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Langmuir Wave Instability And Photoelectron Emission In Irradiated Dusty Plasmas

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Abstract

We have investigated dust charged fluctuation due to the combined effect of Langmuir Wave and Photoelectron Emission in Irradiated Dusty Plasma. The dispersion relation and growth of the Langmuir wave instability is also presented. The applicability of the developed dispersion relation and growth rate of the Langmuir wave instability is analysed graphically.

Keyword: Langmuir Wave, Photoelectron Emission, Irradiated Dusty Plasma.

Introduction

The presence of dust grains can significantly affect the behaviour of plasma in which they are immersed. Both electrons and ions will be collected by the dust grains, but since the electrons move about more swiftly than the ions, the grains tend to acquire a negative charge. Secondary and photoelectron emission from grains in irradiative or energetic plasma environments may also contribute to grain charging and can lead to positively charged grains. Dusty grains with the range of 10nm to 100µm can be found in both natural and laboratory plasmas [1]. Example includes cometary environments, planetary rings, the interstellar medium, and the lower ionosphere [2].

Dust has been found to be a deterimental component of rf plasmas used in the microelectronic processing industry and it may also be present in the limiter region of fusion plasmas due to the sputtering of carbon by energetic particles [3]. Negative and positive dust grains can coexist in some situations of dusty plasma [4, 5]. Dust grains of some special circumstances of dusty plasmas, may be charged significantly by thermionic emission, impact of ionization etc. [6].

The presence of static charged dust grains has been found to modify the existing plasma wave spectra [6], while dust dynamics has been discovered to introduce new eigen modes such as dust-acoustic (DA) mode, Dust Lattice (DL) mode etc. [7,8,9,10]. Collective perturbation of plasma parameters in a dusty plasma, can exhibit self consistent dust charge fluctuations in response to oscillations in the plasma currents following into them. The self consistent dust charge fluctuation oscillation can be sustained by the low frequency oscillation of the order of ion oscillation and this usually leads to the damping of the mode [11, 12]. However, Langmuir wave (which are high frequency electron plasma wave) perturbations can not influence the self consistent dust charge fluctuation oscillation.

Recently, Islam and Nakashim [1] have proposed a different mechanism of sustaining high frequency dust charge fluctuation oscillation by the combined effect of Langmiur wave and photoelectron emission. Langmiur oscillation results; in the build-up of perturbed electron on the dust grain, which can be removed by photoelectric emission. It is observed that the Langmiur wave can be instable due to dust charge fluctuation effect in irradiated streaming dusty plasma, provided electron-neutral collisional damping is negligible.

In this report, we show that the growth rate of Langmiur wave in collisionless plasma in which the streaming velocity of electrons exceeds the wave phase velocity due to dust charge fluctuation effect depends on equilibrium dust grain density, radius of dust grains, thermal velocity of electrons and electron streaming velocity. The paper is organized as follows. The basic theory is formulated in section 2 and the analytical results also presented. Finally, our results are summarized and discussed in section 3.

2 Formulation

We consider homogenous and uniform dusty plasma which is made-up of electrons, negatively/positively charged dust grains, ions and neutrals. The electrons are streaming with a velocity V_{eo} while the neutral gas is taken

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to be at rest. The dust charge $Q_d = \pm Z_d e$, where Z_d is the number of charge on the dust grain and *e* is the electron charge. Assuming a high frequency electrostatic wave with mode $(\omega, \hat{k})$ propagating in the dusty plasma, the dust will acquire a perturbed charge, Q_{d1} where ω and $\hat{k}$ are the frequency and propagation vector of the mode respectively. We shall ignore the ions and dusts dynamics because, high frequency oscillation (like Langmiur oscillations) occur so fast that; the massive ions and dust do not
have time to respond to the oscillating field. Hence, they could be considered to be fixed. Also the ions contribution to the fluctuating dust grain charge is ignored.

The continuity and momentum equations for electrons in the dusty plasma are given as follows:

$$\frac{\partial n_e}{\partial t} + \nabla.(n_e V_e) = 0 \tag{2.1}$$

$$m n_e \left[\frac{\partial V_e}{\partial t} + (V_e.\nabla) V_e \right] = -e n_e E - \nabla p_e - v_e n_e m_e V_e , \tag{2.2}$$

where m, n_e, V_e and P_e are te mass, density velocity and pressure of electron respectively. v_e is the collisional frequency of electrons with neutral atoms/molecules, while E is the electric field.

Equations (2.1) and (2.2) are coupled to the following set of
equations namely: Quasi-neutrality equation

$$n_e = n_i + \frac{Q_d n_d}{e}, \tag{2.3}$$

Poisson's equation

$$-\nabla^2 \phi = 4\pi e \left[\frac{Q_d n_d}{e} - n_e \right], \tag{2.4}$$

and basic dust charging equation

$$\frac{dQ_d}{dt} = I_e + I_{pe} + I_i , \tag{2.5}$$

where I_e, I_{pe} and I_i are the electron current, photoelectric current and ion current collected by the dust grains respectively. While n_d and n_i represent dust density and ion density.

The approximated expression of electron current to positively charged dust grain for electron streaming velocity much larger than the thermal velocity electron is written as;

$$I_e = -\pi r_d^2 (e n_e V_e) \left[1 - \frac{2e(\phi_p - \phi_d)}{m_e V_e^2} \right]. \tag{2.6}$$

while, the photoelectric current has the form:

$$I_{pe} = \pi r_d^2 e n_e \sqrt{\frac{2}{m_e}(h v_p - e\phi_0)}, \tag{2.7}$$

where h, v_p and ϕ_0 are the Planck's constant, irradiation frequency and work function respectively. The dust radius, bulk plasma potential and dust grain surface potential are denoted as r_d, ϕ_p and ϕ_d respectively. It can be observed that, there is no expression for ion current since ion current to dust charge fluctuation had been ignored.

Using the usual linearization technique for equation (2.1) – (2.7) and considering the variation of perturbed quantities as $\exp[i(\hat{k}.\hat{r} - \omega t)]$, we obtain:

$$\varpi n_{ei} - K n_{e0} V_{e1} = 0, \tag{2.8}$$

$$V_{e1} (\varpi + i v_e) - K V_{the}^2 \frac{n_{e1}}{n_{e0}} + \frac{e}{m_e} k \phi_1 = 0 \tag{2.9}$$

$$Q_1 = \frac{4\pi e}{K^2} \left[-n_{e1} + \frac{n_{d0}}{2} Q_{d1} \right], \tag{2.10}$$

$$\frac{dQ_{d1}}{dt} = I_{e1} + I_{pe1}, \tag{2.11}$$

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and

$$I_{e1} = -e\pi r_d^2 \left(n_{e0}V_{e1} + n_{e1}V_{e0}\right)\left[1 + \frac{2e\phi_{d0}}{m_e V_{e0}^2}\right], \qquad (2.12)$$

$$I_{pe1} = \pi r_d^2 e n_{e1}\sqrt{\frac{2}{m_e}\left(h\nu_p - e\phi_0\right)}, \qquad (2.13)$$

where $\overline{\omega} = \omega - KV_{e0}$ is the Doppler shifted frequency and $V_{the} = \sqrt{\frac{K_B T_e}{m_e}}$ is the electron thermal velocity. At equilibrium, $\nabla n_{e0} = \phi_{p0} = 0$ and $I_{e0} + I_{p0} + I_{i0} = 0$; noting that $I_{i1} = 0$. The perturbed electron density is obtained from

equations (2.8) and (2.9) as:

$$n_{e1} = -\frac{ek^2\phi_1 n_{e0}}{m_e\left[\overline{\omega}\left(\overline{\omega} + i\nu_e\right) - k^2V_{the}^2\right]}. \qquad (2.14)$$

Making use of equations (2.12), (2.13) and (2.8), the dust charge

fluctuation from equation (2.11) reduces to

$$Q_{d1} = \frac{i\left|I_{pe0}\right|}{\omega}\frac{n_{e1}}{n_{e0}} - \frac{i\left|I_{e0}\right|}{kV_{e0}}\frac{n_{e1}}{n_{e0}}. \qquad (2.15)$$

The application of equation (2.15) in equation (2.10) gives the linearized Poisson's equation as:

$$\phi_1 = \frac{4\pi e}{k^2}\left[-1 + \frac{i\beta_{pe}}{\omega} - \frac{i\beta}{kV_{e0}}\right]n_{e1}, \qquad (2.16)$$

where $\beta_{pe} = \left(\frac{\left|I_{pe0}\right|}{e}\right)\left(\frac{n_{d0}}{n_{e0}}\right) = \pi r_d^2 n_{d0}V_{pe}$; $\beta = \left(\frac{\left|I_{pe0}\right|}{e}\right)\left(\frac{n_{d0}}{n_{e0}}\right) = \left[1 + \frac{\left(2e\phi_{d0}\right)}{\left(m_e V_{e0}^2\right)}\right]\pi r_d^2 n_{d0}V_{e0}$

and the velocity of photoelectron is $V_{pe} = \sqrt{\frac{2\left(h\nu_p - e\phi_0\right)}{m_e}}$. The terms i$\beta_{pe}$ and $i\beta$ are due to coupling to dust charge fluctuations, while the coupling parameter β represent an effective collision frequency of the streaming electrons with the dust grains. β_{pe} on the other hand, is the effective detachment frequency of photoelectron from the dust grains.

The dispersion relation of Langmiur wave instability in a collisional and streaming dusty plasma with dust charge fluctuation is given as:

$$\omega = \pm\sqrt{\left(\omega_{pe}^2 + k^2V_{the}^2\right)} + kV_{e0} - \frac{i}{2}\nu_e + \frac{i}{2}\left[\frac{\left|I_{pe0}\right|}{\omega\left(kV_{e0} - \omega\right)} + \frac{\left|I_{e0}\right|}{kV_{e0}\left(\omega - kV_{e0}\right)}\right]\frac{\omega_{pe}^2}{e}\frac{n_{d0}}{n_{e0}}, \qquad (2.17)$$

where $\omega_{pe} = \sqrt{\frac{4\pi n_{e0}e^2}{m_e}}$ the electron plasma frequency. The first term on the right hand side of equation (2.17) is the Langmiur mode. The streaming of electron which shifts the real part of the Langmiur wave is represented by the second term. The damping of the Langmiur mode is represented by the electron – neutral collision term given as the third term. While, fourth and fifth imaginary terms are due to the dust charge fluctuation.

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For $V_{e0} > \frac{\omega}{k}$, equation (2.17) reduces to $\omega = \pm\sqrt{\left(\omega_{pe}^2 + k^2 V_{the}^2\right)} + kV_{e0} - \frac{i}{2}v_e + \frac{i}{2}\frac{|I_{pe0}|}{\omega k V_{e0}}\frac{\omega_{pe}^2}{e}\frac{n_{d0}}{n_{e0}}$. (2.18)

If the electron streaming velocity exceeds the wave phase velocity (i.e $V_{e0}>V_{the}$) and considering the case of $k\lambda_{pe} = 1$; the growth rate of Langmiur wave instability in a collisionless dusty plasma $(v_e = 0)$ is written as

$$\gamma = \frac{\pi}{2}\left(r_d^2 n_{d0}\right)\frac{V_{the}^2}{V_{e0}}, \tag{2.19}$$

where the electron Debye length is $\lambda_{De} = \frac{V_{the}}{\omega_{pe}}$ and $V_{e0} \approx V_{pe}$ is considered.

3. Discussion and Conclusion

We have investigated Langmiur wave instability in a collisional and streaming dusty plasma, with dust charge fluctuations to obtain a dispersion relation as while as the growth rate of the wave instability. For the numerical solutions of the developed dispersion relation and growth rate of the Langmiur wave instability for the collisionless dusty plasma, we consider the following numerical parameters: radius of dust grain (r_d) = 10nm [1], dusty density (n_{d0}) = $10^4 \times 10^6 m^{-3}$, streaming velocity of electron (V_{e0}) = 30ev and electron temperature (T_e) = 2ev [13].

In figure 1, we have the variation of growth rate with dust grain radius. As can be observed from the graph, it is seen that as the dust radius increases the growth rate also increases as a graph of an exponential function. In figure 2, we have a linear variation of growth rate with the temperature of the electron. While in figure 3, the variation of growth rate with the streaming electron velocity drops exponentially from maximum to almost zero as the streaming electron velocity increases.

For the plot of the positive real frequency with the streaming velocity, we have a linear variation as presented in figure 4.

We have seen that; the Langmuir wave can be unstable due to dust charge fluctuation effect when the streaming velocity of electrons exceeds the phase velocity of the wave, with the electron-neutral collisional damping neglected. The present study may help in further understanding of dust charge fluctuation in high frequency mode both in natural and laboratory dusty plasmas.

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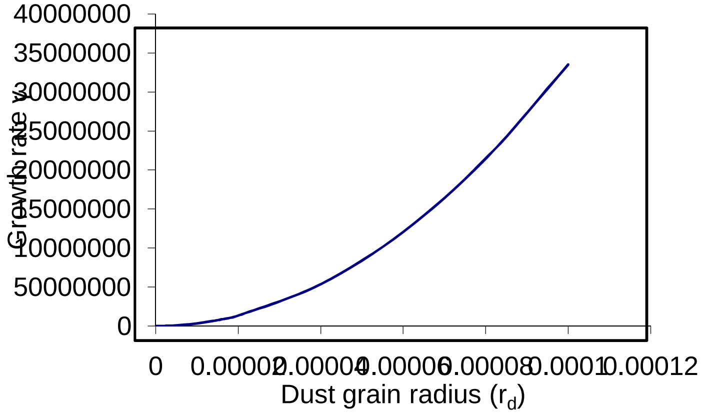

Fig.1: Variation of growth rate with dust grain radius (r_d).

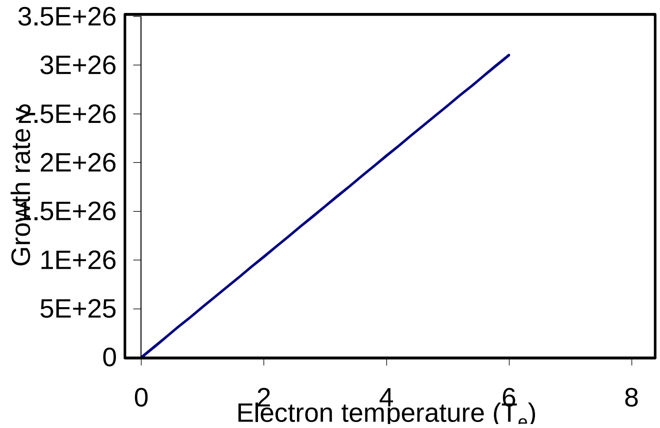

Fig.2: Variation of growth rate with electron temperature.

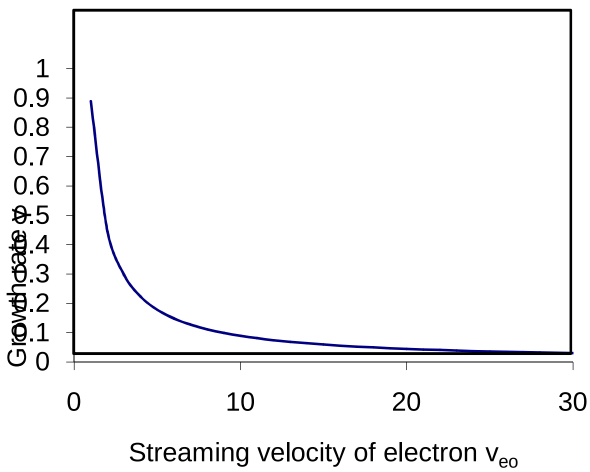

Fig.3: Variation of growth with streaming velocity of electron v_{eo}.

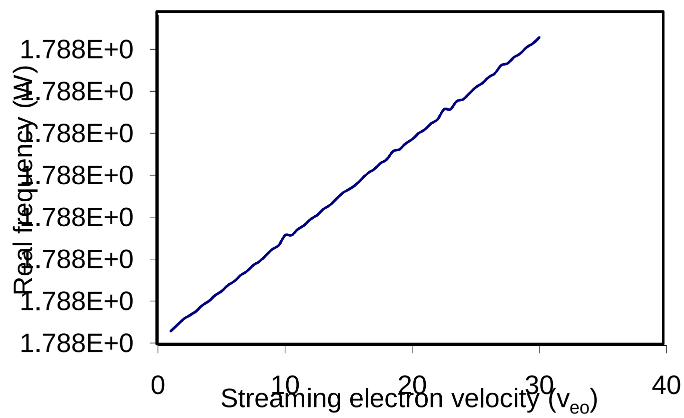

Fig.4: Variation of positive real frequency with streaming velocity

References

1. M. K. Islam and Y. Nakashim (2004). J. Plasma Fusion Res. **6**, 738.
2. F. Verheest. *Waves in Dusty Space Plasma*. (Kliwer Academic, Dordrecht, 2000).
3. R. . Merlino; A. Barkan, C. Thompson and N. D'Angelo (1998). Phys. Plasmas. **5**, 1607.
4. C. K. Goertz. Rev. Geo Phys. **27,** 271.
5. M. Horanyi; B. Walch; S. Robertson and D. Alexander (1998). J. Geo Phys. Res. **103**, 8575.
6. P. K. Shukla and A. A. Mamun. *Introduction to Dusty Plasma Physics.* (10p Press, Bristol, 2002).
7. M. Tribche; R. Hamdi and T. H. Zerguini (2000). Phys. Plasmas, **7**, 4013.
8. M. Tribechi; H. Houili and T. H. Zerguini (2002). Phys. Plasmas, **9**, 419.
9. M. Tribeche; T. H. Zerguini and H. Houili (2002). Phys. Plasmas, **9**, 4879.
10. H. Houili, M. Tribeche and T. H. Zerguini (2002). J. Plasma Phys. **67**, 115.
11. M. R. Jana; A. Sen and P. K. Kaw (1993). Phys. Rev. E. **48**, 3930.
12. M. K. Islam; A. K. Banerjee; M. Salahudelin (2001). Physica Scripta, **64**, 482.

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13. A. A. Samarian; O. S. Vauliina; A. P. Nefedov; V. E. Fortov; B. W. James and O. F. Petrov. (2001). Phys. Rev. E. **64**, 056407-1.

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