have ,

$$E_1 + E_2 = 2E_0\ \mathrm{COS}\ [(\Delta k)x - (\Delta\omega)t]\mathrm{COS}(kx - \omega t)$$

This is a sinusoidally modulated wave. The envelope of the wave is given by $\cos[(\Delta k)x - (\Delta\omega)t]$, is what carries information, it travels at velocity $\Delta\omega$ / Δk.

In the limit $\Delta\omega \rightarrow 0$, we define the group velocity to be

v_g = $d\omega$ / dk , it is this quantity that cannot exceed c.

Plasma oscillation

If the electrons in a plasma are displaced from a uniform background of ions, electric fields will be built up in such a direction as to restore the neutrality of the plasma by pulling the electrons back to their original positions. Because of their inertia, the electrons will overshoot and oscillate around their equilibrium positions with a characteristic frequency known as the plasma frequency. We shall derive an expression for the plasma frequency ω_p in the simplest case, making the following assumptions:

(1) There is no magnetic field (B=0) ; (2) $(KT = 0)$; (3) the ions are fixed in space in a uniform distribution; (4) the plasma is infinite in extent; (5) the electron motions occur only in the x direction; (5) and the last one is that There is no fluctuating magnetic field; this is an electrostatic oscillation which is shown as following:

$$\nabla = \hat{x}\frac{\partial}{\partial x} \qquad E = E\hat{x} \qquad \nabla \times E = 0 \qquad E = -\nabla\phi$$

The plasma frequency is as following:

$$\omega_p = \left(\frac{n_0 e^2}{\varepsilon_\circ m}\right)^{\frac{1}{2}}$$

Numerically, one can use the approximate formula as following:

$$f_P = 9\sqrt{n}$$

This frequency, depending only on the plasma density, is one of the fundamental parameters of plasma. Equation of plasma frequency tells us that if a plasma oscillation is to occur at all, it must have a frequency depending only on n. In particular, ω does not depend on k, so the group velocity $d\omega$ / dk is zero.

Electron plasma waves

There is another effect that can cause plasma oscillation to propagate, and that is thermal motion. Electrons streaming into adjacent layers of plasma with their thermal velocities will carry information about what is happening in the oscillating region. The plasma oscillation can then properly be called a plasma wave. Hence , the motion equation would be as following :

$$mn_\circ\left[\frac{\partial v}{\partial t} + (V.\nabla)V\right] = -n_\circ e(E + V \times B) - \nabla P_e$$

And the linear zed equation of motion is as following :

$$mn_\circ\frac{\partial v}{\partial t} = -n_\circ eE_1 - 3KT_e\frac{\partial n}{\partial x}$$

The electrons ‘s frequencies within thermal motion would be obtained through the following equation in which $V_{th}^2 = \dfrac{2K_B T_e}{m}$:

$$\omega^2 = \omega_P^2 + \frac{3}{2}K^2\ V_{th}^2$$

In above equation , the frequency depends on k and the group velocity is definite as following:

$$V_g = \frac{d\omega}{dk} = \frac{3}{2}\frac{V_{th}^2}{V_\phi}$$

According to the following figure, At any point *P* on this curve, the slope of a line from the origin gives the phase velocity ω / *k*. The slope of the curve at *P* gives the group velocity.

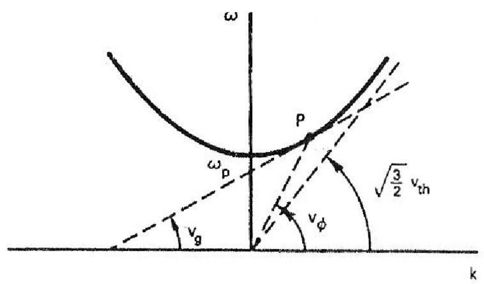

Fig3. Dispersion relation for electron plasma waves

the point that v_g is always less than *c* , can easily be seen from the above graph ,and this graph is a plot of the dispersion relation ω(*k*) as given by the equation . This is clearly always less than $(3 / 2)^{1/2} v_{th}$, which in our non-relativistic theory, is much less than *c*. Note that at large *k* (small λ), information travels essentially at the thermal velocity. At small *k* (large λ), information travels more slowly than v_{th}, even though v_φ is greater than v_{th}. This is because the density gradient is small at large λ, and thermal motion carries very little net momentum into adjacent layers.

Sound waves

The sound waves are the pressure waves propagating from one layer to the next by collisions among the air molecules, and the velocity (c_s) of sound waves in a neutral gas could be obtained as following in which γ ,k and M are respectively atomic coefficient , Boltzmann constant and gas 's molar mass :

$$C_s = \frac{\omega}{k} = \left(\frac{\gamma KT}{M}\right)^{1/2}$$

In the plasma with no neutrals and few collisions, an analogous phenomenon occurs. This is called an ion acoustic wave, or an ion wave.

Ion waves

In the absence of collisions, ordinary sound waves would not occur. Ion can still transmit vibrations to each other because of their charge, however; and acoustic waves can occur through the intermediary of an electric field. Since the motion of massive ions will be involved, these will be low-frequency oscillations, and we can use the plasma approximation $n_i = n_e$.

The ion fluid equation in the absence of a magnetic field is as following in which we have assumed $E = -\nabla\phi$, $\nabla P = \gamma_i K T_i \nabla n$.

$$Mn\left[\frac{\partial v_i}{\partial t} + (V_i.\nabla)V_i\right] = neE - \nabla P = -ne\nabla\phi - \gamma_i K T_i \nabla n$$

Validity of plasma approximation

In deriving the velocity of the waves, we used the neutrality condition $n_i = n_e$ while allowing *E* finite. To see what error was engendered in the process, we now allow n_i to differ from n_e and use the linear zed Poisson equation as following:

$$\varepsilon_\circ \nabla.E = \varepsilon_\circ K^2\phi = e(n_i - n_e)$$

The electron density is given by the linear zed Boltzmann relation is as following:

$$n_e = \frac{e\phi}{KT_e} n_\circ$$

And The ion density is given by the linear zed ion continuity equation is as following:

$$n_i = \frac{k}{\omega} n_\circ V_i$$

And finally Dispersion relation for sound-ion waves would be as following in which by assuming $n_i = n_e$, *the error* $K^2\lambda_D^2$ has been realized and the point is that Since λ_D is very small in most experiments, the plasma approximation is valid for all except the shortest wavelength waves. :

$$V_s = \frac{\omega}{k} = \left(\frac{KT_e}{M}\frac{1}{1+K^2\lambda_D^2} + \frac{\gamma_i K T_i}{M}\right)^{\frac{1}{2}}$$

Electrostatic Ion waves perpendicular to B

when *k* is perpendicular to B_0 , the ion equation of motion would be as following :

$$M\frac{\partial V_i}{\partial t} = -e\nabla\phi + eV_i \times B$$

In which we find the velocity of ion as $V_{ix} = \frac{ek}{M\omega}\phi\left(1 - \frac{\Omega_c^2}{\omega^2}\right)^{-1}$, where $\Omega_c = \frac{eB_\circ}{M}$ is the ion cyclotron frequency; the dispersion relation for electrostatic ion cyclotron waves is as following :

$$\omega^2 = \Omega^2 + k^2 V_s^2$$

Which it is as well as The physical explanation waves, and The ions undergo an acoustic-type oscillation, but the Lorentz force constitutes a new restoring force giving rise to the Ω_c^2 term in above equation. The acoustic dispersion relation $\omega^2 = k^2 V_s^2$ is valid if the electrons provide Debye shielding. In this case, they do so by flowing long distances along B_0. The electrons cannot move in the *x* direction to preserve charge neutrality ; If θ is not exactly π / 2, however, the electrons can move along the dashed line (along B_O) in the following figure to carry charge from negative to positive regions in the wave and carry out Debye shielding. The ions cannot do this effectively because their inertia prevents them from moving such long distances in a wave period, all these have been shown in following figure.

Ponderomotive force

In figure A, B and C; the effect of laser intensity increase on magnetic and electric fields have been shown, and the distribution of electron density in non magnetic plasma has also been shown.

The mechanism of the ponderomotive force can be understood easily by considering the motion of the charge in an oscillating electric field. In the case of a homogeneous field, the charge returns to its initial position after one cycle of oscillation. In contrast, in the case of an inhomogeneous field, the position that the charge reaches after one cycle of oscillation shifts toward the lower field-amplitude area since the force imposed onto the charge at the turning point with a higher field-amplitude is larger than that imposed at the turning point with a lower field amplitude, thus producing a net force that drives the charge toward the weak field area. $\vec{v} \times \vec{B}/C$ Would affect the particle and put it in forward in parallel with pulse. To obtain this force, the field has to be enlarged around $r_\circ$ center in δr displacement.

$$E = E_s(r)\cos(\omega t) = [E_s(r_\circ) + (\delta r_1.\nabla)E_s(r = r_\circ) + ..]\cos(\omega t) = E_1 + E_2 + ..$$

Where $E_s(r)$ is force, and cos(w(t)) involves all the oscillations in laser frequency . We could conclude the following from Maxwell equation ($\frac{\partial B}{\partial t} = -c\nabla \times E$) , in which it could be verified for all higher degrees :

$$B = \frac{-c}{\omega}\sin(\omega t)\nabla \times E_s$$

In the first degree approximation, we would have the following for the oscillated electrical field, in which m is the mass of **e**− and δr is the displacement:

$$m\frac{dv_1}{dt} = -eE_1 \Rightarrow \begin{cases} v_1 = \frac{-e}{m\omega}E_s(r_\circ)\sin(\omega t) \\ \delta r_1 = \frac{e}{m\omega^2}E_s(r_\circ)\cos(\omega t) \end{cases}$$

In second degree approximation, there would be $v_1 \times B_1$ and E_2 electric field . hence , we would have the following :

$$m\frac{dv_2}{dt} = -e[E_2 + v_1 + B_1] = -e[(\delta r_1.\nabla)E + v_1 \times B_1]$$

The following equation would be possible through averaging it on laser period in which this equation, $E_s \times (\nabla \times E_s) = \frac{1}{2}\nabla E_s^2 - E_s.\nabla E_s$, has been utilized :

$$F_{NL} = m\frac{dv_2}{dt} = -\frac{1}{2}\frac{e^2}{m\omega^2}[(E_s.\nabla)E_s + E_s \times (\nabla \times E_s)] = -\frac{e^2}{4m\omega^2}\nabla E_s^2$$

F_{NL} is the nonlinear zed force which could put the effect on electron .

Ponderomotive force acting on the unit volume of plasma electrons within n_e density could be obtained as following:

- $$F_P = n_e F_{NL} = -\frac{n_e e^2}{4m_e\omega^2}\nabla E_s^2 = -\frac{\omega_p^2}{16\pi\omega^2}\nabla E_s^2$$
- From the above equation, it could be concluded that the ratio of ponderomotive force on ions, F_{Pi} , to the applied ponderomotive force on electrons would be as following:

$$\frac{F_{Pi}}{F_{Pe}} = \frac{m_e}{M_i}$$

Therefore, ponderomotive force for electron would be bigger than being for ions, and this is due to the larger mass of ions in laser field.

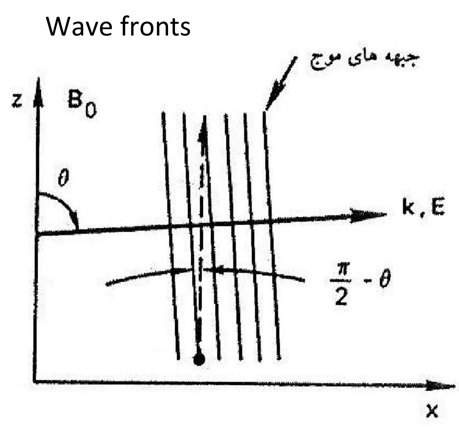

Fig4. Geometry of an electrostatic ion cyclotron wave propagating nearly at right angles to B_o.

The parallel electromagnetic waves with $B_\circ$

The fundamental electromagnetic waves emitting along with $B_\circ$ are the R (right side) and L (left side) waves which have been polarized in a circle form, and the fundamental waves which are emitted in parallel with $B_{\circ}$ are the L waves, and the waves which have been polarized in ellipse form. K would infinite in $\omega = \omega_c$ for R wave; in this case wave would be intensified within the cyclotron motion of electrons. Dispersion relations for two R and L waves which are emitted along with $B_{\circ}$ are as following, in which L wave is orbited in parallel with electrons, in a situation that it does not involve cyclotron intensity, and L wave involves the intensity in $\omega = \Omega_c$,and in this case the wave motion would be orbited within the ion circulation:

$$\tilde{n}^2 = \frac{C^2K^2}{\omega^2} = 1 - \frac{\omega_P^2/\omega^2}{1-(\omega_c/\omega)} \quad \text{(R wave)}$$

$$\tilde{n}^2 = \frac{C^2K^2}{\omega^2} = 1 - \frac{\omega_P^2/\omega^2}{1+(\omega_c/\omega)} \quad \text{(L wave)}$$

we consider a magnetic wave radiating perpendicular to a plasma environment, which is shown in following:

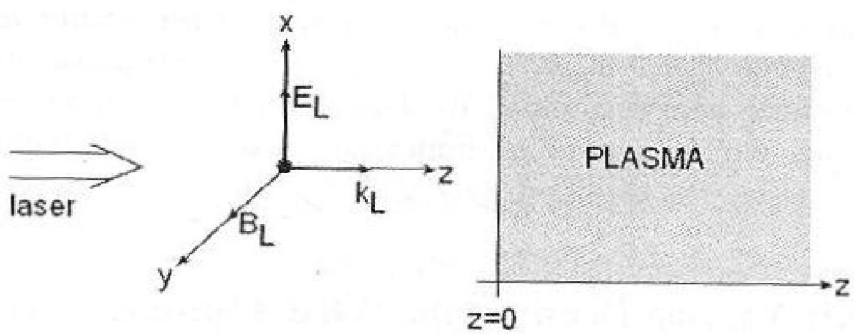

Fig 5- the linearly polarized electromagnetic wave radiating perpendicular to plasma

We assume the plasma environment starts from Z=0 to finite numbers , and the physics 's quantities only allocate to Z coordinate , means that the coordinates would be as $n_e(z)$, $\varepsilon(z,\omega)$, $E_{(r)} = E_{(z)}$. In Cartesian coordinate, the wave equation of electric field would be as $\nabla^2(E) - \nabla[\nabla \cdot E(z)] = \left(\frac{d^2E_x}{dz^2}, \frac{d^2E_y}{dz^2}, o\right)$, in which we would have the following:

$$\begin{pmatrix} \frac{d^2}{dz^2} + \frac{\omega^2\varepsilon}{C^2} & \circ & \circ \\ \circ & \frac{d^2}{dz^2} + \frac{\omega^2\varepsilon}{C^2} & \circ \\ \circ & \circ & E \end{pmatrix} \begin{pmatrix} E_x(z) \\ E_y(z) \\ E_z(z) \end{pmatrix} = \begin{pmatrix} \circ \\ \circ \\ \circ \end{pmatrix}$$

Similarly we would have the following for magnetic field:

$$\nabla\varepsilon \times [\nabla \times B(z)] = \left(-\frac{d\varepsilon}{dz}\frac{B_x}{dz}, -\frac{d\varepsilon}{dz}\frac{B_y}{dz}, \circ\right)$$

$$\begin{pmatrix} \frac{d^2}{dz^2}-\frac{1}{\varepsilon}\frac{d\varepsilon}{dz}\frac{d}{dz}+\frac{\omega^2\varepsilon}{c^2} & \circ & \circ \\ \circ & \frac{d^2}{dz^2}-\frac{1}{\varepsilon}\frac{d\varepsilon}{dz}\frac{d}{dz}+\frac{\omega^2\varepsilon}{c^2} & \circ \\ \circ & \circ & \frac{d^2}{dz^2}+\frac{\omega^2\varepsilon}{c^2} \end{pmatrix}\begin{pmatrix} B_x(z) \\ B_y(z) \\ B_z(z) \end{pmatrix}=\begin{pmatrix} \circ \\ \circ \\ \circ \end{pmatrix}$$

The mentioned equations have been solved for the perpendicular radiance of a linear polarized laser ; and in the mentioned figure the electric field has been selected along with X , and magnetic field oscillates along with y axis , means that $E=(E_{x(z)}\equiv E(z),\circ,\circ)$ and $B=(\circ,B(z),\circ)$, while these fields are emitted along with z axis s the following:

$$K=(\circ,\circ,K)$$

And the mentioned equations would be simplified as following:

$$\frac{d^2E}{dz^2}+\frac{\omega^2\varepsilon}{C^2}E=\circ$$

We assume the D electric function of plasma involves minor changes; in this case the response to electric field would be as following, in which $E_\circ$ and ψ are the minor functions of Z:

$$E(z)=E_\circ(z)\exp\left[\frac{i\omega}{C}\int^z\psi(\zeta)\,d\zeta\right]$$

In this approximation, the wave number of $K(z)$ has been defined as following:

$$K(z)=\frac{\omega\psi(z)}{C}$$

Finally, we would have the following:
the second derivations would be neglected in WKB approximation, means that $\frac{d^2E_\circ}{dz^2}=\circ$. In addition, this approximation would let the zero and first derivations be zero, in which the recent equation would be simplified as following:

$$\varepsilon-\psi^2=0 \qquad 2\psi\frac{dE_\circ}{dz}+E_\circ\frac{d\psi}{dz}=0$$

And the final equation would be as following, in which the common surface of plasma has been inserted in z=0:

$$E_{\circ(z)}=\frac{\text{const}}{\psi^{1/2}}=\frac{\text{const}}{\varepsilon^{1/4}}\,,\ \psi=\varepsilon^{\frac{1}{2}}$$

Also, we could obtain the WKB approximation for electric field in plasma environment as following:

$$E(z)=\frac{E_L}{\varepsilon^{1/4}}\exp\left[\frac{i\omega}{c}\int^z\sqrt{\varepsilon(\omega,\zeta)}\,d\zeta\right]$$

Therefore, the amplitude of electric field in plasma would be obtained through the D electric function, $\varepsilon=1-\frac{\omega_{Pe}^2}{\omega^2}=1-\frac{n_e(r)}{n_{ec}}$, and dispersion relation, $\frac{k^2}{\omega^2}=\frac{\varepsilon}{c^2}$, as following :

$$E_\circ(z)\equiv\frac{E_L}{\varepsilon^{1/4}}=\frac{E_L}{\left(1-(\frac{n_{e(z)}}{n_{ec}})\right)^{\frac{1}{4}}}$$

The mentioned equation shows that the increase of electron density would increase the electric field amplitude, so that, the electromagnetic wave would be emitted higher density. This fact would be realized through the energy‘s flux constancy, and the following would be realized, in which V_g is the group velocity of electromagnetic wave .

$$\frac{V_g|E(z)|^2}{8\pi}=\frac{CE_L^2}{8\pi}$$

Due to the point that the energy flux could be announced as $\frac{cE\times B}{4\pi}$, so it could be observed that the amplitude of electromagnetic field, $B_\circ$, would be decreased in plasma ‘s electromagnetic amplitude ;it means that :

$$B_\circ(z)=B_L\varepsilon^{\frac{1}{4}}$$

To verify WKB approximation, second derivation involves smaller amplitude than first derivations, which is shown in following

:

$$\frac{d^2E_\circ}{dz^2} << \frac{\omega\psi}{c}\frac{dE_\circ}{dz} = k(z)\frac{dE_{\circ(z)}}{dz}, \quad \frac{d^2E_\circ}{dz^2} << \frac{\omega E_\circ}{c}\frac{d\psi}{dz} = E_\circ \frac{dk_{(z)}}{dz}$$

The essential condition for the validity of WKB, would be resulted through summing two above equations:

$$\frac{dE_\circ}{dz} << k(z)E_\circ(z)\frac{\omega\psi E_\circ}{c}$$

The essential condition for WKB approximation would be obtained as following , in which the plasma density has to be changed gradually within the coordinate :

$$\frac{dn_e}{dz} << \frac{8\pi n_{ec}}{\lambda(z)}(1-\frac{n_{e(z)}}{n_{ec}}) = \frac{8\pi n_{ec}\varepsilon(\omega,z)}{\lambda(z)}$$

Now , the electric magnetic has to be solved in WKB approximation , in this case the laser 's magnetic field is along with y. therefore , the magnetic field 's wave equation would be specified through y . Nonetheless, it is not essential to solve this equation, and this is due to the point that the electric magnetic could be solved through the previous equation:

$$B(z) = -\frac{ic}{\omega}\frac{dE(z)}{dz} = \left[E_{\circ(z)}\psi - \frac{ic}{\omega}\frac{dE_{\circ(z)}}{dz}\right]\exp\left[\frac{i\omega}{c}\int^{z} d\zeta\sqrt{\varepsilon(\omega,\zeta)}\right]$$

Now through $E_\circ(z)$ and $\psi(z)$, we could obtain an equation for electric magnetic in plasma environment:

$$B(z) = E_L \varepsilon^{1/4} \exp\left[\frac{i\omega}{c}\int^{z} d\zeta\sqrt{\varepsilon(w,\zeta)}\right]$$

From the previous equations, it could be observed that the magnetic field would be decreased within the increase of electric field in upward electron densities .The WKB approximation is not validate in critical level , where $\varepsilon = \circ$ ، $k = \circ$ and $\lambda = \infty$ .The critical surface plays an important role in plasma laser interaction , in which one part of laser beam would be absorbed there , and the other part would be reflected from this surface .

The analytical solution for the plasma within the constant density gradient

The WKB approximation is a method for finding approximate solutions to linear partial differential equations with spatially varying coefficients. It is typically used for a semi-classical calculation in quantum mechanics in which the wave function is recast as an exponential function, semi - classically expanded, and then either the amplitude or the phase is taken to be slowly changing .The WKB approximation is only validate for density gradients, and in particular case, the cutting density, the WKB approximation would not be effective in which the wave would lose the radiance .therefore , the WKB approximation would be the best solution for the wave emission. Fortunately, an accurate solution could be obtained for the plasma in linear change in density.

Conclusion

Since laser intensity is relevant with the amplitude square, amplitude of magnetic and electric fields in plasma would increase along with the increase of laser intensity. Moreover, due to highly decrease of electron density in lasers through high densities, more decrease would occur in wavelengths fields, and The slope of electron density distribution would increase through the increase of laser pulse intensity.

Figure E,F and G show the effect of increase in external magnetic field on the shape of magnetic and electric fields in diluted magnetic plasma, in this state the intensity of laser would be constant. The external magnetic field would increase the slope of electron density distribution, then as a result an increase in magnetic wavelength and electric fields would occur. Up to the half circulation of pulse distribution in magnetic plasma, pulse magnetic field and external magnetic field would be in the same direction, but in the rest of it, they are in opposite directions. Therefore, a deviation of sinusoidal structure would occur; also it is clear in figure C that while there is increase in external magnetic field comparing to diluted non- magnetic plasma in a condition that external magnetic field and pulse magnetic field are in the same direction, in this case an increase in distribution of electron intensity would occur. If pulse magnetic field and external magnetic field be in opposite directions, distribution of electron density will decrease through the increase of external magnetic field. Figure C and F show that in certain temperature of electron, and in a situation without magnetic field, $\frac{\delta_n}{n_{\circ e}}$ always would be negative. However, in the presence of external magnetic field,

$\frac{\delta_n}{n_{oe}}$ would be expanded toward positive numbers and the portion of density would get more than its primary proportion.

The effect of increase in pulse laser intensity on electric field, magnetic field and ratio of electron density in non- magnetic plasma , has been shown in figure A , B and C; and the Intensity of laser pulse has been shown in $I = 2.5\times10^{15}\ W/cm^2$ (bold lines), $I = 1.0\times10^{15}\ W/cm^2$ (Stretched dotted lines), $I = 0.1\times10^{15}\ W/cm^2$ (dotted lines). $T_e = 10keV$ Electron temperature, $n_{0e} = 1.0\times10^{21}\ cm^{-3}$ maximum of electron density, $n_c = 1.7\times10^{21}\ cm^{-3}$ and critical density.

The effect of increase in external magnetic field has been shown in magnetic field of laser within intensity of $I = 1.0\times10^{15}\ W/cm^2$. A is electric field, B is magnetic field and G is the ratio of electron density, in which Different portions of external magnetic fields have been analyzed. $B_o = 50MG$ (bold lines), $B_o = 20MG$ (stretched dotted lines), $B_o = 0$ (dotted lines). $T_e = 10\,keV$ is electron temperature, $n_{0e} = 1.0\times10^{21}\ cm^{-3}$ is maximum density of electron, and $n_c = 1.7\times10^{21}\ cm^{-3}$ is critical density. Figure G, H and J

Electric field

(Mv/cm)

Magnetic feild (MG)

Electric field

(Mv/cm)

Density ration

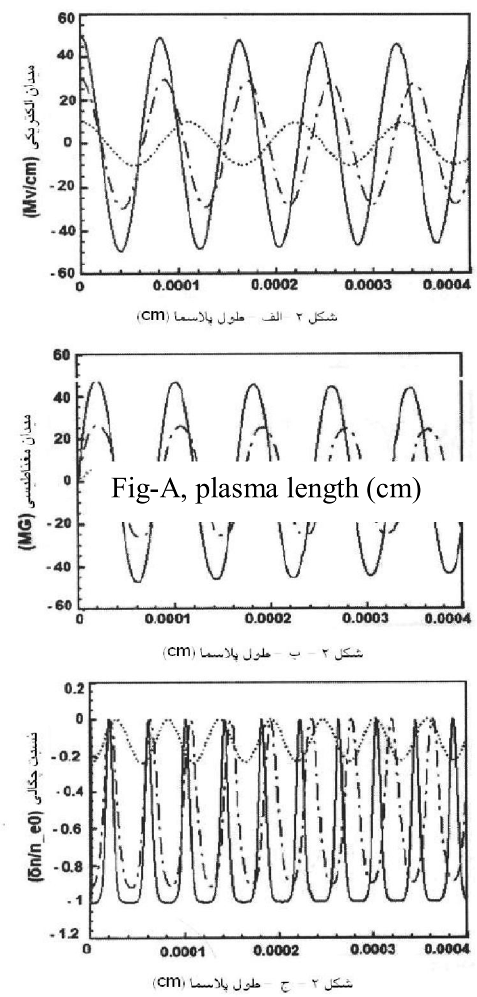

Fig –B, plasma length (cm)

Figure C-plasma length (cm)

Figure A , B and C

Electric field

(Mv/cm)

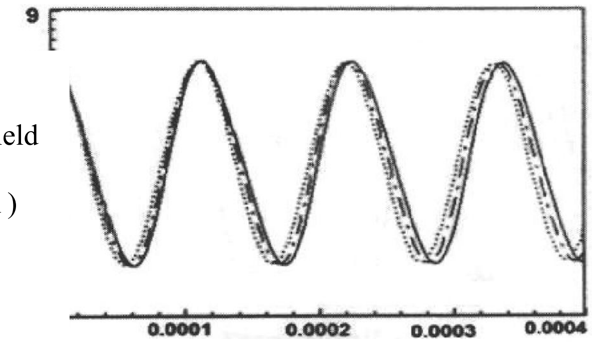

Fig-D, plasma length (cm)

Magnetic feild
(MG)

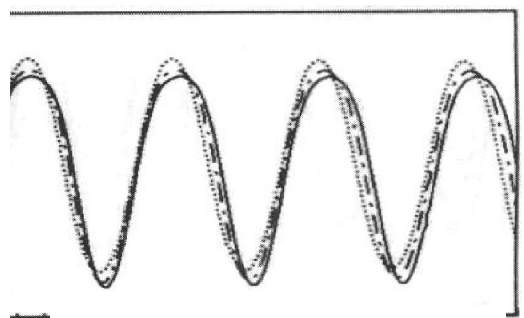

Fig-E, plasma length (cm)

شکل ۳ – ب – طول پلاسما (cm)

Density ration

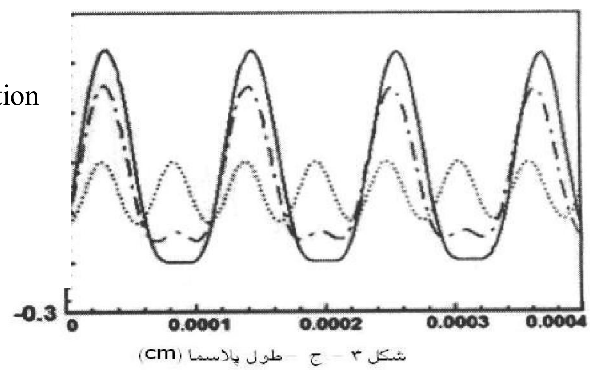

Fig-F, plasma length (cm)

Figure D, E and F

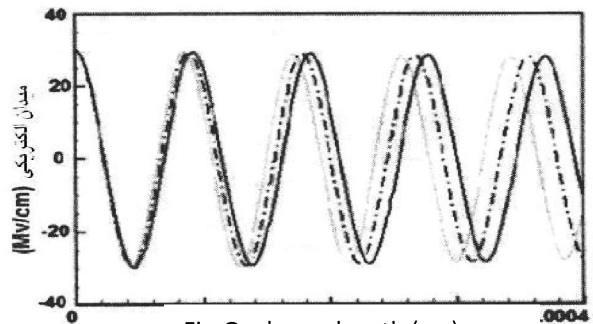

Fig-G, plasma length (cm)

Magnetic feild (MG)

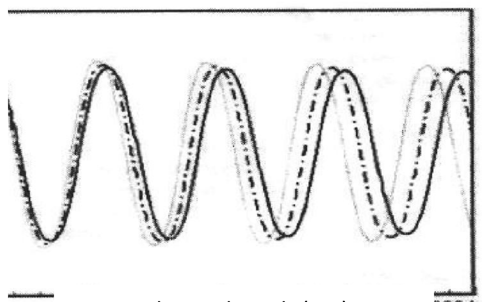

Fig-H, plasma length (cm)

Density ration

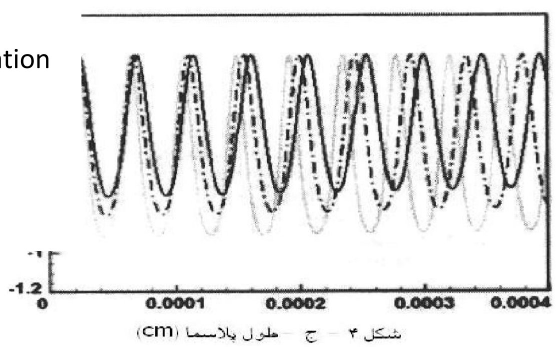

Fig-J, plasma length (cm)

Figure G, H and J

Effect of increase in electron temperature of non-magnetic plasma in lasers would be with the following intensity; $10^{15}\ \mathrm{W/cm^2}$ Electric field, magnetic field, and the ratio of electron density. $T_e = 20\,\mathrm{keV}$ in(bold lines), $T_e = 15\,\mathrm{keV}$ in(stretched dotted lines), $T_e = 10\,\mathrm{keV}$ in(dotted lines). $n_{0e} = 1.0\times10^{21}\ \mathrm{cm^{-3}}$ Shows the maximum electron density and $n_c = 1.7\times10^{21}\ \mathrm{cm^{-3}}$ shows the critical density.

Reference:

1- Shalom Eli Ezer ,2002 ,The interaction of high-power Laser with plasmas
2- D. Dorranian ,M Ghorannevis, , M. Starodubtsev, N. Yugami, and Y. Nishida,(2005) Laser Part. Beams23,583

3- Zobdeh,R. Sadighi-Bonabi, H.Afarideh, E Yazdani, and R. Rezaei-Nsirabad.(2008)Contrib.Plasma Phys.48.555
4- P. Zobdeh. R. Sadeghi-Bonabi,and H. Afarideh,(2008) Plasma Devices Oper.16,105
5- R. Sadighi-Bonabi,S . Ramatallahpor. H. Navid, E. Lotfi, P. Zobdeh, Z. Reiazie, M. Bostandoust, and M. Mohammadian, (2009)Contrib. Plasma Phys. 49,49
6- R. Sadighi-Bonabi, H. A. Navid, and P. Zobdeh,(2009)Laser Part. Beams 27,223
7- S. P. D Mangles, A. G. R. Thomas, O. Lundh, F. Landau, M. C. Kaluza, A. Persson, C. G. Wahistrom, K. Krusheinick, and Z. Najmudin,(2007) Phys. Plasmas14
8- R. Sadeghi-Bonabi, M. Habibi, and E. Yazdani,(2009) Phys. Plasma 16,083105
9- B. Qiao. S.Zhu. C. Y. Zheng, and X. T. He, Phys.(2005) Plasmas 12053104
10- R. Presura, C. Plechaty, D. Martinez, M.S. Bakeman. P.J. Laca. C. Haefner, A. L. Astanovitskiy, and M. Thompson, (2008) IEEE Trans. Plasma Sci. 36,17
11- K. W. Struve, J. L. Porter, and D. C. Rovang, (2008) Megagauss field generation for high-energy-density Plasma science experimments' SANDIA. Report No. SAND-
12- R. E. Siemon, B. S. Baure, T. J. Awe. A. Angelova, S. Fuelling, T. Goodrich, I.R. Lindemuth, V. makhin, W. L. Atchison,R. J. Faehl. R. E. Reinovsky, P. J. Turchi.J. H. Degnan, E. L. Ruden, M. H. Frese, S. F. Garanin, and V. N. Mokhov, (2008) Fusion Energy 27.235
13- A. Sharma and V. K. Tripathi, (2009) Phys. Plasmas 16.043103
14- D. N. Gupta. M. S. Hur, and H. Suk, (2009 Appl. Phys. Lett.91,081505).
15- D. Dorranian, M. Starodubtsev, H. Kawakami. H. Ito, N. Yugami, and Y. Nishid,(2003) Phys. E 68,026409
16- D. Dorranian, M Ghoranneviss, M. Starodubsev, H. Ito, N. Yugami. And Y. Nishida,(2004) Phys. Lett. A 331.77
17- Fransis. H. Bennet, 1994, Trans Lated by Dr, Hussein Mahdian, Esmaeel N amvar, Familiarity with Plasma Phycics and Controlled Flun, University Publicction Center.
18- Seloto, Eurasia,1982, Translated by Akbar Hariri, Hussein Gol Nabbi, Laser Principles, University Publication Center
19- Werdin Joseph Thamson,1995, Translated by. Dr.Mohammad Kazem Mmoravej Faraji, Hussein Gol Nabi, Laser electronic,the academic publication of sanati sharif university
20- Mohamad Qoran Nevis, 2007,plasma physics and its application, Islamic Azad university, Science and Research Branch.

1/8/2012