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Effect of positrons and nonthermal electrons on large amplitude ion-acoustic soliton in unmagnetized plasmas

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ABSTRACT
The large amplitude of an ion-acoustic soliton in a plasma consisting of ions, positrons and nonthermal electrons is considered the pseudo-potential method (SPM). An energy integral equation for the system has been derived with the help of SPM. It is found that compressive and rarefactive solitons exist in the plasma system for selected set of plasma parameters. It is also found that the effect of nonthermal parameters positron concentration ionic temperature ratio positron temperature ratio and Mach number (M) on the characteristics of the large amplitude ion-acoustic compressive and rarefactive solitons are discussed in detail. The amplitude of the ion-acoustic compressive/rarefactive soliton decreases with increase in nonthermal parameters and ionic temperature ratio however an increase in positron temperature ratio and Mach number (M) increases the amplitude of the on-acoustic compressive/rarefactive solitons. The present investigation may be helpful in space and astrophysical plasma system where positrons and nonthermal electrons are present.

Key words: Ion-acoustic solitons, Pseudo potential method, Positrons, Nonthermal electrons

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INTRODUCTION

The study of the linear and nonlinear wave phenomena in electron-positron-ion plasma has been a subject of significant importance for researchers. The pair production generate naturally electron-positron plasmas such as pulsar magnetosphere [1,3], in early universe [2,4], in nucleon stars, active galactic nuclei [6] or and star atmosphere [8]. Several authors [7,11,13,21] studied the ion-acoustic waves in electron-positron-ion (EPI) plasmas.

Crains et al. [10] observed the effect of nonthermal electron distribution on solitary waves. Ion-acoustic solitary waves in plasma with negative ion and nonthermal electrons have been studied by Sabry et al. [14]. Mishra and jain [17] studied the linear and nonlinear ion-acoustic waves in plasma with nonthermal electrons. Chawla et al. [21] investigated the effect of nonthermal electrons on ion-acoustic solitary waves in EPI plasmas.

Many researchers using the Sagdeev potential approach for study large amplitude ion-acoustic solitons/double layers with superthermal electrons [20], EPI [12,13,18], negative ion[9,16], two distinct groups of hot electrons [5,13,19], charge dust grains [15,19] in plasmas.

Bharuthram and Shukla [5] investigated the effect of two distinct groups of hot electrons on large amplitude ion-acoustic double layers in plasmas. Effects of nonthermal electrons and negative ions on amplitude of large amplitude ion-acoustic soliton in plasma with using the Sagdeev potential method is presented by Ghosh et al. [16]. They found that on increasing nonthermal parameters the amplitude of the large amplitude ion-acoustic solitary wave decreases.

In the present paper, my goal is to study the effects of nonthermal electrons and positrons on the large amplitude of ion-acoustic soliton in plasmas. To the best of my knowledge the large amplitude of ion-acoustic solitons in plasmas with positrons and nonthermal electrons has not been studied so far.

BASIC EQUATION

We consider a collisionless plasma consisting of ions, positrons and nonthermal electrons. The dynamics of the plasma is given by the continuity equation, equation of motion and Poisson's equation:

$$\partial_t n + \partial_x (nv) = 0 \tag{1}$$

$$\partial_t v + v\partial_x v = -\partial_x \phi - \sigma n \partial_x n \tag{2}$$

$$\partial_x^2 \phi = n_e - \alpha n_p - (1-\alpha)n \tag{3}$$

$$n_e = \left(1 - \beta\phi + \beta\phi^2\right)e^{\phi} \tag{4}$$

$$n_p = \alpha e^{-\gamma\phi} \tag{5}$$

$$\alpha = \frac{n_{p0}}{n_{e0}},\ \sigma = \frac{T_i}{T_e},\ \gamma = \frac{T_e}{T_p},\ C_s = \sqrt{\frac{T_e}{m}},\ \omega_{pi}^{-1} = \sqrt{\frac{m}{4\pi n_0 e^2}},\ \phi = \frac{T_e}{e} \text{ and } \lambda_D = \sqrt{\frac{T_e}{4\pi n_0 e^2}}$$

Here n is the density of the ion, v is the fluid velocity of the ion which is normalized by ion-acoustic speed C_s and ϕ is the normalized electrostatic wave potential. The space variable (x) and time variable (t) have been normalized by Debye length (λ_D) and inverse of the ion plasma frequency in the mixture ω_{pi}^{-1} respectively. Here $\beta = 4\rho/(1+\rho)$ where ρ is the electron nonthermal parameter which determines the ratio of fast energetic and thermal electrons. Here positron concentration (α), ionic temperature ratio (σ) and positron temperature ratio (γ).

STATIONARY SOLUTION

Let us find out the Sagdeev pseudopotential from basic equations (1) – (3) with introduce the usual transformation

$$\eta = x - Mt \tag{6}$$

where M is the Mach number of soliton.

Using the equation (6) in Eqs. (1) – (3) with the help of Eqs. (4) and (5), the fluid equations be written as

$$-M\partial_\eta n + \partial_\eta (nv) = 0 \tag{7}$$

$$-M\partial_\eta v + v\partial_\eta v = -\partial_\eta \phi - \sigma n \partial_\eta n \tag{8}$$

$$\partial_\eta^2 \phi = n_e - \alpha n_p - (1-\alpha)n \tag{9}$$

Integrating Eqs. (7) - (9) and using appropriate boundary conditions for the unperturbed plasma at $|\eta| = \infty,$ n = 1, v = 0, $\phi(\eta) = 0$ and $d_\eta \phi = 0.$

Find the quadratic equations

$$\sigma n^4 - (M^2 + \sigma - 2\phi)n^2 + M^2 = 0 \tag{10}$$

From equation (10) the ion density (n) is given by

$$n = \frac{\sqrt{2}M}{\left[\left(M^2 + \sigma - 2\phi\right) + \left\{\left(M^2 + \sigma - 2\phi\right)^2 - 4\sigma M^2\right\}^{1/2}\right]^{1/2}} \tag{11}$$

Integrating equation (9) with respect to η with inserting the Eqs. (4), (5) and (11) and multiplying both sides by $d_\eta \phi,$ we obtain

$$\frac{1}{2}\left(d_\eta \phi\right)^2 + V(\phi) = 0 \tag{12}$$

where $V(\phi)$ is the Sagdeev potential which is given by

$$V(\phi) = (1+3\beta) - \left[1+3\beta(1-\phi)+\beta\phi^2\right]e^{\phi} + \frac{\alpha}{\gamma}\left(1-e^{-\gamma\phi}\right)$$
$$-\frac{M(1-\alpha)}{\sqrt{2}}\left[\sqrt{\left(M^2+\sigma-2\phi\right)+\sqrt{\left((M^2+\sigma-2\phi)^2-4\sigma M^2\right)}} + \frac{4\sigma M^2}{3\left[\left(M^2+\sigma-2\phi\right)+\sqrt{\left((M^2+\sigma-2\phi)^2-4\sigma M^2\right)}\right]^{3/2}}\right]$$
$$+(1-\alpha)\left(M^2+\frac{\sigma}{3}\right) \tag{13}$$

For the existence of large amplitude Solitons, the Sagdeev potential must satisfy the following conditions

$$V(\phi)=0, \text{ and } d_\phi V(\phi)=0, \text{ at } \phi=0 \tag{14}$$

$$V(\phi)\Big|_{\phi=\phi_m}=0, \text{ and } d_\phi V(\phi)\Big|_{\phi=\phi_m} <(>)0 \text{ for } \phi_m <(>)0 \tag{15}$$

$$V(\phi)<0 \text{ for } 0<|\phi|<|\phi_m|, \tag{16}$$

Here ϕ_m, represents the maximum value of potential.

$$(1+3\beta) - \left[1+3\beta(1-\phi_m)+\beta\phi_m^2\right]e^{\phi_m} + \frac{\alpha}{\gamma}\left(1-e^{-\gamma\phi_m}\right)$$
$$-\frac{M(1-\alpha)}{\sqrt{2}}\left[\begin{array}{l}\sqrt{\left(M^2+\sigma-2\phi_m\right)+\sqrt{\left((M^2+\sigma-2\phi_m)^2-4\sigma M^2\right)}} \\ + \dfrac{4\sigma M^2}{3\left[\left(M^2+\sigma-2\phi_m\right)+\sqrt{\left((M^2+\sigma-2\phi_m)^2-4\sigma M^2\right)}\right]^{3/2}}\end{array}\right] \tag{17}$$
$$+(1-\alpha)\left(M^2+\frac{\sigma}{3}\right)<0$$

……. for $-\phi_m$ ……….. and …>0 …….. for $+\phi_m$

NUMERICAL ANALYSIS

Sagdeev potential (Eq. (13)) is dependent various plasma parameters e.g. nonthermal parameters $(\beta),$ positron concentration $(\alpha),$ ionic temperature ratio $(\sigma),$ positron temperature ratio (γ) and Mach number (M).

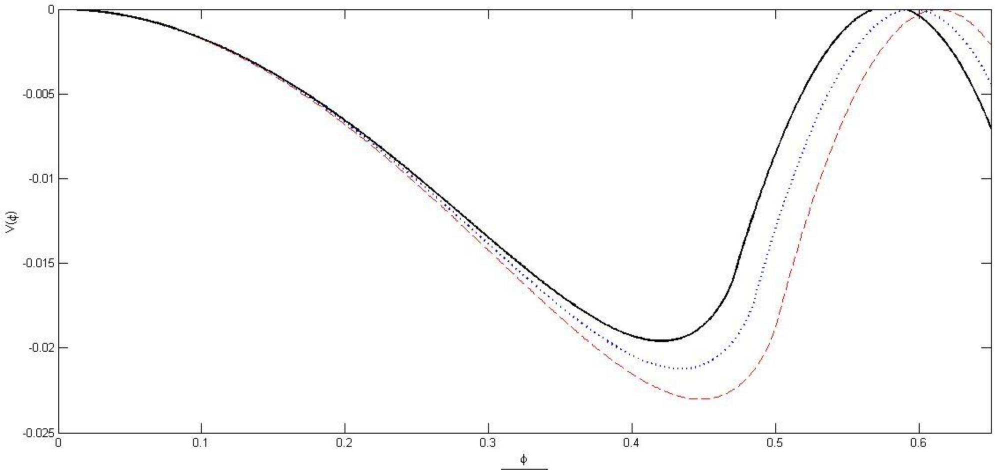

Fig. (1) Variation of the Sagdeev potential $V(\phi)$ with potential ϕ of the compressive ion-acoustic solitons for σ = 0.001, β = 0.001, α = 0.001 and γ = 0.001 having different values of M = 1.30 (red color dashed line), 1.31 (blue color dotted line) and 1.32 (black color solid line).

Figure 1 shows that the variation of the Sagdeev potential (SP) $V(\phi)$ with potential ϕ for different values of Mach number (M) and other plasma parameters are fixed. From figure it is clear that increasing values of M causes increases in amplitude as well as well depth of the Sagdeev potential of the ion-acoustic compressive soliton.

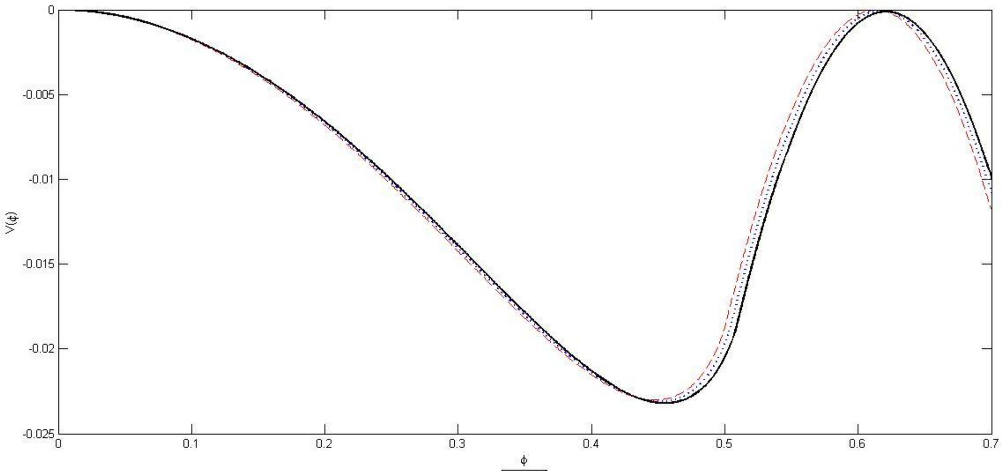

Fig. (2) Variation of the Sagdeev potential $V(\phi)$ with potential ϕ of the compressive ion-acoustic solitons at different values of β = 0.001 (red color dashed line), 0.01 (blue color dotted line) and 0.03 (black color solid line) with fixed value of M = 1.3 and others are the same as in Fig. (1).

In figure 2 display the variation of the Sagdeev potential (SP) $V(\phi)$ versus potential ϕ for various values of nonthermal parameter (β) and for fixed values of all other plasma parameters is mentioned. It is clear from the figure that increasing the values of β results decreases in both amplitude and well depth of the SP of the ion-acoustic compressive soliton.

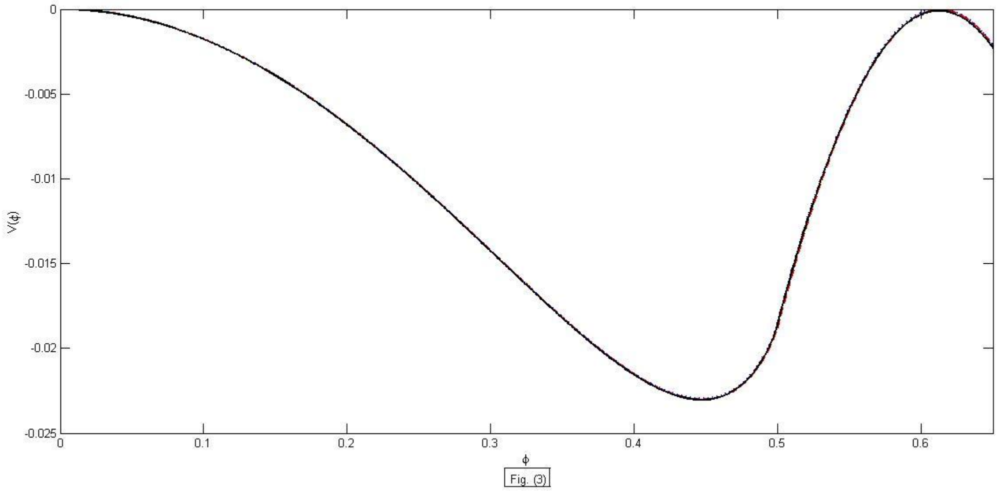

Fig. (3) Variation of the Sagdeev potential $V(\phi)$ with potential ϕ of the compressive ion-acoustic solitons at different values of σ = 0.001 (red color dashed line), 0.003 (blue color dotted line) and 0.006 (black color solid line) with fixed value of M = 1.3 and others are the same as in Fig. (1).

Figure 3 examined the effect of ionic temperature σ by plotting $V(\phi)$ versus ϕ. Increasing values of σ causes reduction in amplitude as well as well depth of the SP of the ion-acoustic compressive soliton.

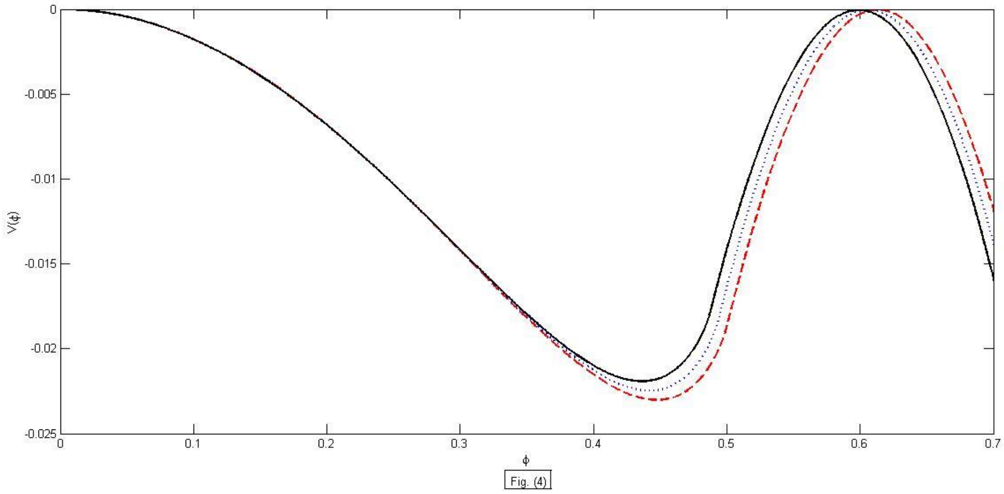

Fig. (4) Variation of the Sagdeev potential $V(\phi)$ with potential ϕ of the compressive ion-acoustic solitons at different values of α = 0.001 (red color dashed line), 0.006 (blue color dotted line) and 0.009 (black color solid line) with fixed value of M = 1.3 and others are the same as in Fig. (1).

In figure 4 depicts the variation $V(\phi)$ versus ϕ for different values of positron concentration α. It is shows that increasing the α leads reduce the amplitude and well depth of the SP of the ion-acoustic compressive soliton.

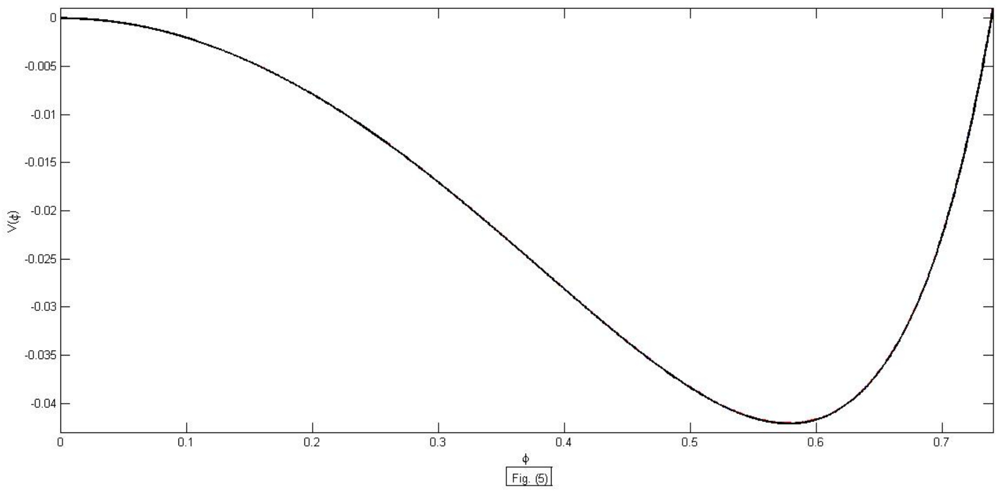

Fig. (5) Variation of the Sagdeev potential $V(\phi)$ with potential ϕ of the compressive ion-acoustic solitons at different values of α = 0.001 (red color dashed line), 0.006 (blue color dotted line) and 0.009 (black color solid line) with fixed value of M = 1.3 and others are the same as in Fig. (1).

In figure 5 the SP $V(\phi)$ against potential ϕ for different values of positron temperature ratio γ. It is found that increasing values of γ results increases in both amplitude and well depth of the SP of the ion-acoustic compressive soliton.

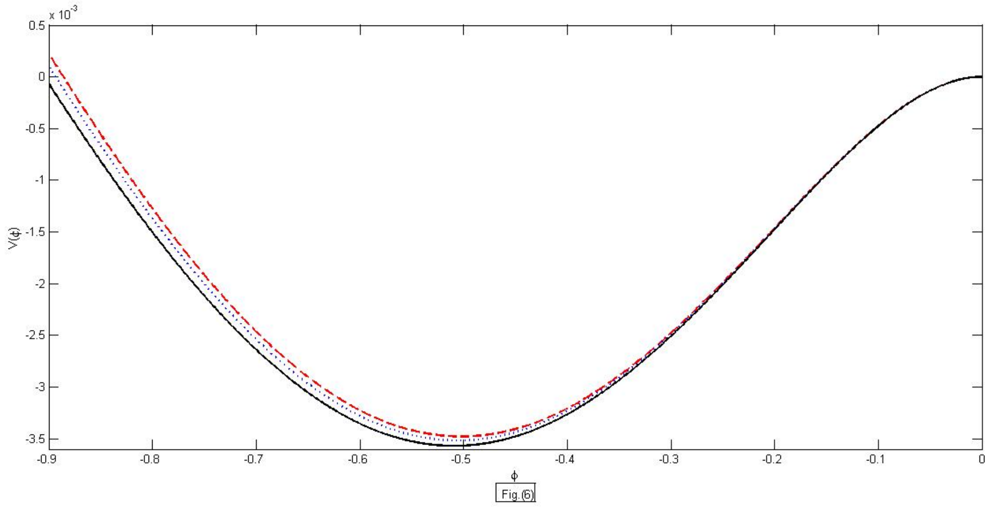

Fig. (6) Variation of the Sagdeev potential $V(\phi)$ with potential ϕ of the rarefactive ion-acoustic solitons at different values of γ = 0.01 (red color dashed line), 0.04 (blue color dotted line) and 0.08 (black color solid line) and with fixed value of σ = 0.1, β = 0.65, α = 0.01 and M = 2.1.

A variation in the SP $V(\phi)$ against potential ϕ for different values of positron temperature ratio γ has been plotted in figure 6. It can be easily seen that by increasing values of γ, the amplitude as well as well depth of the SP of the ion-acoustic rarefactive soliton increases.

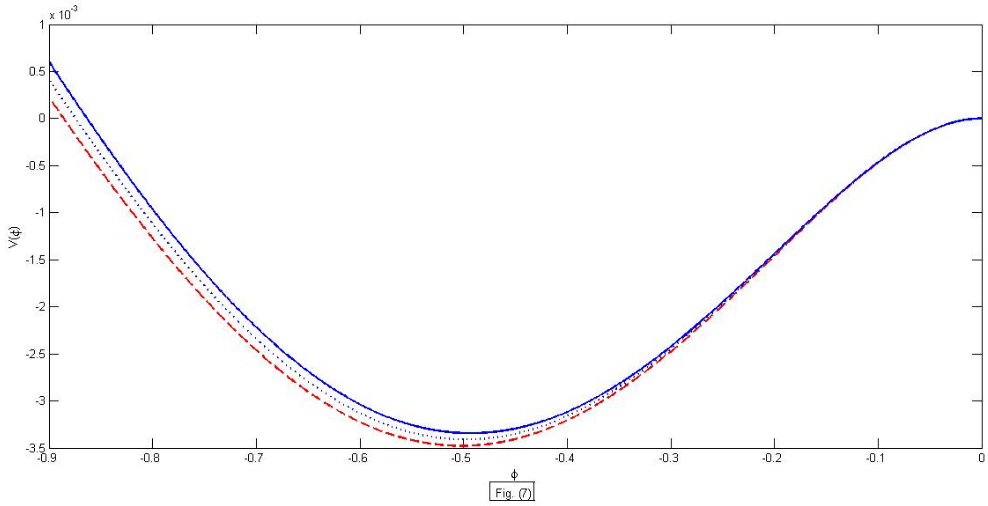

Fig. (7) Variation of the Sagdeev potential $V(\phi)$ with potential ϕ of the rarefactive ion-acoustic solitons at different values of M = 2.100 (red color dashed line), 2.097 (blue color dotted line) and 2.094 (black color solid line) and with fixed value of γ = 0.01 and others are the same as in Fig. (6).

Figure 7 shows that the variation of the $V(\phi)$ against ϕ for different values of M. From figure it is clear that M increase whereas that the amplitude and well depth of the SP increases of the ion-acoustic rarefactive soliton.

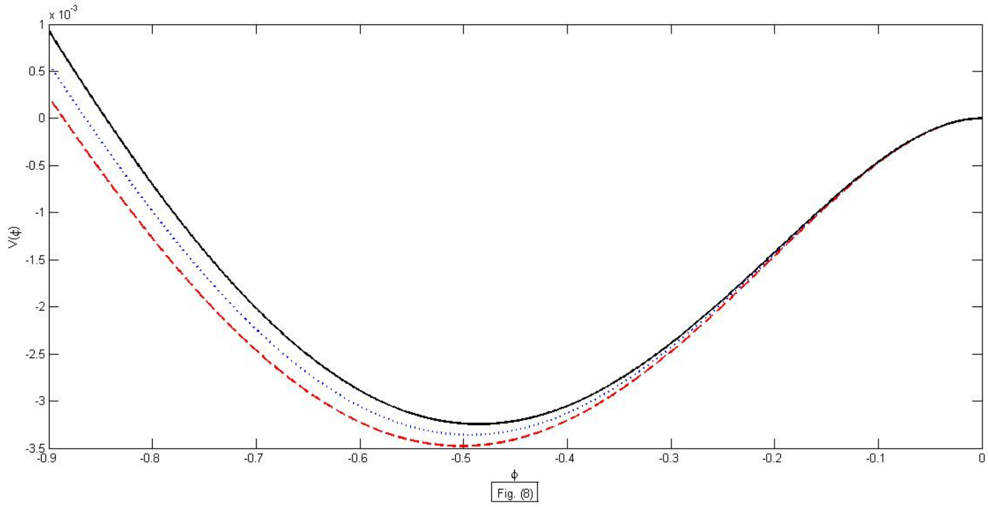

Fig. (8) Variation of the Sagdeev potential $V(\phi)$ with potential ϕ of the rarefactive ion-acoustic solitons at different values of β = 0.650 (red color dashed line), 0.651 (blue color dotted line) and 0.652 (black color solid line) and with fixed value of γ = 0.01 and others are the same as in Fig. (6).

From figure 8 it can be easily seen that by increasing the value of β, the amplitude as well as well depth of the SP of the ion-acoustic rarefactive soliton decreases.

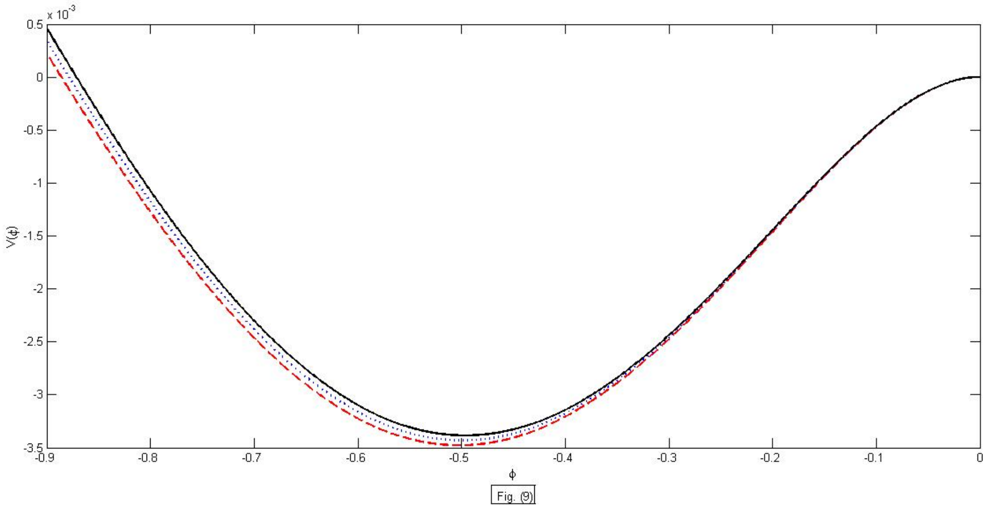

Fig. (9) Variation of the Sagdeev potential $V(\phi)$ with potential ϕ of the rarefactive ion-acoustic solitons at different values of σ = 0.10 (red color dashed line), 0.11 (blue color dotted line) and 0.12 (black color solid line) and with fixed value of γ = 0.01 and others are the same as in Fig. (6).

In figure 9 examined the effect of σ by plotting $V(\phi)$ versus ϕ. It is clear that σ increases whereas that the amplitude and well depth of the SP decreases of the ion-acoustic rarefactive soliton.

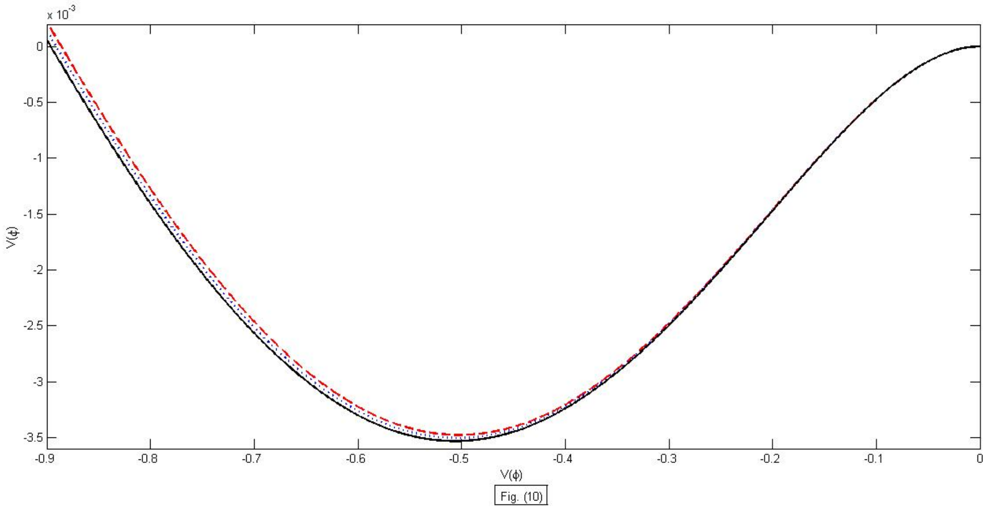

Fig. (10) Variation of the Sagdeev potential $V(\phi)$ with potential ϕ of the rarefactive ion-acoustic solitons at different values of α = 0.010 (red color dashed line), 0.011 (blue color dotted line) and 0.012 (black color solid line) and with fixed value of γ = 0.01 and others are the same as in Fig. (6).

Figure 10 depicts the variation $V(\phi)$ versus ϕ for different values of α. It is shows that increasing the α, the amplitude as well as well depth of the SP of the ion-acoustic rarefactive soliton increases.

Three dimensional shows the variation of Sagdeev potential $V(\phi)$ with potential ϕ and β of the compressive and rarefactive ion-acoustic solitons of figure (11) and figure (12) respectively.

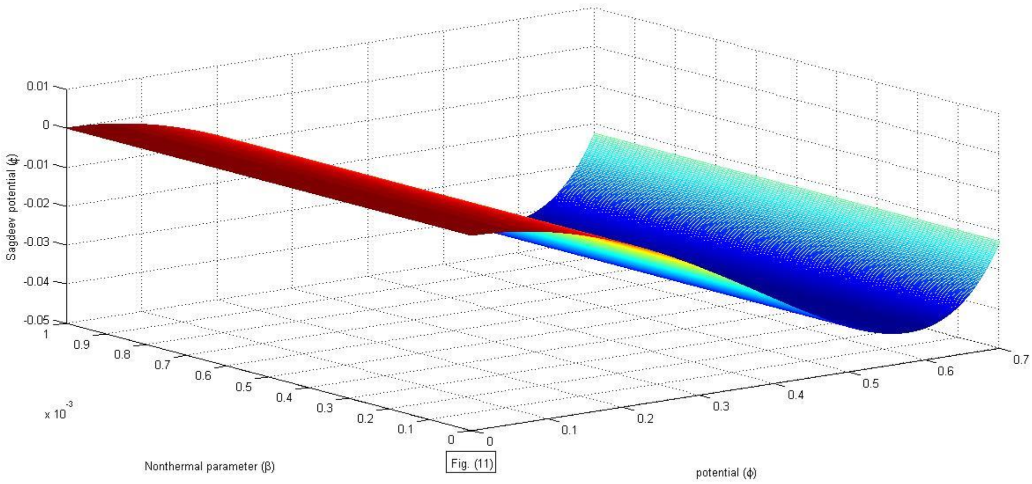

Fig. (11) 3D profile of Sagdeev potential $V(\phi)$ with potential ϕ of the compressive ion-acoustic solitons with nonthermal parameter $(\beta$ = 0 - 0.001) with other plasma parameters as σ = 0.001, , α = 0.001 and γ = 0.001 and M = 1.3.

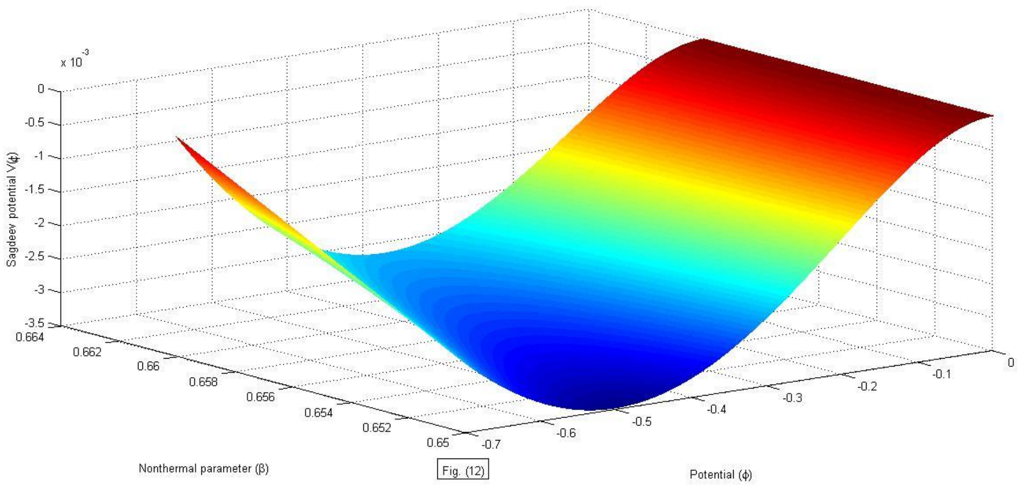

Fig. (12) 3D profile of Sagdeev potential $V(\phi)$ with potential ϕ of the rarefactive ion-acoustic solitons with nonthermal parameter $(\beta$ = 0.65 - 0.66) with other plasma parameters as σ = 0.1, , α = 0.01 and γ = 0.01 and M = 2.1.

CONCLUSIONS

In the present paper, the large amplitude of the ion-acoustic soliton are investigated in a unmagnetized plasma consists of nonthermal electrons and positrons. The effect of nonthermal parameters (β), positron concentration (α), ionic temperature ratio (σ), positron temperature ratio (γ) and Mach number (M) are studied on the characteristics of the ion-acoustic soliton. For given set of plasma parameters on increasing nonthermal parameters (β) [16] and ionic temperature ratio (σ) the amplitude of the ion-acoustic compressive/rarefactive soliton decreases (Jain and Mishra 2013), but it increases with increase in positron temperature ratio (γ) and Mach number (M). Amplitude of the ion-acoustic compressive (rarefactive) soliton decreases (increases) as positron concentration (α) increases for a given set of parameters [18]. The finding results of this paper may be useful for understanding of nonlinear ion-acoustic soliton in plasma containing postrions, ions and nonthermal electrons in space and laboratory plasmas.

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