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The instability of electrostatic wave in a magnetized dusty plasma with nonadiabatic dust charge fluctuation*

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The effects of external magnetized field and nonadiabatic dust charge fluctuation on instability of wave incorporating the nonthermally distributed ions and the temperatures of ion and dust in dusty plasmas are investigated. A linear dispersion relation is obtained. The numerical results show that the external magnetized field, fast ions and nonadiabatic dust charge fluctuation have strong influence on the frequency and the damping of wave.

Keywords: instability, magnetized dusty plasma, nonadiabatic dust charge fluctuation
PACC: 5235S, 5235

1. Introduction

It is well known that the charged dust grains frequently appear in space and laboratory plasmas.[1,2] Usually the dust grains are of micrometer or sub micrometer size, massive and highly charged. When a dust grain is immersed in a quiescent plasma it can acquire charges by several mechanisms such as plasma currents, photoelectric emission and other processes.[3−5] The presence of such highly charged dust particles would significantly modify the collective behaviour of the plasma[6−10] and the existing plasma wave spectra, as well as introduce some new eigen modes, called the "dust ion acoustic" (DIA) wave[11] and the "dust acoustic" (DA) wave[11] in low frequency and very low frequency oscillations. For the DA wave, the inertia is provided by the mass of highly charged heavy dust grains, and the restoring force is provided by the inertialess Boltzmann distributed thermal electrons and ions, whereas the DIA wave is the ordinary ion acoustic wave mode in a dusty plasma with a phase velocity $\propto n_{\rm i0}/n_{\rm e0}$[12] ($n_{\rm i0}(n_{\rm e0})$ is the equilibrium number density of ion (electron)). In a truly dusty plasma, the dust charge is a new dynamic variable $q_{\rm d}$ and its dynamic nature would be important for studying the behaviour of dusty plasma. In the theory of nonadiabatic dust charge fluctuation, it is assumed that the ratio $\tau_{\rm ch}/\tau_{\rm d}$ is small but finite, however, in the theory of adiabatic dust charge fluctuation, it is assumed that $\tau_{\rm ch}/\tau_{\rm d}$ is very small , so that $\tau_{\rm ch}/\tau_{\rm d} = 0$, where $\tau_{\rm ch}$ is the charging time scale and $\tau_{\rm d}$ is the hydrodynamical time scale. In the linear theory , it is known that the nonadiabatic charge variations result in the damping of the linear wave mode,[13−16] whereas in the nonlinear analysis, the nonadiabatic dust charge variations lead to an anomalous dissipation in a plasma. This dissipation causes the generation of shock wave in a dusty plasma.[17−19] The combined effects of the non-ideal contribution and the dust charge fluctuation in the linear as well as the nonlinear regimes of wave propagation have been analysed.[20] It has been shown by Mamun[21] that the dust temperature, fast ions, and external magnetic field have effects on gravitational instability in a dusty plasma, however, the effect of the nonadiabatic dust charge fluctuation has not been considered. Misra *et al*[22] considered the problem of linear dust acoustic and dust ion acoustic wave propagations in a self-gravitating dusty plasma with dust charge variation, ionization, recombination as well as collisional effects due to collisions between the electrons and dust, ion and dust, etc., in a self consistent manner. Ghosh *et*

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al [23] studied the one-dimensional linear dust acoustic wave propagation characteristics incorporating the effects of nonthermally distributed ions, the isothermal pressure variations of dust grains and both nonadiabatic and adiabatic dust charge fluctuation, however, the effect of external magnetic field has not been considered. Most of the previous investigations for the dust charge fluctuation effects, however, have focused on the one-dimensional case.

In this paper, on the assumption that $\tau_{\rm ch}/\tau_{\rm d}$ is small but finite, we investigate the combined effects of the external magnetized field, the nonadiabatic dust charge fluctuation and the fast (nonthermal) ions on the propagation of linear three-dimensional dust acoustic wave in a dusty plasma. It is discussed in great detail how the magnitude of the external magnetic field, the dust charge variation, the presence of nonthermally distributed ions, the temperatures of ions and dust, the angle between $\boldsymbol{K}$ and $\boldsymbol{B}_0$ and the ratio of electron to ion density modify the frequency and damping of low frequency mode.

2. Governing equations

We study the dust acoustic wave propagating in a three-component dusty plasma system, which consists of extremely massive, micron-sized, negatively charged hot dust fluid, nonthermally distributed ions, and Boltzmann distributed electrons, in the presence of an external static magnetic field directing along the z-axis ($B_0 \| z_0$, where z_0 is a unit vector along the z direction). The dust acoustic wave in the regime $kv_{\rm d} \ll \omega \ll kv_{\rm i}, kv_{\rm e}$ ($v_{\rm d}$, $v_{\rm i}$ and $v_{\rm e}$ are dust, ion, and electron thermal velocities, respectively.) is the low-frequency analog of an ion acoustic wave, in which the dust provides the inertia and the inertias of the ions and electrons are neglected. Charge neutrality at equilibrium requires that $n_{\rm i0} = Z_{\rm d0} n_{\rm d0} + n_{\rm e0}$, where $n_{\rm i0}$, $n_{\rm d0}$ and $n_{\rm e0}$ are the unperturbed ion, dust, and electron densities, respectively, and $Z_{\rm d0}$ is the number of electrons residing on a dust grain. The dust acoustic wave dynamics can be described by the following three-dimensional set of continuity, momentum, pressure, and Poisson's equations:

$$\begin{cases} \dfrac{\partial n_{\rm d}}{\partial t} + \nabla \cdot (n_{\rm d} \boldsymbol{V}_{\rm d}) = 0, \\ \dfrac{\partial \boldsymbol{V}_{\rm d}}{\partial t} + \boldsymbol{V}_{\rm d} \cdot (\bigtriangledown \boldsymbol{V}_{\rm d}) + \dfrac{\sigma_{\rm d}}{n_{\rm d}} \nabla p_{\rm d} = (1-q)[\nabla \phi + \omega_{\rm cd} (\boldsymbol{V}_{\rm d} \times \boldsymbol{Z}_0)], \\ \dfrac{\partial p_{\rm d}}{\partial t} + \boldsymbol{V}_{\rm d} \cdot \bigtriangledown p_{\rm d} + \gamma p_{\rm d} \nabla \cdot \boldsymbol{V}_{\rm d} = 0, \\ \nabla^2 \phi = (1-q) n_{\rm d} + n_{\rm e} - n_{\rm i}, \end{cases} \tag{1}$$

where $\boldsymbol{V}_{\rm d} = (u, v, w)$, $\nabla = \left(\dfrac{\partial}{\partial x}, \dfrac{\partial}{\partial y}, \dfrac{\partial}{\partial z} \right)$. $\boldsymbol{V}_{\rm d}$ is the dust fluid velocity normalized to the dust acoustic speed $C_{\rm d} = \sqrt{Z_{\rm d0} T_{\rm i}/m_{\rm d}}$ with $T_{\rm i}$ being the ion-temperature (in energy units) and $m_{\rm d}$ being the mass of negatively charged dust particles; $n_{\rm d}$ is the dust grain number density normalized to $n_{\rm d0}$; $\sigma_{\rm i} = T_{\rm i}/T_{\rm e}$, with $T_{\rm e}$ being the electron-temperature (in energy units); $\mu = n_{\rm e0}/n_{\rm i0}$, $n_{\rm i}$ is the ion number density normalized to $n_{\rm i0}$; $\sigma_{\rm d} = T_{\rm d}/(Z_{\rm d0} T_{\rm i})$ with $T_{\rm d}$ being the dust-temperature (in energy unit); ϕ is the electrostatic potential normalized to $T_{\rm i}/e$ with e being the magnitude of the electron charge; The time and space variables are normalized by the dust plasma period $\omega_{\rm pd}^{-1} = \sqrt{m_{\rm d}/4\pi n_{\rm d0} Z_{\rm d0}^2 e^2}$ and the Debye length $\lambda_{Dd} = C_{\rm d}/\omega_{\rm pd}$, respectively. $\omega_{\rm cd} = (Z_{\rm d0} e B_0)/m_{\rm d}$ is the dust cyclotron frequency normalized to $\omega_{\rm pd}$. $p_{\rm d}$ is the dust pressure normalized to $n_{\rm d0} Z_{\rm d0} T_{\rm d}$. $\gamma = 5/3$ is the adiabatic ration of specific heats.

The distribution function that was chosen by Cairns *et al* [24] is chosen in order to model an ion distribution with a population of fast particles. Therefore, the ion density $n_{\rm i}$ is directly given by

$$n_{\rm i} = \frac{1}{1-\mu}[1 + \beta(\phi + \phi^2)]\exp(-\phi), \tag{2}$$

where $\beta = \dfrac{4\alpha}{1+3\alpha}$, α is a parameter determining the number of fast (nonthermal) ions,

$$n_{\rm e} = \frac{\mu}{1-\mu}\exp(\sigma_{\rm i}\phi). \tag{3}$$

The dust charge $Q_{\rm d} = -Z_{\rm d0} e + q_{\rm d}$, where $q_{\rm d}$ is the variation of the dust charge, becomes $(q-1)$ ($q = q_{\rm d}/Z_{\rm d0} e$) normalized in units of the equilibrium dust charge $Z_{\rm d0} e$. To determine the normalized charge

variable q, we consider the following orbital motion-limited[25] charge current balance equation. In normalized form, it reads as

$$\frac{\tau_{\rm ch}}{\tau_{\rm d}}\left(\frac{\partial q}{\partial t}+\boldsymbol{V}_{\rm d}\cdot\bigtriangledown q\right)=\frac{\tau_{\rm ch}}{Z_{\rm d0}e}(I_{\rm e}+I_{\rm i}), \qquad (4)$$

where $I_{\rm e}$ and $I_{\rm i}$ are the electron and ion currents, respectively. We assume that the dust grain radius (a) $\ll$ the electron gyroradius ($\rho_{\rm e}$). The charging characteristics are not significantly influenced by the existence of external magnetic field, since for $a \ll \rho_{\rm e}$, the curvature effect of the trajectory of an electron (ion) impinging on a dust grain of radius a can be neglected.[26,27] Thus, considering the nonthermally distributed ions, the normalized expressions for the electron and ion currents for spherical dust grains with radius a are given by[28]

$$I_{\rm e}=-\pi a^2 e\sqrt{\frac{8T_{\rm e}}{\pi m_{\rm e}}}n_{\rm e0}\exp(\sigma_{\rm i}\phi)\exp[\chi(q-1)], \qquad (5)$$

$$\begin{aligned}I_{\rm i}=&\pi a^2 e\sqrt{\frac{8T_{\rm i}}{\pi m_{\rm i}}}\frac{n_{\rm i0}}{(1+3\alpha)}\left[\left(\left(1+\frac{24\alpha}{5}\right)\right.\right.\\&+\frac{16\alpha}{3}\phi+4\alpha\phi^2\Big)-\frac{\chi(q-1)}{\sigma_{\rm i}}\Big(\Big(1+\frac{8\alpha}{5}\Big)\\&\left.\left.+\frac{8\alpha}{3}\phi+4\alpha\phi^2\right)\right]\exp(-\phi), \qquad (6)\end{aligned}$$

where $\chi = z_{\rm d0}e^2/4\pi\varepsilon_0 aT_{\rm e}$, $4\pi\varepsilon_0 a$ is the capacitance of the spherical dust grain of radius a. $\tau_{\rm d}(\approx \omega_{\rm pd}^{-1})$ is the dust hydrodynamical time scale and $\tau_{\rm ch}[\approx (\mathrm{d}Q_{\rm d}/\mathrm{d}t)^{-1}]$ is the charging time scale given by

$$\tau_{\rm ch}=\left[\frac{a}{\sqrt{2\pi}}\frac{\omega_{\rm pi}^2}{V_{\rm thi}}\frac{5+8\alpha}{5+15\alpha}\left(1+\chi+\frac{5+24\alpha}{5+8\alpha}\sigma_{\rm i}\right)\right]^{-1}, \qquad (7)$$

where $\omega_{\rm pi}$ and $V_{\rm thi}$ are the ion plasma frequency and the ion thermal velocity, respectively.

3. Dispersion relation

For nonadiabatic charge variation, $\tau_{\rm ch}/\tau_{\rm d}$ is small but finite,[28] we set

$$\frac{\tau_{\rm ch}}{\tau_{\rm d}}=\lambda. \qquad (8)$$

In order to investigate the linear propagation of low frequency wave in a magnetized dusty plasma, we shall carry out a normal analysis. We first express the dependent variables u, v, w, ϕ, q, $n_{\rm d}$, and p in terms of their equilibrium and perturbed parts as $\boldsymbol{V}_{\rm d}=0+\boldsymbol{V}_{\rm d}^{'}$, $\phi=0+\phi^{'}$, $q=0+q^{'}$, $n_{\rm d}=1+n_{\rm d}^{'}$, and $p_{\rm d}=1+p_{\rm d}^{'}$, and the perturbed quantities are proportional to $\exp\mathrm{i}[(k_x x+k_y y+k_z z)-\omega t]$. Then, substituting Eqs.(2),(3) and (5)–(8) into Eqs.(1) and (4), and linearizing Eqs.(1) and (4) with these perturbations, we obtain the following linear dispersion relation:

$$D(\omega,K)=K^2-B+\frac{G}{G\sigma_{\rm d}\gamma-\omega}-\frac{\beta_1}{1-\mathrm{i}\omega\lambda}=0, \qquad (9)$$

where $K^2=K_{\parallel}^2+K_{\perp}^2 (K_{\parallel}^2=k_z^2,\ K_{\perp}^2=k_x^2+k_y^2)$, $B=\dfrac{\beta-\mu\sigma_{\rm i}-1}{1-\mu}$, $G=\dfrac{K^2\omega^2-k_z^2\omega_{\rm cd}^2}{\omega(\omega^2-\omega_{\rm cd}^2)}$ and $\beta_1=\dfrac{\frac{40\alpha}{15+24\alpha}(2\sigma_{\rm i}+\chi)-(\delta\sigma_{\rm i}+\chi)(1+\sigma_{\rm i})}{\chi(1+\chi+\delta\sigma_{\rm i})}$ $\left(\delta=\dfrac{5+24\alpha}{5+8\alpha}\right)$. Equation (9) represents a dispersion relation for low frequency waves in a magnetized plasma consisting of extremely massive, micron-sized, negatively charged hot dust fluid, nonthermally distributed ions, and Boltzmann distributed electrons. The third term represents the contribution from external magnetized field, and the fourth term is due to the effect of the nonadiabatic dust charge fluctuation. We now consider this low frequency mode in two particular cases of interest, namely, parallel propagation ($K_{\perp}^2=0$) and perpendicular propagation ($K_{\parallel}^2=0$).

3.1. Perpendicular propagation ($K_{\parallel}^2=0$)

The dispersion relation for the low frequency mode, which propagates along the external magnetic field, can be expressed from Eq.(9) as

$$\begin{aligned}D(\omega,K_{\perp})=&K_{\perp}^2\left(1+\frac{1}{K_{\perp}^2\sigma_{\rm d}\gamma-(\omega^2-\omega_{\rm cd}^2)}\right)\\&-B-\frac{\beta_1}{1-\mathrm{i}\omega\lambda}=0. \qquad (10)\end{aligned}$$

It is seen from Eq.(10) that the external magnetized field and the nonadiabatic dust charge variation have influence on the dispersion relation for the parallel propagation. The explicit dispersion relation in this case may be obtained by Eq.(10) in the form $D(\omega,K)\equiv D_{\rm r}(\omega,K)+\mathrm{i}D_{\rm i}(\omega,K)=0$, where

$$D_{\rm r}=K_{\perp}^2\left(1+\frac{1}{K_{\perp}^2\sigma_{\rm d}\gamma-(\omega^2-\omega_{\rm cd}^2)}\right)-\beta_1-B, \qquad (11)$$

$$D_i=-\omega\lambda\left[K_{\perp}^2\left(1+\frac{1}{K_{\perp}^2\sigma_{\rm d}\gamma-(\omega^2-\omega_{\rm cd}^2)}\right)-B\right]. \qquad (12)$$

In Eq.(11), for $\omega\equiv\omega_{\rm r}+\mathrm{i}\omega_{\rm i}$, with $|\omega_{\rm i}|\ll|\omega_{\rm r}|$, the real frequency is obtained by setting $D_{\rm r}(\omega,K_{\perp})\equiv 0$. Thus we obtain the real frequency,

$$\frac{\omega_{\rm r}^2}{K_{\perp}^2}=\sigma_{\rm d}\gamma+\frac{\omega_{\rm cd}^2}{K_{\perp}^2}+\frac{1}{K_{\perp}^2-B-\beta_1}. \qquad (13)$$

On the right-hand side of Eq.(13), the first term represents the effect of the temperature of dust, The second term is due to the external magnetized field, and the third term represents the contribution of the nonadiabatic dust charge variation. The damping rate $\omega_{\rm i}$ is calculated from the condition $\omega_{\rm i} = -D_{\rm i}/(\partial D_{\rm r}/\partial\omega_{\rm r})$. Thus, the damping rate is given by

$$\omega_{\rm i} = \frac{\lambda[K_\perp^2\sigma_{\rm d}\gamma - (\omega^2 - \omega_{\rm cd}^2)]^2\left[K_\perp^2\left(1 + \frac{1}{K_\perp^2\sigma_{\rm d}\gamma - (\omega^2 - \omega_{\rm cd}^2)}\right) - B\right]}{2K_\perp^2}. \tag{14}$$

It is obvious from Eqs.(13) and (14) that the frequency and the damping of the low frequency mode along the magnetic field are influenced by the magnitude and the obliquity of the external magnetic field, the dust charge variation, the presence of nonthermally distributed ions, the temperatures of ions and dust, and the ratio of electron to ion density.

3.2. Parallel propagation ($K_\perp^2 = 0$)

The dispersion relation for the low frequency mode, which propagates perpendicular to the magnetic field, can be expressed from Eq.(9) as

$$D(\omega, K_\parallel) = K_\parallel^2\left(1 + \frac{1}{K_\parallel^2\sigma_{\rm d}\gamma - \omega^2}\right) - B - \frac{\beta_1}{1 - {\rm i}\omega\lambda} = 0. \tag{15}$$

Equation (15) indicates that the nonadiabatic dust charge fluctuation has an effect on the dispersion relation for perpendicular propagation, however, the external magnetized field has no effects on this dispersion relation. The frequency and the damping in this case are given respectively by

$$\frac{\omega_{\rm r}^2}{K_\parallel^2} = \sigma_{\rm d}\gamma + \frac{1}{K_\parallel^2 - B - \beta_1}, \tag{16}$$

$$\omega_{\rm i} = \frac{\lambda(K_\parallel^2\sigma_{\rm d}\gamma - \omega^2)^2\left[K_\parallel^2\left(1 + \frac{1}{K_\parallel^2\sigma_{\rm d}\gamma - \omega^2}\right) - B\right]}{2K_\parallel^2}. \tag{17}$$

It is seen from Eqs.(16) and (17) that for the perpendicular propagation the mode depends on the presence of nonthermally distributed ions, the temperatures of ions and dust, and the ratio of electron to ion density. It is also known that λ has no effect on the frequency of the low frequency mode.

4. Numerical results and discussion

We now investigate the influence of the magnitude of the external magnetic field, the dust charge variation, the presence of nonthermally distributed ions, the temperatures of ions and dust, and the ratio of electron to ion density on the propagation of the low frequency mode by using the general dispersion relation, viz. Eq.(9). All results depicted here are for fixed parameters $\gamma = 5/3$, and $\chi = 2$.

Figure 1 illustrates the numerical solutions of Eq.(9) for both the frequency $\omega_{\rm r}$ and the growth rate $\omega_{\rm i}$ against μ for different α. It is clear from Fig.1 that there are two different modes. Figures 1(a) and (b) indicate the frequency and the growth rate of the first mode, respectively. Figures 1(c) and (d) indicate the frequency and the growth rate of the second mode, respectively. It is obvious from Fig.1(a) that for lower values of μ, the frequency of the first mode almost does not vary with α and μ, however, for higher values of μ, the frequency decreases with μ significantly but increases with α slowly. Figure 1(b) shows that for small values of μ, the damping rate of the first mode varies with μ slowly, but increases with α, and when μ is approximately larger than 0.6, the damping rate increases significantly. It is also shown that there exists a critical value of μ, i.e. $\mu_{\rm c}$ and when $\mu < \mu_{\rm c}$ the damping rate increases with μ, however, when $\mu > \mu_{\rm c}$ the damping rate decreases with μ. Furthermore, with the increase of α, the value of $\mu_{\rm c}$ increases. Figures 1(c) and (d) indicate that the frequency and the damping rate of the second mode increase with α, but decrease with μ.

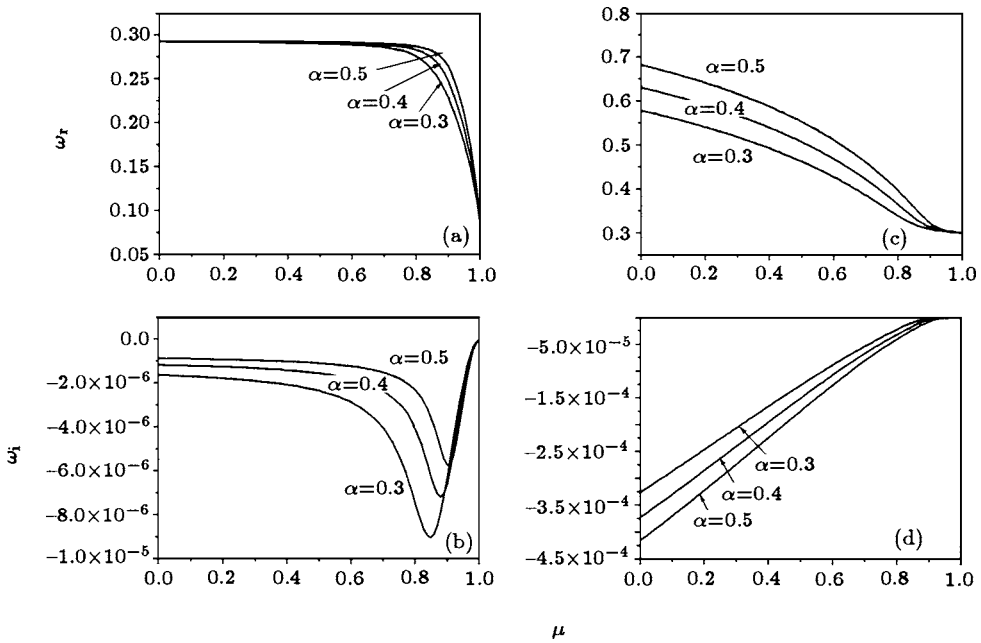


Fig.1. The frequency and the damping rate against μ for different α and $\sigma_{\rm d}$=0.01, $\sigma_{\rm i}$=0.1, $\omega_{\rm cd}$=0.3, k_z=0.49, K=0.5, λ=0.01.

Figure 2 shows the frequency and the damping rate against μ for different $\sigma_{\rm i}$. It is clear that the variations of the frequency and the damping rate of wave with $\mu_{\rm c}$ are similar to those in Fig.1. From Figs.2(a) and (c), we can see that the frequencies of the two modes decrease with $\sigma_{\rm i}$. It is also shown in Fig.2(b) that the damping rate of the second mode increases with $\sigma_{\rm i}$. Furthermore, in Fig.2(d), for small values of μ, the damping rate of the second mode increases with α, but for large values of μ, the damping rate decreases with α.

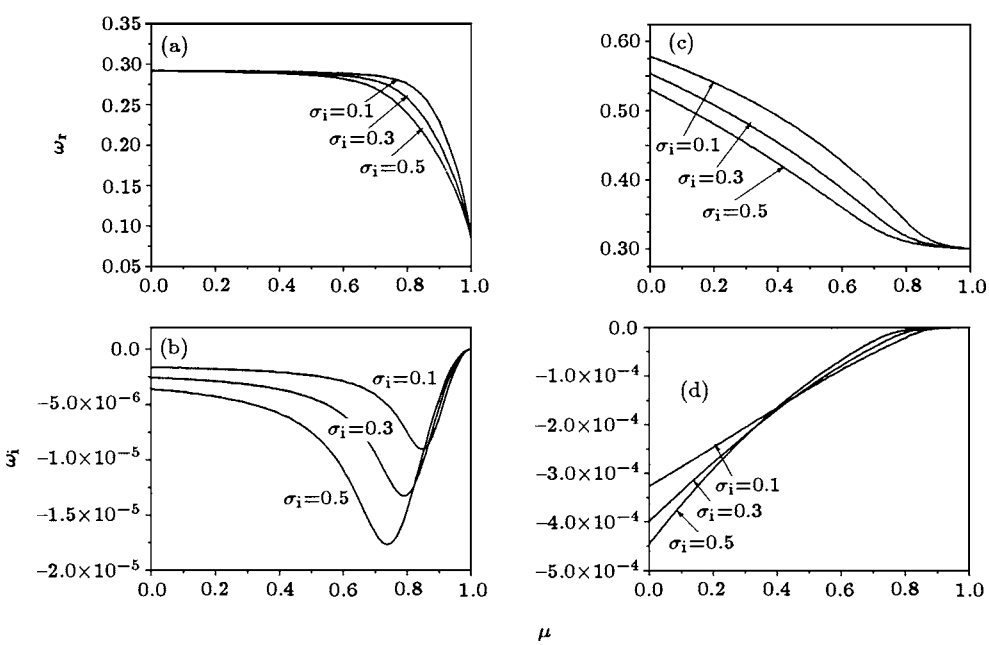


Fig.2. The frequency and the damping rate against μ for different $\sigma_{\rm i}$ and $\sigma_{\rm d}$=0.01, α=0.3, $\omega_{\rm cd}$=0.3, k_z=0.49, K=0.5, λ=0.01.

In Fig.3, we can see the variations of the frequency and the damping rate of the low frequency mode as a function of μ for different K. It can be seen from Fig.3(a) that for lower values of μ, the frequency of the first mode decreases as K increases, but weakly changes with μ, However, for higher values of μ, i.e. $\mu_c > 0.8$, with the increase of μ, the frequency obviously decreases. It is shown in Fig.3(b) that there exists a critical value of K, K_c, and when $K < K_c$, for lower values of μ, the damping rate increases with μ, however, for higher values of μ,the damping rate decreases with μ. It is also clear that when $K > K_c$, the damping rate monotonously decreases with μ. In Figs.3(c) and (d), the frequency and the damping rate of the second mode increase as α increases, but decreases as μ increases.

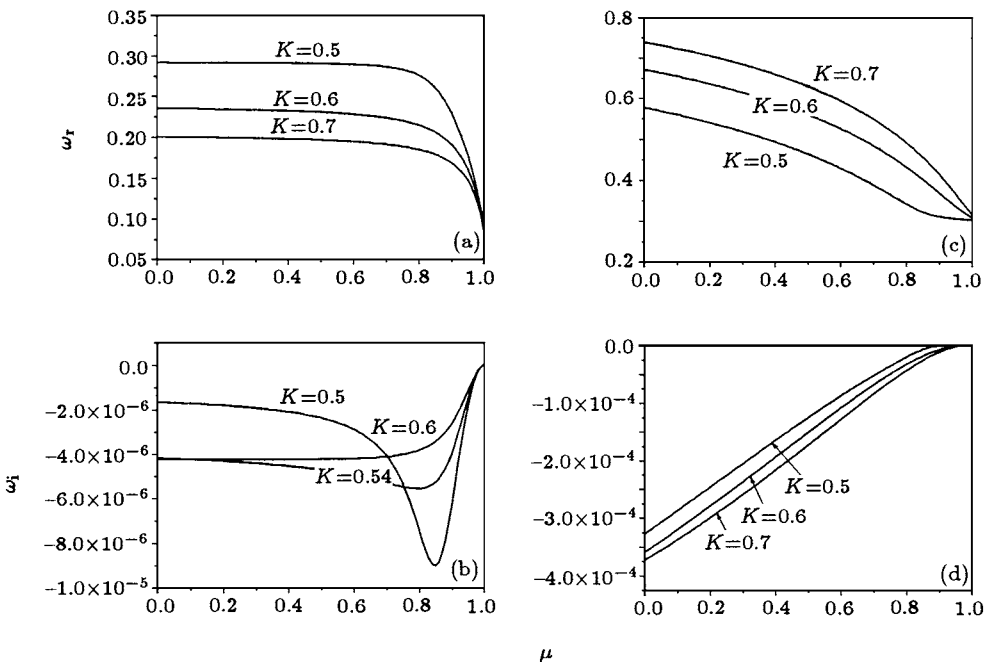


Fig.3. The frequency and the damping rate against μ for different K and σ_d=0.01, σ_i=0.1, α=0.3, ω_{cd}=0.3, k_z=0.49, λ=0.01.

In Fig.4, we display the effect of λ on the frequency and the damping rate of the low frequency mode. It is seen from Figs.4 (a) and (c) that the frequency is independent of λ. It is also shown that for small values of μ, the frequency of the first mode is independent of μ, however, for higher values of μ, the frequency significantly decreases with μ. Figure 4(b) shows that for small values of μ, the damping rate of the first mode varies with μ slowly, but decreases with λ, and when μ is approximately larger than 0.8, the damping rate increases with μ significantly. It is also shown that there exists a critical value of μ, i.e. μ_c, and when $\mu < \mu_c$ the damping rate increases with μ, however, when $\mu > \mu_c$ the damping rate decreases with μ. Furthermore, for lower values of λ, the changing of the damping rate with μ is not significant. Figure 4(d) indicates that the damping rate of the second mode increases with λ but decreases with μ. It is also shown in Figs.4(c) and (d) that for lower values of λ, the damping rate weakly varies with μ.

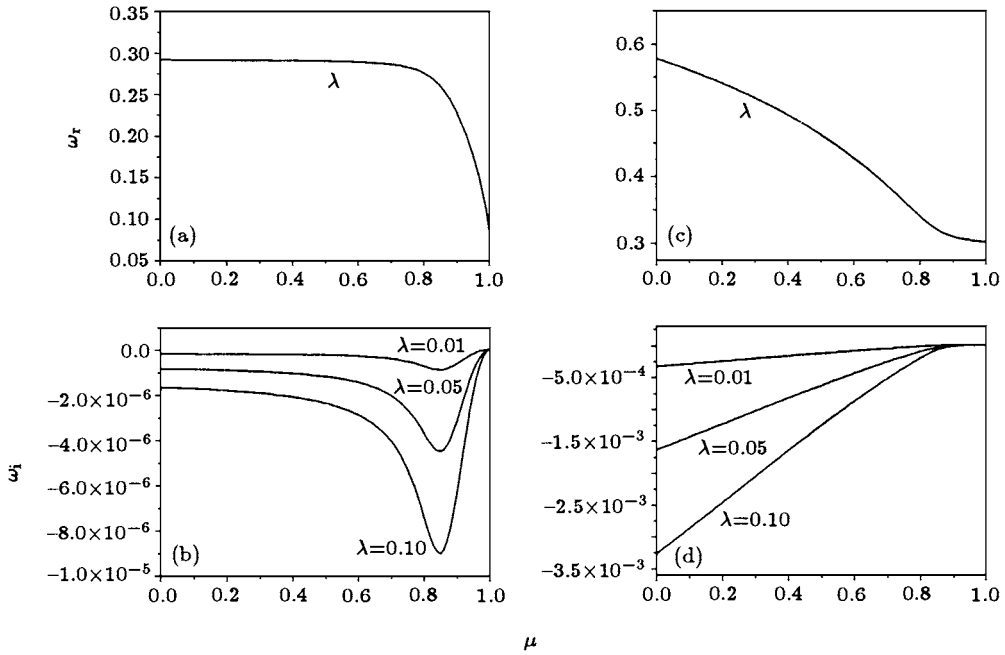


Fig.4. The frequency and the damping rate against μ for different λ and σ_d=0.01, σ_i=0.1, α=0.3, ω_{cd}=0.3, k_z=0.49, K=0.5.

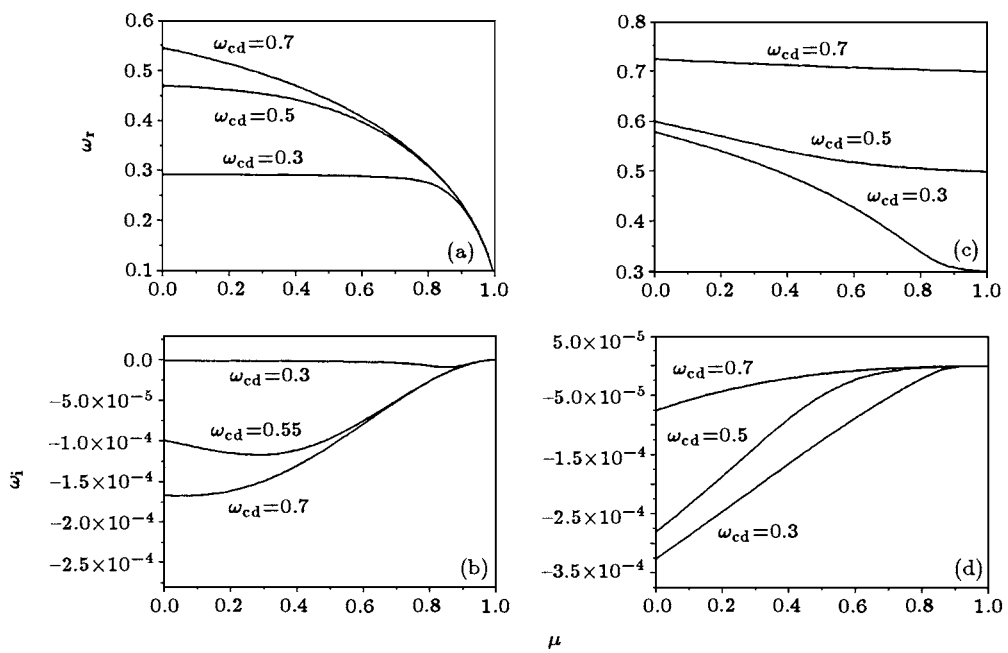


Fig.5. The frequency and the damping rate against μ for different ω_{cd} and σ_d=0.01, σ_i=0.1, α=0.3, k_z=0.49, K=0.5, λ=0.01.

The effects of the external magnetized field on the frequency and the damping rate of the low frequency mode for all values of μ ($\mu \in (0,1)$) are shown in Fig.5. From Fig.5 (a), we can see that for small values of ω_{cd}, when μ is approximately smaller than 0.8, the frequency of the first mode is independent of μ, however, when μ is approximately larger than 0.8, the frequency of the first mode obviously decreases with μ. It is also shown that for higher values of ω_{cd}, the frequency gradually decreases as μ increases. Figure 5(b) indicates that there exist two critical values of $\omega_{cd}, \omega_{cd1} \approx 0.3$ and $\omega_{cd2} \approx 0.6$, and when $\omega_{cd} < \omega_{cd1}$, the corresponding mode shown in Fig.5(a) does not damp significantly; however, when $\omega_{cd} > \omega_{cd2}$, the damping rate increases with ω_{cd} and monotonously decreases with μ. When $\omega_{cd1} < \omega_{cd} < \omega_{cd2}$, there is a

maximum value of the damping rate, and it increases with ω_{cd} but decreases with μ. Figure 5(c) shows that when ω_{cd} is high, the frequency of the second mode is almost independent of μ, and increases with ω_{cd}. It is clear from Fig.5(d) that the damping rate corresponding to the second mode decreases with μ and ω_{cd}.

Figure 6 shows the numerical solutions of Eq.(9) for both the frequency and the damping rate of the low frequency mode against σ_d for different K_z. It is seen from Figs.6(a) and (c) that for the first mode, the frequency does not vary with σ_d slowly but increases with K_z obviously, however, for the other modes, the frequency decreases with K_z but increases with σ_d. Figures 6(b) and (d) indicate that for higher values of σ_d the change of the damping rate of both modes is not significant. It is also shown that when σ_d is low, for the first mode, the damping rate decreases with σ_d, however, for the second mode, the damping rate increases with σ_d. Furthermore, with the increase of K_z the damping rate for both modes decreases.

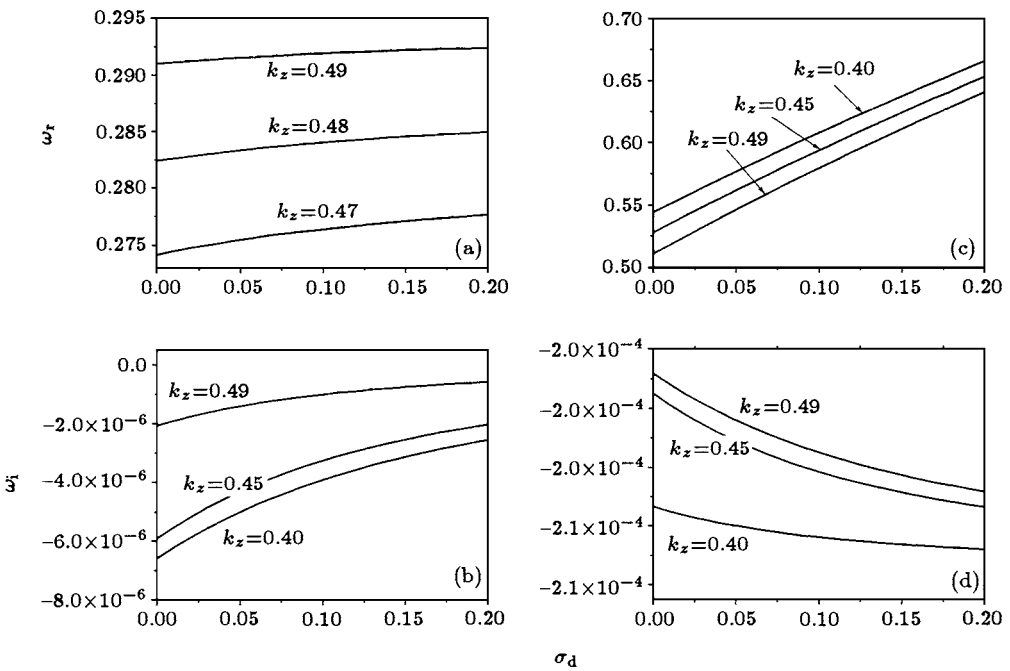


Fig.6. The frequency and the damping rate against μ for different k_z and σ_d=0.01, σ_i=0.1, ω_{cd}=0.3, k_z=0.49, K=0.5, λ=0.01.

5. Conclusion

In summary, the dust acoustic instability is investigated by the kinetic dispersion relation in a magnetized dusty plasma consisting of extremely massive, micron-sized, negatively charged hot dust fluid, nonthermally distributed ions, and Boltzmann distributed electrons. We have analysed the effects of some parameters such as the magnitude of the external magnetic field, the number of fast ions, the nonadiabatic dust charge variation, the temperatures of dust and ion, the angle between $\boldsymbol{K}$ and $\boldsymbol{B}_0$ and the ratio of electron to ion on the instability of the low frequency mode in great detail. With reference to the present study, we can obtain more profound understanding of the features of dust acoustic wave. Furthermore, we expect that the present investigation would be useful for future experiments on low frequency wave.

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