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THE STUDY OF THE WAKEFIELDS IN A PLASMA AND ITS EFFECT ON MATERIAL DEPOSITION, ITCHING, AND CUTTING

by

Nouara TINAKICHE[1]

[1]*Assistant Professor Class "A" (MCA) at the Department of Physics,*

Faculty of Science, U.M.B.B, Boumerdes, ALGERIA

tinakiche_nouara@yahoo.fr , nouara.tinakiche@gmail.com ,

n.tinakiche@univ-boumerdes.dz

Abstract

In this work, I use the fluid equations to study the wakefields generated in a relativistic and collisionless plasma acrossed by a neutrinos beam. We calculate this wakefield by taking into account the collision of these neutrinos with the neutrals of this plasma. This wakefield is very strong and we can consider it as a huge sourse of electric energy in an electron-positron-ion -neutral plasma [1]. This wakefield which is very strong could after a separation of charges accelerate effectively the ions and this will enhance the level of the material Itching, Deposition and Cutting and we can prove approximatly through a special experience and through the deposition process of materials the sense and the direction of this wakefield.

§.1.Introduction

We study in the present work, the generation of nonlinear structures in an electron-positron-ion plasma containing a large fraction of neutrals. We consider a beam of neutrinos passing through this plasma and undergoing collisions only with the neutrals of this plasma. The neutrinos entering in collision with neutrals are considered to have a mass and an induced charge. This allows to the neutrinos to have electromagnetic properties [1,2]. Indeed, according to the works (c.f. Ref.[1,2]), the neutrinos are assumed to have a nonzero charge. It is stated also in [3,4] that a neutrino propagating in a plasma acquires an induced charge. This charge is due to the interaction between the neutrino and the electrons in the plasma. In an electron-positron plasma, the electron-type neutrino induced negative charge, pushes the electrons, and the positrons are attracted by this charge. The resulting charge imbalance due to the charge separation, creates finite amplitude wakefields in the plasma (c.f. Ref.[4]). Though small, this charge permits to neutrinos to undergo processes such as Cherenkov emission or absorption of a photon. The works proving the existence of the mass and the charge of neutrinos (c.f. Ref.[1-6]) justify also the assumption of possible existence of collisions between neutrinos and neutrals. In this paper, we find the expressions of the electric field and the electric potential associated with the wakefield generated by the interaction of neutrinos with neutral-electron-positron-ion plasma taking into account the collision between neutrinos and neutrals in this plasma. On the other hand, the different techniques using plasmas to realize the three processes of itching, deposition, and cutting of materials could be improved by applying the Wakefield acceleration process on the plasmas used in this way to transform materials especially since this the Wakefield acceleration process is a very cheap technique. Knowing the high accelerations which can be reached by applying the Wakefield process on plasmas, we can expect, that the three processes of itching, deposition, and cutting of materials will know a real improvement and this will conduct to a high progress in scientific research and in industry. Such progress will save us enough time and energy and will give us best results and qualities. Knowing the different phenomena occurring in a plasma intended for these three processes of itching, deposition and cutting of materials, we have concluded that the increase of ions acceleration in this plasma will allow us to reach best results and more efficient itching, deposition and cutting of materials. Therefore, in our work, we support the idea that to improve the three processes of itching, deposition and cutting of materials we have to accelerate highly the ions of the plasma using the the Wakefield acceleration process. The paper is organized as follows: in Sec.2, we present the calculus of the maximum growth rate of the SRS process and we discuss and conclude in Sec.3

§.2.Theory

In this paper, we study the generation of large amplitude plasma waves in a neutral-electron-positron-ion plasma. In this work, the collective neutrino-plasma interaction $G_{\sigma\nu}$ occurs due to the effective neutrino weak charge (c.f. Ref.[4]):

$$G_{\sigma\nu}=\sqrt{2}G_F\left[\delta_{\sigma e}\delta_{\nu\nu_e}+\left(I_\sigma-2Q_\sigma\sin^2\theta_w\right)\right]$$

where $G_{\sigma\nu}=-G_{\bar{\sigma}\nu}$,which leads to the coupling of neutrinos to the plasma fluid. Here, σ denotes the electron e^-, the positron e^+ and ion " $\boldsymbol{i}$ " species of the plasma, G_F is the Fermi weak interaction coupling constant, it is given by $\frac{G_F}{(\hbar c)^3}\approx 1.2\times 10^{-5}GeV^{-2}$ (c.f. Ref.[7]),

θ_w is the Weinberg mixing angle $\sin^2\theta_w\approx 0.23$, I_σ is the weak isotopic spin of the particle of the species σ and $Q_\sigma=\frac{q_\sigma}{e}$ is the particle normalized electric charge.

The dynamics of the neutrinos can be described by:

$$\frac{\partial N_\nu}{\partial t}+\nabla.\vec{J}_\nu=0, \tag{1}$$

$$\frac{\partial\,\vec{p}_\nu}{\partial t}+\left(\vec{V}_\nu\,.\nabla\right)\vec{p}_\nu=\sum_\sigma G_{\sigma\nu}\left(\vec{E}_\sigma+\frac{\vec{V}_\nu}{c}\times\vec{B}_\sigma\right)-\nu_{c,\nu}\,\vec{p}_\nu\,, \tag{2}$$

We note that we have added the collisional term $\nu_{c,\nu}\vec{p}_\nu$ in (2), where $\vec{p}_\nu=\gamma_\nu\,m_\nu\,\vec{V}_\nu=\left(\frac{\vec{V}_\nu}{c^2}\right)E_\nu$. m_ν and $\vec{V}_\nu$ are respectively the mass and the velocity of the neutrino and $\gamma_\nu = 1\Big/\sqrt{1-V_\nu^2/c^2}$. $\nu_{c,\nu}$ is the frequency of collision between the neutrinos and neutrals. E_ν is the neutrino energy.

The first term in the right hand side of (2), represents the weak force, $\vec{F}_\nu$, acting on a single neutrino due to the plasma, where $\vec{E}_\sigma = -\nabla N_\sigma - \left(\frac{1}{c^2}\right)\left(\frac{\partial \vec{J}_\sigma}{\partial t}\right)$ and $\vec{B}_\sigma = c^{-1}\vec{\nabla}\times\vec{J}_\sigma$ are respectively the electric and magnetic fields (c.f. Ref.[8]). $\vec{J}_\nu = N_\nu \vec{V}_\nu$ and $\vec{J}_\sigma = N_\sigma \vec{V}_\sigma$ are the neutrino and σ species currents, respectively. In this work, all quantum mechanical effects and strong magnetic fields are neglected [4]. The plasma particles dynamics is described by the continuity and momentum equations, which are respectively:

$$\frac{\partial N_\sigma}{\partial t} + \nabla.\vec{J}_\sigma = 0, \tag{3}$$

$$\frac{\partial \vec{p}_\sigma}{\partial t} + \left(\vec{V}_\sigma . \nabla\right)\vec{p}_\sigma = q_\sigma \vec{E} - \frac{\vec{\nabla}\mathrm{P}_\sigma}{N_\sigma} + \sum_\nu G_{\sigma\nu}\left(\vec{E}_\nu + \frac{\vec{V}_\sigma}{c}\times\vec{B}_\nu\right), \tag{4}$$

Where $\vec{p}_\sigma = \gamma_\sigma m_\sigma \vec{V}_\sigma$ is the momentum of the particle species σ (electrons or positrons or ions) and $\gamma_\sigma = 1\Big/\sqrt{1-V_\sigma^2/c^2}$, $\vec{V}_\sigma$ being the velocity of the electron, the positron or the ion.

The right hand side of the equation (4) represents the total force acting on the plasma due to neutrinos, where $\vec{E}_\nu = -\nabla N_\nu - \left(\frac{1}{c^2}\right)\left(\frac{\partial \vec{J}_\nu}{\partial t}\right)$ and $\vec{B}_\nu = c^{-1}\vec{\nabla}\times\vec{J}_\nu$ are the weak electromagnetic fields [4]. In this set of equations N_σ represents the number density of the species σ (electrons or positrons or ion). $\mathrm{P}_\sigma = N_\sigma K T_\sigma$ is the kinetic pressure, where T_σ is the temperature of the species and K is the Boltzmann constant.

In writing the above equations we have neglected the collisions between electrons, positrons, ions and neutrals. In this paper, we consider a cold plasma where only the collisions between neutrinos and neutrals could occur and we neglect the other collisions between neutrinos and electrons, positrons and ions because the fraction of electrons, the fraction of positrons, and the fraction of ions in the plasma considered are very small compared to the fraction of the neutrals in this plasma.

For reason of simplicity, we consider only the electron-type neutrino supposed to move along the x-direction with the velocity $\vec{V}_\nu$ close to the light velocity c. We suppose also the motion of the other charged species of the plasma unidirectional and its direction is x. In this paper, we neglect also the contribution of the anti-neutrinos. The plasma is supposed to be relativistic, collisionless, cold and unmagnetized. The energy and the density of neutrinos don't change significantly when interacting with the plasma. We assume also that a small part of the energy of the neutrino is transferred to the plasma. In the frame of these assumptions, equation (2) can be rewritten as:

$$\frac{\partial E_\nu(x,t)}{\partial t}+c\frac{\partial E_\nu(x,t)}{\partial x}\approx\sqrt{2}G_F c\left(\frac{\partial}{\partial x}\left(N_{e^+}-N_{e^-}\right)+\frac{1}{c^2}\frac{\partial}{\partial t}\left(J_{e^+}-J_{e^-}\right)\right)-\nu_{c,\nu}\,E_\nu(x,t) \tag{5}$$

To obtain this last equation, we have considered the fact that the ions contribution to the plasma force acting on the electron-type neutrino fluid is negligible. In fact, the effect of the ions on the neutrino effective weak –interaction charge $G_{i\nu}$ is very small compared to the other species effects.

The relation between the electron, positron and ion fluid currents is given by:

$$\vec{J}_i+\vec{J}_{e^+}-\vec{J}_{e^-}=\frac{1}{4\pi e}\frac{\partial\vec{E}}{\partial t}$$

since we are interested to the generation of electrostatic waves. The electric field $\vec{E}$ is associated with the wakefield generated in the plasma. Hence, the equation (5) becomes:

$$\frac{\partial E_\nu(x,t)}{\partial t}+c\frac{\partial E_\nu(x,t)}{\partial x}\approx\sqrt{2}G_F c\left(\frac{\partial}{\partial x}\left(N_{e^+}-N_{e^-}\right)+\frac{1}{4\pi e}\frac{1}{c^2}\frac{\partial^2 E}{\partial t^2}-\frac{1}{c^2}\frac{\partial\vec{J}_i}{\partial t}\right)-\nu_{c,\nu}\,E_\nu(x,t) \tag{6}$$

In other hand, equations (1) and (3) give:

$$\frac{\partial N_\nu}{\partial t} + c\frac{\partial N_\nu}{\partial x} \approx 0 \tag{7}$$

$$\frac{\partial N_{e^-}}{\partial t} + \frac{\partial J_{e^-}}{\partial x} = 0 \tag{8}$$

$$\frac{\partial N_{e^+}}{\partial t} + \frac{\partial J_{e^+}}{\partial x} = 0 \tag{9}$$

$$\frac{\partial N_i}{\partial t} + \frac{\partial J_i}{\partial x} = 0 \tag{10}$$

From (8), (9) and (10), we can deduce the following expression:

$$\left(N_{e^+} - N_{e^-}\right) = \frac{-1}{4\pi e}\frac{\partial E}{\partial x} - N_i$$

In this work, we consider the ions motion very slow because of their inertia ($\vec{V}_i$ and $\vec{J}_i = N_i\vec{V}_i$ are very small). Therefore, the motion equation (4) above written for ions takes the following form:

$eE - \frac{\gamma K T_i}{N_i}\frac{\partial N_i}{\partial x} = 0$, where γ is the adiabatic coefficient, it is equal to $\gamma = 1$ in the isothermal case.

To render appropriate the rest of the calculus, a new independent variable $X = \left(x - V_\phi\, t\right)$ is used, where V_ϕ is the wave phase speed. In the following, we consider $E\left(X\right)$ and $E_\nu\left(X\right)$ as functions of the variable X only.

Hence, equation (6) becomes:

$$\left(c - V_\phi\right)\frac{d\,E_\nu\left(X\right)}{dX} + \sqrt{2}G_F c\frac{1}{4\pi e}\left(1 - \beta_\phi^2\right)\frac{d^2E\left(X\right)}{dX^2} + \nu_{c,\nu}\,E_\nu\left(X\right) + \sqrt{2}G_F c\frac{eE\left(X\right)}{\gamma K T_i}N_i = 0 \tag{11}$$

where $\beta_\phi = \dfrac{V_\phi}{c}$.

-Determination of the electric field $E(X)$ and the electric potential $\varphi(X)$ associated with the wakefield when E_ν is assumed to be constant:

We assume that during the interaction of the electron-type neutrinos with the plasma, their local energy E_ν doesn't change significantly and we set $E_\nu \approx$ constant. We put therefore $\dfrac{d\,E_\nu}{d\,X} \approx 0$ in the equation (11) and we find:

$$\sqrt{2}G_F c \frac{1}{4\pi e}\left(1-\beta_\phi^2\right)\frac{d^2E}{d\,X^2} + \sqrt{2}G_F c \frac{eE}{\gamma K T_i} N_i + \nu_{c,\nu}\, E_\nu = 0 \tag{12}$$

We assume also that $\nu_{c,\nu}$, N_i and T_i are constants and find the expressions of $E(X)$ and $\varphi(X)$. In this case, we have to resolve the following differential equation:

$$\frac{d^2E}{d\,X^2} + C\frac{N_i}{T_i}E + \alpha = 0 \tag{13-a}$$

where,

$$\alpha = \frac{4\pi e\, \nu_{c,\nu}\, E_\nu}{\sqrt{2}G_F c\left(1-\beta_\phi^2\right)} \tag{13-b}$$

and,

$$C = \frac{4\pi e^2}{\gamma K\left(1-\beta_\phi^2\right)}$$

(13-c)

We find the following expressions of $E(X)$ and $\varphi(X)$:

$$E(X)=c_1\cos\left(\sqrt{\frac{CN_i}{T_i}}\,X\right)+c_2\sin\left(\sqrt{\frac{CN_i}{T_i}}\,X\right)-\frac{\alpha T_i}{CN_i} \tag{14}$$

and,

$$\varphi(X)=\sqrt{\frac{T_i}{CN_i}}\left(c_2\cos\left(\sqrt{\frac{CN_i}{T_i}}\,X\right)-c_1\sin\left(\sqrt{\frac{CN_i}{T_i}}\,X\right)\right)+\frac{\alpha T_i}{CN_i}X+c_3 \tag{15}$$

c_1 , c_2 and c_3 are three constants of integration.

From the relations (14) and (15), we remark that the electric field $E(X)$ and the electric potential $\varphi(X)$ associated with the wakefield depend on the value of X ,E_ν, $\nu_{c,\nu}$, N_i and T_i. Therefore the generation and the evolution of the wakefield are affected by the values of these physical quantities. For a given value of E_ν, $\nu_{c,\nu}$, N_i and T_i, we remark also from the relation (13-b) that for $\beta_\phi=1$ (which implies $V_\phi=c$) $E(X)$ is finite and $\varphi(X)=\frac{\alpha T_i}{CN_i}X+c_3$. We see that this result is different of the one found in (c.f. Ref.[9]) and this is due to the introduction of ions to the neutral-electron-positron plasma considered in this previous work. In the work (c.f. Ref.[9]), we found that for $\beta_\phi=1$, $E(X)$ and $\varphi(X)$ become infinite and this leads to the generation of infinitely large wakefields in the plasma. The presence of ions in a neutral-electron-positron plasma modify therefore considerably the results. However, in the work of Serbeto et al [10] the electric potential $\varphi(x,t)$associated with the wakefield is calculated without taking into account the collisions between the neutrinos and the unmagnetized plasma particles (which are electrons and ions). $\varphi(x,t)$is given by [10]:

$$\varphi(x,t)=-\sigma_0\frac{(E_0-E_\nu)}{E_0}\left[1-COS\left(k_e x-\omega_e t\right)\right] \tag{16}$$

with $\sigma_0 = E_0 / \sqrt{2} G_F n_0 \left(2 - \beta_\phi\right)$ (17)

In other hand, the nonlinear interaction between an electron-type neutrino burst and a collisionless magnetized electron-positron plasma without including the collisions between the neutrino and the plasma particles is studied in the work of Serbeto et al [1]. The authors find the following expression for the electric field E:

$$E(x,t) = 3\frac{\omega_p^3}{\omega^3} S_\nu \left(\frac{\Omega_c^2}{2} (kx - \omega t) + \sin(kx - \omega t) \right) \tag{18}$$

where : $S_\nu = \dfrac{E_0 \left(1 - \beta_\phi\right)}{\sqrt{2} G_F N_0} \dfrac{\Delta E_\nu}{E_0}$ (19)

N_0, ω_p, Ω_c and E_0 are the equilibrium electron(positron) number density, the plasma frequency, the normalized gyrofrequency and the initial neutrino energy, respectively. Deep discussion of our results through figures could be found in the works of Nouara Tinakiche [9, 13].

RESULTS AND DISCUSSION:

In this paper, we study the generation of large amplitude plasma waves in a neutral-electron-positron-ion plasma CREATED in a laboratory (in the article [13], we have established the same theory but for an astrophysical plasma). From the theory presented above, the wakefield which is very strong (see the previous work of Nouara Tinakiche [13]) could after a separation of charges accelerate effectively the ions. These ACCELERATED ions will of course:

a) increase surely the velocity and the deep of itching of materials.
b) increase surely the velocity and the density of the deposition of the thin layers of materials.
c) by using a thermal plasma, the heating by the Wakefield process will surely increase the velocity and the thickness of the material cutting.
d) we can also determine approximately through a special experience and through the deposition process of materials the sense and the direction of this Wakefield.

and from the expression of the Wakefield given by Eq.(14), we can deduce that the level of the material Itching, Deposition and Cutting will be improved especially when the following cases ‘’ e, f, g, h ‘’ are realized:

e) we see that the wakefield $E(X)$ increases when the ions density N_i decreases and T_i increases or when the ratio $\frac{CN_i}{T_i} \approx 0$.

f) on the other hand, from the expression of the constant we deduce directly that the Wakefield $E(X)$ increases when the neutrinos energy E_ν is very high.

g) When the collision frequency $\nu_{c,\nu}$ increases, the induced charge and the constant α increase and this fact will lead to the generation of a strong Wakefield $E(X)$.

h) We propose in the present work to increase more and more the acceleration of the ions after their acceleration by the Wakefield process and this by adding a system of electrodes (between the material and the plasma) to increase their acceleration. Through this second acceleration, we hope to enhance more and more the efficiency of the itching, deposit and cutting of materials.

i) We think that the high accelerations of ions reached after this process using the Wakefield process could be very useful in medicine also as in PROTON- THERAPY (very hard dermatitis, bones problems (bones wrong formation for examples) and for disinfection.

Conclusion

In conclusion, we have presented a hydrodynamic description, to study the large amplitude wakefield plasma waves generated by intense electron-type neutrinos beams in a neutral-electron-positron-ion plasma, taking into account the collisions between neutrinos and neutrals. Physically, the generation of wakefields in this plasma is attributed to the induced negative charge that electron-type neutrinos acquire when they pass through the plasma. The induced negative charge pushes the electrons and attracts the positrons. The resulting charge imbalance due to the charge separation, in turn produces finite amplitude wakefields. In this work, we establish the differential equation which expresses the variation of the electric Wakefield and the electric potential associated with the wakefield. This work is mainly an attempt to study the effect of the neutrinos collisions on the wakefields generated in the plasma containing ions besides neutrals, electrons, and positrons. We find that the electric field and the electric potential depend essentially on the value of the collision frequency $\nu_{c,\nu}$ and the ions density N_i and their temperature T_i since we assume that the neutrinos energy E_ν remains approximately unchanged during the interaction neutrinos-plasma. Therefore the generation and the evolution of the wakefield are considerably affected by the value of the collision frequency $\nu_{c,\nu}$ and the ions density N_i and their temperature T_i. Through this study, we conclude that the strong wakefield process could accelerate effectively the ions of the plasma and this will improve considerably the material Itching, the Deposition and Cutting and from this wakefield process we can prove approximatly through a special experience and through the deposition process of materials the sense and the direction of this electric wakefield. We also resume our remarks in the points a, b, c, d, e ,f, g, h, and i in the part of results and discussion of our present work .

AVAILABILITY OF DATA /

Data available in article or supplementary material- The data that supports the findings of this study are available within the article [and its supplementary material].

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