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Instability of dust acoustic mode in streaming and irradiated collisional dusty plasma with dust charge fluctuation

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ABSTRACT
A theoretical investigation of the photoelectric effect through dust charge fluctuation on low frequency electrostatic dust acoustic (DA) mode has been done using fluid model of plasma with negatively charged dust grain. Here we consider collisional effects between charged and neutral particles of plasma, lighter particles streaming along the external electric field. Dispersion relation of DA mode has been derived and instability of DA mode is numerically analyzed using the values of appropriate plasma parameters. It has been found that the instability of DA mode is increased significantly due to photoelectric effect compared to the streaming and collisional effects.

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1. INTRODUCTION

Dusty plasma consists of electrons, ions, highly charged ($Z_d \sim 10^1$ - 10^5) and relatively massive ($m_d/m_+ \sim 10^6 - 10^{12}$) dust grains and neutral particles [1, 2]. In such plasma, micron or sub-micron sized dust grains can be charged by absorbing electrons and ions streaming onto their surface. Since the streaming velocity of electrons is much more than that of the ions they readily sit on the surface of the dust grains and make them negatively charged. On the other hand, charging due to photoelectron emission, thermionic emission, secondary emission, etc. can be significant and dust grains may become positively charged [3, 4]. In the present dust grain charging model we have considered the dust grain as negatively charged in the irradiated dusty plasma. The dust charge can be negative in irradiated dusty plasma when the irradiation frequency becomes less than the threshold frequency of the dust grain material. The dust charge fluctuation model is discussed in detail in section 2.1.

The presence and the mobility of dust grains can modify the existing plasma modes or may introduce new time and space scales leading to new modes, their instabilities and other related phenomena [1, 2]. Theoretical predictions [5 – 11] and experimental observations [4, 12 −15] of waves in dusty plasma have been done by a number of researchers. They extensively studied the wave propagation properties, damping, new modes and instabilities, etc. in un-magnetized or magnetized dusty plasma. Most of the studies have been done considering the dust charge as a constant quantities [2, 8]. On the other hand, in the real plasma, dust charge fluctuation occurs when the conditions in the plasma near the dust grain are changed due to a variety of reasons, such as the wave motion. Considering the dust charge as a time dependable variable, an interesting result of the damping of the electrostatic modes has been investigated [16 – 18]. Obviously, waves and instabilities of the dust modes in irradiated dusty plasma have not been studied extensively. The photoelectric effects are invariably present in the naturally occurring irradiated dusty plasma [19] or can be occurred in irradiated laboratory dusty plasmas [4, 20]. M. K. Islam [21] *et al*, studied the photoelectric effect through dust charge fluctuation on dust modes using Vlasov kinetic model and shown that the high frequency plasma wave can be unstable due to the photoelectric effect in a streaming and irradiated positively charged dust grains in an un-magnetized dusty plasma. Recently V. Kumar [22] *et al.* have studied the photoelectric effect on Jeans instability including work function of grain materials and shown that photoelectric current has destabilizing influence on the growth rate of the Jeans instability.

In this paper, the photoelectric effect on the low frequency electrostatic dust acoustic (DA) mode through dust charge fluctuation in collisional and streaming dusty plasma has been investigated theoretically including surface potential of dust grain in spite of work function of grain materials using fluid model of plasma. It is considered that dust grains are cold ($T_d = 0$) and ions and electrons are as a hot Boltzmann's gas at a finite temperature T_+ and T_e, respectively [11, 14].

The paper is organized as follows: present model of dust charge fluctuation including photoelectric effect has been discussed in Sec. 2.1. In Sec. 2.2 derivation of the general dispersion relation of the electrostatic dust modes using fluid model is presented. Results and discussions of the DA mode with instability are analyzed in Sec. 3. Finally, conclusions of this research work are given in Sec. 4.

2.1. PRESENT MODEL OF DUST CHARGE FLUCTUATION

In irradiated dusty plasma, dust charge fluctuation occurs when the fluctuating electron densities n_{e1} are considered to be piled up on a dust grain due to a variety of reasons, such as the wave motion. So far, in the dust charge fluctuation model, this piled up electrons are neutralled through the absorption of ions by the dust grain. On the other hand, in the present dust charge fluctuation model, photoelectron emission is included. In this model, the fluctuating dust charge is considered to be reached to its equilibrium value through the combined effects of the absorption of ions by the dust grain and the emission of electrons from the dust grain surface by irradiation. In such case, only the piled up electrons on the dust grain surface are removed by irradiation, and hence, dust grain will not be ionized by irradiation. In this regard , the frequency of the irradiated wave $\nu_p$must satisfy the condition $\nu_w > \nu_p > (e\phi_d + e\vartheta_i)/h$ for $\phi_d < 0$, where $\nu_w, e, \phi_d,$ and h are the threshold frequency due to the photoelectric work function of grain materials, elementary charge, dust grain surface potential, and Planck constant, respectively [4, 21]. The last term, $e\vartheta_i/h$ of the above condition is due to the image potential and is very small compared to $(e\phi_d)/h$ [23]. Hence, the effect of image potential can be neglected in the expression of photoelectric current.

Let us consider the parallel waves from irradiated source are incident on a spherical dust grain of cross-sectional area A. Then due to the photoelectric effect, the photoelectric current I_{pe} from the area A can be written as

$$I_{pe} = Aen_e v_{pe}, \qquad (1)$$

where n_e is the density of electron and v_{pe} is the velocity of photoelectron.

The kinetic energy of the photoelectron can be written according to the Einstein relation of the photoelectric effect and using the condition of the frequency of the irradiated wave as:

$$\frac{1}{2} m_e v_{pe}^2 = h\nu_p + e\phi_d. \qquad (2)$$

Here, ν_w is ignored, since the dust grains are not ionized by irradiation. The spectrum of photoelectrons released is often assumed to be a Max-wellian with a temperature T_p which corresponds to an energy $kT_p = h\nu_p + e\phi_d$.

Hence, using Eq. (1) and Eq. (2), for a unidirectional photon flux, the net current due to photoemission of electrons is given by [21, 24, 25]

$$I_{pe} = \pi a_d^2 e n_e \sqrt{\frac{2}{m_e}\left(h\nu_p + e\Phi_d\right)}\, exp\left\{\frac{e\Phi_d}{h\nu_p + e\Phi_d}\right\}. \qquad (3)$$

Here, a_d is the dust grain radius. The exponential factor in Eq. (3) presents the effect of the negatively charged dust grain potential on the photoelectron.

If the streaming velocity of ion (v_{+0}) and electron (v_{e0}) become much larger than their thermal velocity, then electron current (I_e) and ion current (I_+) collected by the dust grains in our dusty plasma model are given by [8]

$$I_e = -\pi a_d^2 e n_e v_{e0}\left[1 + \frac{2e\phi_d}{m_e v_{e0}^2}\right] \qquad (4)$$

and

$$I_+ = \pi a_d^2 e n_+ v_{+0}\left[1 - \frac{2e\Phi_d}{m_+ v_{+0}^2}\right]. \qquad (5)$$

According to our dust grain charging model, the quantities I_{pe}, I_e and I_+ are used in the basic dust grain charging equation, which is then given by

$$\frac{dQ_d}{dt} = I_+ + I_{pe} + I_e. \qquad (6)$$

The present dust charging equation, Eq. 6, has been used to obtain dispersion relation of the low frequency and low phase velocity electrostatic dust modes below the ion cyclotron frequency in the following section.

2.2. DISPERSION RELATION OF ELECTROSTATIC DUST ACOUSTIC MODE

Let us consider homogeneous and uniform dusty plasma consists of different charged and neutral particles of masses m_e, m_+, m_d and m_N, where the subscripts (e), (+), (d) and (N) denotes respectively, the electrons, ions, dust grains and neutral particles. The dust charge is considered as negative, i.e., $Q_d = - Z_d e$, where Z_d being the number of electron residing on a dust grain. It is assumed that dust grains are cold ($T_d = 0$) and ions and electrons have temperature T_+ and T_e, respectively. It is assumed that neutral particles are steady with respect to charged particles. An external zero-order electric field (E_o) has been applied in the plasma.

Continuity and momentum equations for three charged elements of the dusty plasma are taken as follows, respectively:

$$\frac{\partial n_j}{\partial t} + \frac{\partial}{\partial x}\left(n_j \mathrm{v_j}\right) = 0, \quad (7)$$

$$kT_e \frac{\partial}{\partial x} n_e + e n_e E \ = -\nu_e n_e m_e \mathrm{v}_e, \quad (8)$$

$$kT_+ \frac{\partial}{\partial x} n_+ - e n_+ E = -\nu_+ n_+ m_+ \mathrm{v}_+, \quad (9)$$

$$n_d m_d \frac{\partial \mathrm{v}_d}{\partial t} + n_d m_d \mathrm{v}_d \frac{\partial}{\partial x} \mathrm{v}_d + e Z_d n_d E = -\nu_d n_d m_d \mathrm{v}_d. \quad (10)$$

Where n_d , k and T_j (j denotes e, + and d) are the dust densities, Boltzmann constant and temperature of the dusty plasma species, respectively.

The continuity and momentum equations are coupled to the quasi-neutrality equation:

$$n_+ = n_e + Z_d n_d. \quad (11)$$

At zero-order state, the plasma is steady and uniform i.e., $\frac{\partial}{\partial t} \ = 0 = \frac{\partial}{\partial x}$, the electric field E_0 is constant and the velocities of the three charged elements of the dusty plasma are then obtained from Eqs. (8) - (10), respectively, as follows:

$$eE_0 = \ -\nu_e m_e v_{e0}, \quad (12)$$

$$eE_0 = \ \nu_+ m_+ v_{+0} \ \text{ and} \quad (13)$$

$$eZ_{d0} E_0 = \ -\nu_d m_d v_{d0}. \quad (14)$$

The quasi-neutral condition at zero-order state becomes:

$$n_{+0} = n_{e0} + Z_{d0} n_{d0}. \quad (15)$$

From Eqs. (12) – (14), it is seen that streaming velocity of the plasma species depends on the charge of the species, collisional frequency, mass of the species and the zero order electric field.

Let us define the Doppler shifted frequencies are $\Omega_+ = \ \omega - \mathrm{K}_z \mathrm{v}_{+0}$, $\Omega_\mathrm{e} = \ \omega - \ \mathrm{K_z v_{e0}}$ and $\Omega_\mathrm{d} = \ \omega - \mathrm{K_z v_{d0}}$ due to streaming of ions, electrons and dust grains, respectively, where $\mathrm{v_{e0}} \gg \mathrm{v_{+0}} \gg \mathrm{v_{d0}}$. The quantities $\mathrm{C_j^2} = \ \frac{\mathrm{kT_j}}{\mathrm{m_j}}$, are the thermal velocities of charged particles of dusty plasma.

For linearizing Eqs. (6) - (11), all first-order quantities are assumed to have the space and time dependence as $e^{i(Kx-\omega t)}$. Linearizing the continuity equation for charge particles, Eq. (7), we get

$$v_{j1} = \frac{\Omega_\mathrm{j}}{K} \xi_j \quad (16)$$

where $\xi_j = \ \frac{n_{j1}}{n_{j0}}$ (17)

Similarly, linearizing, Eqs. (8) – (10), we obtain:

$$v_{e1} = \frac{-iKC_e^2 \xi_e}{\nu_e} - \ \frac{eE_1}{\nu_e m_e} \,, \quad (18)$$

$$v_{e+} = \frac{-iKC_+^2 \xi_e}{\nu_+} + \ \frac{eE_1}{\nu_+ m_+}, \quad (19)$$

$$v_{d1} = \frac{i\nu_d v_{d0} \xi_d}{e(\Omega_\mathrm{d} + i\nu_d)} + \ \frac{i\nu_d v_{d0} Q_{d1}}{e^2 Z_{d0} (\Omega_\mathrm{d} + i\nu_d)} - i \frac{eZ_{d0} E_1}{m_d (\Omega_\mathrm{d} + i\nu_d)} \ , \quad (20)$$

where E_1 is the perturbed electric field.

Linearizing Eq. (11), we get:

$$\xi_+ = \ \epsilon Z_{d0} \xi_d + \ (1 - \varepsilon Z_{d0}) \xi_e - \ Q_{d1} \epsilon / e \ , \quad (21)$$

here, $\varepsilon = \ n_{d0}/n_{+0}$. Eq. (21) expresses the condition of charge neutrality in first order.

Introducing next the quantities $\mu_+ = \ v_{+0} - \ v_{d0}$ and $\mu_e = \ v_{e0} - \ v_{d0}$ which represent the zero order drifts of the ions and electrons relative to the dust. Therefore, it can be used $\Omega_+ = \ \Omega_d - K\mu_+$ and $\Omega_e = \ \Omega_d - K\mu_e$, in Eq. (16), we obtain from Eqs, (16) and (18) – (20):

$$\xi_e = \ \frac{-eKE_1}{m_e \{iK^2 C_e^2 + \nu_e (\Omega_d - K\mu_e)\}}, \quad (22)$$

$$\xi_+ = \ \frac{eKE_1}{m_+ \{iK^2 C_+^2 + \nu_+ (\Omega_d - K\mu_+)\}} \ \text{ and} \quad (23)$$

$$\xi_d = \ \frac{-Q_{d1}}{eZ_{d0} \{1 - e\Omega_d (\Omega_d + i\nu_d)/(i\nu_d v_{d0} K)\}} - \ \frac{ieKZ_{d0} E_1}{m_d \Omega_d (\Omega_d + i\nu_d)}. \quad (24)$$

Substituting Eq. (24) into Eq. (21), we get:

$$\xi_+ = \ (1 - \varepsilon Z_{d0}) \xi_e - \left\{ \frac{\epsilon Q_{d1}/e}{1 + ie\Omega_d (\Omega_d + i\nu_d)} \right\} - \frac{ieK\varepsilon E_1 Z_{d0}^2}{m_d \Omega_d (\Omega_d + i\nu_d)}. \quad (25)$$

The first order perturbed photoelectron, electron and ion currents are obtained, respectively, from the Eqs. (3) – (5) as

$$\mathrm{I_{pe1}} = | \mathrm{I_{pe0}} | \ \frac{n_{e1}}{n_{e0}}, \quad (26)$$

$$\mathrm{I_{e1}} = |\mathrm{I_{e0}}| \frac{n_{e1}}{n_{e0}} \ , \quad (27)$$

$$\mathrm{I_{+1}} = |\mathrm{I_{+0}}| \frac{n_{+1}}{n_{+0}} \,. \quad (28)$$

Due to the presence of an electrostatic wave the dust will gain a perturbed charge $Q_{d1,}$ which can be obtained from Eq. (6) and using Eqs. (26) - (28) we get:

$$Q_{d1} = \frac{i}{\omega}\left[\left\{|\mathrm{I}_{\mathrm{e0}}| - |\mathrm{I}_{\mathrm{peo}}|\right\}\frac{n_{+1}}{n_{+0}} + \left\{|\mathrm{I}_{\mathrm{peo}}| - |\mathrm{I}_{\mathrm{e0}}|\right\}\frac{n_{e1}}{n_{e0}}\right]. \tag{29}$$

Putting Eq. (29) into Eq. (25) we obtain:

$$\left[\frac{i(\beta_e - \beta_p)/\omega}{1+ie\Omega_d(\Omega_d+i\nu_d)/(K\nu_d v_{d0})}\frac{n_{e0}}{n_{+0}} + 1\right]\xi_+ = \left[(1-\varepsilon Z_{d0}) + \frac{i(\beta_e - \beta_p)/\omega}{1+ie\Omega_d(\Omega_d+i\nu_d)/(K\nu_d v_{d0})}\frac{n_{e0}}{n_{+0}}\right]\xi_e - \frac{ieK\varepsilon E_1 Z_{d0}^2}{m_d\Omega_d(\Omega_d+i\nu_d)}. \tag{30}$$

Where the dust charge fluctuation parameter due to the electron current, $\beta_e = \frac{|\mathrm{I}_{\mathrm{e0}}|}{e}\frac{n_{d0}}{n_{e0}}$ and that of due to the photoelectron current, $\beta_p = \frac{|\mathrm{I}_{\mathrm{peo}}|}{e}\frac{n_{d0}}{n_{e0}}$. The parameters β_e and β_p are like the effective collision frequency of the streaming electrons with the dust grains and the effective detachment frequency of photoelectrons from the dust grains, respectively [21].

The required general dispersion relation for the electrostatic dust-modes in collisionaland streaming dusty plasma including dust charge fluctuation with photoelectric effect is then obtained from Eq. (30) using the value of ξ_e and $\xi_+$from Eqs. (22) and (23), respectively. The obtained dispersion relation is then given by

$$\Omega_I + \Omega_E + \Omega_D = 0. \tag{31}$$

where

$$\Omega_I = \frac{1+i\frac{n_{e0}}{n_{+0}}(\beta_e - \beta_p)/\omega}{-K^2k_BT_+ + im_+\nu_+(\Omega_d - K\mu_+)}, \tag{31a}$$

$$\Omega_E = \frac{(1-\varepsilon Z_{d0})+i\frac{n_{e0}}{n_{+0}}(\beta_e - \beta_p)/\omega}{-K^2k_BT_e + im_e\nu_e(\Omega_d - K\mu_e)} \tag{31b}$$

and

$$\Omega_D = \frac{\varepsilon Z_{d0}^2}{m_d\Omega_d(\Omega_d+i\nu_d)}. \tag{31c}$$

Since, $m_e \ll m_+ \ll m_d$, dust particles are cold ($C_d = 0$), ions and electrons form a hot Boltzmann gas at temperature T_+ and T_e, for low frequency electrostatic dust acoustic mode can be easily write from Eq. (31) as:

$$\Omega_d^2 = \frac{\varepsilon Z_{d0}^2K^2k_BT_+}{m_d\{1+(1-\varepsilon Z_{d0})\tau\}} - i\frac{\varepsilon Z_{d0}^2\acute{F}}{m_d^2\Omega_d^3\{1+(1-\varepsilon Z_{d0})\tau\}^2}, \tag{32}$$

where

$$\acute{F} = m_+m_d\nu_+(\Omega_d - K\mu_+)\Omega_d^3 + (1-\varepsilon Z_{d0})m_e\nu_e(\Omega_d - K\mu_e)T_+\tau m_d\Omega_d^3 + \frac{1}{\omega}\left(\beta_e - \beta_p\right)\frac{n_{e0}}{n_{+0}}K^2k_BT_+T_em_d\Omega_d^3 + \frac{1}{\omega}\left(\beta_e - \beta_p\right)\frac{n_{e0}}{n_{+0}}K^2k_BT_+^2m_d\Omega_d^3 + \varepsilon Z_{d0}^2\nu_d(K^2k_B)^2T_+^2T_e, \tag{33}$$

and

$$\tau = \frac{T_+}{T_e}. \tag{34}$$

Eq. (32) is the dispersion relation of low frequency electrostatic DA mode in collisional and streaming dusty plasma with dust charge fluctuation.

With $\Omega_d = \Omega_R + i\gamma$, where $\Omega_R$is the real part and γ is the growth rate of the DA mode, Eq. (32) can easily be separated into

$$\frac{\Omega_R}{K} = \pm C_{DA} \tag{35}$$

and

$$\gamma = -\frac{\acute{F}}{2\Omega_R^4T_e^2}\frac{C_{DA}^4}{\epsilon Z_{d0}^2k_B^2T_+^2}, \tag{36}$$

where dust acoustic speed, $C_{DA} = \sqrt{\frac{\varepsilon Z_{d0}^2k_BT_+}{m_d\{1+(1-\varepsilon Z_{d0})\tau\}}}$.

Putting the value of $\acute{F}$from Eq. (33) into Eq. (36) we obtain:

$$\gamma = \frac{1}{2}\frac{(1+\tau)(\beta_p - \beta_e)}{1+(1-\varepsilon Z_{d0})\tau}\frac{n_{e0}}{n_{+0}} - \frac{1}{2}\nu_+\frac{C_{DA}^2\left(1-\frac{\mu_+}{\pm C_{DA}}\right)}{C_+^2\{1+\tau(1-\varepsilon Z_{d0})\}} - \frac{1}{2}\nu_e\frac{C_{DA}^2\left(1-\frac{\mu_e}{\pm C_{DA}}\right)}{C_e^2\left\{1+\frac{1}{\tau(1-\varepsilon Z_{d0})}\right\}} - \frac{1}{2}\nu_d. \tag{37}$$

The first term of the Eq. (37) represents the dust charge fluctuation effect in which only electron and photoelectron currents are present, the second, third and fourth terms illustrate the collisional effects with streaming of ions and electrons.

III. RESULTS AND DISCUSSIONS

To investigate the photoelectric effect on the low frequency and low phase velocity electrostatic DA mode through dust charge fluctuation, the dispersion relation of DA mode has been derived using fluid model of plasma including lighter particles (ions and electrons) streaming along the external electric field and collisional effects of charged particles with neutrals without inertia effects of ions and electrons. Here negatively charged

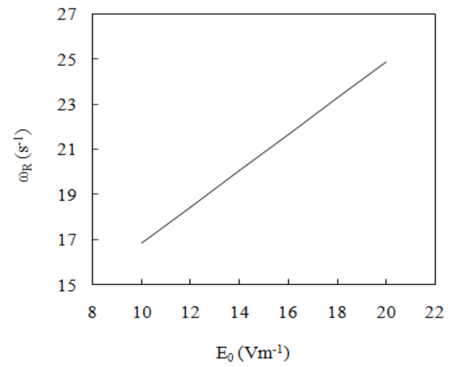

Fig.1. Real (angular) frequency in the dust frame, in s^{-1}, as a function of zero order electric field, in V m^{-1}, for K = 10^3 m^{-1}, ν_d = 2 s^{-1} and ϵZ_{d0} = 0.5.

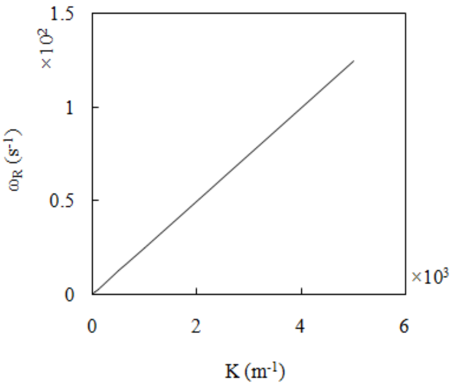

Fig. 2. Real (angular) frequency in the dust frame, in s^{-1}, as a function of wave number, in m^{-1}, for E_0 = 20 Vm^{-1}, ν_d = 2 s^{-1} and ϵZ_{d0} = 0.5.

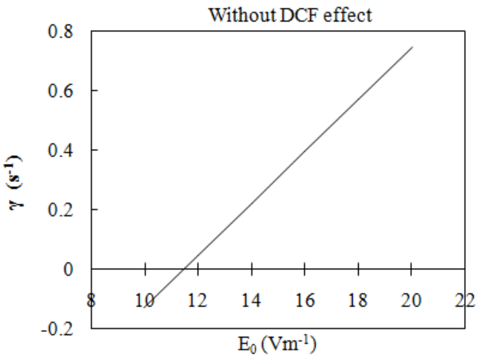

Fig. 3. The growth rate, γ, in s^{-1}, vs. the electric field, in Vm^{-1} for K = 10^3 m^{-1} and ϵZ_{d0} = 0.5.

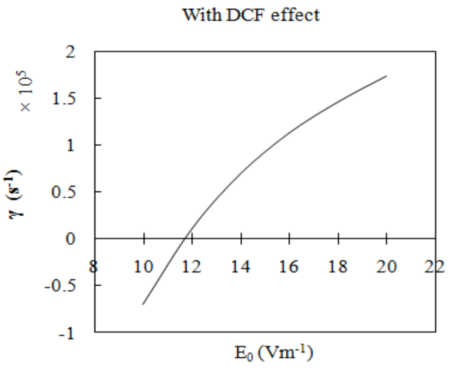

Fig. 4. The growth rate, γ, in s^{-1}, vs. the electric field, E_0, in Vm^{-1}, for K = 10^3 m^{-1}, ν_d = 2 s^{-1}, $h\nu_p$ = 3×10^3 eV and ϵZ_{d0}= 0.5.

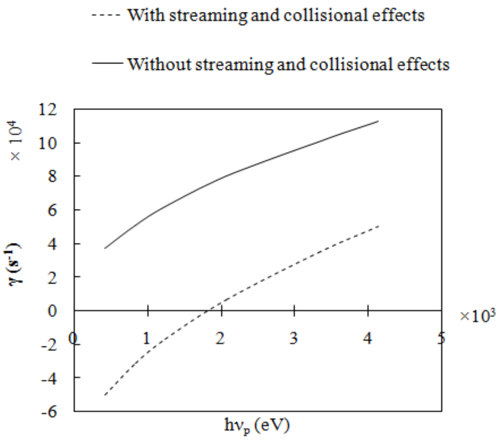

Fig. 5. The growth rate, γ, in s^{-1}, vs. photon energy, $h\nu_p$, in eV for K = 10^3 m^{-1}, ϵZ_{d0} = 0.5, E_0 = 20 Vm^{-1} (dash line) when include streaming and collisional effects and E_0 = 0 (solid line) without streaming and collisional effects.

dust grains are taken to be cold (T_d = 0). The real and imaginary part of DA mode has been analyzed numerically using a set of appropriate plasma parameters listed in Table 1.

Figs. 1 and 2 show the angular frequency of DA mode, ω_R, as functions of the zero-order electric field, E_0 and wave number K, respectively, for ϵZ_{d0} = 0.5, i.e., the negative charge present per unit volume is equally divided between free electrons and dust grains. These figures indicate the linear relationships between the angular frequency and zero-order electric field as well as wave number [11,14].

It is observed that without dust charge fluctuation (DCF) effect, i.e., $\beta_p = \beta_e = 0$, the collisional effects can make the DA mode unstable [cf. Eq. (37)]. In the case of positive dust acoustic speed, $(+)C_{DA}$, it is found that if $\mu_e(\mu_+) > C_{DA}$, then the collisional effects of ion-neutral or electron-neutral give destabilizing effect on DA mode, whereas dust-neutral collisional effect always gives damping with a time period $^1/_{\nu_d}$ [11]. On the other hand, in the case of $(-)C_{DA}$, collisional effects of ion-neutral and electron-neutral give damping of DA mode. Using Eq. (37), without DCF effect, Fig. 3 shows the growth rate, γ, (in s^{-1}) as function of zero-order electric field, E_0, (in Vm^{-1}) for K = 10^3 m^{-1}. In this figure, γ increases linearly with E_0. This figure also shows that DA mode is grown up beyond the critical value of E_0 (i.e., $E_0 \geq 11.5\ Vm^{-1}$). Similar instability was found by N. D'Angelo and R. L. Merlino in 1996 (see Fig. 5 of Ref. 11).

In the limit, $\nu_w > \nu_p > \left|\frac{e\emptyset_d}{h}\right|$, the photon energy is sufficient to remove the piled up electrons from the dust grain in an un-magnetized dusty plasma, i.e., $I_{pe0} \neq 0$. In this limit, the I_{pe0} has destabilizing effect in DA mode [cf. Eq. (37)] provided the other effects are negligible. At $\beta_p > \beta_e$, i.e., effective detachment frequency of photoelectrons from dust grains is greater than the effective collision frequency of the streaming electrons with dust grains, growth rate of DA mode increased. On the other hand, at $\beta_p < \beta_e$, DA mode become damped when collisional effects are insignificant.

In Fig. 4, growth rate, γ, (in s^{-1}) vs zero-order electric field, E_0, (in Vm^{-1}) for DA mode has been plotted including DCF effect at $Z_{d0} = 3\times10^4$. This Figure shows that there is no wave growth at $E_0 \leq 11.5\ Vm^{-1}$, whereas growth rate increases with respect to E_0 up to $E_0 = 20\ Vm^{-1}$. As seen from Figs 3 and 4, instability of DA mode due to DCF effect is five order more than that of without DCF effect.

For $K = 10^3\ m^{-1}$ and $\epsilon Z_{d0} = 0.5$, Fig. 5 shows the growth rate, γ (in s^{-1}), as functions of photon energy, $h\nu_p$ (in eV), including streaming and collisional effects and without streaming and collisional effects. It is observed that if we include streaming and collisional effects then there is no wave growth in the case of $h\nu_p \leq 1.8 \times 10^3\ eV$. In contrast, without streaming (i.e., $E_0 = 0$) and collisional effects, DA mode is excited more below the critical value of photon energy (i.e.,$h\nu_p \leq 1.8\ eV$) (see Fig. 5) and there have no damped.

It is understood from the above discussions that the instability of DA mode occurs significantly due to the photoelectric effect compared to the streaming and collisional effects.

TABLE I. Values of the plasma parameters used in the present numerical study of the DA mode and instabilities [4, 11 – 15].

Parameter	
Ion mass (m_+)	4.7×10^{-26} (Kg)
Dust mass (m_d)	4.2×10^{-15} (Kg)
Electron temperature (kT_e)	4 (eV)
Ion temperature (kT_+)	0.026 (eV)
Dust radius (a_d)	5×10^{-6}m
Electron neutral collision frequency (ν_e)	2.2×10^7 (s^{-1})
Ion neutral collision frequency (ν_+)	8.8×10^2 (s^{-1})
Dust neutral collision frequency (ν_d)	2 (s^{-1})

IV. CONCLUSIONS

Using the fluid model of plasma, a rigorous investigation of the photoelectric effect on the low frequency DA mode, through dust charge fluctuation in an un-magnetized dusty plasma has been done theoretically, considering lighter particles streaming to the direction of external zero-order electric field and collisional effects of charged particles with neutral atoms. The dust grains are considered to be negatively charged as explained in section 2.1. To analyze the low frequency and low phase velocity electrostatic dust modes, necessary general dispersion relation [cf. Eq. (31)]has been derived using fundamental equations of fluid model of plasma. According to our interest, applying some necessary conditions, dispersion relation of DA mode has been derived and numerically analyzed using appropriate plasma parameters.

It is observed that in the absence of dust charge fluctuation (DCF) effect, the DA mode become unstable due to ion-neutral and electron-neutral collisions only if relative drift of ion and electron exceed positive dust acoustic speed. On the other hand, DA mode become damped due to dust-neutral collisions as well as negative dust acoustic speed (cf. Eq. 37). In the presence of DCF effect, DA mode become unstable significantly if effective detachment frequency of photoelectrons is greater than the effective collision frequency of the streaming electrons with dust grains (cf. Eq. 37).

It is found that growth rate increases five order more due to the photoelectric effect than that of due to streaming and collisional effects (see Figs. 3 and 4). It is observed that if streaming and collisional effects are included then no wave growth at $h\nu_p \leq 1.8$, whereas, in this limit, without streaming and collisional effects, DA mode is unstable (see Fig. 5).

It is concluded that the DA mode can be unstable significantly due to photoelectric effect compared to the streaming and collisional effects in which only piled up electrons on dust grains are considered to be removed by irradiation.

In closing, it is stress that the present study should be applied in understanding the photoelectric effects on low frequency electrostatic dust modes in the space science, where dust grains and radiation exist, such as planetary rings, the lower ionosphere of the Earth, interstellar space cloud, etc. as well as irradiated laboratory dusty plasma, such as the edge plasma of the fusion devises, etc.

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