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Weibel instability oscillation in a dusty plasma with counter-streaming electrons

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Abstract

We investigate the Weibel instability (WI) in a dusty plasma which is driven to oscillation by the addition of dust grains in the plasma. Our analysis predicts the existence of three modes in a dusty plasma. There is a high-frequency electromagnetic mode, whose frequency increases with an increase in the relative number density of dust grains and which approaches instability due to the presence of dust grains. The second mode is a damping mode which exists due to dust charge fluctuations in plasma. The third mode is the oscillating WI mode. The dispersion relation and the growth rate of various modes in the dusty plasma are derived using the first-order perturbation theory. The effect of dust grain parameters on frequency and growth rate is also studied and reported.

Introduction

A general property of the dusty plasma system is the spontaneous self-excited oscillation of organized or random motion. This may lead to new instabilities in the presence of dust grains or influence the characteristics of plasma instabilities without dust. Weibel instability (WI) is one such electromagnetic instability which converts the kinetic energy of streaming electrons in plasma into magnetic energy capable of sustaining a collisionless shock. WI is important for an understanding of the energetic electromagnetic emissions of gamma-ray bursts and supernova explosions. WI mainly occurs due to the current neutralization of the beam-plasma interaction (Guskov, 2005; Velarde *et al*., 2005; Zhou and He, 2007) and generates growing electromagnetic vibrations. WI for the first time was observed by Weibel (1959) in 1959, taking bi-Maxwellian electron distribution function, and further a wide range of anisotropic plasma distributions had been studied. Fried (1959) gave a simple explanation of the instability as the superposition of many counter-streaming beams which resembles the two-stream instability.

Pokhotelov and Balikhin (2012) concluded that the frequency of the instability varies proportionally to the electron temperature anisotropy when observed in plasma with a non-zero external magnetic field. The WI in strongly magnetized microwave-produced plasma has been reported by Ghorbanalilu (2006). The effect of magnetic field on WI was examined by Ji-Wei and Wen-Bing (2005), where they have observed that the strong background of magnetic field stabilizes the WI in electron-ion plasmas. The study of space charge in the current filamentation has been conducted by Tzoufras *et al.* (2006), and the generation of the magnetic field was observed via the WI in interpenetrating plasma flows by Huntington *et al.* (2015). An experimental study of filamentation due to the WI in counter-streaming laser-ablated plasmas has also been conducted by Dong *et al.* (2016). The important feature of WI is that it can make the ordinary waves unstable in the presence of temperature anisotropy, and this character of the instability has been investigated by many researchers in their work (Furth, 1963; Hamasaki, 1968; Davidson, 1983; Bashir and Murtaza, 2012; Ibscher and Schlickeiser, 2014; Treumann and Baumjohann, 2014).

Electromagnetic wave fluctuations are a subject of great attraction in the field of dusty plasma. Dahamni *et al.* (2005) have studied the excitation of electromagnetic waves via WI, in the presence of counter-streaming dust beams and agglomeration of dust grains. Dust kinetic Alfven and acoustic waves in a Lorentzian plasma (Rubab *et al*., 2009), Kinetic Alfven wave instability in an unmagnetized dusty plasma (Rubab *et al*., 2011) has been studied to study the effect of dust on these waves. Dispersion relation using many particle distribution functions for investigation on ordinary-wave WI in space plasmas has been derived by Rubab *et al.* (2016).

In this paper, we investigate the role of dust grains on electromagnetic wave modes generated via WI due to counter-propagating electrons. The instability analysis has been carried out in the following section. We have obtained the response of streaming electrons by fluid treatment and the expression for the growth rate of electromagnetic instability by first-order perturbation theory. The Results and Discussion and Conclusion are presented in the final two sections, respectively.

Instability analysis

We consider a dusty plasma comprising of two types of electrons that possess drift velocities $\upsilon_0\hat{z}$ and $-\upsilon_0\hat{z}$, respectively, with ions and dust particles. The equilibrium density of ions is n_{i0}, of dust grains is n_{d0}, and that of electrons is n_{e0}. The charge, mass, and temperature of the electrons, ions, and dust particles are denoted by $(-e, m_e, T_e)$, (e, m_i, T_i), and $(-Q_{d0}, m_d, T_d)$, respectively. Initially, there is no external electric and magnetic field ($E_0 = B_0 = 0$). At equilibrium, the electrons acquire a thermal velocity $v_{te} = (T_e/m_e)^{1/2}$.

A dusty plasma is unstable to a magnetic field perturbation $B_1\hat{y}$ with a wave vector k along the x-axis. We assume that the electromagnetic perturbation due to the magnetic field $\vec{B}_1 = \hat{y}B_1\exp(i\omega t - ikx)$ and the electric field associated with it is given by $\vec{E}_1 = \hat{z}E_1\exp(i\omega t - ikx)$.

The electron's response to the above field can be given by the fluid equation of motion

$$\frac{\partial\vec{\upsilon}}{\partial t} + (\vec{\upsilon}\cdot\nabla)\vec{\upsilon} = -\frac{e\vec{E}}{m_e} - \frac{e}{cm_e}\vec{\upsilon}\times\vec{B} \tag{1}$$

and the equation of continuity

$$\frac{\partial n}{\partial t} + \nabla\cdot(n\vec{\upsilon}) = 0, \tag{2}$$

where $n = n_{e0} + n_{e1}\exp(i\omega t - ikx)$ and $\vec{\upsilon} = \upsilon_0\hat{z} + \vec{\upsilon}_1\exp(i\omega t - ikx)$.

In Eq. (1), the pressure term is neglected. Neglecting the pressure term can be justified as the phase velocity of the wave is greater than the electron thermal velocity$\left(\text{i.e., } \omega/k \gg v_{te}\right)$. On linearization, from Eqs (1) and (2), the perturbed density for electrons is obtained as follows:

$$n_{e1} = \frac{-n_{e0}k_x^2 eE_1\upsilon_0}{im_e\omega^3}, \tag{3}$$

where we have used $\vec{B}_1 = (c\vec{k}\times\vec{E}_1/\omega)$. Perturbed dust grain density can also be obtained from Eq. (2) by replacing n_{e0} by n_{d0}, e by $-Q_{d0}$ (for negatively charged dust grains), υ_0 by υ_{d0}, and m_e by m_d as $n_{d1} = (n_{d0}k_x^2 Q_{d0}E_1\upsilon_{d0}/im_d\omega^3)$.

But $n_{d1} = 0$ as $\upsilon_{d0} = 0$, that is, the dust grain number density will fluctuate only if they have an equilibrium velocity in plasma or the dust grains are mobile.

Whipple *et al.* (1985) and Jana *et al.* (1993) have expressed the dust charge fluctuation in terms of an equation:

$$\frac{dQ_{d1}}{dt} + \eta_1 Q_{d1} = -|I_{e0}|\left(-\frac{n_{e1}}{n_{e0}}\right), \tag{4}$$

where we have considered $n_{i1} \sim 0$ in the present analysis due to a high-frequency regime, $\eta = |I_{e0}|e/C_g(1/T_e + 1/T_i - e\phi_g)$ (dust charging rate), I_{e0} is the equilibrium electron current collected by dust grains, $Q_{d1} = (Q_d - Q_{d0})$ (perturbed dust grain charge), $C_g = a + a^2(\lambda_{De}^{-1})$ (dust grain's capacitance), a is the dust grain radius, and λ_{De} is the electron Debye length. The expression for dust charge fluctuation in Eq. (4) can be rewritten as follows:

$$Q_{d1} = \frac{|I_{e0}|}{i(\omega + i\eta)}\left(-\frac{n_{e1}}{n_{e0}}\right). \tag{5}$$

Putting the value of n_{e1} from Eq. (3) in Eq. (5), we obtain the perturbed dust grain charge as follows:

$$Q_{d1} = \frac{|I_{e0}|}{(\omega + i\eta)}\frac{\upsilon_0 k_x^2 eE_1}{m_d\omega^3}. \tag{6}$$

Using Poisson's equation $\nabla\cdot\vec{E}_1 = 4\pi n_{d0}Q_{d1}$, we obtain

$$\nabla\cdot\vec{E}_1 = \omega_{pe}^2\frac{\beta\upsilon_0}{(\omega + i\eta)}\frac{k_x^2 E_1}{\omega^3}, \tag{7}$$

where $\omega_{pe} = (4\pi n_{e0}e^2/m_e)^{1/2}$ is the electron plasma frequency, and $\beta = (|I_{e0}|/e)(n_{d0}/n_{e0})$ is the dust plasma coupling parameter. Using the charge neutrality condition (Prakash and Sharma, 2009), the dust plasma coupling parameter β can be written as $\beta = 0.397(1-(1/\delta))(a/v_{te})(m_i/m_e)\omega_{pi}^2$, and $\eta = 10^{-2}\omega_{pe}\left(a/\lambda_{De}\right)(1/\delta)$, where η is the time scale of delay.

Using the charge neutrality condition, we obtain the following equation:

$$-en_{i0} + en_{e0} + Q_{d0}n_{d0} = 0 \text{ or } \frac{n_{d0}}{n_{e0}} = (\delta - 1)\frac{e}{Q_{d0}}, \tag{8}$$

where $\delta = n_{i0}/n_{e0}$ is the relative density of negatively charged dust grains in plasma.

The wave equation can be written using Maxwell's equations as follows:

$$\nabla^2\vec{E}_1 - \nabla(\nabla\cdot\vec{E}_1) + \frac{\omega^2}{c^2}\vec{E}_1 = -\frac{4\pi i\omega}{c^2}\vec{J}_{1z}, \tag{9}$$

where J_{1z} is the net perturbed current density.

For plasma electrons propagating in one direction, current densities are obtained by using Eq. (2) as

$$\vec{J}_{e1x} = -n_0 e^2 E_1\tfrac{k_x v_0}{mi\omega^2} \text{ and } \vec{J}_{e1z} = -n_0 e^2 E_1\tfrac{1}{mi\omega}\left[1 + \tfrac{k_x^2 v_0^2}{\omega^2}\right].$$

Analogous expressions may be written for the perturbed current density of plasma electrons moving in other direction. Since the x-component of current density is proportional to υ_0; therefore, they cancel each other in net current density. However, the z-component is proportional to υ_0^2, thus giving the net perturbed current density as follows:

$$\vec{J}_1 = -2n_{e0}e^2 E_1\frac{1}{im_e\omega}\left[1 + \frac{k_x^2\upsilon_0^2}{\omega^2}\right]. \tag{10}$$

Putting the value of $\vec{J}_1$ from Eq. (10) and $\nabla\cdot\vec{E}_1$ from Eq. (7), we can rewrite Eq. (9) as follows:

$$\nabla^2\vec{E}_1 + \nabla\left[\omega_{pe}^2\frac{\beta\upsilon_0}{(\omega + i\eta)}\frac{k_x^2 E_1}{\omega^3}\right] + \frac{\omega^2}{c^2}\vec{E}_1 = -\frac{4\pi i\omega}{c^2}\vec{J}_1. \tag{11}$$

Further, solving Eq. (11), we obtain the following equation:

$$\omega^4 - (k_x^2c^2 + 2\omega_{pe}^2)\omega^2 - 2\omega_{pe}^2 k_x^2\upsilon_0^2 = \frac{i\beta}{(\omega + i\eta)}\omega_{pe}^2\frac{k_x^3\upsilon_0 c^2}{\omega}. \tag{12}$$

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In the absence of dust $\delta(=n_{i0}/n_{e0})=1$, that is, $\beta\to 0$, then Eq. (12) transforms into

$$(\omega^2-\omega_+^2)(\omega^2-\omega_-^2)=0,$$

where

$$\omega_+^2=(k_x^2c^2+2\omega_{pe}^2)+\frac{2\omega_{pe}^2k_x^2\upsilon_0^2}{(k_x^2c^2+2\omega_{pe}^2)} \tag{13}$$

and

$$\omega_-^2=\frac{-2\omega_{pe}^2k_x^2\upsilon_0^2}{(k_x^2c^2+2\omega_{pe}^2)}. \tag{14}$$

Equation (14) of ω_- corresponds to the usual dispersion relation of the WI. Now, we rewrite Eq. (12) in the presence of dust as

$$(\omega^2-\omega_+^2)(\omega^2-\omega_-^2)(\omega+i\eta)\,\omega=i\beta\omega_{pe}^2k_x^3\upsilon_0c^2\cdot \tag{15}$$

Further, we solve Eq. (13) under three limits:

Case I: Solving Eq. (13) for $\omega=\omega_++\Delta_1$, we get the following equation:

$$\Delta_1=i\beta\frac{\omega_{pe}^2k_x^3\upsilon_0c^2}{2\omega_+(\omega_+^2-\omega_-^2)(\omega_+^2+\eta^2)}+\beta\eta\frac{\omega_{pe}^2k_x^3\upsilon_0c^2}{2\omega_+^2(\omega_+^2-\omega_-^2)(\omega_+^2+\eta^2)}.$$

where Δ_1 is a small mismatch in the frequency due to dust particle.

Therefore, the growth rate corresponding to $\omega=\omega_++\Delta_1$ is

$$\Gamma_1=\mathrm{Im}(\Delta_1)=\frac{\beta\omega_{pe}^2k_x^3\upsilon_0c^2}{2\omega_+(\omega_+^2-\omega_-^2)(\omega_+^2+\eta^2)}. \tag{16}$$

Case II: Again, solving Eq. (14) for $\omega=-i\eta+\Delta_2$, we get the following equation:

$$\Delta_2=\frac{-\beta\omega_{pe}^2k_x^3\upsilon_0c^2}{\eta\,(\omega_+^2+\eta^2)\,(\omega_-^2+\eta^2)}. \tag{17}$$

where Δ_2 is the damping mode arising due to dust grain charge fluctuation.

Case III: Solving for $\omega=\omega_-+\Delta_3$, we get the following equation:

$$\Delta_3=\frac{\beta\eta\omega_{pe}^2k_x^3\upsilon_0c^2}{2\omega_-^2(\omega_-^2-\omega_+^2)(\omega_-^2+\eta^2)}+\frac{i\beta\omega_{pe}^2k_x^3\upsilon_0c^2}{2\omega_-(\omega_-^2-\omega_+^2)(\omega_-^2+\eta^2)}. \tag{18}$$

where Δ_3 is a small mismatch in the frequency due to dust particle.

Therefore, the growth rate corresponding to $\omega=\omega_-+\Delta_3$ is

$$\Gamma_3=\mathrm{Im}(\Delta_3)=\frac{\beta\omega_{pe}^2k_x^3\upsilon_0c^2}{2\omega_-(\omega_-^2-\omega_+^2)(\omega_-^2+\eta^2)}. \tag{19}$$

Equation (17) corresponds to the oscillations of WI. Further solving Eq. (17) in the limit of the negligible decay rate of dust charge fluctuations, that is $\eta\approx 0$, and using Eqs (13) and (14), we obtain the frequency of WI oscillation as

$$\frac{\beta k_xc^3}{4\sqrt{2}\omega_{pe}\upsilon_0^2}. \tag{20}$$

The usual expression of WI (Chen, 2006), which is obtained from Eq. (14), is

$$\gamma=\frac{\sqrt{2}\omega_{pe}(\upsilon_0/c)}{[1+2\omega_{pe}^2/k_x^2c^2]^{1/2}}. \tag{21}$$

This growth rate approaches saturation on electron cyclotron frequency and is set to oscillation [cf. Eq. (20)] due to the presence of dust grains in plasma with a frequency proportional to dust coupling parameter β and inversely proportional to electron streaming velocity. The electric and magnetic fields associated with the instability are 90° out of phase, and the growth of magnetic field results in the filamentation structure of WI.

Results and discussion

The dusty plasma parameters used for the calculations are: ion plasma density $n_{i0}=10^8\ \mathrm{cm^{-3}}$, electron plasma density $n_{e0}=0.1\times10^8$–$1\times10^8\ \mathrm{cm^{-3}}$, mass of dust grains $m_d=10^{12}\ m_p$ (for 1 µm grain assuming a mass density of $\sim$1 g/cm^3), temperature of ions and electrons $T_i\approx T_e\approx 0.2$ eV, dust density $n_{d0}=1\times10^4\ \mathrm{cm^{-3}}$, $m_i/m_e=7.16\times10^4$ (potassium), and the average size of the dust grain $a=2$ µm. Using Eq. (19), we have plotted the growth rate Γ_3 (s^{-1}) as a function of perpendicular wave number k_x (cm^{-1}) for different values of $\delta=n_{i0}/n_{e0}$ (relative density of negatively charged dust grains) (cf. Fig. 1). It is observed that the WI grows in the direction of increasing perpendicular wave number. In the present work, we have considered two types of electrons that possess drift velocities $\upsilon_0\hat{z}$ and $-\upsilon_0\hat{z}$. The perturbed magnetic field exerts a force $(-\frac{e}{c}\vec{\upsilon}_0\times B_1)$ (along $+\,x$-axis) on the first type of electrons and force $(+\frac{e}{c}\vec{\upsilon}_0\times B_1)$ (along $-\,x$-axis) on the second type of electrons. The electrons acquire a velocity in the x and $-x$ directions, respectively. Since B_1 is a function of x, this velocity has finite divergence $(\nabla\cdot\upsilon_1\neq 0)$ and gives rise to density perturbation. The density perturbations of the two types of electrons are out of phase by 180°. They couple with $\upsilon_0\hat{z}$ and $-\upsilon_0\hat{z}$, respectively, to produce a current-$\vec{J}_1(1)=-n_1e\vec{\upsilon}_0+(-n_0e\vec{\upsilon}_1)$ due to the first type of electrons and $\vec{J}_1(2)=n_1e\vec{\upsilon}_0-n_oe\vec{\upsilon}_1$ due to the second type of electrons in the z-direction. Total current density in plasma is given by Eq. (10). This current produces the magnetic field in the y-direction, enhancing original magnetic field perturbation. Thus, the perturbation grows with time at the expense of kinetic energy of the counter-streaming electrons. The density of dusty plasma in this scenario of counter-streaming electrons rises due to the combined effect of electron two-stream instability and electron-capturing

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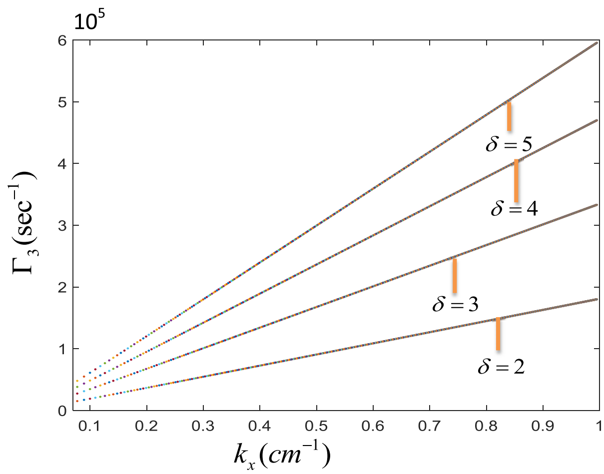

Fig. 1. Growth rate Γ_3 (s^{-1}) as a function of perpendicular wave number k_x (cm^{-1}) for $\delta = 2$, 3, 4, and 5.

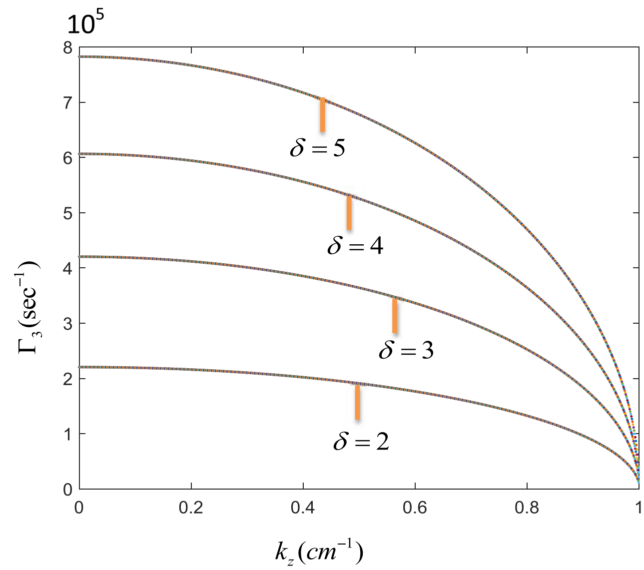

Fig. 2. Growth rate Γ_3 (s^{-1}) as a function of parallel wave number k_z (cm^{-1}) for $\delta = 2$, 3, 4, and 5.

tendency of dust; hence, electromagnetic wave generated due to WI becomes unstable and grows which is also observed by Ross *et al.* (2013) in which they have taken counter-streaming plasma flows. In our case, the growth rate with a perpendicular wave number in the presence of dust resembles with one observed by Huntington *et al.* (2015) in the absence of dust.

Again, using Eq. (19), Figure 2 is plotted which shows the variation of growth rate Γ_3 (s^{-1}) as the function of the parallel wave number k_z (cm^{-1}) for different values of $\delta = n_{i0}/n_{e0}$. It is inferred from Figure 2 that the growth rate of unstable mode decreases as the parallel wave number increases. This shows that the growth rate of instability decreases in the direction of self-generated magnetic field (Huntington *et al.*, 2015) because dust and ion in the plasma get excited in the direction of magnetic field but being heavy and stationary they oscillate at their places, hence reducing the energy of electromagnetic plasma wave along the direction of counter-streaming electrons or self-generated magnetic field. This decrease in the growth rate of unstable mode in the direction of parallel wave number, and an increase in the direction of the perpendicular wave number is also reported by Lazar *et al.* (2008).

Figure 3 shows the growth rate Γ_3 (s^{-1}) as a function of dust grain size a (cm) for different values of δ keeping all the other parameters [cf. Eq. (19)] the same as used for plotting Figure 1. The modification in the growth rate of instability is due to the presence of a large number of dust particles, as the electron-capturing tendency of these particles and dust charging process (Barkan *et al.*, 1994) change the rate of energy transfer between plasma wave and dust particles. This effect of dust grains on the ambient plasma wave has been observed by many researchers in their work. It is observed in Figure 3 that the growth rate of unstable mode first increases, and after acquiring the highest value, it becomes constant for all the values of δ. The growth rate value increases because on adding the dust grains in ambient plasma or by increasing the size of dust grains, the freely moving counter-streaming electrons approach them, raising the surface potential of particles of dust, as a result average dust grain charge Q_{d0} also increases which helps the instability to grow; hence, the enhancement in its growth rate is observed. This result is qualitatively similar to the results of Sharma and Sugawa (1999), Prakash *et al.* (2013), and Prakash *et al.* (2014). The transfer of energy from counter-streaming electrons accelerated by a self-generated

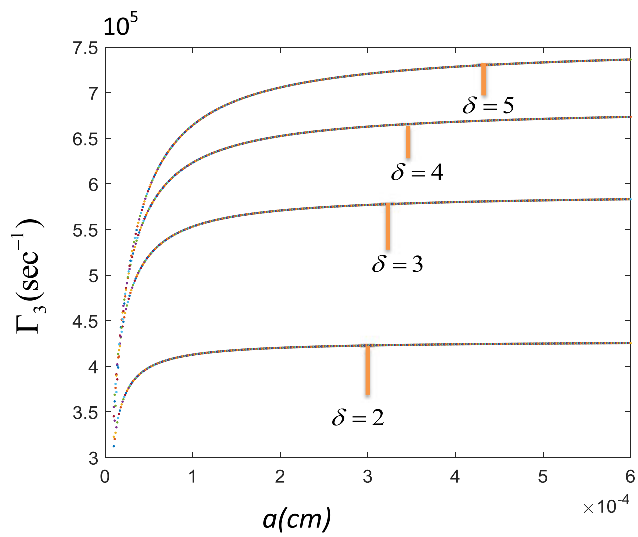

Fig. 3. Growth rate Γ_3 (s^{-1}) as a function of the size of dust grains a (cm) for $\delta = 2$, 3, 4, and 5 with $k_x = 0.5$.

magnetic field to an electromagnetic wave via dust particles modifies the growth rate of instability. It is also observed in Figure 3 that when the size of dust grain becomes greater than 1.5×10^{-4} cm, the growth rate becomes almost constant for all the values of δ. The reason for this is that on further increasing the size of dust grains, the average dust grain charge leads to saturation, as dust grain grabbed enough number of electrons. Also, the plasma system becomes stable because strong self-generated magnetic field overpowers the growth rate (Rubab *et al.*, 2016).

Using Eq. (19), we have plotted the growth rate Γ_3 (s^{-1}) with respect to perpendicular wave number for different values of the velocity of electrons (υ_0) say 2×10^7, 4×10^7, 6×10^7, and 8×10^7 cm/s, taking $\delta = 3$ and dust grain size $a = 1.5 \times 10^{-4}$ cm (cf. Fig. 4). It is observed that the growth decreases first decreases and after acquiring the lowest value it starts increasing gradually

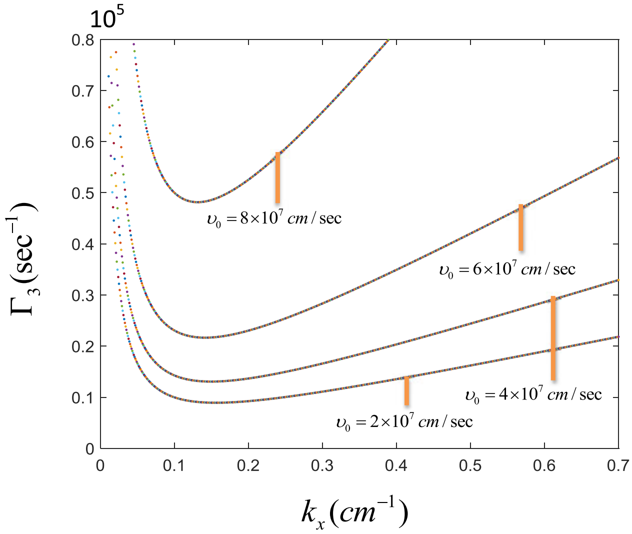

Fig. 4. Growth rate Γ_3 (s^{-1}) as a function of perpendicular wave number k_x (cm^{-1}) for $\upsilon_0 = 2\times10^7$, 4×10^7, 6×10^7, and 8×10^7 cm/s, for $\delta = 3$ and dust grain size $a = 1.5\times10^{-4}$ cm.

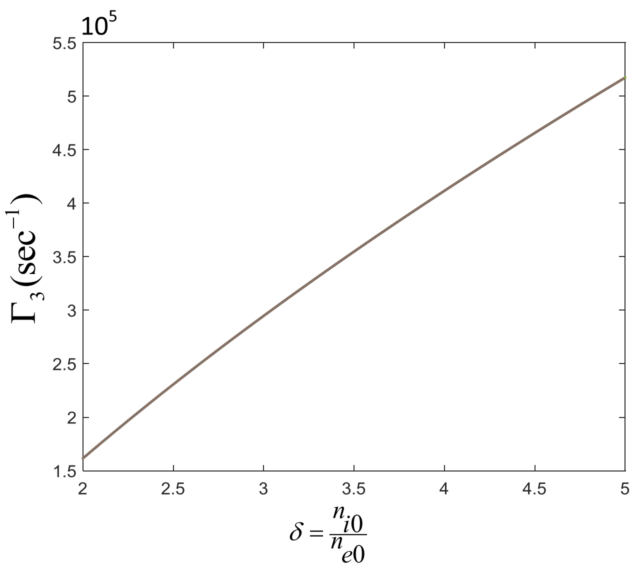

Fig. 5. Growth rate Γ_3 (s^{-1}) as a function δ for $\upsilon_0 = 4\times10^7$ cm/s and dust grain size $a = 1.5\times10^{-4}$ cm.

and goes to its maxima for all the values of υ_0. As the velocity of electrons increases, the efficiency of instability to convert the kinetic energy of the system to magnetic energy takes the energy of electrons to least and the growth rate of plasma wave becomes minimum. The magnetization of dusty plasma due to WI via counter-streaming electrons sharply increases the acceleration and hence the energy of electrons which stimulate them and then increase the growth rate.

Moreover, using the same Eq. (19), the variation in the growth rate of instability Γ_3 (s^{-1}) with respect to δ ($\delta = 1$ is for without dust as $\beta = 0$) by taking $\upsilon_0 = 4\times10^7$ cm/s and $a = 1.5\times10^{-4}$ cm is plotted as Figure 5, and we found that it is increasing with a relative density of negatively charged dust particles (δ). Our results are qualitatively similar to the work done in the field of dusty plasma (Barkan *et al.*, 1994; Chow and Rosenberg, 1995; Sharma and Sugawa, 1999; Sharma *et al.*, 2012; Prakash *et al.*, 2014). This is because of the electrons shielding nature of dust grains that helps in increasing the capacity of counter-streaming electrons to transfer their kinetic energy acquired by magnetization of dusty plasma to WI.

Conclusion

The counter-propagating electrons in an unmagnetized dusty plasma have the capability of generating electromagnetic waves via WI. In the present work, along with the growth rate of instability, a damping mode with frequency $(-\beta\omega_{pe}^2 k_x^3 \upsilon_0 c^2)/(\eta(\omega_+^2+\eta^2)(\omega_-^2+\eta^2))$ is observed, which is mainly due to a well-known dust charge process in the dust plasma system. It is found that the growth rate of unstable mode increases with dust grains' size and with increasing perpendicular wave number; however, it saturates for higher values of dust grain size. The negatively charged dust grains contribute to enhancing the growth rate when observed for different velocities of streaming electrons. Our work may be beneficial in studying the effect of dust particles in the magnetotail region of planetary magnetospheres (Lui *et al.*, 2008).

References

Barkan A, D'angelo N and Merlino RL (1994) Charging of dust grains in a plasma. *Physical Review Letters* **73**, 3093–3096.

Bashir MF and Murtaza G (2012) Effect of temperature anisotropy on various modes and instabilities for a magnetized non-relativistic bi-Maxwellian plasma. *Brazilian Journal of Physics* **42**, 487–504.

Chen FF (2006) *Introduction to Plasma Physics and Controlled Fusion*. New York, USA: Springer.

Chow VW and Rosenberg M (1995) Electrostatic ion cyclotron instability in dusty plasmas. *Planetary and Space Science* **43**, 613–618.

Dahamni MS, Fentazi S and Annou R (2005) Weibel instability of counter-streaming dust beams. AIP Conference Proceedings, Vol. 799. pp. 307–310.

Davidson RC (1983). Kinetic waves and instabilities in a uniform plasma. In Rosenbluth MN and Sagdeev RZ (eds), *Handbook of Plasma Physics*. Amsterdam, North Holland: Elsevier, p. **519**.

Dong QL, Yuan D, Gao L, Liu X, Chen Y, Jia Q, Hua N, Qiao Z, Chen M, Zhu B, Zhu J, Zhao G, Ji H, Sheng Z-M and Zhang J (2016) Filamentation due to the Weibel instability in two counterstreaming laser ablated plasmas. *Journal of Physics: Conference Series* **717**, 0120611–01206114.

Fried BD (1959) Mechanism for instability of transverse plasma waves. *Physics of Fluids* **2**, 337–337.

Furth HP (1963) Prevalent instability of nonthermal plasmas. *Physics of Fluids* **6**, 48–57.

Ghorbanalilu M (2006) The Weibel instability on strongly magnetized microwave produced plasma. *Physics of Plasmas* **13**, 1021101–1021105.

Guskov SY (2005) Thermonuclear gain and parameters of fast ignition ICF-targets. *Laser and Particle Beams* **23**, 255–260.

Hamasaki S (1968) Electromagnetic microinstabilities of plasmas in a uniform magnetic induction. *Physics of Fluids* **11**, 2724–2727.

Huntington CM, Fiuza F, Ross JS, Zylstra AB, Drake RP, Froula DH, Gregori G, Kugland NL, Kuranz CC, Levy MC, Li CK, Meinecke J, Morita T, Petrasso R, Plechaty C, Remington BA, Ryutov DD, Sakawa Y, Spitkovsky A, Takabe H and Park H-S (2015) Observation of magnetic field generation via the Weibel instability in interpenetrating plasma flows. *Nature Physics* **11**, 173–176.

Ibscher D and Schlickeiser R (2014) Solar wind kinetic instabilities at small plasma betas. *Physics of Plasmas* **21**, 0221101–0221104.

Jana MR, Sen A and Kaw PK (1993) Collective effects due to charge fluctuation dynamics in a dusty plasma. *Physical Review E* **48**, 3930–3933.

Ji-Wei L and Wen-Bing P (2005) Effect of guiding magnetic field on Weibel instability. *Chinese Physics Letters* **22**, 1976–1979.

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Lazar M, Schlickeiser R, Poedts S and Tautz RC (2008) Counterstreaming magnetized plasmas with kappa distributions—I. Parallel wave propagation. *Monthly Notices of the Royal Astronomical Society* **390**, 168–174.

Lui ATY, Yoon PH, Mok C and Ryu C-M (2008) Inverse cascade feature in current disruption. *Journal of Geophysical Research* **113**, A00C061–A00C0612.

Pokhotelov OA and Balikhin MA (2012) Weibel instability in a plasma with non-zero external magnetic field. *Annales Geophysicae* **30**, 1051–1054.

Prakash V and Sharma SC (2009) Excitation of surface plasma waves by an electron beam in a magnetized dusty plasma. *Physics of Plasmas* **16**, 093703–093712.

Prakash V, Sharma SC, Vijayshri V and Gupta R (2013) Surface wave excitation by a density modulated electron beam in a magnetized dusty plasma cylinder. *Laser and Particle Beams*, 31, 411–418.

Prakash V, Sharma SC, Vijayshri V and Gupta R (2014) Effect of dust grain parameters on ion beam driven ion cyclotron waves in a magnetized plasma. *Progress in Electromagnetics Research M* **36**, 161–168.

Ross JS, Park HS, Berger R, Divol L, Kugland NL, Rozmus W, Ryutov D and Glenzer SH (2013) Collisionless coupling of ion and electron temperatures in counterstreaming plasma flows. *Physical Review Letters* **110**, 1450051–14500510.

Rubab N, Erkaev NV and Biernat HK (2009) Dust kinetic Alfven and acoustic waves in a Lorentzian plasma. *Physics of Plasmas* **16**, 1037041–1037046.

Rubab N, Erkaev NV, Biernat HK and Langmayr D (2011) Kinetic Alfven wave instability in a Lorentzian dusty plasma: non-resonant particle approach. *Physics of Plasmas* **18**, 0737011–0737018.

Rubab N, Chian AC-L and Jatenco-Pereira V (2016) On the ordinary mode Weibel instability in space plasmas: a comparison of three-particle distributions. *Journal of Geophysical Research: Space Physics* **121**, 1874–1885.

Sharma SC and Sugawa M (1999) The effect of dust charge fluctuations on ion cyclotron wave instability in the presence of an ion beam in a plasma cylinder. *Physics of Plasmas* **7**, 444–448.

Sharma SC, Sharma K and Walia R (2012) Ion beam driven ion-acoustic waves in a plasma cylinder with negatively charged dust grains. *Physics of Plasmas* **19**, 073706–073711.

Treumann RA and Baumjohann W (2014) Brief communication: Weibel, firehose and mirror mode relations. *Nonlinear Processes in Geophysics* **21**, 143–148.

Tzoufras M, Ren C, Tsung FS, Tonge JW, Mori WB, Fiore M, Fonseca RA and Silva LO (2006) Space-charge effects in the current-filamentation or Weibel instability. *Physical Review Letters* **96**, 1050021–1050024.

Velarde P, Ogando F, Eliezer S, Martinez-Val JM, Perlado JM and Murakami M (2005) Comparison between jet collision and shell impact concepts for fast ignition. *Laser and Particle Beams* **23**, 43–46.

Weibel ES (1959) Spontaneously growing transverse waves in a plasma due to an anisotropic velocity distribution. *Physical Review Letters* **2**, 83–84.

Whipple EC, Northdrop TG and Mendis DA (1985) The electrostatics of dusty plasma. *Journal of Geophysical Research* **90**, 7405–7413.

Zhou CT and He XT (2007) Influence of a large oblique incident angle on energetic protons accelerated from solid-density plasmas by ultraintense laser pulses. *Applied Physics Letters* **90**, 031503–031506.