PRAMANA © Indian Academy of Sciences Vol. 83, No. 6
— journal of December 2014
physics pp. 1015–1024

The effect of positive dust mass on instability in four-component magnetodustyplasma in the presence of polarization force

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MS received 2 September 2013; revised 15 March 2014; accepted 20 March 2014
DOI: 10.1007/s12043-014-0827-1; ***e*Publication:** 20 September 2014

Abstract. A theoretical investigation has been carried out on the growth rate of instability of the low-frequency electrostatic waves in a partially ionized four-component magnetodustyplasma in the presence of polarization force. Utilizing the method of linear mode analysis, the results of investigation have been presented. The findings of the investigation reveal that the polarization force, the external magnetic field and the dust temperature have a tendency to destabilize the system by increasing the growth rate of instability. On the other hand, the positive dust mass causes the instability growth rate to decrease, thereby stabilizing the system.

Keywords. Positive dust; polarization force; instability; magnetized dusty plasma.

PACS Nos 52.27.LW; 52.35.LV; 52.25.XZ; 52.35.BJ

1. Introduction

There has been a great deal of interest in understanding the dusty plasma both in the laboratory and in the space plasma systems. Dusty plasmas are very common in molecular clouds, protostellar disks, asteroid zones, planetary rings, cometary tails, in star formation regions, accretion disks of young stellar objects, solar winds, etc. [1,2]. Dusty plasmas can be utilized to understand the dynamics and the fragmentation of the star formation, the galactic structure and its evolution, the spoke formation in Saturn's ring, etc. [3–10]. Recently, many papers have been published by taking into account the two- or three-component plasma [11–16]. But, the dusty plasmas can be positively as well as negatively charged together with a significant amount of neutral particles. Very recently, many authors [17–21] have studied the effects of polarization force on the dust-acoustic waves. But, they have ignored the effects of polarization force in the presence of positive dust mass. The existence of positive dust together with the negative dust in both laboratory and space plasma systems is now established. There are many direct evidences of the existence of the positively- and negatively-charged dust in different regions of space, for example, the Earth's mesosphere [22], cometary tails [23], Jupiter's magnetospheres [24,25] etc. The coexistence of the positively- and negatively-charged dust with the heavier (larger) being positive and the lighter (smaller) being negative [26–31] or vice versa [32] have been observed in laboratory devices [26–28,32]. In laboratory, certain mechanisms can be used to produce positively-charged dusty plasma. These mechanisms include the thermionic emission induced by radiative heating [33], the secondary emission of electrons from the surface of the dust grain [34], the photoemission in the presence of a flux of ultraviolet photons [35,36], etc. Although some authors have shown that the negatively-charged dust is heavier than the positively-charged dust, the reverse also is true. The triboelectric charging by Shukla and Rosenberg and Lacks and Levandovsky [37,38] has demonstrated the fact that the positively-charged dust is heavier (massive) than the negatively-charged dust. The waves and instabilities in a partially ionized dusty magnetoplasma can be studied in three regimes: (1) the electrostatic force can be stronger than the gravitational force, (2) the electrostatic force can be equal to the gravitational force and (3) the electrostatic force can be weaker than the gravitational force. In case of the laboratory dusty plasma of some particular cases like the plasma confinement process in tokamak, mirror machine, Z-pinch, θ-pinch, etc., where plasma particles interact in a strong magnetic field, the electromagnetic force becomes greater than the gravitational force. In planetary atmosphere and interstellar media like in the thickness of Jovian ring, spoke formation in the Saturn's ring etc., the electrostatic forces balance the gravitational forces. The gravitational force exceeds the electrostatic force in the formation of large-scale objects due to the gravitational condensation [39]. However, in some particular cases, the polarization force has a strong influence on a highly-ionized and strongly-coupled dusty plasma. According to Khrapak [40], the polarization force is negligibly small in steady-state condition but, it is quite important for low-frequency dusty plasma and must be taken into consideration. In highly-charged and strongly-coupled dusty plasmas (i.e. $\Gamma > 1$, where Γ is the coupling parameter) [41], the interaction between negatively- and positively-charged dust grains becomes a dominant factor. But for weakly-coupled dusty plasmas ($\Gamma < 1$), the interaction between negatively- and positively-charged dust grains is less important and negligible. So, we can avoid the interaction between positively- and negatively-charged dust grains for a weakly-coupled and partially-ionized magnetodustyplasma, which has been considered in our paper. In an unmagnetized dusty plasma, the polarization force acting on a dust grain can be mathematically given [19,40,42,43] as

$$\mathbf{F}_p = -\frac{q_{\rm d}^2}{2\lambda_{\rm d}^2}\nabla\lambda_{\rm d}, \tag{1}$$

where $q_{\rm d} = -Z_{\rm d}e$, $Z_{\rm d}$ is the number of electrons on the dust grain surface, $\lambda_{\rm d}$ is the Debye length and e is the magnitude of the electronic charge. The polarization force parameter resulting from the polarization force can be given [17] as

$$P = \frac{|Q|e}{16\pi\epsilon_0\lambda_{\rm d}k_{\rm B}T_{\rm i}}\left(1-\frac{T_{\rm i}}{T_{\rm e}}\right), \tag{2}$$

where Q, $T_{\rm i}$, $T_{\rm e}$, $k_{\rm B}$ and ϵ_0 are, respectively, the grain charge, temperature of ions, temperature of electrons, Boltzmann constant and permittivity of the free space. From eqs (1) and (2) we can see that the polarization force is charge independent, i.e. the polarization force will always be of the same nature whether the charge is positive or negative and it acts in the direction opposite to that of the electric force [17,18]. The polarization force arises mainly due to the polarization of plasma ions around the dust grain and its direction is always in the direction of decreasing Debye length, regardless of the sign of the charge of the dust grain [18]. So, the polarization force will not be modified in positively-charged dust. In this paper, we have neglected the masses of the electron and the ion, which are million to billion times lighter than the dust particle. The effect of neutral particles has also been neglected for mathematical simplification.

This paper is organized as follows. We have presented the governing equations in §2. The dispersion relation is derived in §3. Numerical analysis is performed in §4. Finally, results and discussions are provided in §5.

2. Governing equations

We consider a self-gravitating, partially ionized, magnetodustyplasma containing electrons, ions, negatively- as well as positively-charged dust particles in the presence of polarization force. At equilibrium, the quasineutrality condition requires $Z_{\rm n}n_{\rm n0} + n_{\rm e0} = Z_{\rm p}n_{\rm p0} + Z_{\rm i}n_{\rm i0}$, where $Z_{\rm n}$ ($Z_{\rm p}$) is the number of electrons (protons) on the surface of the negative (positive) dust grain, $n_{\rm n0}$ ($n_{\rm p0}$) is the equilibrium number density of the negative (positive) dust grain, $n_{\rm e0}$ ($n_{\rm i0}$) is the equilibrium number density of electron (ion). $Z_{\rm i}$ indicates the number of ions in the plasma system and it becomes one for singly-charged ion. We assume that the dusty plasmas are immersed in a non-uniform external magnetic field, $\mathbf{B}_0 = \hat{z}B_0(x)$ where $\hat{z}$ is a unit vector pointing to the z-axis. The macroscopic state of the system can be described by using the equation of continuity, the equation of motion, the Maxwell's field equation [44] and the Poisson's equation [45,46] as

$$\frac{\partial N_{\rm s}}{\partial t} + \nabla\cdot(N_{\rm s}\mathbf{u}_{\rm s}) = 0, \tag{3}$$

$$\left(\frac{\partial}{\partial t} + \mathbf{u}_{\rm n}\cdot\nabla\right)\mathbf{u}_{\rm n} = -\frac{Z_{\rm n}e}{m_{\rm n}}\nabla\phi\,(1-P) - \frac{Z_{\rm n}e}{m_{\rm n}c}\mathbf{u}_{\rm n}\times\mathbf{B} - \nabla\phi_{\rm gn}, \tag{4}$$

$$\left(\frac{\partial}{\partial t} + \mathbf{u}_{\rm p}\cdot\nabla\right)\mathbf{u}_{p} = \frac{Z_{\rm p}e}{m_{\rm p}}\nabla\phi\,(1-P) + \frac{Z_{\rm p}e}{m_{\rm p}c}\mathbf{u}_{\rm p}\times\mathbf{B} - \nabla\phi_{\rm gp}, \tag{5}$$

$$0 = -e\left(\mathbf{E} + \frac{1}{c}\mathbf{u}_{\rm e}\times\mathbf{B}\right), \tag{6}$$

$$0 = e\left(\mathbf{E} + \frac{1}{c}\mathbf{u}_{\rm i}\times\mathbf{B}\right), \tag{7}$$

$$(\nabla\times\mathbf{B}) = \frac{4\pi e N_{\rm s}}{c}\left(\mathbf{u}_{\rm n} + \mathbf{u}_{\rm e} - \mathbf{u}_{\rm p} - \mathbf{u}_{\rm i}\right), \tag{8}$$

$$\nabla^2 \phi = -4\pi e \left(n_{\rm i} + Z_{\rm p} n_{\rm p} - n_{\rm e} - Z_{\rm n} n_{\rm n} \right), \tag{9}$$

$$\nabla^2 \phi_g = 4\pi G \left(\frac{m_{\rm p}}{Z_{\rm p}} + \frac{m_{\rm n}}{Z_{\rm n}} \right) N_{\rm s}, \tag{10}$$

where $N_{\rm s}$ represents the number density of the species s (e, i, n, p). $\mathbf{u}_{\rm n}$ ($\mathbf{u}_{\rm p}$) is the negative (positive) dust fluid velocity, $m_{\rm n}$ ($m_{\rm p}$) is the negative (positive) dust fluid mass. G, e and $\mathbf{E}$ are, respectively, the universal gravitational constant, the magnitude of the electronic charge and the electric field. c and $\mathbf{B}$ are the the speed of light in vacuum and the external magnetic field, respectively. ϕ and $\phi_{\rm g}$ are respectively, the electrostatic and the self-gravitational potential. Finally, P represents the strength of the polarization force [45]. Also, the subscripts e, i, n, p are used to indicate respectively, the electron, the ion, the negatively- and the positively-charged dust.

3. Dispersion properties

In order to study the dispersion properties of the electrostatic waves in the partially ionized and the self-gravitating magnetodustyplasma, we carry out a normal mode analysis as in Mamun and Shukla [39]. We want to express the dependent variables in terms of their perturbed and equilibrium parts by assuming that there is no plasma flow at equilibrium. Taking the equilibrium density and the magnetic field gradient along x-direction, we can write

$$\left. \begin{array}{l} N_{\rm s} = n_{\rm s0}(x) + n_{\rm s} \\ \mathbf{u}_{\rm s} = 0 + \mathbf{u}_{\rm s} \\ \mathbf{B} = \hat{z} B_0(x) + \mathbf{B}_1 \\ \phi = 0 + \phi \\ \phi_{\rm g} = 0 + \phi_{\rm g} \end{array} \right\} . \tag{11}$$

Thus, the governing equations (3)–(10) are linearized as

$$\frac{\partial n_{\rm s}}{\partial t} + \nabla \cdot (n_{\rm s0} \mathbf{u}_{\rm s}) = 0, \tag{12}$$

$$\frac{\partial \mathbf{u}_{\rm n}}{\partial t} = -\frac{Z_{\rm n} e}{m_{\rm n}} \nabla \phi (1 - P) - \frac{Z_{\rm n} e}{m_{\rm n} c} \mathbf{u}_{\rm n} \times \mathbf{B}_0 - \nabla \phi_{\rm gn}, \tag{13}$$

$$\frac{\partial \mathbf{u}_{\rm p}}{\partial t} = \frac{Z_{\rm p} e}{m_{\rm p}} \nabla \phi (1 - P) + \frac{Z_{\rm p} e}{m_{\rm p} c} \mathbf{u}_{\rm p} \times \mathbf{B}_0 - \nabla \phi_{\rm gp}, \tag{14}$$

$$0 = -e \left(\mathbf{E} + \frac{1}{c} \mathbf{u}_{\rm e} \times \mathbf{B}_0 \right), \tag{15}$$

$$0 = e \left(\mathbf{E} + \frac{1}{c} \mathbf{u}_{\rm i} \times \mathbf{B}_0 \right), \tag{16}$$

$$(\nabla \times \mathbf{B}_1) = \frac{4\pi e n_{\rm s0}}{c} \left(\mathbf{u}_{\rm n} + \mathbf{u}_{\rm e} - \mathbf{u}_{\rm p} - \mathbf{u}_{\rm i} \right), \tag{17}$$

$$\nabla^2\phi = -4\pi e\left(n_{\rm i} + Z_{\rm p}n_{\rm p} - n_{\rm e} - Z_{\rm n}n_{\rm n}\right), \tag{18}$$

$$\nabla^2\phi_{\rm g} = 4\pi G\left(\frac{m_{\rm p}}{Z_{\rm p}} + \frac{m_{\rm n}}{Z_{\rm n}}\right)n_{\rm s}. \tag{19}$$

Utilizing eqs (15) and (16) together with eq. (17) into eq. (13) one gets

$$\begin{aligned}\frac{\partial \mathbf{u}_{\rm p}}{\partial t} + \frac{c}{4\pi e n_{\rm p0}}\frac{\partial}{\partial t}(\nabla\times\mathbf{B}_1) = &-\frac{Z_{\rm n}e}{m_{\rm n}}\nabla\phi\,(1-P)\\ &-\frac{Z_{\rm n}e}{m_{\rm n}c}\left\{\mathbf{u}_{\rm p} + \frac{c}{4\pi e n_{\rm p0}}\nabla\times\mathbf{B}_1\right\}\\ &\times\mathbf{B}_0 - \nabla\phi_{\rm gn}.\end{aligned} \tag{20}$$

Now, to simplify mathematics without loosing any physics insight, we assume that the perturbed magnetic field is along the z-axis and all other perturbed quantities point to the y-axis. These two assumptions enable us to express eq. (20) as

$$\begin{aligned}\frac{\partial \mathbf{u}_{\rm p}}{\partial t} = &-\frac{c}{4\pi e n_{\rm p0}}\frac{\partial}{\partial t}\frac{\partial B_1}{\partial y}\hat{i} - \frac{Z_{\rm n}e}{m_{\rm n}}\nabla\phi\,(1-P)\\ &-\frac{Z_{\rm n}eB_0u_{\rm p}}{m_{\rm n}c}\hat{i} + \frac{Z_{\rm n}B_0}{4\pi m_{\rm n}n_{\rm p0}}\frac{\partial B_1}{\partial y}\hat{i} - \nabla\phi_{\rm gn}.\end{aligned} \tag{21}$$

Subtracting eq. (21) from eq. (14) and then differentiating with respect to y one can show

$$\begin{aligned}&(1-P)\left(\frac{Z_{\rm p}}{m_{\rm p}} + \frac{Z_{\rm n}}{m_{\rm n}}\right)e\frac{\partial^2\phi}{\partial y^2} + \left(\frac{Z_{\rm p}}{m_{\rm p}} + \frac{Z_{\rm n}}{m_{\rm n}}\right)\frac{eB_0}{c}\frac{\partial u_{\rm p}}{\partial y}\\ &+\frac{\partial^2\phi_{\rm g}}{\partial y^2} + \frac{c}{4\pi e n_{\rm p0}}\frac{\partial}{\partial t}\frac{\partial^2 B_1}{\partial y^2} - \frac{Z_{\rm n}B_0}{4\pi m_{\rm n}n_{\rm p0}}\frac{\partial^2 B_1}{\partial y^2} = 0,\end{aligned} \tag{22}$$

where we have assumed that $\nabla\phi_{\rm gn} - \nabla\phi_{\rm gp} = \nabla\phi_{\rm g}$. Assuming the dusty plasma to be Maxwellian, we can show from eq. (12)

$$\frac{\partial u_{\rm s}}{\partial y} = -\frac{Z_{\rm s}se}{T_{\rm s}}\frac{\partial\phi}{\partial t}, \tag{23}$$

where $s = 1$ for negative dust or electron and -1 for positive dust or ion. It is easy to express eq. (17) as

$$\frac{\partial B_1}{\partial y} = -\frac{4\pi\sigma}{c}\frac{\partial\phi}{\partial y}, \tag{24}$$

where σ represents the conductivity of the dusty plasma. Using eq. (23) into eqs (18) and (19) and then, using them into eq. (22) together with eq. (24) we have

$$\begin{aligned}&(1-P)\left(\frac{Z_{\rm p}}{m_{\rm p}} + \frac{Z_{\rm n}}{m_{\rm n}}\right)\left(\frac{1}{\lambda_{\rm e}^2} + \frac{1}{\lambda_{\rm i}^2} + \frac{Z_{\rm n}}{\lambda_{\rm n}^2} + \frac{Z_{\rm p}}{\lambda_{\rm p}^2}\right)\phi\\ &+\frac{Z_{\rm p}}{T_{\rm p}}(\omega_{\rm cn} + \omega_{\rm cp})\frac{\partial\phi}{\partial t} + \left(\frac{\omega_{\rm Jn}^2}{T_{\rm n}} - \frac{\omega_{\rm Jp}^2}{T_{\rm p}}\right)\phi\\ &-\frac{\sigma}{e^2n_{\rm p0}}\frac{\partial}{\partial t}\frac{\partial^2\phi}{\partial y^2} + \frac{\omega_{\rm cn}\sigma}{e^3n_{\rm p0}}\frac{\partial^2\phi}{\partial y^2} = 0,\end{aligned} \tag{25}$$

where $\omega_{\rm cn} = Z_{\rm n} e B_0 / m_{\rm n} c$ and $\omega_{\rm cp} = Z_{\rm p} e B_0 / m_{\rm p} c$ are, respectively, the cyclotron frequency for the negative and the positive dust, $\omega_{\rm Jn} = \sqrt{4\pi G m_{\rm n} n_{\rm no}}$ and $\omega_{\rm Jp} = \sqrt{4\pi G m_{\rm p} n_{\rm po}}$ are, respectively, the Jean frequency for the negative and the positive dust, $T_{\rm n}$ ($T_{\rm p}$) is the temperature for the negative (positive) dust in the unit of energy. $\lambda_{\rm e}$, $\lambda_{\rm i}$, $\lambda_{\rm n}$ and $\lambda_{\rm p}$ are, respectively, the Debye length for the electron, the ion, the negative dust and the positive dust. Now, making a Fourier transformation of eq. (25), i.e. replacing $\partial/\partial t$ by $-i\omega$ and $\partial/\partial y$ by ik (noting that k is only along y-axis), we obtain the desired dispersion relation for low-frequency electrostatic wave as

$$(1-P)\left(\frac{Z_{\rm p}}{m_{\rm p}}+\frac{Z_{\rm n}}{m_{\rm n}}\right)\left(\frac{1}{\lambda_{\rm e}^2}+\frac{1}{\lambda_{\rm i}^2}+\frac{Z_{\rm n}}{\lambda_{\rm n}^2}+\frac{Z_{\rm p}}{\lambda_{\rm p}^2}\right)$$

$$-\frac{iZ_{\rm p}}{T_{\rm p}}\left(\omega_{\rm cn}+\omega_{\rm cp}\right)\omega+\left(\frac{\omega_{\rm Jn}^2}{T_{\rm n}}-\frac{\omega_{\rm Jp}^2}{T_{\rm p}}\right)-\frac{\sigma\omega k^2}{e^2 n_{\rm p0}}-\frac{\sigma\omega_{\rm cn}k^2}{e^3 n_{\rm p0}}=0. \tag{26}$$

4. Numerical analysis

In order to analyse eq. (26) numerically, we use the plasma parameters used experimentally by Bandyopadhyay [47] and Nakamura [48]. We have taken $m_{\rm p}/m_{\rm n} = x$, $Z_{\rm p}/Z_{\rm n} = y$, $T_{\rm n}/T_{\rm p} = z$, $\lambda_{\rm p} = 0.001\lambda_{\rm e}$, $\lambda_{\rm n} = 0.01\lambda_{\rm e}$ and $\lambda_{\rm i} = 0.1\lambda_{\rm e}$. The frequency of the wave is normalized by the negative dust Jean frequency, $\omega_{\rm Jn} = \sqrt{4\pi G m_{\rm n} n_{\rm n0}}$ and the wave vector is normalized by $k_{\rm J} = 1/\lambda_{\rm n}$.

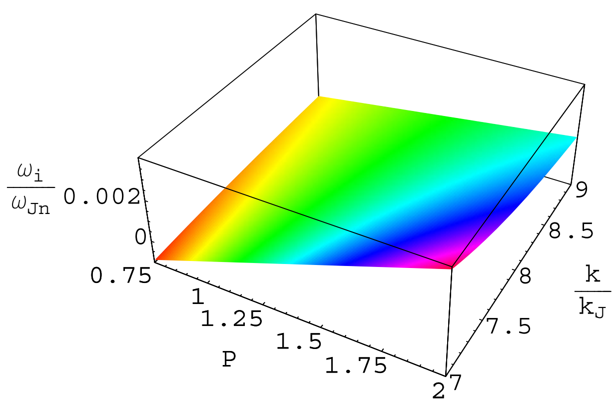

Figure 1. The variation of instability (growth rate) of the electrostatic wave with the polarization force parameter P and the normalized wave number. For other parameters, we have taken $x = 1$, $y = 10$, $z = 10$, $Z_{\rm n} = 3000$, $T_{\rm p} = 0.01 \times 1.6 \times 10^{-13}$ erg, $\sigma = 5.8 \times 10^5$ mho/cm, $\omega_{\rm cn}/\omega_{\rm cp} = 5$, $\omega_{\rm Jp}/\omega_{\rm Jn} = 6$, $\lambda_{\rm e} = 0.37$ cm, $n_{\rm p0} = 4 \times 10^4$ cm^{-3}, $c = 3 \times 10^{10}$ cm/s, $e = 4.8 \times 10^{-10}$ stat Coulomb and $m_{\rm n} = 10^{-11}$ g.

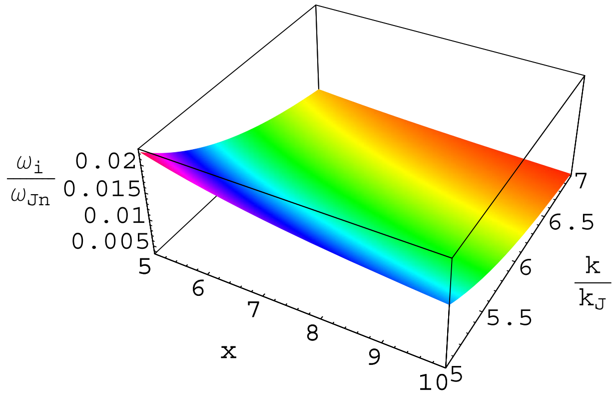

Figure 2. The variation of instability (growth rate) of the electrostatic wave with the ratio of the positive dust mass to negative dust mass x and the normalized wave number. For other parameters, we have taken $P = 2$, $y = 10$, $z = 10$, $Z_n = 3000$, $T_p = 0.01 \times 1.6 \times 10^{-13}$ erg, $\sigma = 5.8 \times 10^5$ mho/cm, $\omega_{cn}/\omega_{cp} = 5$, $\omega_{Jp}/\omega_{Jpn} = 6$, $\lambda_e = 0.37$ cm, $n_{p0} = 4 \times 10^4$ cm^{-3}, $c = 3 \times 10^{10}$ cm/s, $e = 4.8 \times 10^{-10}$ stat Coulomb and $m_n = 10^{-11}$ g.

5. Results and discussions

In this paper, we have shown the dependency of instability (growth rate) of the low-frequency electrostatic wave on different plasma parameters for astrophysical and laboratory plasma systems. We have paid particular attention for showing the effects of positive

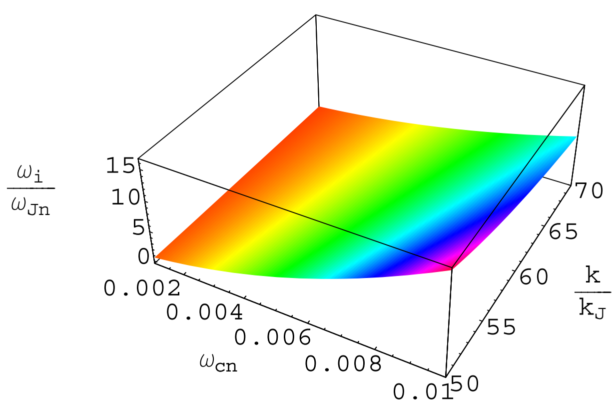

Figure 3. The variation of instability (growth rate) of the electrostatic wave with the negative dust cylotron frequency (related to external magnetic field), ω_{cn} and the normalized wave number. For other parameters, we have taken $x = 10$, $P = 1$, $y = 10$, $z = 10$, $Z_n = 3000$, $T_p = 0.01 \times 1.6 \times 10^{-13}$ erg, $\sigma = 5.8 \times 10^5$ mho/cm, $\omega_{cn}/\omega_{cp} = 5$, $\omega_{Jp}/\omega_{Jn} = 6$, $\lambda_e = 0.37$ cm, $n_{p0} = 4 \times 10^4$ cm^{-3}, $c = 3 \times 10^{10}$ cm/s, $e = 4.8 \times 10^{-10}$ stat Coulomb and $m_n = 10^{-11}$ g.

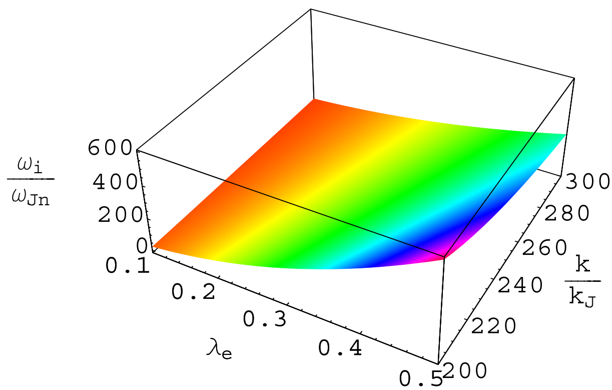

Figure 4. The variation of instability (growth rate) of the electrostatic wave with the Debye length of the electron λ_e and the normalized wave number. For other parameters, we have taken $P = 2$, $x = 10$, $y = 10$, $z = 10$, $Z_n = 3000$, $T_p = 0.01 \times 1.6 \times 10^{-13}$ erg, $\sigma = 5.8 \times 10^5$ mho/cm, $\omega_{cn}/\omega_{cp} = 5$, $\omega_{Jp}/\omega_{Jn} = 6$, $n_{p0} = 4 \times 10^4$ cm^{-3}, $c = 3 \times 10^{10}$ cm/s, $e = 4.8 \times 10^{-10}$ stat Coulomb and $m_n = 10^{-11}$ g.

dust mass and the polarization force on the instability of the electrostatic wave. As shown in figure 1, the instability (growth rate) of the electrostatic wave increases rapidly with the polarization force and it decreases with the normalized value of the wave vector. This variation of instability (growth rate) agrees with the results found by Prajapati [45]. The decrease of instability (growth rate) with the normalized wave number also satisfies the Mamun and Shukla's investigations [39]. Figure 2 shows the variation of instability (growth rate) with the positive to negative dust mass ratio, x. Here, we see that if the positive dust mass (in comparison with the negative dust mass) increases, then, the instability (growth rate) significantly decreases, thereby stabilizing this mode of electrostatic wave. This is completely a new phenomenon which shows the stabilizing effect of low-frequency electrostatic wave. Thus, the concept of positive dust together with negative dust in an electron–ion plasma is logically consistent. The instability (growth rate) also decreases with the normalized value of the wave vector. Figure 3 describes the variation of instability (growth rate) with the negative dust cyclotron frequency and the normalized wave vector. As dust cyclotron frequency is proportional to external magnetic field, we observe that the external magnetic field tends to destabilize this mode of electrostatic wave. In figure 4, we have plotted the variation of instability (growth rate) with the Debye length of the electron. As the Debye length is a function of temperature, we can infer from figure 4 that the increase in temperature destabilizes the low-frequency electrostatic wave. As the temperature increases, the constituents of the plasma acquire energy. This extra energy helps to increase the randomness of the system. So, we expect that the graphical results might be consistent with this physical concept. This result partially supports the result obtained by Kopp [1]. We expect that these results might be helpful in understanding the existence and the effect of positive dust in the planetary atmospheres and in the laboratory plasma system under the polarization force.

Acknowledgements

M Emamuddin thankfully acknowledges the financial support of the National University, Gazipur, Bangladesh and the deputation granted by the Ministry of Education, Bangladesh. The authors are also grateful to the anonymous reviewer for the constructive suggestions and guidelines regarding this work.

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