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Characteristic Features of Double Layers in Rotating, Magnetized Plasma Contaminated with Dust Grains with Varying Charges

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The evolution and the characteristic features of double layers in a plasma under slow rotation and contaminated with dust grains with varying charges under the effect of an external magnetic field are studied. The Coriolis force resulting from the slow rotation is responsible for the generation of an equivalent magnetic field. A comparatively new pseudopotential approach has been used to derive the small amplitude double layers. The effect of the relative electron-ion concentration, as well as the temperature ratio, on the formation of the double layers has also been investigated. The study reveals that compressive, as well as rarefactive, double layers can be made to co-exist in plasma by controlling the dust charge fluctuation effect supplemented by variations of the plasma constituents. The effectiveness of slow rotation in causing double layers to exist has also emanated from the study. The results obtained could be of interest because of their possible applications in both laboratories and space.

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I. INTRODUCTION

A great deal of interest has been generated in the recent past in unraveling the physics of charged dust particles, which are characterized by their ubiquitous presence in the laboratory [1–3], as well as astrophysical and space environments [4,5], with a view to understanding the linear and the nonlinear propagations of the electrostatic excitations that are visible in laboratory devices and space. Dust charge fluctuations have been observed to provoke damping of the dust-acoustic (DA) [6,7] and the dust-ion-acoustic (DIA) [8] waves (DIAWs) in an unmagnetized dusty plasma. Theoretical [5,8] and experimental [9,10] studies have led to a proper understanding of the linear properties of DIAWs in dusty plasmas. From a parallel standpoint, focus was also laid on the nonlinear propagation of DIAWs with a view to unraveling the features of localized electrostatic perturbations in space and laboratory dusty plasmas [11–14].

In the past few years, the double layer has been a topic of significant interest because of its relevance in cosmic applications [15–18], confinements of plasmas in tandem mirror devices [19], ion heating in linear turbulence heating devices [20], *etc.* Theoretical [21, 22], as well as experimental [23–25], studies of ion-acoustic double layers in plasmas have been carried out in a comprehensive manner. Merlino and Loomis [26] experimentally observed a strong double layer in a plasma consisting of positive ions, negative ions, and electrons. Ion-acoustic double layers have been observed in auroral and magnetospheric plasmas [27]. Using the reductive-perturbation method, several authors [28,29] have studied weak ion-acoustic double layers in different plasma systems.

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II. BASIC EQUATIONS AND DERIVATION OF THE SAGDEEV POTENTIAL EQUATION

The plasma model under consideration consists of electrons and ions contaminated with dust grains with varying charges. The plasma under slow rotation with a uniform angular velocity Ω at an angle θ to the x-axis has been implanted in an externally-applied magnetic field H_0, which is also inclined at an angle θ to the x-axis in the xy plane. In studies conducted earlier [30, 31], the Coriolis force generated due to slow rotation was observed to generate an equivalent magnetic field, but in those studies, the Coriolis force was considered in isolation. Thus our motivation here is to see the plasma behaviour under the combined effect of an external magnetic field and a magnetic field generated due to rotation. Moreover, we assumed that $T_d \ll T_\alpha$, $\alpha = i, e$ (where i and e stand for electrons and ions respectively, d represents the dust-charged grains and T is the temperature) because of which the inertia of electrons and ions, can be approximated by using the following Boltzmannian relations:

$$\begin{aligned} n_e &= n_{e0} \exp\left(\frac{e\phi}{KT_e}\right), \\ n_i &= n_{i0} \exp\left(-\frac{e\phi}{KT_i}\right). \end{aligned} \tag{1}$$

The Boltzmann relations for electrons and ions are based on the assumption that the phase velocity is much less than the thermal velocities of electrons and ions, *i.e.*, $\frac{\omega}{k} \ll v_{T_{e,i}}$, where $v_{T_{e,i}}$ are the thermal velocities. Moreover, $H_T = H_0 + 2\Omega(\frac{cm_{e,i}}{q_{e,i}}) = H_0 + \bar{H}$ is the modified magnetic field, which represents the combination of an applied magnetic field H_0 and the generation of a similar field $\bar{H}$ by the Coriolis force. Consequently, the momentum equations of electrons and ions follow from the Boltzmann relations.

The basic equations governing the plasma dynamics for dust grains in a magnetized, rotating plasma, along with the use of $\eta = 2\Omega$, can be written in the following simplified forms:

$$\frac{\partial n_d}{\partial t} + \frac{\partial (n_d v_x)}{\partial x} = 0, \tag{2}$$

$$\frac{\partial v_x}{\partial t} + v_x \frac{\partial v_x}{\partial x} = -\frac{q_d}{m_d}\frac{\partial \phi}{\partial x} - \frac{q_d v_z \eta \sin\theta}{m_d c}, \tag{3}$$

$$\frac{\partial v_y}{\partial t} + v_x \frac{\partial v_y}{\partial x} = \frac{q_d v_z \eta \cos\theta}{m_d c}, \tag{4}$$

$$\frac{\partial v_z}{\partial t} + v_x \frac{\partial v_z}{\partial x} = -\frac{q_d v_y \eta \cos\theta}{m_d c} + \frac{q_d v_x \eta \sin\theta}{m_d c}. \tag{5}$$

These equations are supplemented by Poissons equation given by

$$\frac{\partial^2 \phi}{\partial x^2} = 4\pi e\left[n_e - n_i - \frac{q_d n_d}{e}\right], \tag{6}$$

where m_d is the mass of a dust charged grain of radius 'r' moving with velocity v_d (v_x, v_y, v_z) and charge density n_α ($\alpha = i, e, d$, with $n_{\alpha 0}$ being the values in the equilibrium state); $q_d = -z_d e$ is the surface charge of the dust grain ('z' being the atomic number); ϕ is the electrostatic potential. The current is generated from ions and electrons; consequently, the dust charge equation is due to both, and accordingly, the charge q_d follows from the charge equation as

$$\frac{dq_d}{dt} = I_i + I_e, \tag{7}$$

where

$$\begin{aligned} I_i &= \pi r^2 e\sqrt{\frac{8T_i}{\pi m_i}} n_i \left(1 - \frac{eq_d}{rT_i}\right), \\ I_e &= -\pi r^2 e\sqrt{\frac{8T_e}{\pi m_e}} n_e \exp\left(\frac{eq_d}{rT_e}\right) \end{aligned} \tag{8}$$

are the currents generated from ions and electrons, respectively.

This equation holds good under the condition $r \ll \lambda_d \ll \lambda_{mfp}$ (where λ_d is the plasma Debye length and λ_{mfp} is the mean free path for ion or electron collisions), which, in turn, is valid under the orbital-motion-limited (Bernstein and Rabinowitz) [32] theory. Noteworthy is that most of the laboratory, as well as the astrophysical, dusty plasmas are capable of satisfying this limit. Furthermore, when the mean gyroradius is large enough in comparison to the radius of the charged dust grain, the magnetic field, as well as the equivalent magnetic field due to rotation have no notable effect on the charging of the dust grains. Under the backdrop of this broad assumption, the above charging model has been used in a dynamical system.

The basic equations are normalized by using the following normalizing parameters: $\bar{x} = \frac{x}{\rho}$, $\bar{t} = \frac{t}{\alpha\omega_d}$, $\bar{\phi} = \frac{e\phi}{KT_e}$, $\bar{n}_d = \frac{n_d}{n_{d0}}$, $\bar{z}_d = \frac{z_d}{z_{d0}}$, $\bar{v}_d = \frac{v_d}{c_d}$, where z_{d0} denotes the equilibrium dust charge, along with the use of the following notations: $\rho = \frac{c_d}{\alpha\omega_d}$, $\omega_d = \frac{ez_0\Omega}{cm_d}$, $\alpha^2 = \frac{1}{\gamma\delta_1 + \delta_2}$, $\delta_1 = \frac{n_{i0}}{z_{d0}n_{d0}}$, $\delta_2 = \frac{n_{e0}}{z_{d0}n_{d0}}$, $\gamma = \frac{T_e}{T_i}$, $\lambda_d^2 = \frac{KT_e}{4\pi e^2 n_{d0} z_{d0}}$, $c_d^2 = \frac{n_{d0}KT_eT_i}{m_d z_{d0}^2(n_{i0}T_e + n_{e0}T_i)}$. This allows us to write Eqs. (1) - (7) as follows:

$$\begin{aligned} n_e &= \exp(\phi), \\ n_i &= \exp(-\gamma\phi), \end{aligned} \tag{9}$$

$$\frac{\partial \bar{n}_d}{\partial \bar{t}} + \frac{\partial (\bar{n}_d \bar{v}_x)}{\partial \bar{x}} = 0, \tag{10}$$

$$\frac{\partial \bar{v}_x}{\partial \bar{t}} + \bar{v}_x \frac{\partial \bar{v}_x}{\partial \bar{x}} = \frac{\bar{z}_d}{\alpha^2}\frac{\partial \bar{\phi}}{\partial \bar{x}} + \frac{\bar{z}_d \bar{v}_z \sin\theta}{\alpha}, \tag{11}$$

$$\frac{\partial \bar{v}_y}{\partial \bar{t}} + \bar{v}_x \frac{\partial \bar{v}_y}{\partial \bar{x}} = -\frac{\bar{z}_d \bar{v}_z \cos\theta}{\alpha}, \tag{12}$$

$$\frac{\partial \bar{v}_z}{\partial \bar{t}} + \bar{v}_x \frac{\partial \bar{v}_z}{\partial \bar{x}} = \frac{\bar{z}_d \bar{v}_y \cos\theta}{\alpha} - \frac{\bar{z}_d \bar{v}_x \sin\theta}{\alpha}, \tag{13}$$

$$
\begin{aligned}
\frac{\lambda_d^2}{\rho^2}\frac{\partial^2\bar{\phi}}{\partial\bar{x}^2} &= \bar{z}_d\bar{n}_d + \delta_2\bar{n}_e - \delta_1\bar{n}_i, &(14)\\
\frac{d\bar{z}_d}{d\bar{t}} &= \frac{\alpha\omega_d\bar{n}_{d0}}{e\bar{z}_{d0}}\left[I_i + +I_e\right]. &(15)
\end{aligned}
$$

For the generating currents of ions and electrons to dust grains, we have

$$
\begin{aligned}
&I_i = \pi r^2 e\sqrt{\frac{8T_i}{\pi m_i}}\delta_1\bar{n}_i\left(1-\gamma\bar{z}_d\right),\\
&I_e = -\pi r^2 e\sqrt{\frac{8T_e}{\pi m_e}}\delta_2\bar{n}_e\exp\left(-\bar{z}_d\right).
\end{aligned} \tag{16}
$$

With a view to demonstrating the double layers through the derivation of the Sagdeev potential equation, we take recourse to a pseudopotential analysis and define a dependent variable as $\xi = x - Mt$, where M is the wave velocity normalized by c_d . The basic Eqs. (10) - (15) then take the following form (omitting the bars):

$$
\begin{aligned}
M\frac{dn_d}{d\xi} + \frac{d\left(n_d v_x\right)}{d\xi} &= 0, &(17)\\
M\frac{dv_x}{d\xi} + v_x\frac{dv_x}{d\xi} &= \frac{z_d}{\alpha^2}\frac{d\phi}{d\xi} + \frac{z_d v_z\sin\theta}{\alpha}, &(18)\\
M\frac{dv_y}{d\xi} + v_x\frac{dv_y}{d\xi} &= -\frac{z_d v_z\cos\theta}{\alpha}, &(19)\\
M\frac{dv_z}{d\xi} + v_x\frac{dv_z}{d\xi} &= \frac{z_d v_y\cos\theta}{\alpha} - \frac{z_d v_x\sin\theta}{\alpha}, &(20)\\
\frac{\lambda_D^2}{\rho^2}\frac{d^2\phi}{d\xi^2} &= n_d z_d + \delta_2\exp\left(\phi\right) - \delta_1\exp\left(\gamma\phi\right), &(21)\\
-M\frac{dz_d}{d\xi} &= \frac{\alpha\omega_d n_{d0}}{e z_{d0}}\left[I_i + I_e\right]. &(22)
\end{aligned}
$$

Integration of Eqs. (17), (18) and (20), along with the use of appropriate boundary conditions, $v_d \to 0, \phi \to 0$ and $n_d \to 1$ as $\xi \to \pm\infty$, gives the velocity components as

$$
\begin{aligned}
v_x &= M\left(1-\frac{1}{n_d}\right), &(23)\\
v_y &= M\cot\theta\left(1-\frac{1}{n_d}\right) - \frac{\cot\theta}{\alpha^2 M}\int_0^\phi n_d z_d d\phi, &(24)\\
v_z &= -\frac{1}{\alpha\sin\theta}\left(1+\frac{\alpha^2M^2}{z_d n_d^3}\frac{dn_d}{d\phi}\right)\frac{d\phi}{d\xi}. &(25)
\end{aligned}
$$

Using Eqs. (23) - (25), Eq. (19) can be evaluated as

$$
\frac{d}{d\xi}\left[A\left(n_d, z_d\right)\frac{d\phi}{d\xi}\right] = z_d - n_d z_d - \frac{n_d z_d\cos^2\theta}{\alpha^2M^2}\int_0^\phi n_d z_d d\phi. \tag{26}
$$

Equation (26) can be modified to the form

$$
\begin{aligned}
&\frac{1}{2}\frac{d}{d\phi}\left[A\left(n_d, z_d\right)\frac{d\phi}{d\xi}\right]^2\\
&= A\left(n_d, z_d\right)\left[z_d - n_d z_d - \frac{n_d z_d\cos^2\theta}{\alpha^2M^2}\int_0^\phi n_d z_d d\phi\right],
\end{aligned} \tag{27}
$$

along with the simplification of $A\left(n_d, z_d\right) = 1 + \frac{\alpha^2M^2}{z_d n_d^3}\frac{dn_d}{d\phi}$ in Eq. (27) as

$$
\begin{aligned}
A\left(n_d, z_d\right) &= 1 + \frac{\alpha^2M^2}{z_d n_d^3}\left[\frac{d}{d\phi}\left(\frac{z_d n_d}{z_d}\right)\right]\\
&= 1 + \frac{\alpha^2M^2}{\left(z_d n_d\right)^3}\left[z_d\frac{d\left(z_d n_d\right)}{d\phi} - \left(z_d n_d\right)\frac{dz_d}{d\phi}\right].
\end{aligned} \tag{28}
$$

Further simplification of the above equation to the standard form of the Sagdeev potential equation for studying the double layers is not possible. $A(n_d, z_d)$ creates a complication, and the equation fails to lead to a derivation of the standard form of the Sagdeev potential equation. In the studies conducted earlier [30,31], a pseudopotential analysis was used to derive small-amplitude double layers. While those studies considered the dust charge to be constant, the present study tries to trace the nature of double layers in dusty plasma with dust charge fluctuations being considered.

The terms containing higher powers of ε are neglected in Eq. (27); then, that equation can be written as

$$
z_d n_d = \delta_1 n_1 - \delta_2 n_e + \varepsilon\frac{d^2\phi}{d\xi^2}, \tag{29}
$$

which can be simplified further as

$$
z_d n_d = \delta_1 n_1 - \delta_2 n_e + \frac{\varepsilon}{2}\frac{d}{d\phi}\left(\frac{d\phi}{d\xi}\right)^2 + K_1, \tag{30}
$$

where K_1 is the integration constant, which is calculated to be zero when the boundary condition

$$
\frac{d\phi}{d\xi} = 0, \tag{31}
$$

is used. Thus Eq. (30) takes the form

$$
z_d n_d = \delta_1 n_1 - \delta_2 n_e + \frac{\varepsilon}{2}\frac{d}{d\phi}\left(\frac{d\phi}{d\xi}\right)^2. \tag{32}
$$

As a sequel to the works of Ma and Liu [33], who consideration the charging time of the dust grains to be quite small in comparison to the hydrodynamic time scale, we obtain

$$
z_d = 1 - \left(1-\gamma^2\right)\phi. \tag{33}
$$

When all the assumptions and modifications are taken into consideration, Eq. (26) takes the following form:

$$\frac{d}{d\phi}\left[A\left(n_d,z_d\right)\frac{d\phi}{d\xi}\right]\frac{d\phi}{d\xi}$$
$$= z_d-\left[\delta_1 n_i-\delta_2 n_e+\frac{\varepsilon}{2}\frac{d}{d\phi}\left(\frac{d\phi}{d\xi}\right)^2\right]-\left[\delta_1 n_i-\delta_2 n_e+\frac{\varepsilon}{2}\frac{d}{d\phi}\left(\frac{d\phi}{d\xi}\right)^2\right]B\int_0^{\phi}\left[\delta_1 n_i-\delta_2 n_e+\frac{\varepsilon}{2}\frac{d}{d\phi}\left(\frac{d\phi}{d\xi}\right)^2\right]d\phi. \quad (34)$$

which has been further simplified as

$$\frac{dA}{d\phi}\left[\frac{d\phi}{d\xi}\right]^2+\frac{A}{2}\frac{d}{d\phi}\left[\frac{d\phi}{d\xi}\right]^2$$
$$= z_d-\left[\delta_1 n_i-\delta_2 n_e+\frac{\varepsilon}{2}\frac{d}{d\phi}\left(\frac{d\phi}{d\xi}\right)^2\right]-\left[\delta_1 n_i-\delta_2 n_e+\frac{\varepsilon}{2}\frac{d}{d\phi}\left(\frac{d\phi}{d\xi}\right)^2\right]B\int_0^{\phi}\left[\delta_1 n_i-\delta_2 n_e+\frac{\varepsilon}{2}\frac{d}{d\phi}\left(\frac{d\phi}{d\xi}\right)^2\right]d\phi. \quad (35)$$

Expansion of Eq. (35) up to the third term [34] yields

$$\left[\frac{d\phi}{d\xi}\right]^2 = C_1\phi^2-C_2\phi^3+C_3\phi^4=-V\left(\phi\right), \quad (36)$$

where C_1, C_2, and C_3 are constants that can be computed in a self-consistent manner. Eq. (36) is used in Eq. (35); thereafter, similar orders are balanced, which leads to some algebraic relations. These relations, after some mathematical manipulations, take the following forms:

$$C_1 = \frac{\left(\gamma\delta_1+\delta_2-k-B\right)}{\left[1-\alpha^2M^2\left(\gamma\delta_1+\delta_2-k\right)+\varepsilon\right]}, \quad (37)$$

$$C_2 = \frac{2}{3}\left[\frac{C_1\left\{3\alpha^2M^2+\frac{1}{\alpha^2}+M^2-\frac{B\varepsilon}{\alpha^2}+B\varepsilon\left(1+\varepsilon C_1\right)\right\}+\frac{1}{4}\left(2\delta_2-\delta_1\gamma^2\right)-\frac{B\gamma}{2}-\frac{B}{\alpha^2}}{B\varepsilon-\varepsilon-1-\alpha^2M^2}\right], \quad (38)$$

$$C_3 = \frac{-3\alpha^2M^2C_2-3\alpha^2M^2\left(\gamma\delta_1+\delta_2\right)C_1-\frac{3}{2}\alpha^2M^2\left(\gamma\delta_1+\delta_2\right)C_2-\frac{B}{6}\delta_1\gamma^3-\frac{B}{6}\delta_2-\frac{B}{2}\gamma^2+\frac{B\delta_2}{2}+\frac{3}{2}\varepsilon C_2}{2\left(1+\alpha^2M^2+B\varepsilon\right)}. \quad (39)$$

Thus, the modified Sagdeev potential equation is found, and the salient features of the double layers can be determined from

$$\mathrm{V}(\phi) = -\left(C_1\phi^2-C_2\phi^3+C_3\phi^4\right). \quad (40)$$

Finally, we impose the condition for the double layers on $\frac{\partial V}{\partial\phi}=0$ and at $\phi=\phi_m$, which allows one to modify Eq. (40) as

$$C_1 = C_2\phi_m-C_3\phi_m^2, \quad (41)$$
$$C_1 = \frac{3C_2}{2}\phi_m-2C_3\phi_m^2. \quad (42)$$

Equation (41) and (42) further give

$$C_2 = 2C_3\phi_m, \quad (43)$$
$$C_1 = C_3\phi_m^2. \quad (44)$$

Thus, Eq. (36) can be expressed as

$$\left[\frac{d\phi}{d\xi}\right]^2 = C_3\phi_m^2\phi^2-2C_3\phi_m\phi^3+C_3\phi^4. \quad (45)$$

The above equation yields the requisite conditions for the existence of double layers [35], viz.

$$C_2^2 = 4C_1C_3, \quad (46)$$

as well as

$$C_3 > 0. \quad (47)$$

On integration of Eq. (45), the profile of the double layers can be evaluated using

$$\phi = \frac{1}{2}\phi_m \left(1 \pm \tan\frac{\xi}{\delta}\right), \tag{48}$$

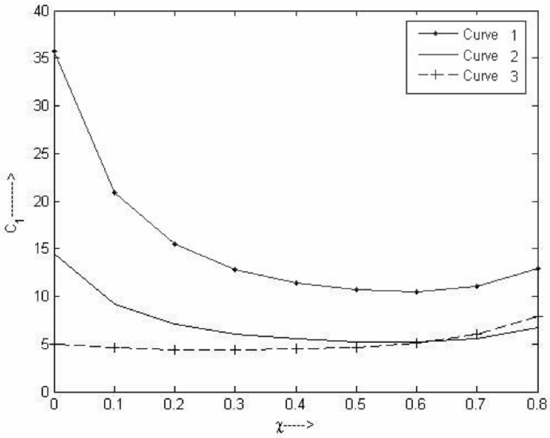
$$\phi_m = \frac{C_2}{2C_3}, \tag{49}$$

$$\delta = \frac{2C_3}{C_2}. \tag{50}$$

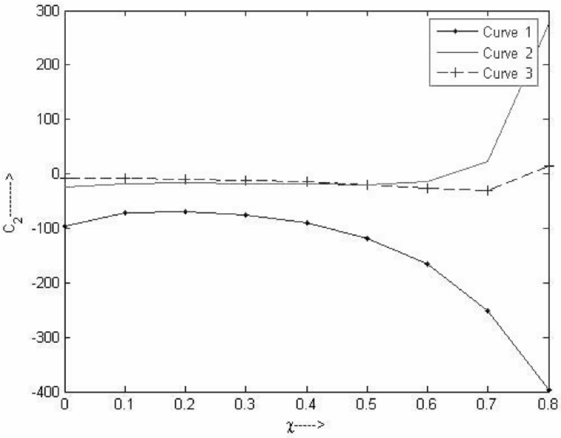
In Fig. 1, we plot the variations of the parameters C_1, C_2 and C_3 with a relative concentration of electron, χ, with the other parameters having the values $\theta = 60^0$, $M = 0.6$, $\gamma = 2$, $\epsilon = 0.001$ (Curve 1); $\theta = 50^0$, $M = 0.7$, $\gamma = 1.5$, $\epsilon = 0.001$ (Curve 2); $\theta = 60^0$, $M = 0.6$, $\gamma = 1.5$, $\epsilon = 0.001$ (Curve 3). A cursory look at Figs 1(a) and 1(c) shows that both C_1 and C_3 have positive values while Fig. 1(b) indicates that C_2 can assume positive, as well as negative, values. The positive values of C_2 are indicative of the existence of positive double layers; on the other hand, the negative values of C_2 correspond to the existence of rarefactive double layers. Worth mentioning here is that compressive solitary waves have been observed in the magnetosphere by the Viking spacecraft [36] and by the Freja scientific satellite [37]. Thus, parameter C_2 has a pivotal role in giving rise to compressive and rarefactive double layers.

To analyze the impact of the variation of the temperature ratio γ on the existence of double layers, we plot in Fig. 2 the variation of the parameters C_1, C_2 and C_3 with γ, with the other parameters having the values $\theta = 50^0$, $M = 0.3$, $\chi = 0.7$, $\epsilon = 0.001$ (Curve 1); $\theta = 60^0$, $M = 0.6$, $\theta = 60^0$, $M = 0.6$, $\chi = 0.5$, $\epsilon = 0.001$ (Curve 2); $\theta = 50^0$, $M = 0.65$, $\chi = 0.2$, $\epsilon = 0.001$ (Curve 3). If we analyze Figs 2(a) and 2(c), we come to the conclusion that the formation of double layers for higher temperature ratios is not temperature ratios is not feasible. From Eq. (47), a necessary condition for the existence of double layer has been found to be $C_3 > 0$. Moreover, Eq. (44) reveals that the condition $C_1 > 0$ should also be satisfied. As a result, the fluctuations of C_1 with increasing of γ in Curves 2 and 3 suggest that double layer formation is possible only for values of the electron-ion temperature ratio. Again, the fluctuation of Curve 2 in Fig. 2(c) is also indicative of the fact that existence of double layers for higher temperature ratios is not viable.

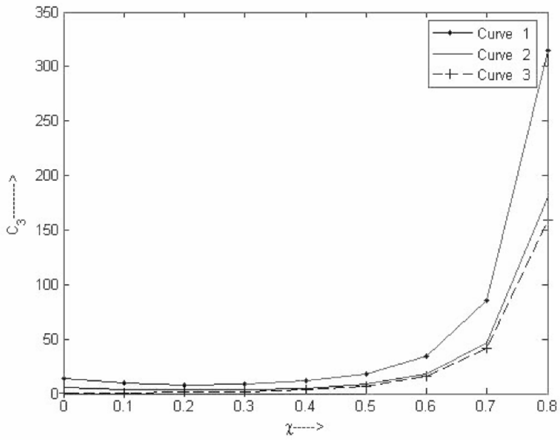
However, C_2 can assume both positive and negative values. The positive values of C_2 correspond to the formation of compressive double layers while its negative values correspond to the formation of rarefactive double layers. The fluctuation of the value of C_2 with higher values of γ in Fig. 2(b) is a pointer to the co-existence of compressive, a well as rarefactive, double layers based on positive and negative values of C_2 respectively.



(a)

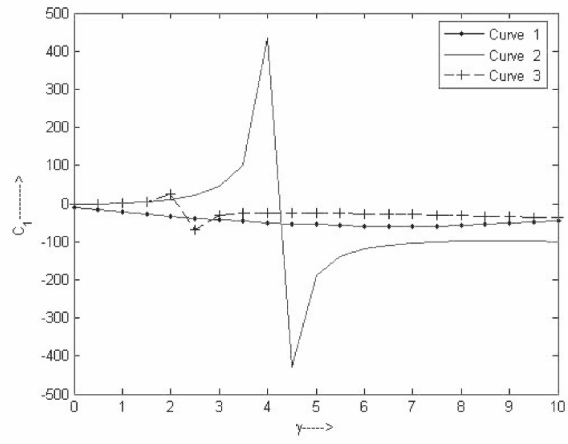


(b)

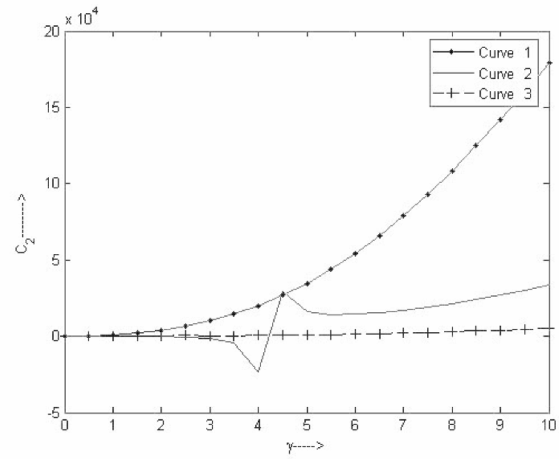


(c)

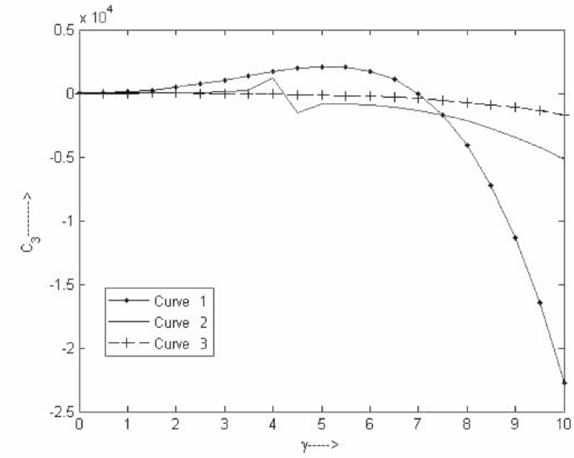
Fig. 1. Variations of (a) C_1, (b) C_2, and (c) C_3 with a relative concentration of electron χ for $\theta = 60^0$, $M = 0.6$, $\gamma = 2$, $\epsilon = 0.001$ (Curve 1); $\theta = 50^0$, $M = 0.7$, $\gamma = 1.5$, $\epsilon = 0.001$ (Curve 2); $\theta = 60^0$, $M = 0.6$, $\gamma = 1.5$, $\epsilon = 0.001$



(a)



(b)



(c)

Fig. 2. Variations of (a) C_1, (b) C_2, and (c) C_3 with the temperature ratio γ for $\theta = 50^0$, $M = 0.3$, $\chi = 0.7$, $\epsilon = 0.001$ (Curve 1); $\theta = 60^0$, $M = 0.6$, $\theta = 60^0$, $M = 0.6$, $\chi = 0.5$, $\epsilon = 0.001$ (Curve 2); $\theta = 50^0$, $M = 0.65$, $\chi = 0.2$, $\epsilon = 0.001$

III. CONCLUSION

The model that we have considered may be said to contain a magnetized plasma under slow rotation containing dust grains with varying charges. Dust charge fluctuations are found to have a considerable impact on the existence of compressive, as well as rarefactive, double layers. When the wave propagates with high amplitude, it is prone to collapse, resulting in the formation of a narrow wave packet. This corresponds to the generation of high electric pressure. Consequently, the magnetic pressure also grows in the region, and as a result, the narrow wave packet produces a depression in the plasma density. The production of a high electric field accelerates the fast moving electrons to charge neutrals, as well as the dust particles, to a high potential, resulting in radiation in the double layers. The studies further reveal that the relative electron concentration, as well as the temperature ratio, have marked effects on the pattern of evolution of the double layer. These study can be extended further by taking the fluctuations of the size, as well as the shape, of the individual dust charged grains into consideration. The new observations emanating from these studies might help in deciphering certain basic features of nonlinear plasma dynamics.

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