Effect of secondary electron emission on the Jeans instability in a dusty plasma

Susmita Sarkar, Banamali Roy, Saumyen Maity, Manoranjan Khan, and M. R. Gupta

Citation: Physics of Plasmas (1994-present) **14**, 042106 (2007); doi: 10.1063/1.2718926
View online: http://dx.doi.org/10.1063/1.2718926
View Table of Contents: http://scitation.aip.org/content/aip/journal/pop/14/4?ver=pdfcov
Published by the AIP Publishing

Effect of secondary electron emission on the Jeans instability in a dusty plasma

Susmita Sarkar,[a)] Banamali Roy,[b)] Saumyen Maity,[c)] Manoranjan Khan,[d)] and M. R. Gupta
Centre for Plasma Studies, Jadavpur University, Kolkata-700032, India

(Received 25 January 2007; accepted 2 March 2007; published online 27 April 2007)

In this paper the effect of secondary electron emission on Jeans instability in a dusty plasma has been investigated. Due to secondary electron emission, dust grains may have two stable equilibrium states out of which one is negative and the other is positive. Here both cases have been considered separately. It has been shown that secondary electron emission enhances Jeans instability when equilibrium dust charge is negative. It has also been shown that growth rate of Jeans instability reduces with increasing secondary electron emission when equilibrium dust charge is positive.
 [DOI: 10.1063/1.2718926]

I. INTRODUCTION

The dust grains immersed in a plasma become highly charged due to collision with ambient electrons and ions; the presence of such highly electrically charged heavy mass dust particles causes the sustenance of very low frequency modes known as dust acoustic (DA) modes[1] and also affects the ion acoustic mode which is being called the dust ion acoustic mode.[2]

If the plasma electrons have sufficiently high energy, then electrons hitting a single dust grain may ionize the dust material resulting in ejection of electrons producing the secondary electron current. This is equivalent to the flow of a positive current to the dust surface. The secondary electron yield depends on the nature of the dust material and the kinetic energy of the incident electrons. Pavlu *et al.*[3] and Zilavy *et al.*[4] observed that secondary electrons have small energies and can not produce new secondaries. When the dust grains are irradiated by ultraviolet radiation, they emit electrons and become positively charged.[5–13] This is usually the case for very small grains in cosmic and laboratory plasmas. Since the higher thermal velocity of electrons is higher than ions, the dust grains usually acquire a negative charge in a low-temperature laboratory dusty plasma.[11] However, in a Q machine, positively charged dust grains may be produced by replacing the plasma electrons with negative ions whose thermal velocity is smaller than that of positive ions.[12] This might also be the situations where negative and positive dust grains can coexist.[14–16] Accordingly, it is essential to include both the orbital limited motion (OML)[17] and secondary electron emission[13] currents in the dust charging equation and examine the effect of the secondary electron yield on the Jeans instability in a self-gravitating dusty plasma when the dust grains are either negatively or positively charged.

The Jeans instability of a self-gravitating dusty plasma system is a mode of particular interest to space and astrophysical plasma situations. This Jeans instability itself is a well-known phenomenon[18,19] and in a dusty plasma it is of particular interest and have been studied by several authors since the last decade.[20–26] A modification of Jeans instability has been reported by Delzano and Lapenta[27] considering Lennard-Jones like shielding potential. Jacobs and Shukla[28] reported that the magnetic field and ion-neutral collisions are stabilizing factors for the Jeans instability in a partially ionized astrophysical plasma. In astrophysical environment, the effects of self-gravity and dust grains are also important.[29,30] Recently, Shukla and Stenflo[31] studied Jeans instability in a quantum dusty plasma and suggested that at quantum scales the collapse of self-gravitating dust objects can be arrested. Vladimirov *et al.*[32] pointed out that the equilibrium state of plasma as well as the ion acoustic wave propagation are significantly modified in the complex plasma in presence of negative ions due to relevant processes such as ionization, electron attachment, diffusion, positive-negative ion recombination, plasma particle collision, as well as elastic Coulomb and inelastic dust charging collision. Negatively charged ions are also very important for reactive laboratory and technological plasmas.[33,34] The role of negative ions in a complex plasma in presence of both thermal and nonthermal positive ions[35,36] have been recently reported. But the effect of secondary electron emission on the growth of Jeans instability is still not explored.

In this paper, we have investigated the growth of Jeans instability in presence of secondary electron emission for both negatively and positively charged dust grains. We have seen that for negatively charged dust grains, secondary electron emission enhances Jeans instability whereas this instability is suppressed when dust grains are positively charged. In the subsequent sections these two cases are investigated separately.

[a)]Permanent address: Department of Applied Mathematics, University of Calcutta, 92, A. P. C. Road, Kolkata-700009, India. Electronic mail: susmita62@yahoo.co.in
[b)]Permanent address: Department of Mathematics, Bengal Institute of Technology, Tech Town, Kolkata-700150, India. Electronic mail: banamaliroy@yahoo.co.in
[c)]Electronic mail: saumyenmaity@yahoo.co.in
[d)]Permanent address: Department of Instrumentation Science, Jadavpur University, Kolkata-700032, India. Electronic mail: mkhan_ju@yahoo.com

II. GRAIN CHARGING CURRENTS

The ambient plasma ion current I_i, primary electron current I_e and the secondary electron current I_e^s to as well as from the dust grains given below are the usual orbital motion limited (OML) based expressions,[17]

$$I_i = \pi a^2 e \sqrt{\frac{8T_i}{\pi m_i}} n_i \begin{cases} \exp\left(\frac{-eq_d}{aT_i}\right) & : q_d > 0, \\ \left(1 - \frac{eq_d}{aT_i}\right) & : q_d < 0, \end{cases}$$

$$I_e = -\pi a^2 e \sqrt{\frac{8T_e}{\pi m_e}} n_e \begin{cases} \left(1 + \frac{eq_d}{aT_e}\right) & : q_d > 0, \\ \exp\left(\frac{eq_d}{aT_e}\right) & : q_d < 0. \end{cases} \tag{1}$$

In general the secondary electrons ejected from the dust grains are distributed with temperature T_s different from the temperature T_e of the ambient plasma electrons,[17]

$$I_e^s = 3.7\delta_M \sqrt{\frac{8T_e}{\pi m_e}} n_e \begin{cases} \exp\left(\frac{eq_d}{aT_e}\right) F_5(E_M/4T_e) & : q_d < 0, \\ \left(1 + \frac{eq_d}{aT_e}\right) \exp\left(\frac{eq_d}{aT_e} - \frac{eq_d}{aT_s}\right) F_{5,B}(E_M/4T_e) & : q_d > 0. \end{cases} \tag{2}$$

Here, a is the grain radius, m_e (m_i) the electron (ion) mass, T_e (T_i) the electron (ion) temperature, and δ_M is the maximum yield of secondary electrons which occurs when the impinging electron has the kinetic energy E_M.[37] The functions $F_5(x)$ and $F_{5,B}(x)$ are given by[13]

$$F_5(x) = x^2 \int_0^\infty u^5 \exp[-(xu^2 + u)]du;$$

$$F_{5,B}(x) = x^2 \int_B^\infty u^5 \exp[-(xu^2 + u)]du, \tag{3}$$

where $x = E_M/4T_e$ and $B = \sqrt{(eq_d/aT_e/x)}$.

Inclusion of secondary electron current along with primary electron and ion current in the grain charging equation gives rise to three charge equilibrium states[13,16,38] corresponding to the vanishing of the total current,

$$I_{tot} = I_i + I_e + I_e^s. \tag{4}$$

When $I_e^s = 0$, the dust surface is negatively charged. When $I_e^s \neq 0$, depending on the values of the different plasma and dust parameters, the above equation may possess multiple roots defining different charge states with varying stability properties.[16] The equilibrium state $q_d = q_{d0}$, $n_e = n_{e0}$, $n_i = n_{i0}$ is stable provided $(\partial I_{tot} \partial q_d)_{eq} < 0$ and unstable when the same is >0. For sufficiently weak or strong secondary electron emission, there exists only one equilibrium charge state with $q_d < 0$ or $q_d > 0$. For secondary electron emission of intermediate strength, three equilibrium charge states may exist.[9,10,13,16,38] The lowest charge state is negative while for the highest one, the dust charge is positive and both are stable states. The intermediate state dust charge is also positive but it is unstable as $(\partial I_{tot} \partial q_d)_{eq} > 0$. Any small change in I_{tot} may cause shift of this dust charge state to the neighboring stable one: $q_{d0} = -Z_{d0}e$ or the higher positive charge state $q_{d0} = +Z_{d0}e$, Z_{d0} is the number of charges on the dust grains in equilibrium. In this paper we shall investigate Jeans instability in both cases when stable equilibrium dust charge is positive or negative.

III. CASE I: EQUILIBRIUM DUST CHARGE IS NEGATIVE

When secondary electron emission is included in the analysis, the plasma is to be considered as consisting of four components viz. ions, primary electrons (temperature T_e), secondary electrons (temperature T_s). For negatively charged dust grains ($q_d < 0$), secondary electrons are emitted without any barrier of attracting potential. In this case, the current balance equation has only one solution if $1 - 3.7\delta_M F_5(x) > (m_e T_i / m_i T_e)^{1/2}$; and no solution otherwise.[13] So we can assume $T_s = T_e$, so that the plasma may be assumed to consist of three components, electrons, ions and negatively charged dust grains.

A. Grain charging equation

The charging equation for the dust grain is

$$\frac{\partial q_d}{\partial t} + v_d \frac{\partial q_d}{\partial x} = I_i + I_e + I_e^s = I_{tot}. \tag{5}$$

The negatively charged equilibrium dust charge state is given by, $I_{tot}(q_d = q_{d0}, \phi = 0) = 0$, where $q_{d0} = -Z_{d0}e$ is the equilibrium charge on the dust surface and ϕ is the plasma potential.

Substituting $(I_i)_{eq}$, $(I_e)_{eq}$ and $(I_e^s)_{eq}$ as given by (1) and (2) with $q_{d0}=-Z_{do}e$, $n_i(\phi=0)=n_{i0}$, $n_e(\phi=0)=n_{e0}$ for negatively charged dust grains, we obtain the following equilibrium state ion-electron density ratio in the dusty plasma:

$$\frac{n_{i0}}{n_{e0}}=\sqrt{\frac{m_i}{m_e}}\frac{\sqrt{\sigma}}{\sigma+z_0}\exp(-z_0)\alpha_{1s}, \tag{6}$$

with $\alpha_{1s}=1-3.7\delta_M F_5(x)$; $z_0=Z_{d0}e^2/aT_e$; $\sigma=T_i/T_e$. Using current balance equation $I_{e0}+I_{i0}+I_{e0}^s=0$, we have the dust charging frequency ν_{D1}, as

$$\nu_{D1}=\frac{a/\lambda_{Di}}{\sqrt{2\pi}}\omega_{pi}(1+\sigma+z_0). \tag{7}$$

The linearized equation for small charge variation $q_{d1}=Z_{d0}eq_1$ about the equilibrium state $q_{d0}=-Z_{d0}e$ is given by

$$\frac{\partial q_1}{\partial t}=-\nu_{D1}q_1+\nu_D\left(\frac{\delta n_i}{n_{i0}}-\frac{\delta n_e}{n_{e0}}\right), \tag{8}$$

where

$$\nu_D=\frac{a/\lambda_{Di}}{\sqrt{2\pi}}\omega_{pi}\left(\frac{\sigma+z_0}{z_0}\right). \tag{9}$$

B. Basic equations

For negatively charged dust grains we can take $T_s=T_e$, the population of secondary electrons is not distinguishable from that of the ambient plasma electrons. So the charge neutrality condition reads as

$$n_{i0}-n_{e0}-Z_{d0}n_{d0}=0. \tag{10}$$

Let us consider the propagation of low phase velocity DA waves in an unmagnetized dusty plasma whose constituents are electrons, ions and extremely massive charged dust grains. The dust size and the intergrain spacings are much smaller than the dusty plasma Debye radius. We also assume that there are significant number of charged dust grains within the Debye sphere, so that the DA wave spectrum, arises due to collective interactions. The electron and ion number densities in the electrostatic DA wave potential ϕ are, respectively,

$$n_e=n_{e0}\exp\left(\frac{e\phi}{T_e}\right), \tag{11}$$

$$n_i=n_{i0}\exp\left(-\frac{e\phi}{T_i}\right). \tag{12}$$

The dust component is modeled as a warm fluid, the dust dynamics of which is governed by the dust continuity equation

$$\frac{\partial n_d}{\partial t}+\frac{\partial}{\partial x}(n_d v_d)=0 \tag{13}$$

and the dust momentum equation

$$\frac{\partial v_d}{\partial t}+v_d\frac{\partial v_d}{\partial x}=-\frac{q_d}{m_d}\frac{\partial\phi}{\partial x}-\frac{T_d}{n_d m_d}\frac{\partial n_d}{\partial x}-\frac{\partial\psi}{\partial x}. \tag{14}$$

The above equations are closed with the Poisson equation for the overall charge balance,

$$\frac{\partial^2\phi}{\partial x^2}=-4\pi(en_i-en_e+q_d n_d) \tag{15}$$

and mass densities

$$\frac{\partial^2\psi}{\partial x^2}=4\pi G m_d(n_d-n_{d0}), \tag{16}$$

where we have neglected the gravitational effects of ions and electrons. Here m_d is the mass of the charged dust grains moving with velocity v_d and n_d is the dust number density, ϕ and ψ are the electrostatic and gravitational potentials, q_d is the dust grain charge.

It should be noted that for a gravitating plasma, the assumption of an equilibrium value n_{d0} of the dust number density n_d is a consequence of what is known as Jeans swindle.

C. Dispersion relation for negatively charged dust grains

Linearizing Eqs. (11) and (12) about the equilibrium state $n_e=n_{e0}$, $n_i=n_{i0}$, $v_d=0$, $\phi=0$ and $\psi=0$ we obtain electron and ion density which fluctuations are given by

$$\delta n_e=n_{e0}\Phi;\quad \delta n_i=-n_{i0}\Phi/\sigma, \tag{17}$$

and for the dust fluid, the dust density perturbation is related to Φ by,

$$\frac{\delta n_d}{n_{d0}}=-\frac{k^2C_{da}^2}{\omega^2+\omega_{Jd}^2-k^2V_{td}^2}\Phi, \tag{18}$$

where $C_{da}=\sqrt{Z_{d0}T_e/m_d}$ is the dust acoustic speed, $\omega_{Jd}^2=4\pi G m_d n_{d0}$ is the squared Jeans frequency, and $V_{td}=\sqrt{T_d/m_d}$ is the dust thermal speed. To derive the above relation, we use Eqs. (13), (14), and (16).

Substituting these in the linearized Poisson equation and under the approximation $\omega\ll\nu_{D1}$ and $k^2\lambda_{De}^2\ll 1$, we obtain the dispersion relation for DA waves in a self-gravitating complex plasma in presence of secondary electron emission,

$$1+\frac{n_{i0}}{\sigma n_{e0}}+\frac{Z_{d0}n_{d0}}{n_{e0}}\frac{\nu_D}{\nu_{D1}}(1+i\omega/\nu_{D1}) -\frac{Z_{d0}n_{d0}}{n_{e0}}\frac{k^2C_{da}^2}{\omega^2+\omega_{Jd}^2-k^2V_{td}^2}=0, \tag{19}$$

where $\beta_d=\nu_D(1+1/\sigma)$ and we use Eq. (8), which shows that real part ω_r of the frequency $\omega=\omega_r+i\omega_i$ is given by

$$\frac{\omega_r^2}{k^2C_{da}^2}=\sigma_d+\frac{(n_{i0}/n_{e0}-1)}{1+\frac{n_{i0}}{\sigma n_{e0}}+\frac{\nu_D}{\nu_{D1}}(n_{i0}/n_{e0}-1)}-\frac{\omega_{Jd}^2}{k^2C_{da}^2} \tag{20}$$

where $\sigma_d=V_{td}^2/C_{da}^2$.

The decay or growth rate is given by

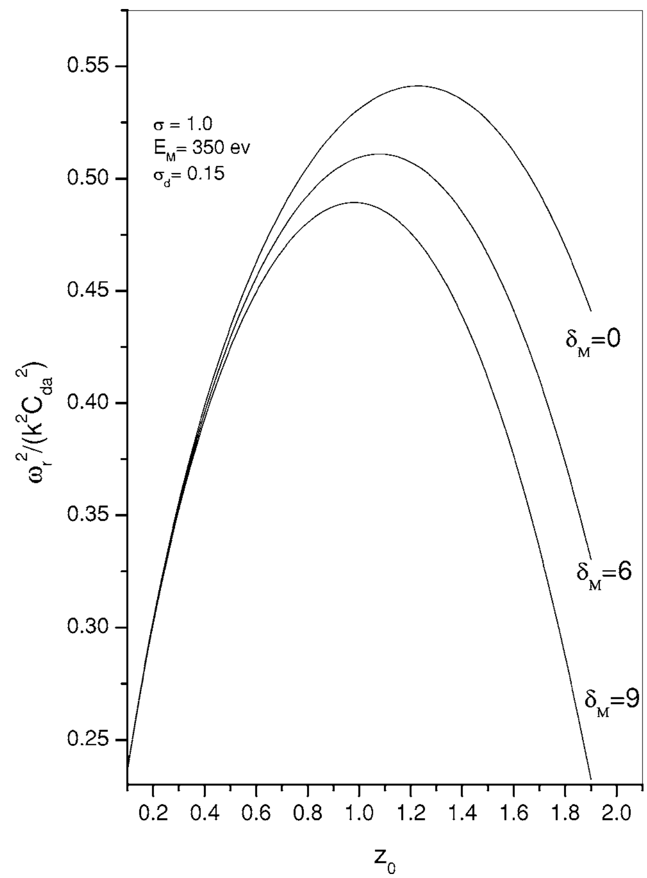

FIG. 1. Plot of the square of the normalized real frequency $\omega_r^2/k^2C_{da}^2$ against z_0 of DA wave $\omega_{Jd}^2=0$ for negatively charged dust grains for different plasma parameters.

$$\omega_i = -\frac{k^2C_{da}^2}{2\nu_{D1}}\frac{(n_{i0}/n_{e0}-1)^2}{\left(1+\frac{n_{i0}}{\sigma n_{e0}}+\frac{\nu_D}{\nu_{D1}}(n_{i0}/n_{e0}-1)\right)^2} \tag{21}$$

which is always negative.

Equation (20) can be written in the form $\omega_r^2=\Omega_d^2-\omega_{Jd}^2$, where

$$\Omega_d^2 = \sigma_d + \frac{(n_{i0}/n_{e0}-1)}{1+\frac{n_{i0}}{\sigma n_{e0}}+\frac{\nu_D}{\nu_{D1}}(n_{i0}/n_{e0}-1)},$$

and n_{i0}/n_{e0} is given by Eq. (6). Magnitude of Ω_d increases with z_0 but after a certain value of $z_0\approx 1$, Ω_d decreases. Figure 1 shows that as secondary emission increases, Ω_d decreases which leads to an instability when $\Omega_d<\omega_{Jd}$. Thus secondary electron emission enhances Jeans instability for negatively charged dust grains. In a physical situation negatively charged dust grains repel lighter electrons and attracts heavier ions which pronounces charge condensation and hence helps in gravitational collapse. These phenomena create favorable situations for the onset of Jeans instability.

IV. CASE II: EQUILIBRIUM DUST CHARGE IS POSITIVE

When equilibrium dust charge is positive only those electrons will be emitted from the dust grains which have sufficiently high energy. When the dust grains are positively charged i.e., $q_d>0$, the dust grains attracts the negative electrons and only those electrons will be emitted from the dust grains which can overcome that attracting potential. For this reason secondary electrons must have higher thermal energy to overcome attracting potential. Thus the emitted secondary electrons must have higher temperature T_s than the primary electron temperature T_e. So plasma should be considered as a collection of four components: ions, primary electrons, secondary electrons and positively charged dust grains.

A. Grain charging equation

An equilibrium state with positively charged dust is also possible, $(q_d)_{eq}=q_{d0}=Z_{d0}e$. Setting $n_i(\phi=0)=n_{i0}$, $n_e(\phi=0)=n_{e0}$ and $q_{d0}=Z_{do}e$ in equation $I_{i0}+I_{e0}+I_{e0}^s=0$ and using the expressions for $(I_i)_{eq}$, $(I_e)_{eq}$ and $(I_e^s)_{eq}$ as given by (1) and (2) for positively charged dust grains, we obtain

$$\frac{n_{i0}}{n_{e0}} = \sqrt{\frac{m_i}{m_e}}\frac{(1+z_0)}{\sqrt{\sigma}}\exp(-z_0/\sigma)\alpha_{1s}, \tag{22}$$

where $\alpha_{1s}=1-3.7\delta_M F_{5,B_0}(x)\exp(z_0-z_0/\sigma_s)$; $\sigma_s=T_s/T_e$. The positively charged state for dust grain is stable provided, $(\partial I_{\rm tot}/\partial q_d)_{eq}=-\nu_{D1}<0$ where

$$\nu_{D1} = \frac{a/\lambda_{Di}}{\sqrt{2\pi}}\omega_{pi}\exp(-z_0/\sigma)\left[1+\frac{\sigma\alpha_{2s}}{(1+z_0)\alpha_{1s}}\right], \tag{23}$$

$$\alpha_{2s} = 1-3.7\delta_M F_{5,B_0}(x)\left[1-(1+z_0)\left(1-1/\sigma_s + \frac{z_0^2}{2x}\frac{\exp[-z_0-\sqrt{z_0/x}]}{F_{5,B_0}(x)}\right)\right]\exp(z_0-z_0/\sigma_s). \tag{24}$$

Equations (1), (2), and (5) lead to the linearized equation for the charge variation q_1, which is given in Eq. (8), where

$$\nu_D = \frac{a/\lambda_{Di}}{\sqrt{2\pi}}\omega_{pi}\left(\frac{\sigma}{z_0}\right)\exp(-z_0/\sigma). \tag{25}$$

B. Basic equation

For positively charged dust grains, the emitted secondary electrons must have higher temperature T_s than primary electron temperature T_e, secondary electrons are distinguishable from primary electrons and form a separate population. Thus plasma under consideration in this case consists of four components, primary electrons, ions, secondary electrons (temperature T_s) and positively charged dust grains satisfying the charge neutrality condition,

$$n_{i0}-n_{e0}-n_{s0}+Z_{d0}n_{d0}=0. \tag{26}$$

Primary electrons, secondary electrons and ions are considered to be Boltzmann distributed whereas the positively charged dust grains are inertial. They satisfy the basic equations (11)–(16) along with the equation for secondary electrons,

$$n_s = n_{s0}\exp(e\phi/T_s). \tag{27}$$

C. Dispersion relation

Linearizing the basic equations about the equilibrium values we obtain the following density fluctuations for primary electrons, ions and secondary electrons, respectively,

$$\delta n_e = n_{e0}\Phi; \quad \delta n_i = -n_{i0}\Phi/\sigma; \quad \delta n_s = -n_{s0}\Phi/\sigma_s; \tag{28}$$

and for the dust fluid, the dust density perturbation is related to Φ by

$$\frac{\delta n_d}{n_{d0}} = \frac{k^2C_{da}^2}{\omega^2+\omega_{Jd}^2-k^2V_{td}^2}\Phi. \tag{29}$$

On substituting the above quantities and q_1 in the linearized Poisson equation for positively charged dust grains, for long wavelength approximation and $\omega \ll \nu_{D1}$, we obtain the following dispersion relation for DA waves:

$$1+\frac{n_{i0}}{\sigma n_{e0}}+\frac{n_{s0}}{\sigma_s n_{e0}}+\frac{Z_{d0}n_{d0}}{n_{e0}}\frac{\nu_D}{\nu_{D1}}(1+i\omega/\nu_{D1}) - \frac{Z_{d0}n_{d0}}{n_{e0}}\frac{k^2C_{da}^2}{\omega^2+\omega_{Jd}^2-k^2V_{td}^2}=0, \tag{30}$$

which gives the real frequency ω_r by

$$\frac{\omega_r^2}{k^2C_{da}^2} = \sigma_d + \frac{Z_{d0}n_{d0}/n_{e0}}{1+\frac{n_{i0}}{\sigma n_{e0}}+\frac{n_{s0}}{\sigma_s n_{e0}}+\frac{\beta_D}{\nu_{D1}}\frac{Z_{d0}n_{d0}}{n_{e0}}} - \frac{\omega_{Jd}^2}{k^2C_{da}^2} \tag{31}$$

and the growth rate ω_i by

$$\omega_i = -\frac{k^2C_{da}^2\beta_D}{2\nu_{D1}^2}\left(\frac{A}{\frac{Z_{d0}n_{d0}}{n_{e0}}}+\frac{\beta_D}{\nu_{D1}}\right)^{-2} \tag{32}$$

where $A=1+n_{i0}/\sigma n_{e0}+n_{s0}/\sigma_s n_{e0}$. Equation (31) can be written in the form $\omega_r^2=\Omega_d^2-\omega_{Jd}^2$, where

$$\Omega_d^2 = \sigma_d + (Z_{d0}n_{d0}/n_{e0})(A+(\beta_D/\nu_{D1})Z_{d0}n_{d0}/n_{e0})^{-1}.$$

Numerical estimation shows that as secondary emission yield increases, Ω_d^2 increases which in turn reduces the chance of instability. Thus, when equilibrium dust charge is positive, enhanced secondary emission suppresses Jeans instability. As secondary emission increases, positively charged dust grains acquire more positive charges. They attract more lighter electrons and repel more heavier ions. This phenomenon resists charge condensation and gravitational collapse. Hence threshold of Jeans instability becomes higher.

V. NUMERICAL RESULTS

Here, δ_M is the ratio of the emitted electrons to the incident electrons. So large values of δ_M means larger number of electrons emitted from dust grains which makes the equilibrium dust grains positively charged. So δ_M for positively charged dust grains have considered higher values 22, 24 as compared to that of 0, 6, 9 for negatively charged dust grains as for smaller number of emitted secondary electrons causes the equilibrium dust charge negative. In this case, $1-3.7\delta_M F_5(x) > (m_eT_i/m_iT_e)^{1/2}$ with $m_eT_i/m_iT_e \ll 1$. So we can take $\delta_M=0$ which means there is no secondary electron emission and the dust grains are charged only by plasma current. Hence, the dust grains in this case are negatively charged. But positively charged dusts are produced due to the emission of secondary electron. So in this case δ_M cannot have zero value. We have, $E_M/4T_e \gg 1$ and $3.7\delta_M \sim E_M/4T_e$.

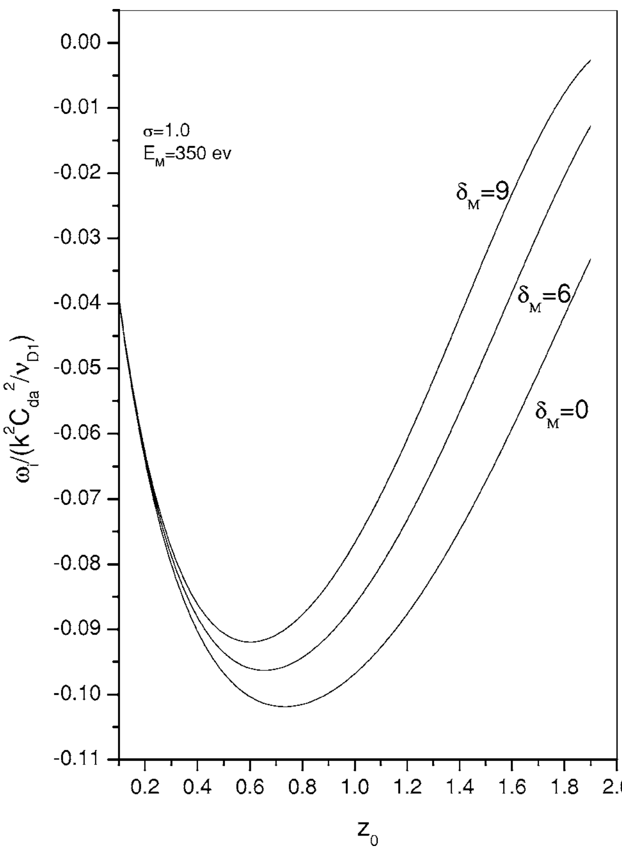

FIG. 2. Plot of normalized imaginary frequency $\omega_i/(k^2C_{da}^2/\nu_{D1})$, as given by Eq. (21) against z_0 of DA wave for negatively charged dust grains for different plasma parameters.

For numerical computation, we use the secondary emission data given by Ref. 13. For negatively charged dust grains we use Al_2O_3 material and for this material δ_M can take the values 2–9, E_M (eV)$\sim$350–1300. On the other hand for positively charged dust grains, we use MgO material. For this material $\delta_M \sim 3$–25 and E_M (eV)$\sim$400–1500.

For negatively charged dust grains, n_{i0}/n_{e0} given by (6) depends on different values of $z_0=Z_{d0}e^2/aT_e$, $\sigma=T_i/T_e$, δ_M, E_M, etc. Charge neutrality equation gives us the condition $n_{i0}/n_{e0}>1$ and the plasma parameter are chosen accordingly. The charge on the dust grains is determined by the current balance equation $I_{i0}+I_{e0}+I_{e0}^s=0$, on the basis of above mentioned plasma parameters. Also, dust thermal speed < dust acoustic speed, then the ratio $V_{td}^2/C_{da}^2=\sigma_d<1$. Figure 1 is plotted for ω_r^2 against z_0 for $\sigma=1$, $\sigma_d=0.15$, $E_M=350$ eV, $\delta_M=0$, 6 and 9. Figure 1 shows that, ω_r^2 increases with z_0 and attains peak value around $z_0 \approx 1$ (i.e., $Z_{d0}e^2/aT_e \approx 1$) and then decreases sharply, but ω_r^2 decreases with increase in secondary electron emission intensity for all values of z_0. Hence, secondary electron emission induces the increase in the Jeans instability for negatively charged dust grains,

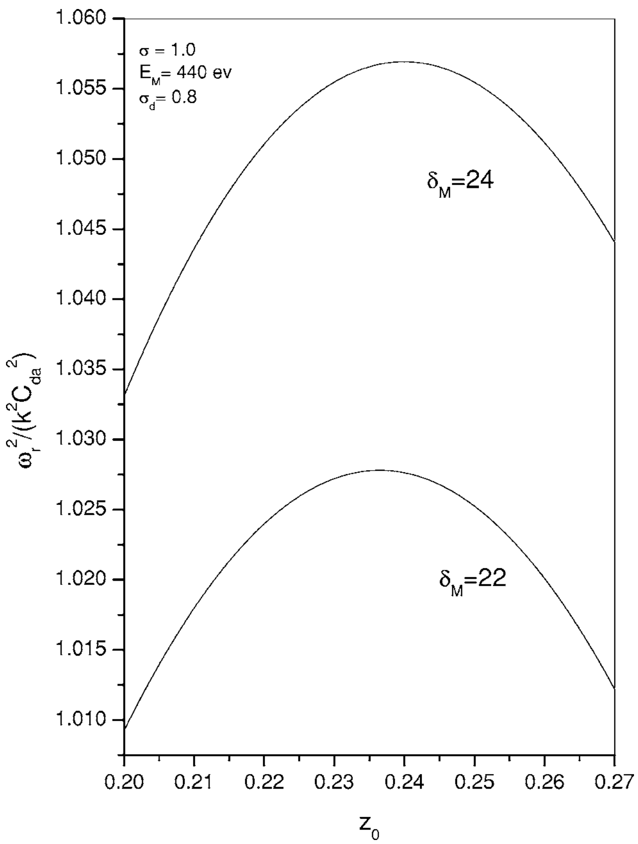

FIG. 3. Plot of the sure of the normalized real frequency $\omega_r^2/k^2C_{da}^2$ against z_0 of DA wave $\omega_{Jd}^2=0$ for positively charged dust grains for different plasma parameters.

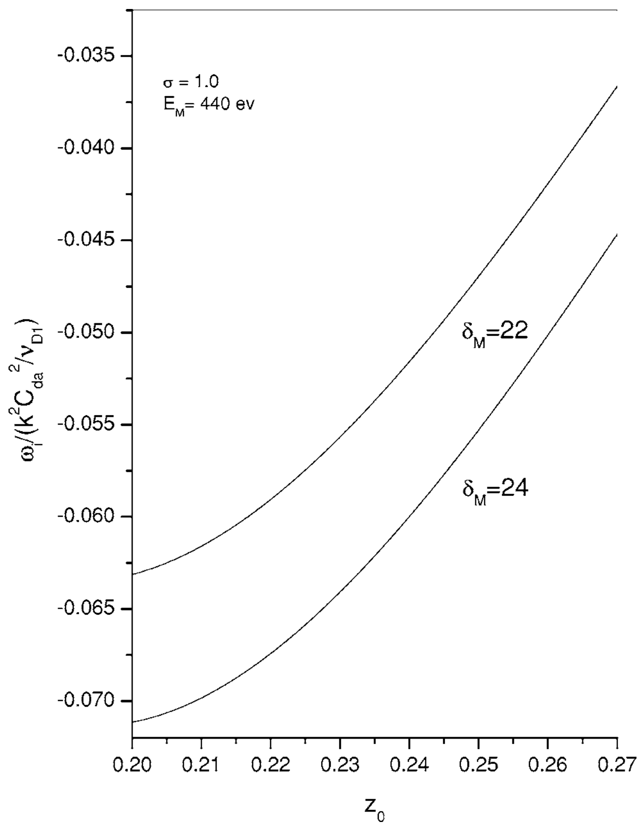

FIG. 4. Plot of normalized imaginary frequency $\omega_i/(k^2C_{da}^2/\nu_{D1})$, as given by Eq. (32) against z_0 of DA wave for positively charged dust grains for different plasma parameters.

which is evident from Fig. 1. Figure 2 is plotted for ω_i against z_0 and this shows that magnitude of ω_i decreases as secondary electron emission intensity increases.

For positively charged dust grains, the corresponding quantities are also shown graphically. Figure 3 gives the plot of ω_r^2 against z_0 for $\delta_M=22$, 24, $\sigma_s=1.01$ and $\sigma_d=0.8$. It is found that in each case as δ_M increases, ω_r^2 increases. This implies that secondary electron emission intensity suppresses the Jeans instability when equilibrium dust charge is positive. The damping rate ω_i is given by Eq. (32). It is clear from Fig. 4 that, ω_i is always negative as δ_M increases, so that waves are purely damped for this case.

VI. CONCLUSION

From the result obtained in this work, it is seen that the presence of secondary electron emission in a dusty plasma enhances the Jeans instability for $q_{d0}<0$. It has been found that for $q_{d0}>0$, waves are purely damped about the equilibrium. From our result it is observed that the negatively charged dust grains repel lighter electrons and attract heavier ions which pronounces charge condensation and increase mass of the dust grains. This increased dust mass pronounces gravitational effect and hence Jeans instability. Our result also shows that enhanced secondary emission reduces the threshold of Jeans instability. On the other hand positively charged dust grains attract lighter electrons and repel heavier ions which resist charge condensation by restricting dust mass enhancement. This phenomenon reduces gravitational effect and hence growth rate of Jeans instability. As secondary electron emission increases the dust grains acquire more positive charges which acquire more electrons and repel more heavier ions, so it increases threshold of Jeans instability.

Our results can be useful in understanding the behavior of DA waves in space and astrophysical plasmas where dust grains are often found to be charged positively by ultraviolet (UV) irradiation. The results are also applicable to laboratory experiments, where the behavior of the dust grains are charged by a UV source.[5–7]

ACKNOWLEDGMENT

The authors would like to thank the referee for valuable comments leading to improvements of the manuscript.

[1]N. N. Rao, P. K. Shukla, and M. Y. Yu, Planet. Space Sci. **38**, 543 (1990).
[2]P. K. Shukla and V. P. Silin, Phys. Scr. **45**, 508 (1992).
[3]J. Pavlu, J. Safrankova, Z. Nemeck, and A. Velyhan, in *Dusty Plasmas in the New Millennium*, Third International Conference on the Physics of Dusty Plasmas, Durban 2002, edited by R. Bharuthram, M. A. Hellberg, P. K. Shukla, and F. Verheest (American Institute of Physics, New York, 2002), p. 382–385.
[4]P. Zilavy, Z. Sternovsky, I. Cermak, Z. Nemeck, and J. Safrankova, Vacuum **50**, 139 (1998).
[5]V. W. Chow, D. A. Mendis, and M. Rosenberg, IEEE Trans. Plasma Sci. **22**, 179 (1994).
[6]M. Rosenberg and D. A. Mendis, IEEE Trans. Plasma Sci. **23**, 177 (1995).
[7]M. Rosenberg, D. A. Mendis, and D. P. Sheehan, IEEE Trans. Plasma Sci. **27**, 239 (1999).

[8] L. A. Bringol and T. W. Hyde, Adv. Space Res. **20**, 1539 (1997).
[9] M. Horyani, S. Robertson, and B. Walch, Geophys. Res. Lett. **22**, 2079 (1995).
[10] B. Walch, M. Horyani, and S. Robertson, Phys. Rev. Lett. **75**, 838 (1995).
[11] A. Barkan, N. D'Angelo, and R. L. Merlino, Phys. Rev. Lett. **73**, 3043 (1994).
[12] N. D'Angelo, J. Phys. D **37**, 860 (2004).
[13] N. Meyer-Vernet, Astron. Astrophys. **105**, 98 (1982).
[14] O. Havnes, J. Troim, T. Blix, W. Mortensen, L. I. Naesheim, E. Thrane, and T. Tonnesen, J. Geophys. Res. **101**, 10839 (1996).
[15] M. Horyani, B. Walch, S. Robertson, and D. Alexander, J. Geophys. Res. **103**, 8575 (1998).
[16] C. K. Goertz, Rev. Geophys. **27**, 271 (1989).
[17] J. E. Allen, Phys. Scr. **45**, 497–503 (1992).
[18] E. W. Kobb and M. S. Turner, *The Early Universe* (Addison-Wesley, Reading, MA, 1992), p. 324.
[19] K. Avinash and P. K. Shukla, Phys. Lett. A **189**, 470 (1994).
[20] B. P. Pandey, K. Avinash, and C. B. Dwivedi, Phys. Rev. E **49**, 5599 (1994).
[21] F. Verheest and P. K. Shukla, Phys. Scr. **55**, 83 (1997).
[22] F. Verheest, P. Meuris, R. L. Mace, and M. A. Hellberg, Astrophys. Space Sci. **254**, 253 (1997).
[23] P. K. Shukla and F. Verheest, Astrophys. Space Sci. **262**, 157 (1999).
[24] S. R. Pillay and F. Verheest, J. Plasma Phys. **71**, 177 (2005).
[25] B. P. Pandey and G. S. Lakhina, Pramana **50**, 191 (1998).
[26] P. Meuris, F. Verheest, and G. S. Lakhina, Planet. Space Sci. **45**, 449 (1997).
[27] G. L. Delzanno and G. Lepenta, Phys. Rev. Lett. **94**, 175005 (2005).
[28] G. Jacobs and P. K. Shukla, J. Plasma Phys. **71**, 487 (2005).
[29] P. K. Shukla and A. A. Mamun, *Introduction to Dusty Plasma Physics* (Institute of Physics, Bristol, 2002), p. 159.
[30] P. K. Shukla and L. Stenflo, Proc. R. Soc. London, Ser. A **462**, 403 (2006).
[31] P. K. Shukla and L. Stenflo, Phys. Lett. A **355**, 378 (2006).
[32] S. V. Vladimirov, K. Ostrikov, M. Y. Yu, and G. E. Morfill, Phys. Rev. E **67**, 036406 (2003); K. Ostrikov, I. B. Denysnko, S. V. Vladimirov, S. Xu, H. Sugai, and M. Y. Yu, *ibid.* **67**, 056408 (2003).
[33] K. Ostrikov, Rev. Mod. Phys. **77**, 489 (2005).
[34] S. V. Vladimirov and K. Ostrikov, Phys. Rep. **393**, 175 (2004).
[35] S. Sarkar, B. Roy, M. Khan, and M. R. Gupta, Phys. Scr. **73**, 506 (2006).
[36] B. Roy, S. Sarkar, M. Khan, and M. R. Gupta, Phys. Plasmas **13**, 102904 (2006).
[37] E. J. Sternglass, Phys. Rev. **108**, 1 (1957).
[38] M. Horanyi, Annu. Rev. Astron. Astrophys. **34**, 383 (1996).