# Parametric Coupling in Electron-Positron Plasmas

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**Abstract**: an unmagnetized electron/ion plasma supports three types of waves, namely, the Langmuir wave of a frequency greater than the electron plasma frequency, the ion-acoustic wave of a frequency lower than the ion plasma frequency (low frequency range) and the electromagnetic wave. Nonlinear coupling of these waves that occurs during laser/plasma interaction is a key issue in energy dissipation assessment. In this note, the heavy ion component is replaced by positrons, which respond promptly to any high frequency excitation (like electrons), and hence their contribution is to be considered in the determination of the nonlinear dispersion relation of the parametrically generated modes.

## Introduction

Electron-positron plasmas are a category of a wide range of what are called pair plasmas. Electron-positron plasmas are composed of electrons and positrons that have opposite charges but have the same mass. This lack of mass difference between electrons and positrons leads inexorably to the disappearance of any phenomenon that may arise due to it, such as ion-acoustic low-frequency waves, which occur in conventional electron-ion plasma (but no longer exist in a pair plasma). These plasmas are frequently encountered in active galactic nuclei, pulsar magnetosphere, solar flares, during ultra-short laser pulse/matter interaction and interplanetary space [1-5]. It has been reported also that non relativistic electron-positron plasmas may be produced by an interacting electron beam with high Z targets, or with a positron plasma stored in a Penning trap [6]. In this note, we attempt to study parametric instabilities occurring during an electromagnetic (EM) pump wave/pair plasma interaction. The non-linear dispersion relation is derived and the non-linear growth rate is deduced.

## Theory

Following Liu and Tripathi [7], we consider the propagation of an EM pump wave in a plasma, i.e., $\overrightarrow{E_0} = \overrightarrow{E_0}\exp[-i(\omega t - k_0.z)]$, and $\overrightarrow{B_0} = \overrightarrow{k_0} \times \overrightarrow{E_0}/\omega_0$. Electrons and positrons acquire an oscillatory velocity, $\vec{v}_{0e} = e\vec{E}_0/i\, m_e\omega_0$, and $\vec{v}_{0p} = -e\vec{E}_0/i\, m_p\omega_0$.

A pair of waves are excited, viz., a low frequency electrostatic wave, $\phi = \phi\exp[-i(\omega t - \vec{k}.\vec{r})]$, and a sideband EM wave $(\overrightarrow{E_1}, \overrightarrow{B_1})$, where the matching conditions are met, $\overrightarrow{k_1} = \vec{k} - \overrightarrow{k_0}$ and $\omega_1 = \omega - \omega_0$. The pump and the sideband waves exert low frequency ponderomotive forces $\overrightarrow{F_{pe}} = e\,\nabla\phi_p$ and $\overrightarrow{F_{pp}} = -\,e\,\nabla\phi_{pp}$, where,

$$\phi_{pp} = -\frac{m_e}{m_p}\phi_p = -\frac{m_e}{m_p}\frac{1+\chi_e+\chi_p}{\frac{m_e}{m_p}\chi_e - \chi_p}\phi \qquad (1)$$

The ponderomotive and the self-consistent low frequency forces drive density oscillations that couple to oscillatory velocities to give rise to a density current at frequency, $\omega_1$, which used in the wave equation gives,

$$D_1\varepsilon = -\frac{k^2|\overrightarrow{v_0}|^2}{4}(1-cos^2\delta_1)\left(\left(\frac{m_e}{m_p}\right)^2\chi_p + \chi_e\left[1+\left(1+\frac{m_e}{m_p}\right)^2\chi_p\right]\right) \qquad (2)$$

where, $\delta_1 = ang\,(\overrightarrow{E_0}, \overrightarrow{k_1})$, $\varepsilon = 1+\chi_e+\chi_p$, and $D_1 = \omega_1^2 - \omega_p^2(1+\frac{n_{0p}}{n_{0e}}\frac{m_e}{m_p}) - k_1^2c^2$. In the absence of the pump wave, the dispersion relation of the two modes in case of equal mass and density, $\omega_1^2 = k_1^2c^2 + 2\omega_p^2$ and $\omega^2 \approx 2\omega_p^2$.

In the case of ions, i.e., $\frac{m_e}{m_p} \ll 1$, we retrieve the usual equation,

$$D_1\varepsilon = -\frac{k^2|\overrightarrow{v_0}|^2}{4}(1-cos^2\delta_1)(1+\chi_i)\chi_e \qquad (3)$$

Whereas for non streaming positrons having the same density as the electrons, one may find that the nonlinear growth rate for, $\chi_e \sim -1, \frac{\partial\varepsilon}{\partial\omega} \sim \frac{4}{\omega}, \frac{\partial D_1}{\partial\omega_1} \sim 2\omega_1$, is given by,

$$\gamma_M \approx \frac{k\,|\overrightarrow{v_0}|}{4}\sqrt{\frac{\omega}{\omega_0-\omega}(1-cos^2\delta_1)} \approx 2^{1/4}\gamma_{M,ion} \qquad (4)$$

## Conclusion

To conclude we recall that due to the mass of the positron, which is comparable to the electron mass, collective phenomena occurring on the ion timescale disappear. In addition, high frequency modes supported by a pair plasma such as EM and ES waves, propagate with modified phase and group velocities. Non-linear interaction of these modes is also affected by the lack of mass difference between electrons and positrons. In this note, we derived the non-linear dispersion relation and deduced the non-linear growth rate of some parametric processes. In the case of SRS, the non-linear growth rate experiences a twenty percent increase with respect to the one calculated in an electron-ion plasma.

## References

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