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Abstract:

The propagation of dust acoustic (DA) solitary waves in two-dimension dusty plasma containing adiabatic electrons and ions and negatively charged dust fluid has been investigated by considering a new expression for the polarization force effect. The Kadomstev–Petviashvili (KP) equation is derived by using reductive perturbation technique. The stability analysis is discussed for the existence of DA solitary waves. The expression for the energy of DA solitary waves has been derived as well. The effects of the adiabaticity of electrons-ions, ion temperature, electrons-to-ions density ratio and polarization force on the basic properties of the DA solitary waves have been investigated. It is shown that the effects of adiabaticity, ion temperature and polarization force significantly modify the basic properties (amplitude, width and speed) of the DA solitary waves. It is also shown that the soliton energy is increased with the increase of adiabatic index but decreased with the increase of polarization force.

Keywords: Adiabatic dusty plasma; Kadomtsev–Petviashvili equation; polarization force; Solitary wave solution.

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1. Introduction

The study of nonlinear phenomena in the field of dusty plasmas have become one of the most important topic in plasma physics. A dusty plasma comprise charged heavy dust particles, electrons and ions. Such plasmas can be found nearly everywhere in space, such as in comet tails and planetary rings, interstellar clouds, magnetospheres, as well as in many industrial and laboratory plasmas [1-7]. Due to the electrons typically have a larger thermal speed than the ions, dust grains embedded in a plasma are often negatively charged. As a consequence of the presence of charged dust grains in a plasma, different types of collective processes exist and very rich wave modes can be excited. One of these modes is the low-frequency dust acoustic (DA) wave, which arises due to the restoring force, that comes from the thermal pressures of both the electrons and ions, while the inertia is due to the dust mass. Theoretically, DA wave was first reported by Rao *et al*.[8] in an unmagnetized dusty plasmas, which consisting of inertial charged dust fluid, Boltzmann distributed electrons and ions. Experimentally, a number of authors have established the existence of DA waves in dusty laboratory plasmas [9-12].

In addition to DA waves, there has been significant progress in the study of the associated nonlinear structures such as DA solitary waves or solitons, which arise due to a balance between nonlinear effects and dispersion. Solitons are a particular type of solitary wave which maintain their shape and speed after interactions and have been extensively studied in mathematics and physics due to their stable structure and also because they arise as solutions to various exactly solvable models including the Korteweg-de Vries (KdV), Kadomstev–Petviashvili (KP) equation and the nonlinear Schrödinger (NLS) equation. Earlier, a number of theoretical investigations have been carried out in this direction [13-16].

Another interesting feature of dusty plasma physics is that the embedded charged dust particles in a dusty plasma may experience several forces that play an important role in the dynamics of these particles and thus modifying the properties of the DA waves. Two of these effective forces are the electric and the polarization forces. In fact, the polarization force arises due to any kind of deformation of the Debye sheath around the particulates in the background of non-uniform plasmas and it is always in the direction of decreasing Debye length λ_D [17, 18]. The effect of polarization force on the propagation characteristic of DA wave was first applied by Khrapak *et al*.[19]. They showed that the phase velocity of DA waves decreases with the increase of the strength of polarization force.

Recently, a number of researchers have studied the characteristics of linear and nonlinear DA wave structures in the presence of polarization force effect in homogeneous and non-homogeneous plasma. For example, Bandyopadhyay *et al*. [20] studied the propagation of DA solitary waves in a dusty plasma containing Maxwellian electrons and ions, and negatively charged dust grains, including polarization force effect. They derived the KdV type equation by using reductive perturbation method. They found that, with an increase of the polarization force, the amplitude (width) of a solitary wave increases (decreases). Mamun *et al*.[21] considered Maxwellian electrons and ions as well as strongly coupled negatively charged dust in presence of the effect of polarization force, which arises due to the polarization of electrons around the positively charged dust grain. Asaduzzaman and Mamun [22] studied the effects of modified polarization force on the linear DA waves in a nonuniform dusty plasma containing adiabatic electrons and ions and negatively charged dust grains. They found that the phase velocity of the DA waves increases with the increase of the adiabaticity of both electrons and ions, but it decreases with the increase of the polarization force. El-Labany *et al*. [23] illustrated that the nonlinearity coefficient in the nonlinear DA wave propagation increases by increasing the polarization force. Mayout *et. al*. [24] studied the effect of the polarization force on the DA soliton energy and fund that, the soliton energy decreases with an increase in the effects of plasma-dust particles polarization interaction. Recently, El-Labany *et. al*. [25] have investigated the nonlinear characteristics of DA solitary waves through KdV–Burgers equation in a polytropic complex plasma containing adiabatic electrons and ions and negatively charged dust grains including the effects of modified polarization force. They shown that an increase in the value of the modified polarization parameter leads to a fast decay and diminishes the oscillation amplitude of the DA damped cnoidal wave. In the most of the above investigations, KdV equation or its variants for one-dimensional study, has been derived by using reductive perturbation method [26].

Although the nonlinear characteristics of DA solitary waves in a dusty plasma were studied by means of the KP equation, yet the effect of polarization force (which can lead to any significant changes in the nonlinear characteristics of DA solitary waves) on

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two dimensional DA solitary waves through of the KP equation in dusty plasma has not received the attention of researchers. Moreover, all of the above theoretical investigations are valid only under the condition $T_e \gg T_i$, in which the polarization force arises mainly due to the polarization of plasma ions around the dust grain (which is not congruous in general) where T_e and T_i are the electron and ion temperatures respectively. Therefore, in the present investigation, we intend to study the dynamics of DA solitary waves in two-dimensions in a dusty plasma containing adiabatic electrons-ions, and negatively charged dust grains in the presence of generalized polarization force effect. We introduce a generalized expression for the influence of the polarization force, which is a more generalized in realistic situation (space and laboratory environment). We have set up and solved the KP equation for DA solitary waves and explored the combined effects of different plasma parameters (viz., generalized polarization force and the adiabatic parameter.) on the characteristics and energy of DA solitary wave.

This paper is organized as follows: the theoretical model and a set of normalized basic equations describing the system are given in Sec.2. Sec.3, deals with the derivation of the KP equation. In Sec. 4 the stationary solution of KP equation and stability analysis are given. The expression for energy of solitary waves is derived in Sec.5. The results and discussion are presented in Sec. 6. Finally, conclusions are given in Sec.7.

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2. Theoretical model

Let us consider a three-component unmagnetized two-dimensional dusty plasma system consisting of adiabatic electrons and ions, and negatively charged dust fluid in the presence of generalized polarization force. In low frequency phenomena in the regime where dust dynamics is important, the inertia of the electrons and ions can be neglected, and the dynamics of adiabatic electrons and ions are considered. Thus, the densities of adiabatic electrons and ions can be written as,

$$n_e = n_{e0}\left(1+\frac{\gamma-1}{\gamma}\sigma\theta_i\phi\right)^{1/\gamma-1}, \quad (1)$$

$$n_i = n_{i0}\left(1-\frac{\gamma-1}{\gamma}\sigma\phi\right)^{1/\gamma-1}, \quad (2)$$

where $n_{e0}(n_{i0})$ is the equilibrium density of electrons (ions), $T_{e0}(T_{i0})$ is the equilibrium temperature of electrons (ions) and γ is the adiabatic index of electrons-ions. In an isothermal process one has $\gamma = 1$, in an adiabatic process without heat transfer we have $\gamma = (2+N)/N$, with N begin degree of freedom (i.e., $\gamma = 3$ for one-dimensional adiabatic flow, $\gamma = 2$ for two-dimensional adiabatic flow and $\gamma = 5/3$ for three-dimensional adiabatic flow). We define $\theta_i = T_{i0}/T_{e0}$ is the ion-to-electron temperature ratio and $\phi = e\varphi/k_B T_0$ is the normalized electrostatic potential, in which φ is electrostatic potential and $T_0 = \sigma T_{i0}$ is the effective temperature with $\sigma = (1-\rho)/(1+\rho\theta_i)$. The equilibrium densities of electrons (n_{e0}) and ions (n_{i0}) are related to the equilibrium dust density (n_{d0}) and the dust charge number (Z_d) by the charge neutrality condition as, $n_{i0} = n_{e0} + Z_d n_{d0}$.

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The fluid equations including the polarization force term in the dust momentum equation that governing the dust component in our system are described by the continuity, the momentum and the Poisson equation which can be written as, respectively,

$$\frac{\partial n_d}{\partial t} + \nabla \cdot (n_d \boldsymbol{U}_d) = 0, \tag{3}$$

$$\left(\frac{\partial}{\partial t} + \boldsymbol{U}_d \cdot \nabla\right)\boldsymbol{U}_d = \frac{Z_d e}{m_d}\nabla\varphi - \frac{Q_d^2}{8\pi\epsilon_0 m_d}\frac{\nabla\lambda_D}{\lambda_D^2} - \frac{\mu_d k_B T_d}{m_d}\frac{\nabla n_d}{n_d}, \tag{4}$$

$$\nabla^2\varphi = \frac{e}{\epsilon_0}(n_e + Z_d n_d - n_i). \tag{5}$$

In the above equations, n_d is the dust number density, $\boldsymbol{U}_d$ represent the velocity vector of the dust fluid, T_d is the dust temperature, m_d is the dust grain mass and $\mu_d = (1/k_B T_d)(\partial P_d/\partial n_d)$ is the compressibility coefficient which is related to the coupling parameter [27].

For notational clarity, we normalize the dynamic variables appearing in the Eqs. (3)-(5). The dust density, dust velocity, and electrostatic potential are then normalized as $n = n_d/n_{d0}$, $\boldsymbol{U} = \boldsymbol{U}_d/C_d$ and $\phi = \varphi/\varphi_0$respectively, where $C_d = (Z_d k_B T_0/m_d)^{1/2}$ and $\varphi_0 = k_B T_0/e$. The linearized Debye length λ_D is normalized as $\Lambda_D = \lambda_D/\lambda_{D0}$ where $\lambda_{D0} = (\epsilon_0 k_B T_0/n_{d0} Z_d e^2)^{1/2}$ is the Debye length. The time and space variables are normalized by the plasma period $\omega_{pd}^{-1} = \left(\epsilon_0 m_d/n_{d0} Z_d^2 e^2\right)^{1/2}$and Debye length λ_{D0} respectively. Thus, we can rewrite the basic equations [i.e., Eqs. (3)-(5)] in the following normalized forms:

$$\frac{\partial n}{\partial t} + \nabla \cdot (n\boldsymbol{U}) = 0, \tag{6}$$

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$$\left(\frac{\partial}{\partial t}+\boldsymbol{U}\cdot\nabla\right)\boldsymbol{U}=\nabla\phi-2R\frac{\nabla\Lambda_D}{\Lambda_D^2}-\mu_d\sigma_d\frac{1}{n}\nabla n \tag{7}$$

$$\nabla^2\phi=\frac{\rho}{1-\rho}\left(1+\frac{\gamma-1}{\gamma}\sigma\theta_i\phi\right)^{\frac{1}{\gamma-1}}-\frac{1}{1-\rho}\left(1-\frac{\gamma-1}{\gamma}\sigma\phi\right)^{\frac{1}{\gamma-1}} \tag{8}$$
$$+n,$$

where $\sigma_d=T_d/Z_dT_0$, $R=Z_de^2/16\pi\epsilon_0k_BT_0\lambda_{D0}$ is the polarization parameter, which determining the effect of the polarization force and $\rho=n_{e0}/n_{i0}$ is the electron-to-ion number density ratio at equilibrium. Here, $\nabla=(\partial/\partial x\ ,\partial/\partial y)$ and $\boldsymbol{U}=(u,\mathrm{v})$ where u and v are the velocity components of the dust grains in x-and y-directions, respectively.

Furthermore, we assume that the normalized potential is small, such that $\phi\ll 1$. As a consequence of this, we may expand the functions appearing in the Eqs. (1) and (2) such that

$$n_e=n_{e0}\left(1+\frac{\sigma\theta_i}{\gamma}\phi+\frac{2-\gamma}{2\gamma^2}\sigma^2\theta_i^2\phi^2+\cdots\right), \tag{9}$$

$$n_i=n_{i0}\left(1-\frac{\sigma}{\gamma}\phi+\frac{2-\gamma}{2\gamma^2}\sigma^2\phi^2+\cdots\right). \tag{10}$$

For the purpose of deriving the KP equation for this system, we only require up to the ϕ^2 term.

Now, To derive the generalized expression for polarization force, looking at the normalized Debye length Λ_D, which appear in Eq. (7), we see that

$$\Lambda_D=\lambda_D/\lambda_{D0}=\left(\frac{n_{i0}T_{e0}+n_{e0}T_{i0}}{n_iT_{e0}+n_eT_{i0}}\right)^{1/2}. \tag{11}$$

Substituting Eqs. (9) and (10) into Eq. (11), we can see that, the normalized Debye length, Λ_D simplifies to

$$\Lambda_D = (1 + \alpha_1\phi + \alpha_2\phi^2 + \cdots)^{-1/2}, \quad (12)$$

where the coefficients α_1 and α_2 (which are related to the plasma parameters ρ, θ_i and γ) are respectively given by

$$\alpha_1 = \frac{\sigma\left(1 - \rho\theta_i^2\right)}{\gamma(1 + \rho\theta_i)}, \quad \alpha_2 = \frac{\sigma^2(2 - \gamma)\left(1 + \rho\theta_i^3\right)}{2\gamma^2(1 + \rho\theta_i)}.$$

Substituting Eq. (12) into Eq. (7), the normalized momentum equation [i.e, Eq.(7)] can be simplified to

$$\left(\frac{\partial}{\partial t} + \boldsymbol{U} \cdot \nabla\right)\boldsymbol{U} = (1 - \mathrm{P}_1 - \mathrm{P}_2\phi)\nabla\phi - \mu_d\sigma_d\frac{\nabla n}{n}, \quad (13)$$

where $\mathrm{P}_1 = R\alpha_1$ and $\mathrm{P}_2 = R\,(\alpha_1^2 - 4\alpha_2)/2$.

It is clear that, the polarization force in our model is a function of adiabatic index (γ), the ratio of electron background density to ion background density (ρ) and the ratio of electron temperature to ion temperature θ_i. This feature adds a new physics to the whole system. It is clear that when $T_{e0} \gg T_{i0}$, the parameters P_1 and P_2 in Eq. (13), which are related to the polarization force, respectively reduce to the same parameters Γ_1 and Γ_2 which derived by El-Labany *et al*. [25]

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3. Derivation of KP equation

In order to derive the KP equation, we employ the well-known standard reductive perturbation method [26]. According to this method, we choose the independent variables as

$$\xi = \epsilon(x - \lambda t),\ \ \tau = \epsilon^3 t, \quad \eta = \epsilon^2 y, \tag{14}$$

where ϵ is a small $(0 < \epsilon \leq 1)$ dimensionless expansion parameter which characterizes the strength of nonlinearity in the system and λ is the phase velocity of the DA solitary waves along the x-direction. The physical dependent quantities are expanded about their equilibrium values in power series of ϵ as

$$F = F_0 + \epsilon^2 F_1 + \epsilon^4 F_2 + \cdots, \tag{15}$$

with $F = (n, u, \phi)$, and $F_0 = (1, 0,0)$,

whereas

$$\mathrm{v} = \epsilon^3 \mathrm{v}_1 + \epsilon^5 \mathrm{v}_2 + \cdots. \tag{16}$$

Substituting Eqs. (14)-(16) into Eqs. (6), (8), and (13), and then equating the coefficients of different powers of ϵ, from the lowest order terms of the continuity, and the momentum equations, we get

$$n_1 = \frac{(1 - P_1)}{\mu_d \sigma_d - \lambda^2} \phi_1, \tag{17}$$

$$u_1 = \frac{\lambda(1 - P_1)}{\mu_d \sigma_d - \lambda^2} \phi_1. \tag{18}$$

The lowest order term of y-component of momentum equation is

$$\lambda \frac{\partial \mathrm{v}_1}{\partial \xi} = \mu_d \sigma_d \frac{\partial n_1}{\partial \eta} - (1 - P_1) \frac{\partial \phi_1}{\partial \eta}, \tag{19}$$

and the lowest order term of Poisson's equation yield

$$n_1 + \delta_1 \phi_1 = 0. \tag{20}$$

The phase velocity of DA solitary waves is obtained from the lowest order Poisson’s equation (20) together with Eq.(17), which is given by

$$\lambda = \sqrt{\frac{(1 - \mathrm{P}_1)}{\delta_1} + \mu_d \sigma_d}. \tag{21}$$

It can be noted from equation (21) that the phase velocity is modified due to inertialess adiabatic electron-ion and polarization force.

To the next higher terms ($\sim\epsilon^4$) of the continuity, and the momentum equations, we have

$$\frac{\partial n_1}{\partial \tau} - \lambda \frac{\partial n_2}{\partial \xi} + \frac{\partial u_2}{\partial \xi} + \frac{\partial}{\partial \xi}(n_1 u_1) + \frac{\partial \mathrm{v}_1}{\partial \eta} = 0, \tag{22}$$

$$\begin{aligned} \frac{\partial u_1}{\partial \tau} - \lambda \frac{\partial u_2}{\partial \xi} + \mu_d \sigma_d \frac{\partial n_2}{\partial \xi} - (1 - \mathrm{P}_1) \frac{\partial \phi_2}{\partial \xi} + u_1 \frac{\partial u_1}{\partial \xi} \\ - \lambda n_1 \frac{\partial u_1}{\partial \xi} - \mathrm{P}_2 \phi_1 \frac{\partial \phi_1}{\partial \xi} - (1 - \mathrm{P}_1) n_1 \frac{\partial \phi_1}{\partial \xi} = 0, \end{aligned} \tag{23}$$

and the next higher order of Poisson's equation is

$$n_2 = -\delta_1 \phi_2 - \delta_2 \phi_1^2 + \frac{\partial^2 \phi_1}{\partial \xi^2}, \tag{24}$$

where the coefficients δ_1 and δ_2 are given by

$$\delta_1 = \frac{1}{\gamma}, \quad \delta_2 = \frac{\sigma^2 (2 - \gamma)\left(\rho \theta_i^2 - 1\right)}{2\gamma^2 (1 - \rho)}.$$

Eliminating the second-order perturbed quantities that appeared in Eqs. (22)-(24) with the help of equations Eqs. (17)-(20), we obtain the KP equation as

$$\frac{\partial}{\partial \xi}\left(\frac{\partial \phi_1}{\partial \tau}+A\phi_1\frac{\partial \phi_1}{\partial \xi}+B\frac{\partial^3 \phi_1}{\partial \xi^3}\right)+C\frac{\partial^2 \phi_1}{\partial \eta^2}=0, \qquad (25)$$

where the nonlinear, dispersive, and diffractive coefficients A, B, and C are respectively given by

$$A=-\frac{1}{2\lambda\delta_1}[2\lambda^2(\delta_1^2+\delta_2)+\delta_1(1-P_1)+\mathrm{P}_2-2\mu_d\sigma_d\delta_2],$$

$$B=\frac{\lambda^2-\mu_d\sigma_d}{2\lambda\delta_1},$$

and

$$C=\frac{\lambda}{2}.$$

4. Solution of KP equation and stability analysis

In order to find the solitary wave solution of KP equation (25), we have define the transformed coordinate $\chi=\xi+\eta-V_0\tau$ of the co-moving frame where V_0 represents the velocity of the co-moving frame with solitary wave. Using single variable transformation, KP Eq. (25) is converted into an ordinary differential equation and integrating with used the boundary conditions ($d^m\phi_1/d\chi^m\to 0$ as $\chi\to\infty, m=0,1,2$), we get

$$B\frac{d^2\phi_1}{d\chi^2}+\frac{A}{2}\phi_1^2-(V_0-C)\phi_1=0. \qquad (26)$$

Multiplying both sides of Eq.(26) by $d\phi_1/d\chi$, and then integrating once with taking into account the above boundary conditions, we can get the energy conservation equation as

$$\frac{1}{2}\left(\frac{d\phi_1}{d\chi}\right)^2 + V(\phi_1) = 0, \tag{27}$$

where

$$V(\phi_1) = \frac{A}{6B}\phi_1^3 - \frac{(V_0 - C)}{2B}\phi_1^2, \tag{28}$$

refers to the classical pseudo-potential. Thus, the solitary wave solution of the KP equation (25) is

$$\phi_1 = \phi_m \mathrm{sech}^2\left(\frac{\chi}{L}\right). \tag{29}$$

It is quite evident from above solitary wave solution that the peak amplitude of the solitary wave i.e., $\phi_m = 3(V_0 - C)/A$ is dependent on the nonlinearity coefficient while the solitary wave width $L = \sqrt{4B/(V_0 - C)}$ depends on the dispersive coefficient. If we consider the propagation of DA solitary wave in the two-dimensional KP equation, the solution may become unstable. It is, therefore, obligatory to address the stability of the KP equation. Note that the necessary condition for a stable solitary wave solution (29) is

$$\left[\frac{d^2V(\phi_1)}{d\phi_1^2}\right]_{\phi_1=0} < 0.$$

According to this condition, we obtain

$$\left[\frac{d^2V(\phi_1)}{d\phi_1^2}\right]_{\phi_1=0} = -\frac{(V_0 - C)}{B}. \tag{30}$$

From Eq. (30) it is found that $(V_0 - C)/B$ should be positive for the existence of solitary wave solution (29). This condition is always possible only if $B > 0$ and $(V_0 - C) > 0$ or $B < 0$ and $(V_0 - C) < 0$. Now from the expression of dispersive coefficient B, we have B is always positive. This means that $(V_0 - C) > 0$ and $V_0 > C$ must be satisfied. Thus, for a stable solitary wave solution, the condition $V_0 > \lambda/2$ must always possible. This then has to be taken into account when choosing the value of V_0 in the present study.

5. Energy of solitary wave

The study of the amplitude and width of solitary waves is a common way to further recognize the waves in plasmas, so it is of great importance to see the variation of solitary wave energy with various plasma parameters. The solitary wave energy E_S can be obtained by using the following integral [28, 29]

$$E_S = \int_{-\infty}^{\infty} U_1^2 \, d\chi, \tag{31}$$

where $U_1 \left(= \sqrt{u_1^2 + \mathrm{v}_1^2}\right)$ is the resultant velocity of the dust fluid with u_1 and v_1 are the first order perturbed velocities of the dust fluid in the x and y-directions, respectively. From Eqs. (18), (19) and (29), it is convenient to determine the first order perturbed velocities of the dust fluid in the x- and y-directions, respectively

$$u_1 = -\frac{\lambda(1 - P_1)}{\lambda^2 - \mu_d \sigma_d} \phi_m \mathrm{sech}^2\left(\frac{\chi}{L}\right), \tag{32}$$

$$\mathrm{v}_1 = -\frac{\lambda(1 - P_1)}{\lambda^2 - \mu_d \sigma_d} \phi_m \mathrm{sech}^2\left(\frac{\chi}{L}\right). \tag{33}$$

By substituting Eqs. (32) and (33) into Eq. (31) and after integration, we obtain

$$E_S = 24\delta_1 \left(\frac{V_0 - C}{A}\right)^2 L(1 - \mathrm{P}_1 + \mu_d \sigma_d \delta_1). \tag{34}$$

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6. Results and discussion

We numerically investigate the characteristic properties of the dust acoustic solitary waves in typical dusty plasmas. the typical numerical values of the physical parameters are selected based on actual experimental data [30, 31]. $n_{e0} = 5 \times 10^{13}\, m^{-3}$; $n_{i0} = 1 \times 10^{14}\, m^{-3}$; $T_{i0} = 600K$; $T_{e0} = (1 - 1.16) \times 10^{4}K$; and $Z_d = (1 - 2) \times 10^{4}$. Figure 1 shows the dependence of phase velocity λ of solitary wave on the both of adiabaticity of electrons-ions γ and the polarization force (thorough the parameter R). Note that, there is large phase velocity is obtained with adiabatic case ($\gamma = 2$), while for isothermale case ($\gamma = 1$), the phase velocity λ becomes smaller. We can also see that the phase velocity λ decreases with polarization parameter R for two cases.

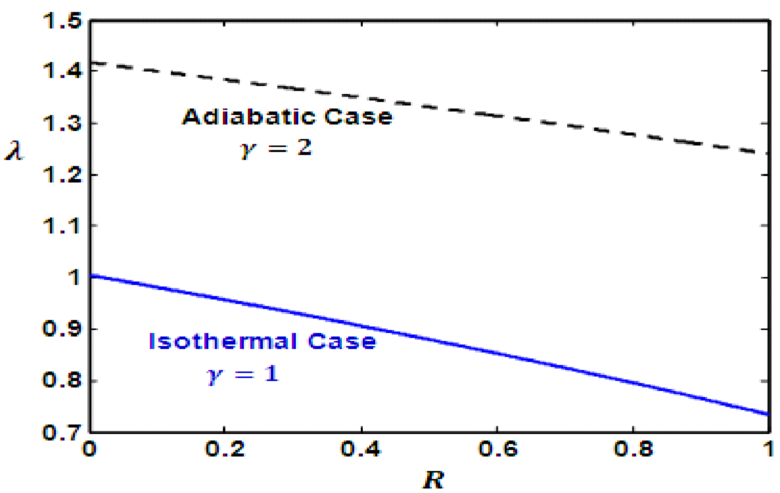

Figure 1: Variation of phase velocity λ against polyrization parametr R for adiabatic case ($\gamma = 2$) and isothermal case ($\gamma = 1$), with $\sigma_d = 0.001$, $\theta_i = 0.06$, $\rho = 0.5$, and $\mu_d = 1$.

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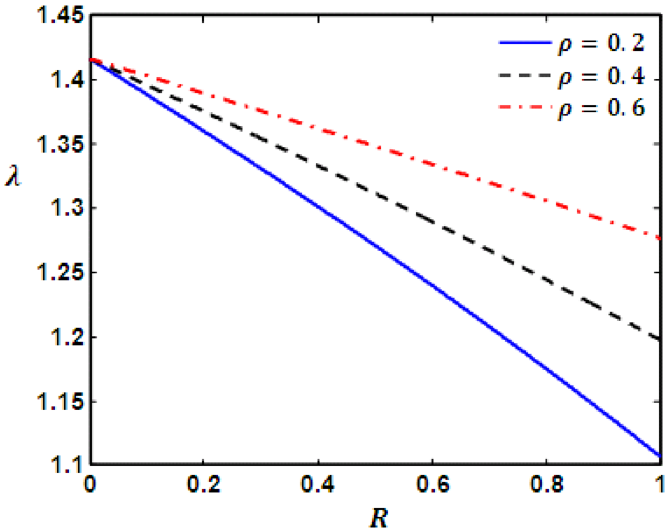

Figure 2: Variation of phase velocity λ against polyrization parametr R for different values of ρ with $\gamma = 2$, $\sigma_d = 0.001$, $\theta_i = 0.06$, and $\mu_d = 1$.

Figure 2 represents the variations of λ with respect to polyrization force parameter R for different values of ρ. It seems that the phase velocity λ decreases with the increase of polarization force (R). For a finite value of R the phase velocity increases with the increase of ρ. Furthermore, it is obvious from figure 2 that for $R = 0$ (i.e., in the absence of polarization effect), the the phase velocity is fixed for a variation in density ratio ρ. This means that the phase velocity independent on ρ in the absence of polarization effect.

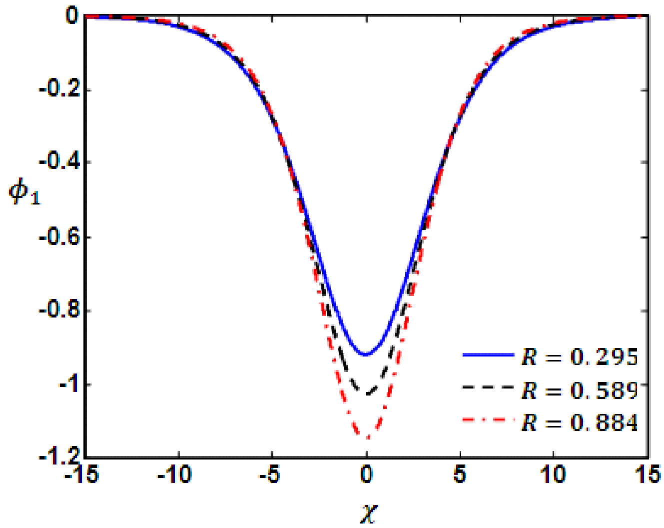

Figure 3: The electrostatic potential profiles ϕ_1 against χ for different values of polyrization parametr R with $\gamma = 2$, $\sigma_d = 0.001$, $\theta_i = 0.06$, $\rho = 0.5$, $\mu_d = 1$, and $V_0 = 1$.

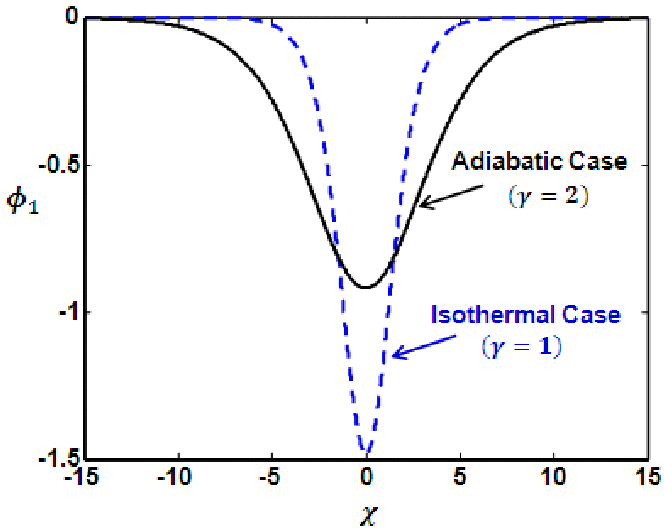

Figure 4: The electrostatic potential profiles ϕ_1 against χ for two different values of γ with $\sigma_d = 0.001$, $\theta_i = 0.06$, $\rho = 0.5$, $\mu_d = 1$, and $V_0 = 1$.

Figure 3 depicts the electrostatic potential profile of DA solitary waves ϕ_1 against χ for different values of polarization parameter R. It can be seen that the solitary structure enlarges as R increases. In the other words, the amplitude of the solitary wave profile increases, whereas the width decreases slightly. Physically, this is because the polarization force causes a modification of the restoring force and thus the solitary wave profile. Figure 4 depicts the effects of adiabaticity of electrons–ions γ on the electrostatic potential of DA solitary waves in the presence of polarization force. It is observed that, in the isothermal case (i.e., $\gamma = 1$), the pulse profile of DA solitary waves becomes taller and narrower, while due to adiabaticity of electrons-ions (i.e., $\gamma = 2$), the pulse profile becomes shorter and wider. In the other words, for adiabatic case, the amplitude of DA solitary waves decreases, but the width decreases.

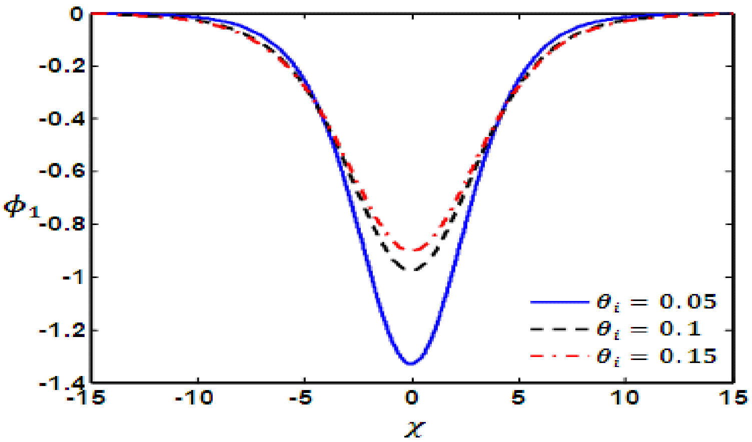

Figure 5: The electrostatic potential profiles ϕ_1 against χ for different values of ion tempreture reaue θ_i with $T_e = 11600K$, $T_i = \theta_i T_e$, $\sigma_d = 0.001$, $\gamma = 2$, $\rho = 0.5$, $Z_d = 2 \times 10^4$, $\mu_d = 1$, and $V_0 = 1$.

The effect of ion temperature (through ion temperature ratio θ_i where electron temperature is kept fixed) on the pulse profile of DA solitary waves in the presence of polarization force is shown in Fig. 5. It is seen that increasing the ion temperature leads to a decrease in the amplitude and width of DA solitary waves. This means that when ion temperature is high, the polarization force will be smaller.

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It is concluded that the properties of the DA solitary waves are modified significantly in the presence of polarization force.

The influences of the polarization force as well as other plasma parameters (i.e., γ, θ_i) on the energy of solitary waves (solitons) are also investigated. The results are shown graphically in the figures 6 and 7. Figure 6 shows the dependence of solitary wave energy E_s on the adiabatic index γ, and the polarization force (vai R). It is observed that the soliton energy increases as R increases for all values of γ (i.e., for both adiabatic and isothermal cases). We can also see that in the isothermal case ($\gamma = 1$), large maximum solitary wave energy is obtained, but in the adiabatic electrons-ions case ($\gamma = 2$), minimum solitary wave energy is obtained. In the figure 7 the solitary wave energy E_s have been plotted against θ_i (where electron temperature is kept fixed) for different values of ρ in the presence of polarization force. This figure shows that the solitary wave energy decreases with θ_i, and increases with ρ.

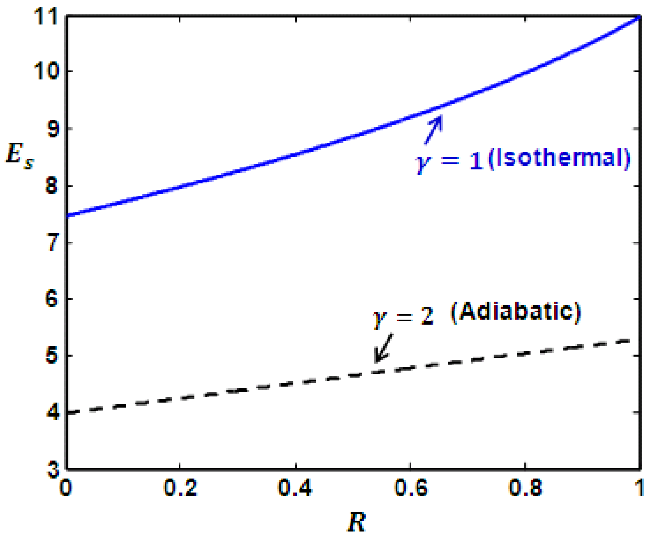

Figure 6: Variation of solitary wave energy E_s against polarization parameter R for two different values of γ with $\theta_i = 0.06$, $\rho = 0.5$, $\sigma_d = 0.001$, $\mu_d = 1$, and $V_0 = 1$.

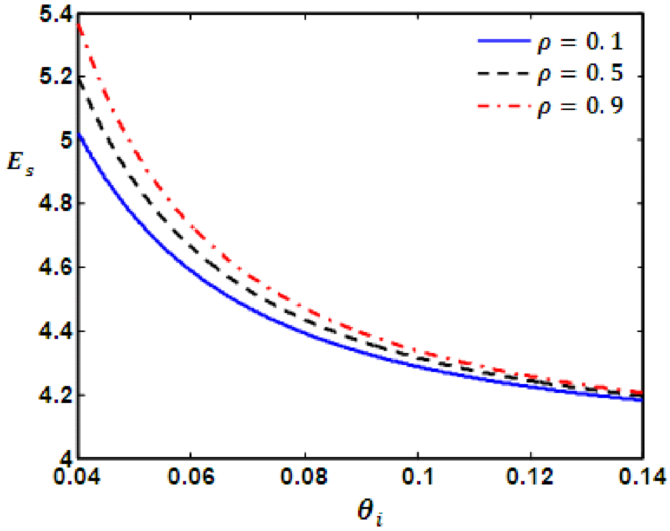

Figure 7: Variation of solitary wave energy E_s against θ_i for different values of polyrization parametr R with $\sigma_d = 0.001$, $\gamma = 2$, $Z_d = 2 \times 10^4$, $T_{e0} = 1.16 \times 10^4 K$, $\mu_d = 1$, and and $V_0 = 1$.

7. Conclusion

In this paper, the modifications arising in the nonlinear propagation of two dimensional DA solitary waves due to the presence of polarization force acting on the dust grains are theoretically investigated in a dusty plasma medium containing adiabatic electrons and ions, and negatively charged dust fluid. We have carry out a reductive perturbation technique to obtain the KP equation which governs the behavior of the two-dimensional small amplitude DA solitary waves. It is observed that, only negative potential solitary waves can exist in our medium. The stability analysis is also discussed with respect to the sufficient condition for soliton stability. The effects of polarization force R, ion temperature θ_i, density ratio ρ and adiabaticity of electrons–ions γ on DA solitary waves have been studied . We find that, the phase velocity of DA solitary waves is decreased by the effects of polarization force, but is increased by the effect of adiabaticity of electrons and ions. Due to polarization force effect, the density ratio leads to increases in the phase velocity. The solitary wave potential is significantly modified by polarization force the adiabaticity of electrons and ions, the ion temperature and the ratio of electron density to ion density. It is found that with an increase of the polarization force, the solitary wave amplitude increases, whereas the width decreases. Moreover, the variation of energy E_s of solitary wave (or soliton) with physical parameters is also observed. In the isothermal case, the soliton energy E_s is comparatively larger than that of adiabatic case. Finally, the present results should elucidate the excitation of the nonlinear DA solitary waves in different space and laboratory dusty plasmas.

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