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Dust acoustic shock waves in magnetized dusty plasma

Yashika GHAI, Nimardeep KAUR, Kuldeep SINGH and N S SAINI

Department of Physics, Guru Nanak Dev University, Amritsar-143005, India

E-mail: nssaini@yahoo.com

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Abstract

We have presented a theoretical study of the dust acoustic (DA) shock structures in a magnetized, electron depleted dusty plasma in the presence of two temperature superthermal ions. By deriving a Korteweg–de Vries–Burgers equation and studying its shock solution, we aim to highlight the effects of magnetic field and obliqueness on various properties of the DA shock structures in the presence of kappa-distributed two temperature ion population. The present model is motivated by the observations of Geotail spacecraft in the Earth’s magnetotail and it is seen that the different physical parameters such as superthermality of the cold and hot ions, the cold to hot ion temperature ratio, the magnetic field strength, obliqueness and the dust kinematic viscosity greatly influence the dynamics of the shock structures so formed. The results suggest that the variation of superthermalities of the cold and hot ions have contrasting effects on both positive and negative polarity shock structures. Moreover, it is noted that the presence of the ambient magnetic field affects the dispersive properties of the medium and tends to make the shock structures less wide and more abrupt. The findings of present investigation may be useful in understanding the dynamics of shock waves in dusty plasma environments containing two temperature ions where the electrons are significantly depleted.

Keywords: dusty plasma, KdV–Burgers, superthermal distribution, Earth’s magnetotail

(Some figures may appear in colour only in the online journal)

1. Introduction

A subtle balance between different plasma properties gives rise to the formation of various types of nonlinear waves and structures in plasma. In the presence of weak dispersive effects, if the nonlinear effects are balanced by dissipation in a given medium, shock waves are formed. Solar flares, black holes, turbulence, supernovae, distribution of high energy particles and the effects of magnetic field are some important sources for occurrence of the shock waves. The nonlinear effects are associated with the faster propagation of higher amplitude parts than the lower amplitude parts of the wave whereas dissipative effects may arise because of fluid viscosity, inter-particle collision or may be due to Landau damping phenomena. Shock waves are assumed to give rise to cosmic rays by accelerating charged particles in the Universe and hence, understanding the shock structures gives crucial insights into various astrophysical phenomena. In the past several decades, shock structures have been investigated in different types of plasma environments by many authors in the framework of Korteweg–de Vries–Burgers (KdV–B) [1–5], Burgers [6, 7] and modified Burgers equation [8]. Dust being inevitable in most of the astrophysical, space and laboratory plasma environments becomes charged. The charged dust tends to influence the dynamics of waves propagating in these media and forms a dusty plasma [9]. Such charged dust particles are also responsible for giving rise to certain new types of wave modes of low frequency viz. dust acoustic waves (DAWs) [10], dust ion acoustic waves (DIAWs) [11, 12], DA shock waves [13] and dust lattice waves [14] in a plasma. From the pioneer work reported by Rao et al [10], numerous authors have investigated DAWs and associated nonlinear structures in different types of plasma environments. Zhang and Wang investigated the influence of dissipative effects as well as transverse perturbations on DAWs in an unmagnetized plasma containing electrons and two temperature ions all of which follow the Boltzmann distribution [1]. They derived a Kadomtsev Petviashvili (KP)–Burgers equation and obtained a shock solution for DA solitary waves. To study the propagation
properties of dust acoustic nonlinear structures (shocks and solitons), a modified KdV–B equation has also been derived in a homogeneous unmagnetized, collisionless and dissipative dusty plasma containing negatively charged dust grains in the presence of Boltzmann distributed electrons and the ions obeying the vortex-like distribution [3]. Shahmansouri [5] derived a KdV–B equation for the DIAsWs in a magnetized complex plasma consisting of inertial fluid ions, kappa distributed electrons and negatively charged dust grains while considering the dissipation due to dust charge fluctuation effects and further discussed the dynamics of shock waves. In another study, a theoretical investigation of DA shock waves in an unmagnetized dusty plasma containing negatively charged mobile dust fluid, electrons obeying Boltzmann distribution and two temperature ions obeying q-nonextensive and nonthermal distribution was performed [7].

In many laboratory and space dusty plasmas, the charging of massive, micron or sub-micron sized dust particles occur due to the attachment of electrons and ions to the grain surface [11, 15, 16]. The electrons are lighter than ions and have a higher flux to the uncharged surface which leads to negative charging of the dust particles at equilibrium. Such a charging of dust grains due to collection of electrons may sufficiently deplete the background electron population and the plasma is considered to be an electron depleted plasma. Various authors have investigated the dynamics of dust acoustic shock structures in electron depleted dusty plasma environments considering charged particles obeying different types of distributions. Using Sagdeev pseudopotential approach, Shahmansouri and Tribeche [17] studied DA solitary structures and double layers in an electron depleted unmagnetized dusty plasma containing two temperature superthermal ion population. They scrutinized the effect of the superthermal character of ions on the properties of the soliton and double layers and observed that as the superthermality of ions increase, the amplitude of DA solitons increase whereas that of DA double layers decrease. A three-dimensional KP equation has been derived to study the characteristics of propagation of DA solitary waves in an unmagnetized electron depleted dusty plasma in the presence of two temperature superthermal ions [18]. Sahu and Tribeche [19] employed reductive perturbation technique to investigate the properties of cylindrical and spherical DA solitary and shock waves in an unmagnetized electron depleted dusty plasma consisting of ions obeying Tsallis distribution in the framework of KdV–B equation.

Various satellite observations have reported that the charged particles in astrophysical and space environments are far removed from their thermodynamic equilibrium due to their extremely high temperatures and low densities. The distribution functions of such particles are deviated from Maxwellian distributions and follow the Lorentzian distribution functions of such particles are deviated from their extremely high temperatures and low densities. The far removed from their thermodynamic equilibrium due to charged particles in astrophysical and space environments are.

Our aim is to complete the previous studies of various authors and scrutinize the effects of the obliqueness of propagation and the strength of magnetic field on the propagation properties of DA shocks. A number of investigations in the study of DA shock structures have been reported, but the combined effects of magnetic field, obliqueness and the superthermality of charged particles on the characteristics of DA shock waves by deriving KdV–B equation has not been reported so far. We shall derive a KdV–B equation in a magnetized dusty plasma comprising of two temperature cold
and relatively hotter ions obeying kappa-distribution while assuming a sufficient depletion of electrons and highlight the combined effects of the magnetic field strength as well as the superthermality of ions on the characteristic properties of DA shock waves. Our parametric regime is motivated by the Geotail spacecraft observations in the Earth’s magnetotail. It is noteworthy that the existence of slow mode shocks has been asserted by various other observations in this region, which may be responsible for accelerating cosmic waves. Hence, it is of paramount interest to study the dynamics of DAWs and shock structures in this region while considering the presence of external magnetic field.

The manuscript is organized as follows. The fluid model equations used to derive the KdV–B equation are presented in section 2. In section 3, we have presented a detailed derivation of KdV–B equation and its solution. Sections 3.1 and 4 are devoted to the findings and conclusions of the present investigation.

2. The fluid model equations

We consider a magnetized, electron depleted dusty plasma containing two temperature ions obeying kappa distribution such as that in the Earth’s magnetotail. The normalized fluid equations for the present plasma system have been written as follows:

\[
\frac{\partial n_d}{\partial t} + \nabla \cdot (n_d \mathbf{u}_d) = 0, \quad (1)
\]

\[
\frac{\partial \mathbf{u}_d}{\partial t} + (\mathbf{u}_d \cdot \nabla) \mathbf{u}_d = \nabla \phi - \mathbf{u}_d \times \Omega_d + \eta \nabla^2 \mathbf{u}_d, \quad (2)
\]

\[
\nabla^2 \phi = (n_d - n_c - n_h), \quad (3)
\]

where, \(n_d\) is the charged dust grains density which is normalized by their equilibrium number density \(n_{d0}\); \(n_c\) and \(n_h\) depict the number densities of cold and hot ion species which are normalized by \(Z_d n_{d0}\). The equilibrium condition: \(n_c + n_h = Z_d n_{d0}\) becomes \(\mu + \nu = 1\), where \(\mu = \frac{n_c}{Z_d n_{d0}}\) and \(\nu = \frac{n_h}{Z_d n_{d0}}\). \(\mathbf{u}_d = u_x \mathbf{i} + v_y \mathbf{j} + w_z \mathbf{k}\) where, \(u, v\) and \(w\) represent the velocities of dust grains in the \(x, y\) and \(z\) directions that are normalized by the dust acoustic speed \(C_d = (Z_d T_c/m_d)^{1/2}\). \(\phi\) is the electrostatic potential normalized by \(T_c/e\). The spatial coordinates are normalized by the dust Debye length \(\lambda_{dD} = (T_c/e^2 Z_d n_{d0})^{1/2}\) whereas temporal coordinate by the inverse of the dust plasma frequency \(\omega_{pd}^{-1} = \left(4\pi e^2 Z_d n_{d0}/m_d\right)^{-1/2}\).

The dust kinematic viscosity \(\eta\) arising due to dust–dust collisions is normalized by \(\eta_{dD} \approx \eta_0 \omega_{pd}^{-1}\). The ambient magnetic field is taken along \(z\)-direction i.e., \(\mathbf{B} = B_0 \mathbf{k}\) and \(\Omega_d = \omega_{cd}\), where \(\omega_{cd} = Z_d e B / m_d\) is dust cyclotron frequency. The expressions for the densities of cold and hot ion species are obtained by integrating their kappa-type distribution functions in the presence of an electrostatic potential \(\phi\), and are represented in normalized form as

\[
\begin{align*}
n_c = \mu \left(1 + \frac{\phi}{\kappa_c - 3/2}\right)^{-\kappa_c + 1/2}, \\
n_h = \nu \left(1 + \frac{\theta \phi}{\kappa_h - 3/2}\right)^{-\kappa_h + 1/2},
\end{align*}
\]

where, \(\theta = T_c/T_h\) is the cold to hot ion temperature ratio. The parameters \(\kappa_c\) and \(\kappa_h\) are significant in the present case and hold a physical meaning when \(\kappa > 3/2\), where \(s = c, h\) for cold and hot ions respectively. In the limit \(\kappa_c, \kappa_h \to \infty\), equation (4) agrees with the Maxwellian case expressions. We assume small disturbance of the electrostatic potential (i.e., \(\phi \ll 1\)). In this regime, we expand the densities of cold and hot ions given in equation (4) using Taylor’s expansion and substitute in equation (3) to obtain

\[
\nabla^2 \phi = n_d - 1 + C_1 \phi - C_2 \phi^2 + C_3 \phi^3, \quad (5)
\]

where,

\[
\begin{align*}
C_1 &= \frac{\left(\kappa_c - \frac{1}{2}\right)}{(\kappa_c - \frac{3}{2})^{1/2}} + \frac{\theta \left(\kappa_h - \frac{1}{2}\right)}{(\kappa_h - \frac{3}{2})^{1/2}}, \\
C_2 &= \frac{\left(\kappa_c^2 - \frac{1}{2}\right)}{(\kappa_c - \frac{3}{2})^{3/2}} + \frac{\theta^2 \left(\kappa_h^2 - \frac{1}{2}\right)}{(\kappa_h - \frac{3}{2})^{3/2}}, \\
C_3 &= \frac{\left(\kappa_c^2 - \frac{1}{2}\right)}{(\kappa_c - \frac{3}{2})^{3/2}} + \frac{\theta \left(\kappa_c^2 - \frac{1}{2}\right) \left(\kappa_h + \frac{3}{2}\right)}{(\kappa_h - \frac{3}{2})^{3/2}}.
\end{align*}
\]

3. The fluid model equations

In order to derive KdV–B equation that governs the dynamics of DA shock waves in a magnetized electron depleted dusty plasma, we use the reductive perturbation method [33] and introduce the stretched spatial and temporal coordinates in following form:

\[
\xi = \epsilon^{1/2}(l_x x + l_y y + l_z z - V_0 t), \quad \tau = \epsilon^{3/2} t, \quad (6)
\]

where \(\epsilon\) identifies nonlinearity in system and is a small parameter such that \(\epsilon \ll 1\). \(l_x, l_y, l_z\) signify the direction cosines of wave vector \(k\) along \(x, y\) and \(z\)-axis and \(l_x^2 + l_y^2 + l_z^2 = 1\). \(V_0\) represents the DA phase speed normalized by dust acoustic speed \(C_d\). For the case of weak damping, the dust kinematic viscosity that arises due to dust–dust collisions can be considered small but finite. Hence, we assume that

\[
\eta \approx \epsilon^{1/2} \eta_0, \quad (7)
\]

where \(\eta_0\) is a parameter having finite value. The dependent physical quantities \(n_d, u, v, w\) and \(\phi\) are expanded about their
equilibrium values in a power series given as:

\[
\begin{align*}
n_n &= 1 + \epsilon n_{d1} + \epsilon^2 n_{d2} + ..., \\
u &= \epsilon^3/2 u_1 + \epsilon^2 u_2 + ..., \\
v &= \epsilon^3/2 v_1 + \epsilon^2 v_2 + ..., \\
w &= \epsilon w_1 + \epsilon^2 w_2 + ..., \\
\phi &= \epsilon \phi_1 + \epsilon^2 \phi_2 + ....
\end{align*}
\]  

(8)

The power of \( \epsilon \) signifies the magnitude of perturbation of that physical quantity. Higher power of \( \epsilon \) denotes lower magnitude of perturbation. If the order of perturbation in nonlinearity is same as dissipation in a given medium, then the nonlinear effects get balanced by the dissipative effects, thus giving rise to shock waves. The dissipative effects arise due to kinematic viscosity of dust particles in a given plasma medium. The space and time are stretched as given by equation (6) where \( \xi \) is the space-like co-ordinate and \( \tau \) is the time-like co-ordinate. The stretching in kinematic viscosity is given by equation (7). The perturbations in other physical quantities such as density, velocity and potential etc., have been presented by equation (8). Since, the Lorentz force acts only in the direction perpendicular to the ambient magnetic field (z-direction in the present case), the order of perturbation in \( v_z \) and \( v_y \) is taken to be lower than that in \( v_x \). By substituting equations (6)–(8) in equations (1)–(3) and equation (5) while equating various powers of \( \epsilon \), the lowest order of \( \epsilon \) gives

\[
\begin{align*}
n_{d1} &= \frac{-1^2 \phi_1}{V_0^2}, \\
w_1 &= \frac{l_x \phi_1}{V_0}, \\
v_0 &= \frac{l_x}{\sqrt{C_1}}.
\end{align*}
\]  

(9) (10) (11)

The \( x \) and \( y \)-components of the momentum equation at lowest order of \( \epsilon \) reduce to

\[
\begin{align*}
u_1 &= \frac{l_x}{\Omega_d} \frac{\partial \phi_1}{\partial \xi}, \\
v_1 &= \frac{l_x}{\Omega_d} \frac{\partial \phi_1}{\partial \zeta}.
\end{align*}
\]  

(12)

At the next higher order of \( \epsilon \), we retrieve the following set of equations:

\[
\frac{\partial n_{d1}}{\partial \tau} - V_0 \frac{\partial n_{d2}}{\partial \xi} + \frac{\partial}{\partial \xi} (l_x u_2 + l_x v_2 + l_x w_2 + l_x n_{d1} w_1) = 0,
\]  

(13)

\[
\frac{\partial w_1}{\partial \tau} - V_0 \frac{\partial w_2}{\partial \xi} + l_x w_1 \frac{\partial \phi_1}{\partial \xi} = l_x \frac{\partial \phi_2}{\partial \xi} + \eta_0 \frac{\partial^2 w_1}{\partial \xi^2},
\]  

(14)

\[
\frac{\partial^2 \phi_1}{\partial \xi^2} = n_{d2} + C_1 \phi_2 - C_2 \phi_2^2,
\]  

(15)

\[
u_2 = -\frac{V_0 l_x}{\Omega_d} \frac{\partial \phi_1}{\partial \xi},
\]  

(16)

\[
v_2 = -\frac{V_0 l_x}{\Omega_d} \frac{\partial \phi_1}{\partial \zeta}.
\]  

(17)

By rearranging equations (13)–(17) to eliminate the first order perturbed quantities using equations (9)–(12), we obtain the following KdV–B equation:

\[
\frac{\partial \phi_1}{\partial \tau} + A \frac{\partial \phi_1}{\partial \xi} + B \frac{\partial^3 \phi_1}{\partial \xi^3} = C \frac{\partial^2 \phi_1}{\partial \xi^2}.
\]  

(18)

Equation (18) steers the nonlinear evolution of obliquely propagating DA shock waves in an electron depleted, magnetized dust plasma comprising of two temperature superthermal ions, where the nonlinear, dispersion and dissipation coefficients \( A, B \) and \( C \) are respectively given by

\[
A = \left( \frac{V_0^2}{l_x^2} C_2 - \frac{3 l_x^2}{2 V_0} \right).
\]  

(19)

\[
B = \left( 1 + \frac{1 - l_x^2}{\Omega_d^2} \right) \frac{V_0^2}{2 l_x^2},
\]  

(20)

\[
C = \frac{\eta_0}{2}.
\]  

(21)

It is noted that the obliqueness of propagation (\( l_x \)), the strength of magnetic field (\( \Omega_d \)) and the superthermality of ions (\( \eta_0, \eta_1 \)) affect the nonlinearity coefficient \( A \) and dispersion coefficient \( B \). However, the dissipative effects via dissipation coefficient \( C \) are dependent on the dust kinematic viscosity \( \eta_0 \) only. The value of dispersion coefficient \( B \) is always positive and the magnitude of nonlinear coefficient \( A \) for given set of parameters decides the polarity of shocks structures so formed.

### 3.1. Analytical solution of the KdV–B equation

To investigate the shock-like analytical solution of KdV–B equation (18), we shall use the tanh-method [34] and consider a frame of reference that advances with shock speed. The space-like (\( \xi \)) and time-like (\( \tau \)) coordinates in such frame are expressed as \( \zeta = \alpha (\xi - V \tau) \) and \( \tau = \tau \), where \( V \) is the shock speed and \( \alpha^{-1} \) indicates the extent of shock structures. After transforming to new variables, equation (18) becomes

\[
-V \frac{d \phi_1}{d \zeta} + A \frac{d \phi_1}{d \xi} + B \frac{d^3 \phi_1}{d \xi^3} = C \frac{d^2 \phi_1}{d \xi^2}.
\]  

(22)

Integrating equation (22) once and using appropriate boundary conditions, \( \phi_1 \to 0 \), \( \frac{d \phi_1}{d \zeta} \to 0 \) and \( \frac{d \phi_1}{d \xi} \to 0 \) for \( \zeta \to \infty \), we obtain

\[
-V \phi_1 + \frac{A}{2} (\phi_1)^2 + B \frac{d^2 \phi_1}{d \xi^2} = C \frac{d \phi_1}{d \zeta}.
\]  

(23)

Using hyperbolic tangent (tanh) method [8, 34], we obtain the shock solution of KdV–B equation as

\[
\phi_1(\xi, \tau) = \phi_{\text{max}} \left( 1 - \frac{1}{4} \left[ 1 + \tanh \left( \frac{\zeta - V \tau}{W} \right) \right]^2 \right),
\]  

(24)

where \( \phi_{\text{max}} = 12C^2/25AB \) signifies the peak amplitude of shocks, \( W = \alpha^{-1} \) is 10B/C and \( V = 6C^2/25B \) represent the width and speed of shock structures respectively.

### 4. Results and discussion

In the framework of KdV–B equation, we have studied the properties of dust acoustic shock waves in an electron
depleted magnetized dusty plasma environment containing cold and hot ions obeying Kappa-distribution. The positive (negative) values of the coefficient of nonlinear term of KdV–B equation (A) represent the formation of positive (negative) potential shock structures for the given set of physical parameters. Using expression of the nonlinear coefficient A, we obtain the critical value of the ratio of the cold ions to the dust number density $\mu$ above (below) which negative (positive) potential shock structures are formed. Figure 1 shows that the critical value of $\mu$ decreases (increases) with an increase in the superthermality of hot (cold) ions i.e, decrease in $\kappa_h$ and $\kappa_c$. In other words, the positive potential shocks are formed at lower values of cold ions to dust number density ratio if there is a higher number of superthermal hot ions present. Further, the solution of KdV–B equation shows explicit dependence upon various physical parameters such as superthermality of hot and cold ions (via $\kappa_h$ and $\kappa_c$), cold to hot ion temperature ratio (via $\theta$), strength of the magnetic field (via $\Omega_d$), obliqueness (via $\ell_z$) and kinematic viscosity (via $\eta_d$). Hence, it is important to investigate the properties of the shock solution with variations of these physical parameters. Figures 2–9 depict the shock profile governed by KdV–B equation with variation of different physical parameters. Figures 2 and 3 depict the variation of positive and negative potential shock profiles with superthermality of the hot ions ($\kappa_h$) and it is inferred that with an increase in superthermality of the hot ions i.e, with decrease in $\kappa_h$, the peak amplitude of positive potential shock structures increases whereas that of the negative potential shock structures decreases. The results are contrasted to that of Shahmansouri and Tribeche [17] who reported that the amplitude of the DA double layers (type of shock waves) decrease with increase in superthermality of the hot ions in the absence of magnetic field. Figures 4 and 5 depict that the peak amplitude of the positive potential shocks decreases and that of the negative potential shocks increases with an increase in superthermality of the cold ions, i.e., decrease in $\kappa_c$. From figures 6 and 7, we observe the effect of variation of dust kinematic viscosity as well as the ratio of cold to hot ion temperature on the properties of shock structures. It is seen that the peak amplitude of the positive (negative) potential shocks decreases (increases) with decrease in cold to hot ions temperature ratio. In other words, if the temperature of hot ions becomes substantially greater than that of the colder ions, the positive potential shocks of lower amplitude whereas negative potential shocks of higher amplitude are formed. The dust kinematic viscosity also
influences the amplitude as well as the width of the shock structures as observed from figures 6 and 7. A more viscous dust fluid supports both positive and negative potential shocks of higher amplitude.

The magnetic field exerts a force on a moving charged particle called the Lorentz force that acts in a direction perpendicular to both the direction of the magnetic field and to the direction in which the charged particle is moving and the particle’s trajectory shapes into a helix. In the present investigation, the effect of magnetic field on the properties of DA shock waves comes into play via dispersion coefficient $B$ in terms of normalized dust cyclotron frequency $\Omega_d$. The influence of variation of magnetic field strength as well as obliqueness of DAWs with the direction of the ambient magnetic field on the properties of shock structures is presented in figures 8 and 9. Both positive and negative potential shock structures tend to possess larger peak amplitudes for high magnetic field strength and less obliqueness of DAWs with the direction of the magnetic field. However, the width of shock structures decreases with an increase in the magnetic field strength as shown in figure 10. The physical explanation is that the strength of magnetic field effects the dispersive properties of plasma by making it difficult to disperse the plasma in a direction perpendicular to the magnetic field. It is also inferred that more obliquely propagating DAWs give rise to wider shocks. The variation of width of shock structures with various physical parameters is depicted in figure 11. We find that the width of shock structures decreases with increase in superthermality of the hot ions and decrease in superthermality of the cold ions. The shock

**Figure 4.** Variation of positive potential shock profile governed by KdV Burgers equation with different values of superthermality of cold ions ($\kappa_c$) with parameters $\mu = 0.2$, $\theta = 0.1$, $\eta_0 = 0.8$, $\kappa_0 = 3.25$ and $l_c = 0.85$, $\Omega_d = 0.2$. Red (solid) curve for $\kappa_c = 4$, blue (dashed) curve for: $\kappa_c = 4.25$ and black (dotted) curve for: $\kappa_c = 4.5$.

**Figure 5.** Variation of negative potential shock profile governed by KdV Burgers equation with different values of superthermality of cold ions ($\kappa_c$) with parameters $\mu = 0.26$, $\theta = 0.1$, $\eta_0 = 0.8$, $\kappa_0 = 3.25$ and $l_c = 0.85$, $\Omega_d = 0.2$. Red (solid) curve for $\kappa_c = 4$, blue (dashed) curve for: $\kappa_c = 4.25$ and black (dotted) curve for: $\kappa_c = 4.5$.

**Figure 6.** Variation of positive potential shock profile governed by KdV Burgers equation with different values of cold to hot ions temperature ratio ($\theta$) and dust kinematic viscosity $\eta_0$ with parameters $\mu = 0.17$, $\kappa_c = 4.25$, $\kappa_0 = 3.75$ and $l_c = 0.85$, $\Omega_d = 0.2$. Red (solid) curve for $\theta = 0.1$, $\eta_0 = 0.8$, blue (dashed) curve for: $\theta = 0.095$, $\eta_0 = 0.8$ and black (dotted) curve for: $\theta = 0.1$, $\eta_0 = 0.9$.

**Figure 7.** Variation of negative potential shock profile governed by KdV Burgers equation with different values of cold to hot ions temperature ratio ($\theta$) and dust kinematic viscosity $\eta_0$ with parameters $\mu = 0.17$, $\kappa_c = 4.25$, $\kappa_0 = 3.75$ and $l_c = 0.85$, $\Omega_d = 0.2$. Red (solid) curve for $\theta = 0.1$, $\eta_0 = 0.8$, blue (dashed) curve for: $\theta = 0.095$, $\eta_0 = 0.8$ and black (dotted) curve for: $\theta = 0.1$, $\eta_0 = 0.9$. 

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structures formed are wider for higher values of dust kinematic viscosity $\eta_0$.

5. Conclusions

We have presented an investigation of dust acoustic shock waves in a magnetized dusty plasma containing two temperature superthermal cold and hot ions that obey kappa-distribution while considering sufficient depletion of background electrons. By employing the reductive perturbation technique, we have derived a KdV–B equation to highlight the effects of superthermality of the ions, magnetic field and obliqueness on characteristics of the DA shocks in the present case. It is remarked that both positive and negative polarity shock structures may exist in such plasma environments. It is noteworthy that the presence of an ambient magnetic field influences the dispersive properties of the medium as the higher magnetic field values make the plasma system less dispersive and hence, the shock structures formed are narrower for high magnetic field strength. On the other hand, the peak amplitude of shock waves increases with an increase in the value of magnetic field strength. A contrasting behavior is observed for obliqueness and it is noted that the increase in obliqueness of the wave to the direction of magnetic field makes the shock structures less abrupt and more wide. The findings of the present investigation may give crucial physical insights into the formation and properties of DA shock structures in magnetized dusty plasma environments containing two temperature superthermal ions such as that reported by the Geotail spacecraft in the Earth’s magnetotail.
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ORCID iDs

Kuldeep SINGH https://orcid.org/0000-0003-3526-8085

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