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TIME DEPENDENT PRESSURE GRADIENT EFFECT ON UNSTEADY MHD COUETTE FLOW AND HEAT TRANSFER OF A COUPLE STRESS FLUID

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ABSTRACT

The unsteady Magnetohydrodynamic flow of an electrically conducting viscous incompressible couple stress fluid bounded by two parallel non-conducting porous plates has been studied with heat transfer considering the Hall effect. The fluid is acted upon by a uniform and exponential decaying pressure gradient. An external uniform magnetic field is applied perpendicular to the plates and the fluid motion is subjected to a uniform suction and injection. The two plates are kept at different but constant temperatures while the Joule and viscous dissipations are taken into consideration. Solutions for the governing momentum and energy equations are obtained using transform technique. The effect of magnetic field, couple stress parameter, unsteady pressure gradient, Hall term and velocity of suction and injection on both the velocity and temperature distribution are examined.

Key –words: *MHD Flow. Heat transfer, couple stress, electrically conducting fluids, unsteady pressure.*

INTRODUCTION

The flow of an electrically conducting couple stress fluid under the action of a transversely applied magnetic field has applications in many devices such as magnetohydrodynamic (MHD) power generator, MHD pumps, accelerators, aerodynamics heating, electrostatic precipitation, polymer technology, petroleum industry, purification of molten metal's from non-metallic inclusions and fluid droplets-sprays. Hartmann flow of a Newtonian fluid with heat transfer, subjected to different physical effects have been studied by many authors. [1-9].These results are important for design of the duct wall and cooling arrangements.

The flows of couple stresses fluids have many practical application in modern technology and industries, led various researchers to attempt diverse flow problems related to several Non-Newtonian fluids one such fluid that has attracted the attention of numerous researchers in fluid mechanics during the last five decades in the theory of couple stress fluid proposed by Stokes [10]. Classical theory of viscous Newtonian fluids that allow the sustenance of couple stresses and body couples in the fluid medium. The concept of couple stresses arises due to the way in which the mechanical interactions in the fluid medium are modeled. Singh and Pathak [11] have discussed unsteady flow of a dusty viscous fluid through a uniform pipe with sector of a circle as cross-section, and pulsatile flow of blood with micro-organism through a uniform pipe with sector of a circle as cross-section in the presence of transverse magnetic field has been investigated by Rathod and Parveen [12]. Also unsteady flow of a dusty magnetic conducting couple stress fluid through a pipe and the flow of a conducting fluid in a circular pipe has been investigated by many authors. Gudiraju *et. al*, [13], Dube and Sharma [14], Ritter and Peddison [15], Chamkha [16], investigated steady two phase vertical flow in a pipe.

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Dube and Sharma [14] and Ritter and Peddieson [15] have reported solutions for unsteady dusty-gas flow in a circular pipe in the absence of a magnetic field and particle-phase viscous stress. Rathod and Baderunissa [17] have studied by the pulsatile flow of blood in capillaries of small exponential divergence with volume fraction of micro-organism. Rathod et. al, [18] have reported solution for couette flow of a conducting dusty visco-elastic fluid through two flat plate under the influence of transverse magnetic field. Rathod and Rasheeda [19-20] investigated unsteady flow of a dusty magnetic conducting couple stress fluid through a circular pipe and ion slip effect on the unsteady flow of a dusty couple stress fluid through a circular pipe. Rathod and Rasheeda [21] have studied by unsteady MHD couette flow with heat transfer of a couple stress fluid under exponential decaying pressure gradient. The effect of time dependent pressure gradient on unsteady dusty fluid was studied by Rukmangadachari [22] in a rectangular duct and time dependent pressure gradient effect on unsteady MHD couette flow and heat transfer of a caisson fluid was studied by Attia *et. al,* [23].

Attia [24] studied the influence of the Hall current on the velocity and temperature fields of an unsteady Hartmann flow of a conducting Newtonian fluid between two in finite non-conducting horizontal parallel and porous plates. Attia *et. al,* [23] studied time dependent pressure gradient effect on unsteady MHD couette flow and heat transfer of a caisson fluid. The extension of such problem to the case of couette flow couple stress fluid has been done in the present study. In the present work time dependent pressure gradient effect on unsteady MHD couette flow and heat transfer of a couple stress fluid. The upper plate is moving with a uniform velocity while the lower plate is stationary. The fluid is acted upon by an exponentially decaying pressure gradient, uniform suction and injection from above and below low, respectively, the fluid is also subjected to a uniform magnetic field perpendicular to the plates. The Hall current is taken into consideration while the induced magnetic field is neglected by assuming a very small magnetic Reynolds number [5]. The two plates are kept at different but constant temperature. This configuration is a good approximation of some practical situation such as heat exchangers, flow meters, and pipes that connect system components. The joule and viscous dissipations are taken into consideration in the energy equation. The governing momentum and energy equation are solved by using transform technique. [cosine transform (25)]. The inclusion of magnetic field, unsteady pressure gradient, the Hall current, the suction and injection, and also couple stress parameter leads to some interesting effects on both the velocity and temperature fields.

FORMULATION OF THE PROBLEM

The fluid is assumed to be laminar, incompressible and obeying a flows between Two infinite horizontal plates located at the y = $\pm$h planes and extend from x = - ∞ to ∞ and from z = ∞ to ∞**.** The upper plate is suddenly set into motion and moves with a uniform velocity u_0, while the lower plate is stationary. The upper plate is simultaneously subjected to a step change in temperature from T_1toT_2. then, the upper and lower plates are kept at two constant temperatures T_2&T_1 respectively, with $T_2>T_1$ the fluid is acted upon by an exponentially decaying pressure gradient $\frac{\partial p}{\partial x}$ in the x-direction, and a uniform suction from above and injection from below which are applied at t = o, a uniform magnetic field B_0 is applied in the positive y–direction and is assumed undisturbed as the induced magnetic field is neglected by assuming a very small magnetic Reynolds number [4]. The Hall effect is taken into consideration and consequently a z – component for the velocity is expected to arise. The uniform suction implies that the fluid velocity vector is given by v=ui+v_oj+wk., The fluid motion starts from rest at t=0 on the no-slip condition at the plates in z–direction implies that the fluid velocity has no z – component at y= $\pm$h. The initial temperature of the fluid is assumed to be equal to T_1. Since the plates are infinite in the x and z –direction, the physical quantities do not change in these direction.

The flow of the fluid is governed by the momentum equation

$$\rho \frac{Dv}{Dt} = \nabla (\mu \nabla v) - \nabla p + J*B_o + \eta \nabla^2(\nabla^2 u) \tag{1}$$

Where ρ is density of the fluid and μ is apparent viscosity, η is couple stress parameters.

If the Hall term is retained, the current density J is by

$$j = \sigma [\nu \times B_o - \beta (J \times B_o)] \tag{2}$$

Where σ is the electric conductivity of the fluid and β is the Hall factor [5].

Equation (2) may be solved in J to gives.

$$JxB_o = -\frac{\sigma B_o^2}{1+m^2} [(u + mw) P + (w\text{-mu})k] \tag{3}$$

Where m is the Hall parameter and m = $\sigma\beta$ B_o. Thus the two components of the momentum equation (1)

$$\rho \frac{\partial u}{\partial t} + \rho\gamma_0 \frac{\partial u}{\partial y} = -\frac{\partial p}{\partial x} + \frac{\partial}{\partial y}\left(\mu \frac{\partial u}{\partial y}\right) + \eta \frac{\partial^2}{\partial y^2}\left(\frac{\partial^2 u}{\partial y^2}\right) - \frac{\sigma B_o^2}{1+m^2} \quad (u + mw) \tag{4}$$

$$\rho \frac{\partial \omega}{\partial t} + \rho\gamma_0 \frac{\partial \omega}{\partial y} = \frac{\partial}{\partial y}\left(\mu \frac{\partial u}{\partial y}\right) - \frac{\sigma B_o^2}{1+m^2} (w - mu)\nu \tag{5}$$

Where $\frac{\partial p}{\partial x}$ $= e^{-at}$ is the unsteady pressure gradient.

The energy equation with viscous dissipation is given by

$$\rho c_p \frac{\partial T}{\partial t} + \rho c_p \gamma_0 \frac{\partial T}{\partial y} = k \frac{\partial^2 T}{\partial y^2} + \mu \left(\frac{\partial u}{\partial y}\right)^2 + \frac{\sigma B_o^2}{1+m^2}(u^2 + w^2) \tag{6}$$

Where c_p and k are the specific heat capacity and thermal conductivity of the fluid respectively, the second and third terms on the right hand side represent the viscous and Joule dissipation respectively. Each of this term has two components. This is because the Hall effect about a velocity w in the z– direction. The initial and boundary conduction of the problem are given by

u = w = o at t≤o, and w = o at y = - h and y = h for t >o, u = o at y = - h for t>o, u = u_o at y = - h for t>o. (7)

T = T_1 at t≤o, T = T_2 at y = h and T = T_1 at y = - h for t>o.

Equation (4), (5) and (6) can be made dimensionless by introducing the following dimensionless variables and parameters.

$\hat{x} = \frac{x}{h}, \hat{y} = \frac{y}{h}, \hat{z} = \frac{z}{h}, \hat{t} = \frac{t u_0}{h}, \hat{u} = \frac{u}{U_o}$

$\hat{w} = \frac{w}{u_o}, P_r = \frac{p}{\varrho \cup_o}, \theta = \frac{T-T_1}{T_2-T_1},$

$R_e = \frac{\varrho h \cup_o}{\mu_o}, \hat{\mu} = \frac{\mu}{\mu_o}$

$\alpha = \frac{dp}{dx}$ is the constant pressure in the steady pressure gradient, $\overline{(\propto)^2} = \frac{h^2\mu}{\eta}$ is the couple stress parameter.

Re = $\frac{\varrho \cup_o h}{\mu_o}$ Reynolds number, S = $\frac{\varrho \gamma_0 h}{\mu_o}$ the suction paratec.

$P_r = \frac{\varrho C_p \cup_o h}{\mu}$ is Prandtl number, $E_c = \frac{\varrho \cup_o h}{\varrho C_p h(T_2 - T_1}$ is the Eckert number, $H_a^2 = \frac{\sigma B_o^2 h^2}{\mu_o}$ the Hartman number & equation (4), (5) and (6) after dropping caps for convenience.

$$\frac{\partial u}{\partial t} + \frac{S}{Re}\frac{\partial u}{\partial y^2} - \propto e^{-at} + \frac{1}{Re}\frac{\partial}{\propto y}\left(\frac{\mu \partial u}{\partial y}\right) - \frac{1}{\propto^2 Re}\frac{\partial^4 u}{\partial y^4} - \frac{H_a^2}{1+m^2}(u + mw) \tag{9}$$

$$\frac{\partial w}{\partial t} + \frac{S}{Re}\frac{\partial w}{\partial y} = \frac{1}{Re}\left[\frac{\partial}{\partial y}\left(\frac{\mu \partial w}{\partial y}\right) - \frac{H_a^2}{1+m^2}(w - mu)\right] \tag{10}$$

$$\frac{\partial \theta}{\partial t} + \frac{S}{Re}\frac{\partial \theta}{\partial y} = \frac{1}{Pr}\frac{\partial^2 \theta}{\partial y^2} + Ec\left(\frac{\partial u}{\partial y}\right)^2 + \frac{H_a^2 Ec}{(1+m^2)}(u^2 + w^2) \tag{11}$$

u = w = o for t ≤o and u = w at y = -1

w = o, u = 1, at y = 1 for t >o. (12)

θ = o for t ≤o and θ = o at y = -1, θ = 1 at y = 1 for t >1 (13)

Where α is the constant pressure gradient $\left(\frac{dp}{dx}\right)$ and a is the decaying parameter.

Applying cosine transform to equations (9), (10) & (11)

$$\frac{\partial \bar{u}}{\partial t} + x_1 \bar{u} + x_2 = x_3 \bar{w} \tag{14}$$

$$\frac{\partial \bar{w}}{\partial t} + y_1 \bar{w} = y_2 \bar{u} \tag{15}$$

$$\frac{\partial \bar{\theta}}{\partial t} + \bar{z}_1 \bar{\theta} = \bar{z}_2 = (\bar{u}^2 + \bar{w}^2) + \bar{u}^2 \bar{z}_3 \tag{16}$$

where $x_1 = \frac{S}{Re} + \frac{\mu}{Re} - \frac{1}{\propto^2 Re} + \frac{H_a^2}{Re(1 \pm m^2)}$

$x_2 = \frac{\propto e^{-at}(-1)^m}{\eta}, \quad x_3 = \frac{-m H_a^2}{Re(1+m^2)}$

$y_1 = \frac{S}{Re} + \frac{\mu}{Re} + \frac{H_a^2}{Re(1+m^2)}$

$y_2 = \frac{m H_a^2}{Re(1+m^2)}, \quad \bar{z}_1 = \frac{S}{Re} + \frac{1}{P_r}, \quad \bar{z}_2 = \frac{E_c H_a^2}{1+m^2}, \quad \bar{z}_3 = Ec.$

Applying Inverse Cosine transform

$$\bar{u} = \sum_{m=o}^{\infty} \frac{x_2 y_1}{y_{12}} \frac{2}{\propto}\left(\frac{\beta_2 e^{\beta_1 t} - \beta_1 e^{\beta_2 t}}{\sqrt{y_{11}^2 - 4y_{12}}} + 1\right) \text{Cos}\,\frac{(2m+1)\pi y}{2\propto} \tag{17}$$

$$\bar{w} = \sum_{m=o}^{\infty} \frac{x_2 y_2}{y_{12}} \frac{2}{\propto} \left(\frac{\alpha_2 e^{\alpha_1 t} - \alpha_1 e^{\alpha_2 t}}{\sqrt{x_{11}^2 - 4x_{12}}} + 1 \right) \mathrm{Cos}\, \frac{(2m+1)\pi y}{2\propto} \tag{18}$$

$$\bar{\theta} = \bar{z}_4 \left[\frac{1}{(y_{11}^2 - 4y_{12})} \left(\frac{\beta_2^2 (e^{2\beta_1 t} - e^{-\bar{z}_1 t})}{2\beta_1 + \bar{z}_1} + \frac{\beta_1^2 (e^{2\beta_2 t} - e^{-\bar{z}_1 t})}{2\beta_2 + \bar{z}_1} - \frac{2\beta_1 \beta_2 (e^{(\beta_1 + \beta_2)t} + e^{-\bar{z}_1 t})}{(\beta_1 + \beta_2) + \bar{z}_1} \right) \right] + \frac{2}{\sqrt{y_{11}^2 - 4y_{12}}} \left(\frac{\beta_2^2 (e^{\beta_1 t} - e^{-\bar{z}_1 t})}{\beta_1 + \bar{z}_1} - \frac{\beta_1 (e^{\beta_2 t} - e^{-\bar{z}_1 t})}{\beta_2 + \bar{z}_1} + \frac{(1 - e^{-\bar{z}_1 t})}{\bar{z}_1} \right) \tag{19}$$

Where

$x_{11} = x_1 + y_1, \quad x_{12} = x_1 y_1 - y_2 x_3$

$\propto_1 = \frac{-X_{11} + \sqrt{x_{11}^2 - 4x_{12}}}{2}, \quad \propto_2 = \frac{-X_{11} - \sqrt{x_{11}^2 - 4x_{12}}}{2},$

$y_{11} = x_1 + y_1, \quad y_{12} = x_1 - y_2 x_3.$

$\beta_1 = \frac{-y_{11} + \sqrt{y_{11}^2 - 4y_{12}}}{2}, \quad \beta_2 = \frac{-y_{11} - \sqrt{y_{11}^2 - 4y_{12}}}{2},$

$\bar{z}_4 = E_c \left(\sum_{m=1}^{\propto} \frac{x_2}{y_{12}} \frac{2}{\propto} \mathrm{Cos}\left(\frac{(2m+1)}{2\propto} \pi y\right) \right)^2 \left(\frac{H_a^2}{1+m^2} (y_1^2 + y_2^2) + \mu y_1^2 \right)$

Computations have been made for $\propto = 5$, $P_r = 1$, R_e =l, $H_a = 3$ and $E_c = 0.2$, plotted the graph for different values of couple stress parameter, Hartman, suction parameter decaying parameter and time by using “Mathematics” Result and Discussion.

The profiles of the velocity u, w and temperature respectively for various values of time t and for couple stress parameter $\overline{\propto^2}$ = q = 0.1, 0.5, 1.5, for y = o, s = 1, m =3 and for μ=0.0, 0.05, and 0.1, have been computed, it is observed that increasing couple stress parameter decrease velocity and temperature in fig. 1(a), (b) and (c).

Fig 2(a) (b) and (c) shows the variation of the velocity components u and w and the temperature at the central plane of the channel (y = o) with time for various values of the Hall parameter m and μ = 0.0, 0.05, and 0.1, in these figures S = o, q = 0.5 in 2 (a), (b) shows that u, w increase with increasing ‘m’ for all values of μ, but in fig. 2 (b) shows the influence of μ on w depends on t and more clear when m is large. It is observed that, increasing μ decreases w and increasing m increases w.

Figure 2 (c) and shows that the influence of m on θ depends on t. Increasing θ at small times but this is reversed at large times. This is due to the fact that, for small time u and w are small and an increase in m increases u but decrease w then, Joule dissipation which is also proportional to $\left(\frac{1}{1+m^2}\right)$ decreases. For large times increasing m increases both u and w and m turn, increases the Joule and viscous dissipations. This accounts for the crossing of the curve of θ with time for all values of μ. It is also observed that increasing μ decreases the temperature both u and w their gradients which decreases the Joule and viscous dissipations. These figures shows also that the time at which θ reaches steady state value increases with increasing m while it is not greatly affected by changing μ. Fig. 3 (a) (b) and (c) present the profiles of the velocity components u and w and the temperature θ for various values of time it and for μ = 0.0, 0.05, 0.1 the figures are evaluated for m = 3, s = 1, q = 0.5, it is clear from Figures 3 (a) (b) and (c) that effect of μ on u, w and θ depends on t and y. Figure 3 (a) shows, that, for small t, increasing the μ decreases u for small y but this is reverse for large y. As time develops increasing μ increases u for all y. Figure 3(b) & (c) shows that increasing μ increasing w for all values of y.

For large t, increasing μ decreases w and θ for small t and all values of y, this can be attributed to the fact that increasing μ will delay the attainment of maxima of u, w and θ. It is also observed from figures 3 (a), (b) and (c) that the velocity components u, w and θ do not reach their steady state monotonically. It is observed also that the velocity component u reaches the steady state faster than w which, in turn, reaches the steady state faster than θ. This is expected as u is the sources of w. while both u and w act as sources for the temperature.

Figures 4 (a), (b) and (c) show that the variation of the velocity components u and w and temperature θ. at the central plane of the channel (y =o) with time. This figures shows the results for various values of the decaying parameter a = 0, 1, 2 and for μ = 0.0, 0.05 and 0.1. In these fig. s = 1, m = 3, q = 0.1, fig. 4 (a). u decreases with increasing a for all values of μ. It is observed also that the time at which u reaches its steady state value decreases with increasing a for a = 0, but that occurs earlier for constant pressure gradient (a = o), Increasing μ increases u for all values a bout with small difference in fig. 4 (b). The velocity component w decreases with increasing a. This figure indicates that the influence of μ on w depends on t and becomes more clear when the decaying parameter a = o but this influence μ more decreases w for a = o.

Fig. 4 (c) shows that the influence of a on θ depends on t. It is observed that increasing a decreases θ while it is not greatly affected by changing μ. The figure shows also that the time at which θ reaches its steady state value decreases with increasing a while it is not greatly affected by changing μ.

Fig.5(a), (b) and (c) show the profiles of the velocity components u w and the temperature θ, respectively for various values of time a and for t=0.2,1, and 2. The figures are evaluated for m=3, $\mu = 0.05$ and s=1.It is clear from fig 5(a), (b) that the effect of decaying parameter a on u and w depend on t and y. Fig 5(a) (b) shows that for small t, increasing a decreases u, w for all values of y and a. It is also observed that increasing a decreases u for all values of y with significant difference at medium and large t. It is also observed that the constant pressure gradient a=0 is greatly different from unsteady pressure gradient. This can be attributed to the fact that increasing a will decrease the pressure gradient which mainly generates the velocity u. Fig 5(c) shows the temperature θ profile does not reach its steady atate monotonically, increasing a decreases θ for all values of y and a. It is also observed that increasing a decreases θ for all values of y with no significant difference at medium and large t. It is also observed that the constant pressure gradient a=0 is greatly different from unsteady pressure gradient. This can be attributed to the fact that increasing a will decrease the pressure gradient which mainly generates the velocity u and w. This is expected as u is the source of w, while both u and w act as sources for the temperature.

CONCLUSION

A transform technique is used to save the transient coutte flow and heat transfer of a couple stress fluid under the influence of unsteady pressure gradient and uniform magnetic field. In the present work, we study Hall effect, couple stress parameter, the effect of the decaying parameter a and the Hall parameter m on the velocity and temperature distributions are studied. The decaying parameter a affects the main velocity components u and w and the temperature θ. The Hall term affects the main velocity components u in the $\varkappa$ – direction and gives rise to another velocity component w in the z – direction.

The results show that the influence of the parameters a and μ on u and w depend on time and Hall parameter m. It is also found that the effect of m on w and θ depends on time for all values of μ which accounts for a cross over in the w-t and θ-t graphs for various values of m. The effect of m on the magnitude of θ depends on μ and becomes more pronounced in case of small μ. It is also found that the effect of a and q on the magnitude of θ depends on μ and becomes more pronounced in case of small μ.

Fig.-1(a)

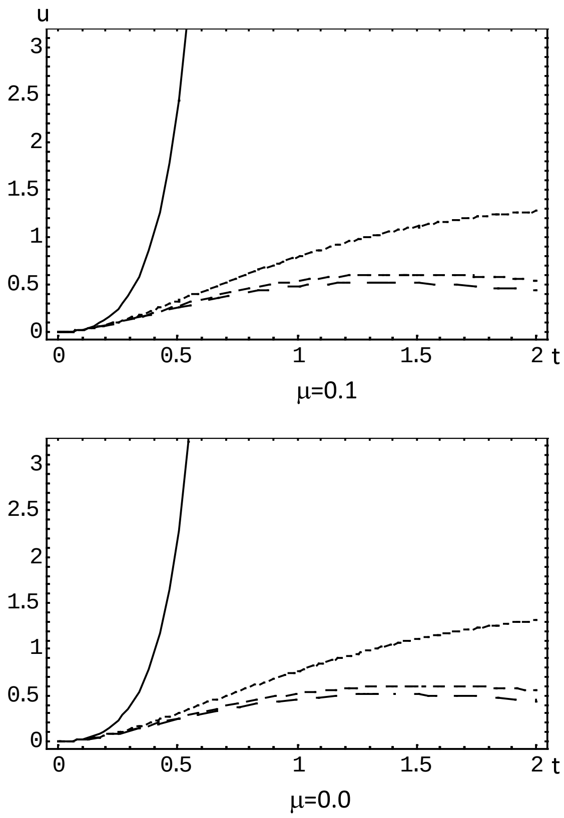
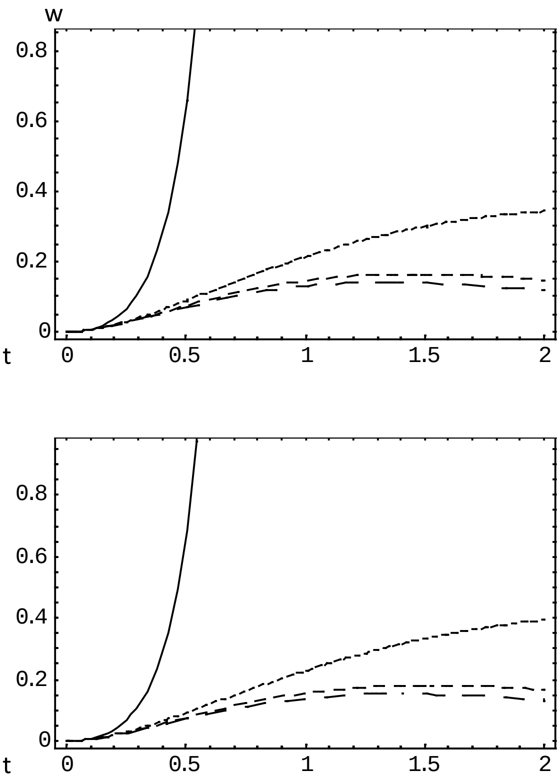
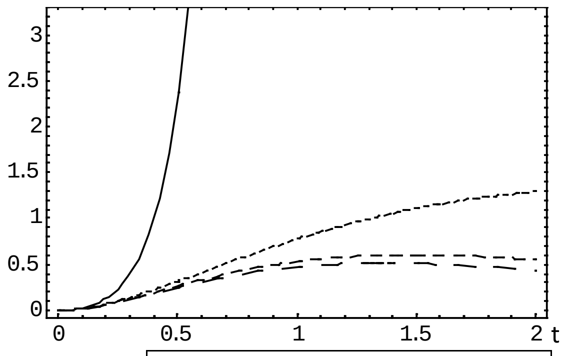
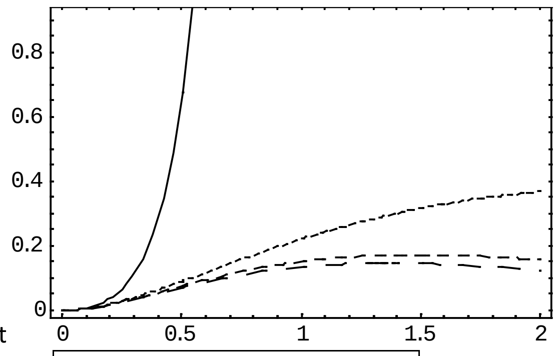


Fig.-1(b)







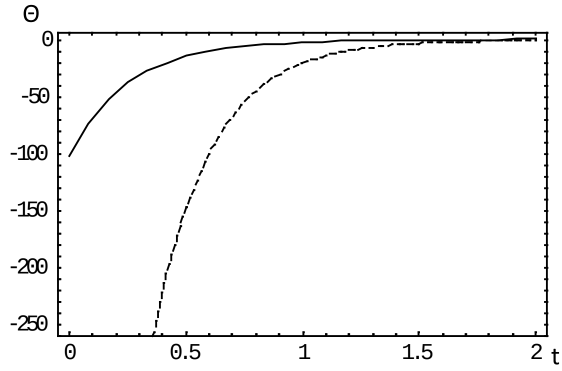
;_______q=0.5.....q =1,_______ a =1.5,

_______q=0.5.....q =1,_____q =1.5

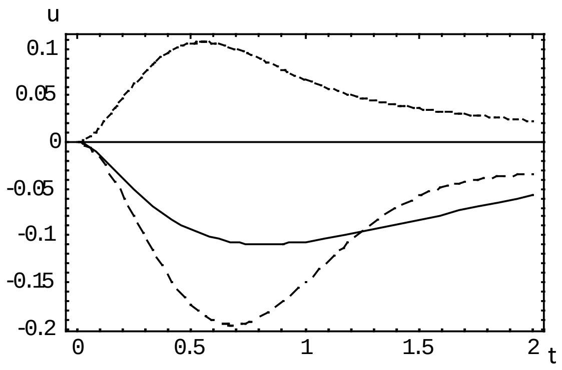
Fig.-1a, 1b, 1c: Effect of couple parameter q on u, w, θ **at** y=0 for various values of m S=1)

Fig.- 1(c)

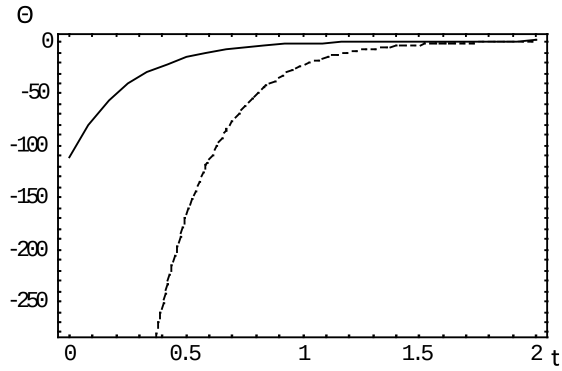
Fig.- 2(a)



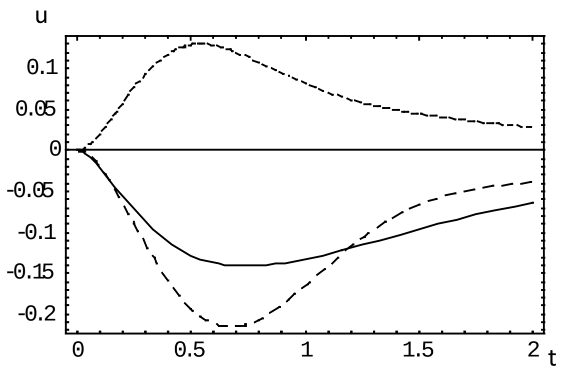
μ=0.5



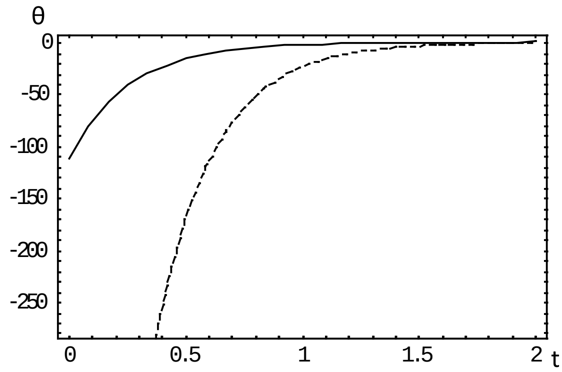
μ=0.0



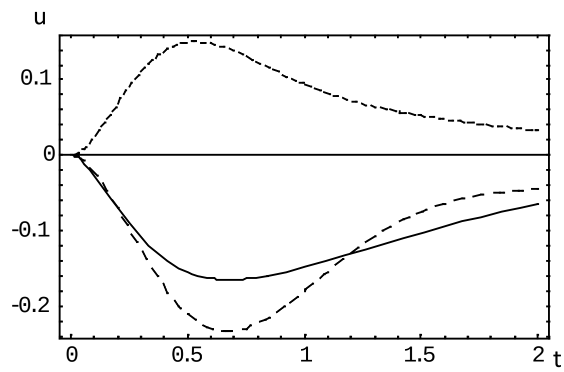
μ=0.1



μ=0.05



μ=0.01



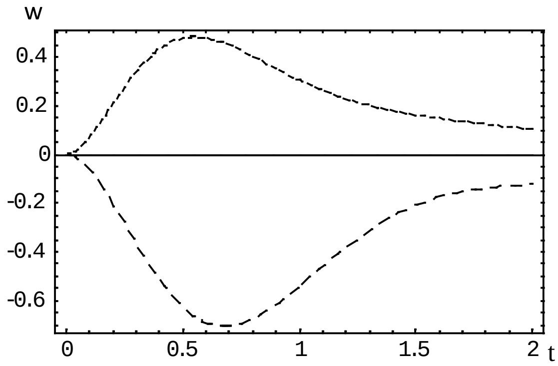
μ=0.1

;_______q=0.5.....q =1,_______ a =1.5,

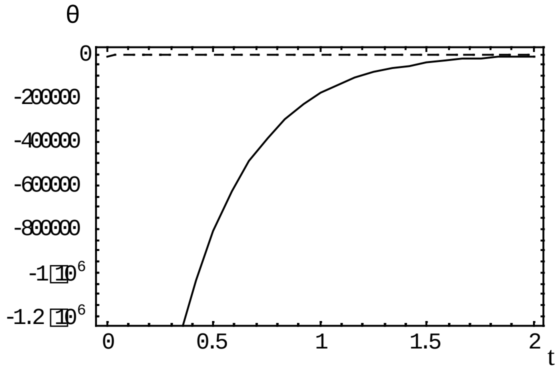
______m=0.0.....m =1,____q=2

Fig.-2(b)

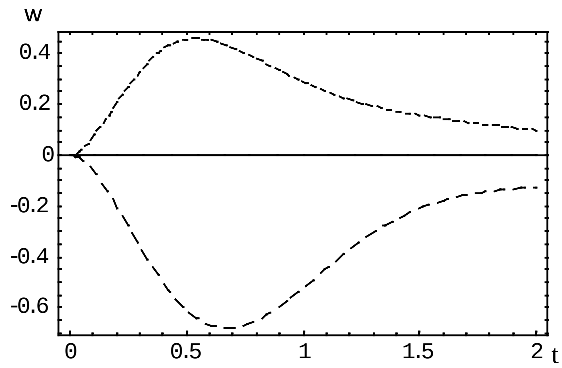
Fig.-2(c)



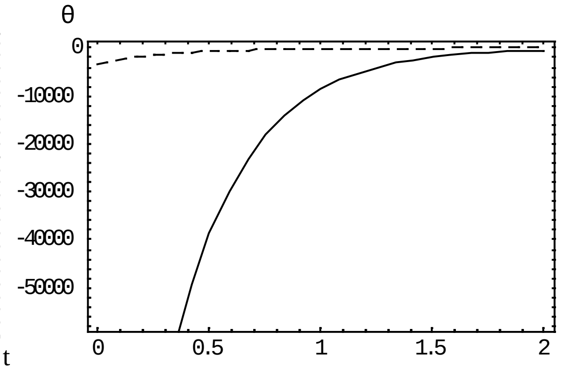
μ=0



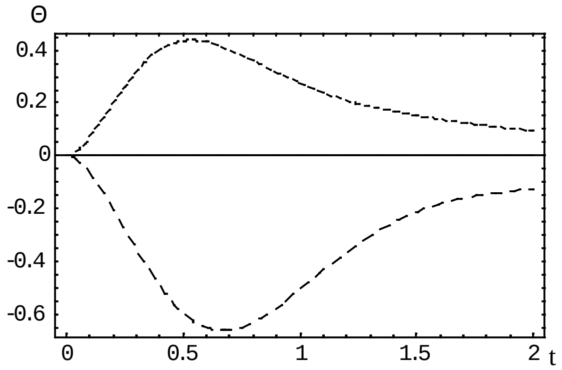
μ=0



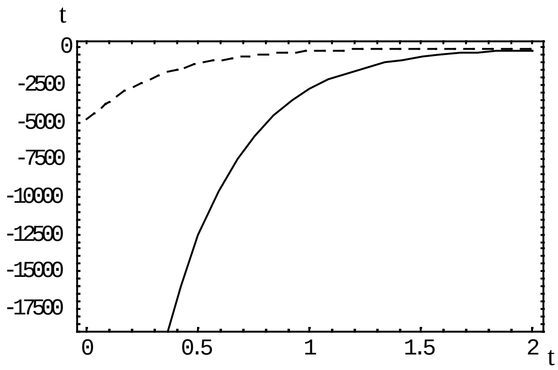
μ=0.05



μ=0.1



μ=0.1

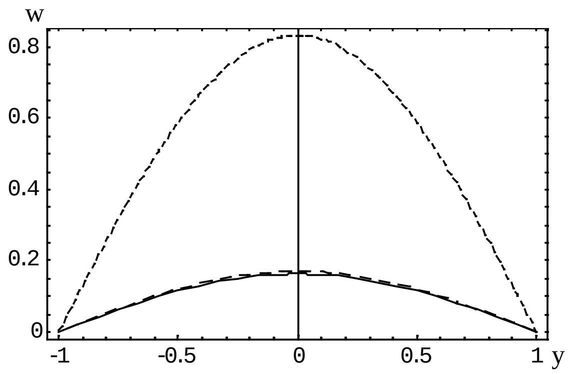


μ=0.1

;_______m=0......m =1,______ m =2, _______m=0......m =1,______ m =2

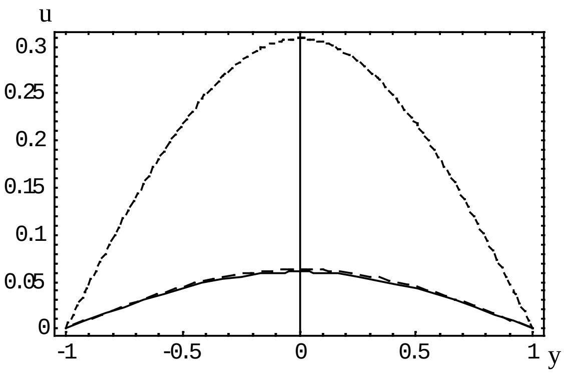
Fig.-2a, 2b, 2c: Effect of Hall curremt m on u, w, θ **at** y=0 for various values of μ (a=3, S=0)

Fig.-3(a)

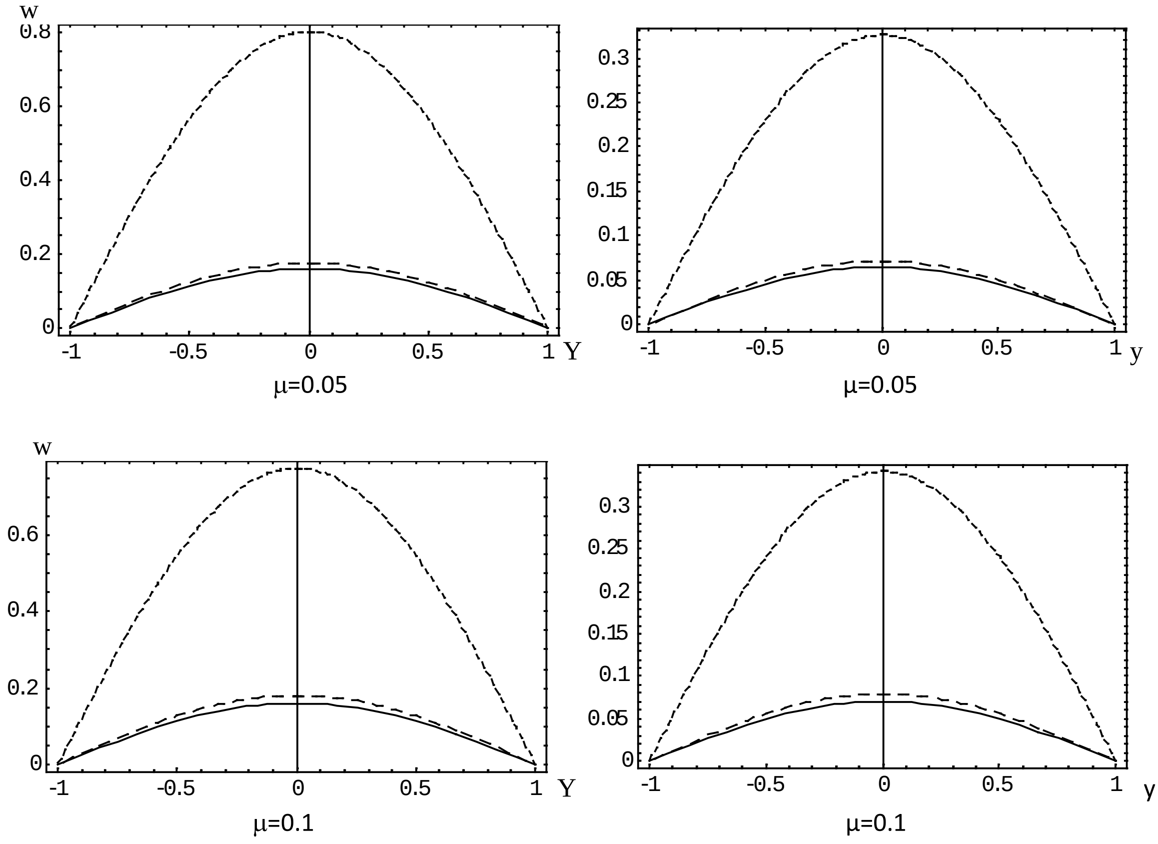


μ=0.0

Fig.-3(b)



μ=0.0



;_______t=0.2......t =1,_______t =2,   _______t=0.2,.....t =1,_______ t =2

Fig. - 3a, 3b, 3c: The variation of time t on u, w, θ **at** m=3 for various values of μ (a=1, S=0)

Fig.- 3(c)

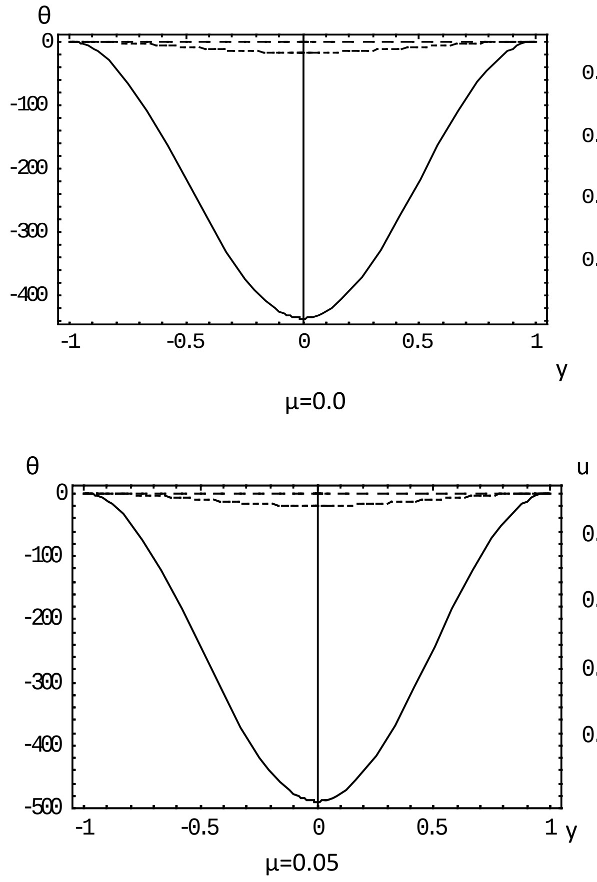
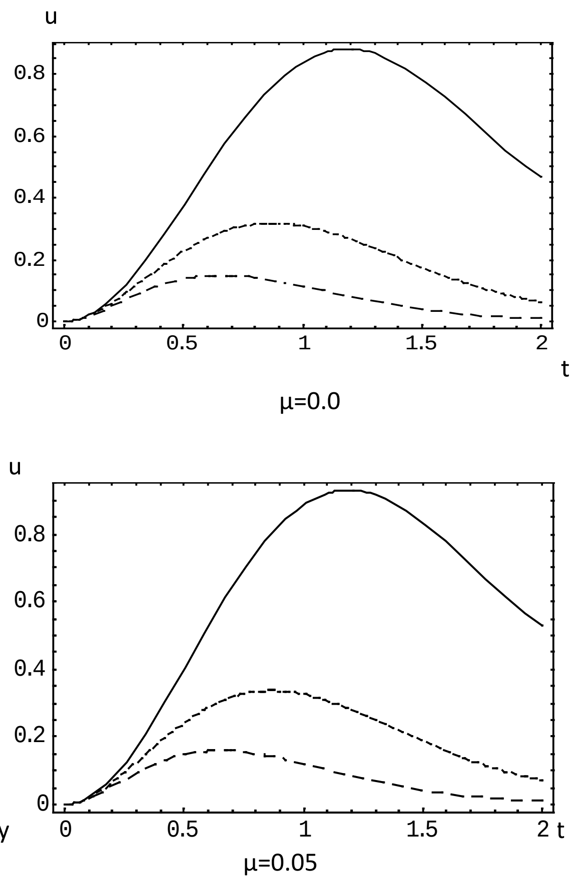
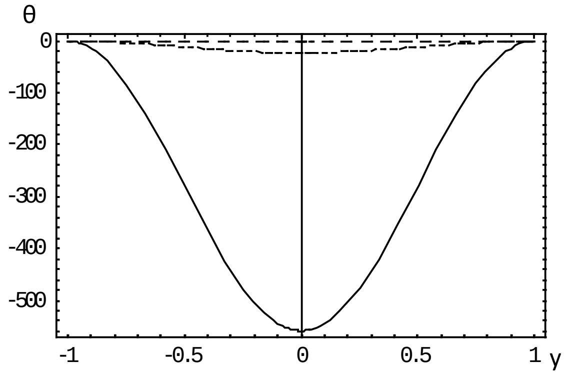


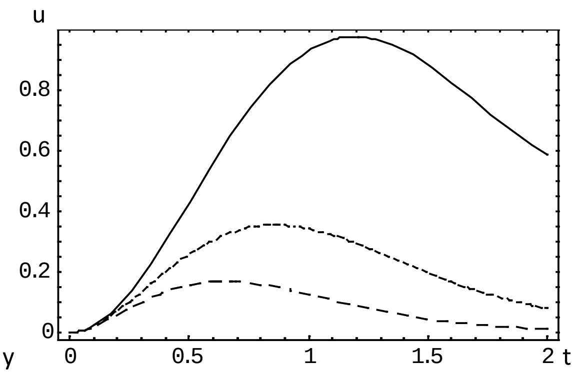
Fig.- 4(a)





μ=0.1

;_______t=0.2......t =1,_______t =2,

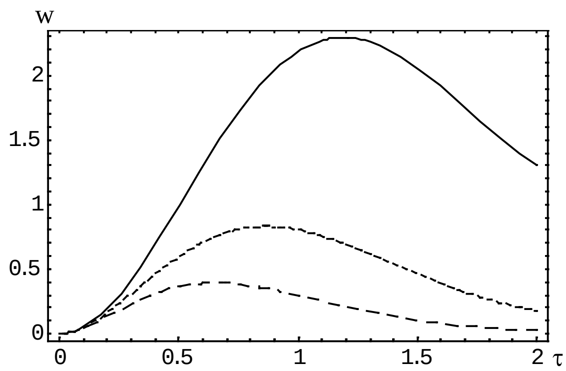


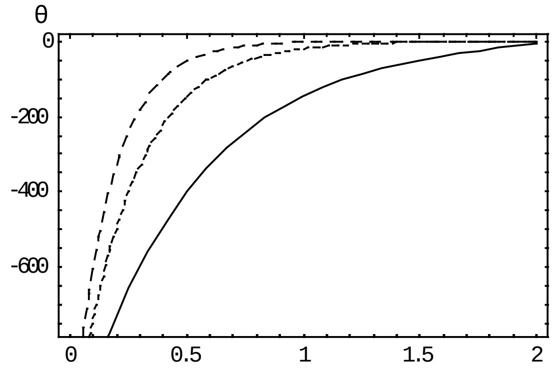
μ=0.1

_______a=0.,.....a =1,_______ a =2

Fig.- 4(b)

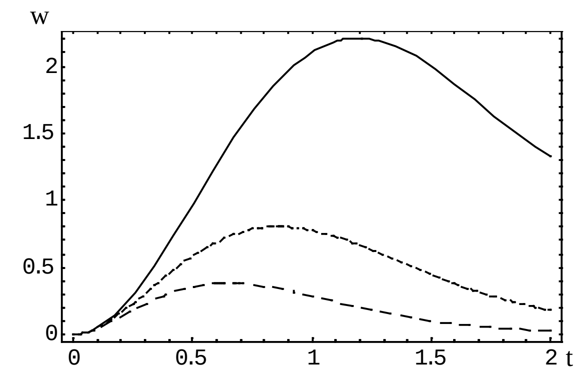
Fig. - 4(c)

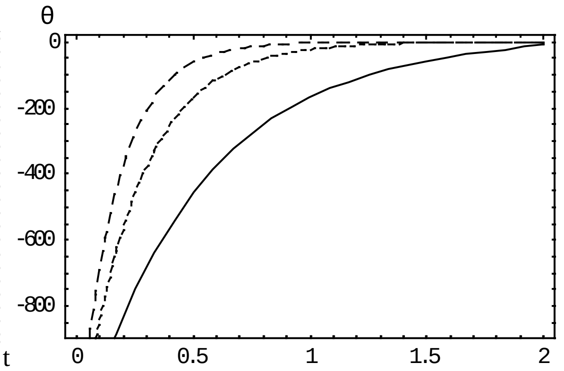




μ=0.05;

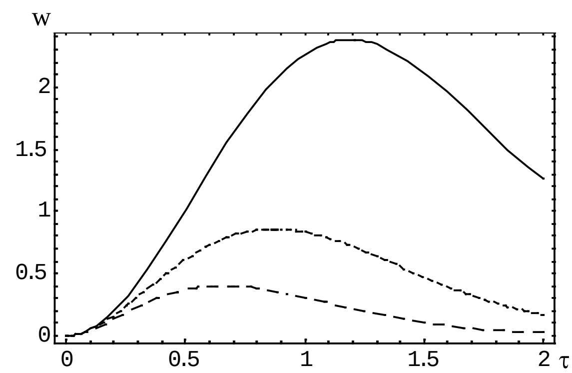
μ=0.05

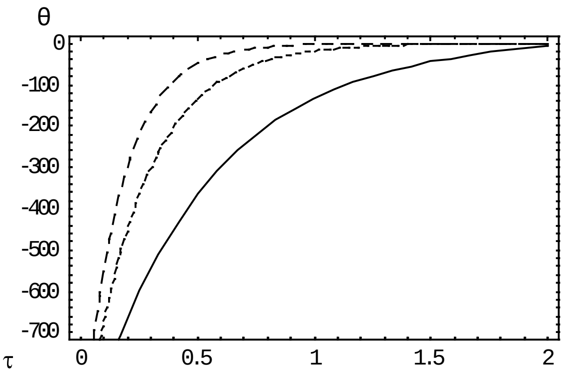




μ=0.1;

μ=0.1;





μ=0;

μ=0;

_______a=0......a =1,_______ a =2,

_______a=0......a =1,_______ a =2

Fig.- 4a, 4b, 4c: Effect of decaying parameter a on u, w, θ **at** y=0 for various values of μ (m=3, S=1)

Fig. -5(b)

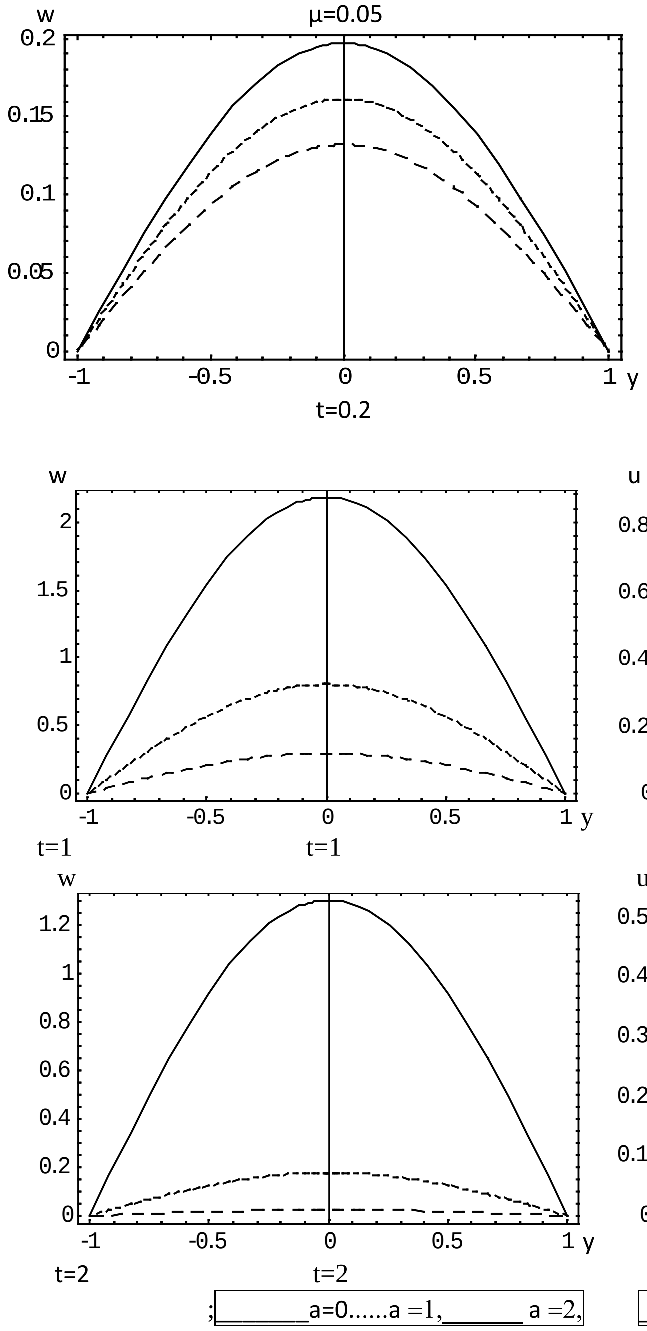


Fig.- 5(a)

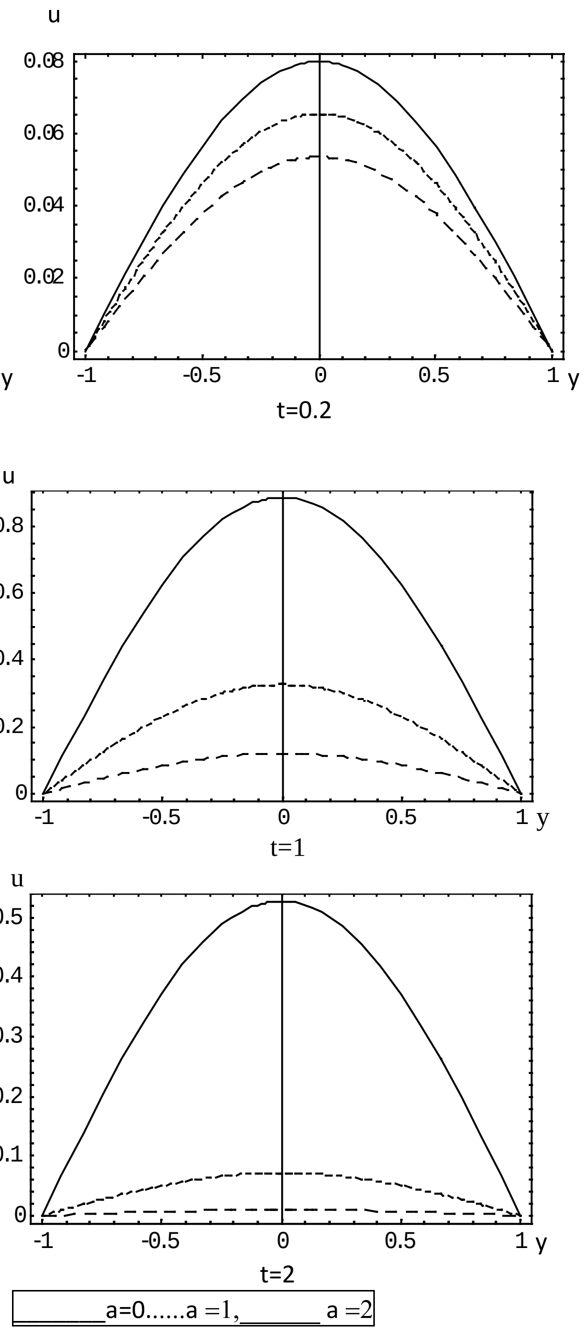
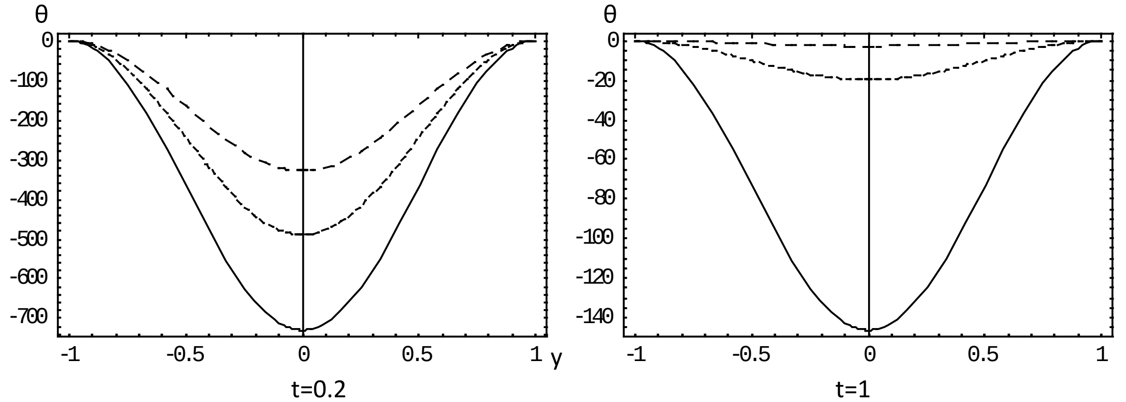


Fig.- 5a, 5b, 5c: Effect of decaying parameter a on the distribution of u, w, θ with y for various values of t (μ=0.05, m=3, S=1)

Fig.- 5(c)



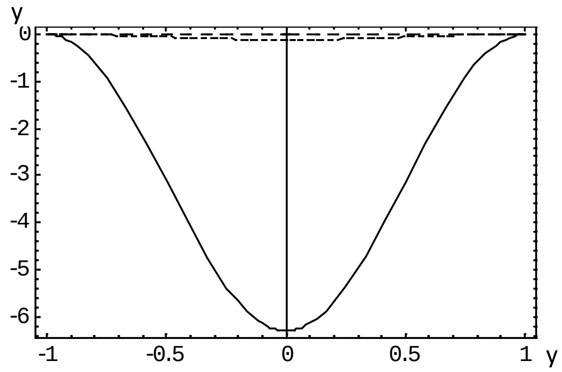


Fig.-5a, 5b, 5c: Effect of decaying parameter a on the distribution of u, w, θ with y for various values of t (μ=0.05, m=3, S=1)

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