CHAPTER IV

SCREENING OF A MOVING SOURCE

In this chapter screening of a moving test source will be analyzed. The chapter begins with an introduction for the motivation for studying the screening of a moving source in QGP. Then the derivation of the basic equations describing the screening will be presented In the last section numerical solutions of the equations will be discussed.

4.1 INTRODUCTION: The screening of color electric fields is important, because it is a reflection of collective behavior of the QGP, which in turn has influence on its hadronization. As a consequence, the screening property leads to signatures for detecting the formation of QGP in the laboratory. For example, it was proposed[1] that if the plasma is produced in heavy ion collisions, then charge anti-correlations between pions of similar rapidity would be weakened. In another study, Matsui and Satz[2] suggested that if the screening length Λ_D is less than the "Bohr" radius of quark-antiquark (in particular $c\bar{c}$) pair, the production of J/ψ ($c\bar{c}$) meson would be suppressed. This can also serve as a signature of QGP in heavy ion collision experiments. The NA38 experiment at CERN has indeed observed suppression in J/ψ production. However, non-plasma explanations of the experiments, in the form of collisional loss by a hot hadron gas[3], have also been put forward, and as yet there is no consensus that the observed J/ψ suppression is due to the screening in QGP.

It should be stressed that, these different mechanisms proposed for the J/ψ suppression, lead to different results for the magnitude and the pattern for the suppression. Therefore, it is possible, at least in principle, to distinguish the genuine plasma effects from other effects. At this juncture, it thus appears useful to study other dynamical effects, that can arise in the plasma, and which can affect the screening of a color test source. In this chapter, we study one such effect, viz., screening of a moving test source. It is quite realistic to consider such an effect, because the q-$\bar{q}$ pairs are indeed moving in the plasma. The problem of screening of moving test source has been analyzed in the Coulomb plasma literature[4]. The analysis show that the expression for the Debye shielding viz., $\phi = q/r\exp(-r/\Lambda_D)$ is not only valid for the static point source, but also valid for the moving particles as long as their velocity is much less than the thermal velocity of the plasma particles. This behavior is strongly modified when the test particle's velocity is greater than the thermal velocity of the plasma particles. Similar study for a moving source screening has been carried out in QGP[5] and not surprisingly it was found that, for massless particles, when the test source is moving with a relativistic velocity then the screened potential become strongly anisotropic. It should be mentioned that in this study[5] the plasma was considered to be essentially abelian.

It is obviously of interest to examine, if some genuine non-perturbative non-abelian effects can influence, the screening of a moving test source. This is because the color charge evolution equations of the hydrodynamic equations we derived in chapter II indicate that when the plasma is moving in a static color potential, its color charge precession can occur. This can make the screening of the moving source in QGP different than that in a Coulomb plasma. To carry out the non-perturbative study of the screening we have used the CHD equations derived in the second chapter. As the CHD equations have been obtained in the cold collisionless limit we have extended them by adding a pressure gradient term in the momentum balance equation to incorporate finite temperature effects, which are crucial to the study of screening. Using these extended equations, and equation of state for a massless quark gas, we have obtained a closed set of equations, for the colored particles and the color field amplitudes.

In a non-abelian theory it is difficult to study the screening of a test charge because the charge of the test source can flow into the gauge fields and vice versa. Hence it is useful to have a gauge invariant definition of the charge which can be used as a measure of the screened charge of a test source. The definition of a gauge invariant charge arising from the expression for an effective Debye length is used to examine the non-abelian screening.

The equations governinig the screening of a moving point source has a two dimensional cylindrical geometry, demanding solutions of coupled non-linear partial differential equations. Clearly, numerical work to solve them can be quite involved. Hence for simplification, instead of a point source we have considered the screening of an infinitely thin slab test charge. The results, thus obtained, cannot be directly applied to screening of a moving point source but we believe they might reveal qualitatively new features of non-abelian screening.

It will be shown that due to the non-abelian effects, screening of a moving test source is significantly modified compared to the static source screening, even when the test source is moving with a non-relativistic velocity.

4.2 Basic Equations for Screening : As mentioned earlier we have extended the CHD equations, by including finite temperature effects in the form of a pressure gradient term in the force equation, and an equation of state relating the pressure with temperature. Such finite temperature effects arise, in a natural way, from a kinetic theory approach for deriving the hydrodynamical equations (see for example Heinz[6]). The extended CHD equations in the non-relativistic limit are,

$$\frac{\partial n_A}{\partial t} + \nabla.(n_A \vec{V}_A) = 0 \tag{4.1a}$$

$$m_A\left(\frac{\partial}{\partial t} + \vec{V}_A.\vec{\nabla}\right)\vec{V}_A = gI_{Aa}\left(\vec{E}_a + \vec{V}_A \times \vec{B}_a\right) - \frac{1}{n_A}\vec{\nabla} P_A \tag{4.1b}$$

$$\left(\frac{\partial}{\partial t} + \vec{V}_A.\vec{\nabla}\right)I_{Aa} = -g\varepsilon_{abc}\left(A^o_b - \vec{V}_A.\vec{A}_b\right)I_{Ac} \tag{4.1c}$$

where m_A and P_A denote the mass and the pressure of particles of specie A, and the fields $\vec{E}_a$ and $\vec{B}_a$ are defined by $E^i_a = F^{io}_a$ and $B^i_a = \frac{1}{2}\varepsilon^{ijk}F^{ik}_a$. In the non-relativistic limit these equations are subjected to color neutrality conditions $\sum_A n_{Ao} I_{Aao} = 0$, where the suffix 'o' denotes equilibrium values. In Eq. (4.1b) one must include a term involving collisions between particles belonging to the two different species. This term is neglected in the present study and the justification for it is given in Appendix A.

Eqs. (4.1) do not yet form a complete set of equations. They can be made complete by choosing an equation of state (eos) for the plasma. Equation of state and number density for a massless massless ideal gas are given by

$$P_A = h_s N_d T_A^{\,4} \tag{4.2a}$$

$$n_A = d_s\, N_d\, T_A^{\,3} \tag{4.2b}$$

where N_d is number of degree of freedom, h_s and d_s are factors which depends upon the choice of statistics. For a massless quark gas h_s= 7/8 $(\pi^2/90)$ and d_s= $3/4(\zeta(3)/\pi^2)$. For an SU(2) quark gas with a single flavor N_d= 4. Then, we use the relation

$$P_A = (h_s/d_s) n_A T_A \tag{4.2c}$$

Equations (4.1-4.2) together with the Yang-Mills equations (see Chapter 2) form a closed set. We now simplify these equations. We consider a plasma comprising of two species (particles and antiparticles). Since our interest is to find out, how the color electric field of a moving test source is screened by the plasma, we go to a frame in which the test charge is at rest, but the plasma is moving. We assume that when no perturbation is introduced in the plasma the two species move with equal velocity V_o in the z-direction and have equal equilibrium density n_o. The color neutrality condition in equilibrium is then $I_{1ao} = -I_{2ao}$ and the net equilibrium current is zero. If the point test charge is at rest at origin, then the equations for the colored fluid (Eqs. 4.1) and the Yang-Mills equations are most conveniently described in cylindrical geometry. All dynamical variables (n_A, $\vec{V}_A$, I_{Aa}, T_A, A^a_μ) depend, in general, on the cylindrical coordinates (z,ρ,θ). The symmetry in the problem, however, reduces this dependence to coordinates z and ρ only, so that the dynamic quantities are independent of the azimuthal angle θ. But for the case of an infinitely thin slab, the symmetry will make these quantities independent of ρ. Before we write down the equations for screening it is worth emphasizing again that, our interest is in non-abelian features of screening, and the simple 1-dimensional problem (as we shall see) exhibits some of them. The actual two dimensional problem, of the screening of a point charge, would surely contain these effects with different geometrical factors, and perhaps some additional features, not present in the 1-dimensional geometry.

As the point source is immersed in the fluid, the colored fluids are polarized and color potentials and color currents get generated. We restrict our attention to the steady state problem by setting all time derivatives $\frac{\partial}{\partial t} = 0$. The coupling with the magnetic sector may dropped if the velocity of the test source is non-relativistic i.e. $V_o << 1$ and hence we set $A^1 = A^2 = 0$. In addition we choose to work in an axial gauge with $A^3_a = 0$. Thus, we need to consider only the time like component A^o_a of the color potential.

The equations for studying screening of an infinite sheet source can be obtained from Eqs. (4.1) and the Yang-Mills equations. With the flow in z-direction they are,

$$\frac{d^2 A^o_a}{dz^2} = -g\sum_A n_A I_{Aa} - 4\pi\, g\, K^a \delta(z) \tag{4.3a}$$

$$g\, \varepsilon_{abc}\, A^o_b \frac{d}{dz} A^o_c = g\sum n_A\, V_A\, I_{Aa} \tag{4.3b}$$

$$\frac{d}{dz}(n_A\, V_A) = 0 \tag{4.3c}$$

$$g\, I_{Aa} \frac{d}{dz} A^o_a = -\frac{1}{n_A} \frac{d}{dz} P_A \tag{4.3d}$$

$$V_A \frac{d}{dz} I_{Aa} = -g\, \varepsilon_{abc}\, A_b^o\, I_c \tag{4.3e}$$

Eq (4 3a) and (4.3b) are respectively, the Gauss law and Ampere's law relevant to the Yang-Mills fields. In Eq. (4.3a) K^a is the color charge component of the test sheet source. An interesting non-abelian feature is seen in Eq. (4.3b) where, unlike the electrodynamic (abelian) plasma, the steady state currents, affect the static potential in the non-abelian plasmas. In writing Eq. (4.3d), we have ignored the mean energy of each specie compared to the thermal energy of that specie i.e. $\bar{m}_A V_A^2 << T_A$. This is justified as thermal velocity of the plasma particles is comparable to the velocity of light (due to the choice of eos).

Eq. (4.3c) may be readily solved to yield

$$n_1 V_1 = n_o V_o = n_2 V_2 \tag{4.4}$$

Combining (4.4) with (4 3b) we find

$$I_{1a} + I_{2a} = \frac{1}{n_o V_o}\, \varepsilon_{abc}\, A_b^o \frac{d}{dz} A_c^o \tag{4.5}$$

Eq (4.5) may be used to eliminate I_{2a} as a variable.

The force balance equation i.e. Eq. (4.3d) can also be integrated, and we get,

$$T_A = T_o - \frac{\beta\, d_s}{4\, h_s} I_{1b} A_b \tag{4.6}$$

so that the corresponding density is

$$n_A = N_d\, d_s\, T_o^3 \left(1 - \frac{\beta\, d_s}{4\, h_s T_o} I_{1b} A_b\right)^3$$

where S_A is 1 for A = 1 and -1 for A = 2.

Introducing dimensionless variables, we next substitute, $A_a^o = a_o A_a$, $I_{1a} = i_o I_a$, $T_A = T_o t_A$ and $x = z/\Lambda_D$ in the equations, where a_o, i_o, T_o are some normalizing factors, and Λ_D is the linear ("perturbative") Debye length defined by $\Lambda^{-2} = \left(3N_d d_s{}^2/2h_s\right) g^2 i_o^2 T_o^2$. We obtain,

$$\frac{d^2}{dx^2} A_a = I_a(I_b A_b) + 1/3(\beta d_s/4h_s)\, I_a(I_b\, A_b)^3 - \alpha\, \varepsilon_{abc} A_b \frac{d}{dx} A_c \left(1 + \beta d_s/4h_s I_b A_b\right)^3 \text{-source term} \qquad (4.7a)$$

$$\frac{d}{dx} I_a = -\alpha \left(1 - \beta d_s/4h_s I_b A_b\right)^3 \varepsilon_{abc}\, A_b\, I_c \qquad (4.7b)$$

We have defined $\alpha = \dfrac{g\, a_o\, \Lambda_D}{n_o V_o}$, $\beta = \dfrac{g\, i_o\, a_o}{T_o}$

Eqs (4.7a-b) are the final equations describing the screening of a moving ($V_A \neq 0$) test sheet source in a classical QGP.

The parameter $\beta = \dfrac{g\, i_o\, a_o}{T_o}$ is essentially the ratio of "average" potential energy per particle to the average kinetic energy. Thus, as for the electrodynamic plasma parameter, it may also be related to the plasma parameter i.e $\beta = \dfrac{1}{n\, \Lambda^3}$. If we take Debye length $\Lambda_D \sim 1/4$ - 1/3 fm and a typical energy density ~ 2-5 Gev/fm^{3}of the QGP then $\beta \sim 10^{-1} - 10^{-2}$ The parameter $\alpha = \dfrac{g\, a_o\, \Lambda_D}{V_0}$ characterizes the strength of the non-abelian terms in Eq (11a-b). We express it in terms of other physical quantities that we are familiar with, i.e. $\alpha = \dfrac{g a_0 \Lambda_D}{n_0 V_0} = g\beta(\sigma\, \Lambda_D^4\, \varepsilon_{th})^{1/2}(\dfrac{1}{V_0})$,where σ is the mass density and ε_{th} is the thermal energy of the plasma particles. In order to have an estimate about the range of values that α can take, let us assume (arbitrarily) that the test source which moves with non-relativistic velocity V_0, has value V_0 (max)= 0.4. We then get $\alpha > g\ 10^{-2}$.

Introducing dimensionless variables, we next substitute, $A_a^o = a_o A_a$, $I_{1a} = \imath_o I_a$, $T_A = T_o t_A$ and $x = z/\Lambda_D$ in the equations, where a_o, $\imath_o$, T_o are some normalizing factors, and Λ_D is the linear ("perturbative") Debye length defined by $\Lambda^{-2} = \left(3N_d d_s{}^2/2h_s\right) g^2 i_o^2 T_o^2$. We obtain,

$$\frac{d^2}{dx^2}A_a = I_a(I_b A_b) + 1/3(\beta d_s/4h_s)\, I_a(I_b\, A_b)^3 \qquad (4.7a)$$
$$-\alpha\ \varepsilon_{abc} A_b \frac{d}{dx} A_c \left(1 + \beta d_s/4h_s I_b A_b\right)^3 \text{-source term}$$

$$\frac{d}{dx}\, I_a = -\alpha \left(1 - \beta d_s/4h_s I_b A_b\right)^3 \varepsilon_{abc}\, A_b\, I_c \qquad (4.7b)$$

We have defined $\alpha = \dfrac{g\ a_o\ \Lambda_D}{n_o V_o}$, $\beta = \dfrac{g\ i_o\ a_o}{T_o}$

Eqs. (4.7a-b) are the final equations describing the screening of a moving ($V_A \neq 0$) test sheet source in a classical QGP.

The parameter $\beta = \dfrac{g\ i_o\ a_o}{T_o}$ is essentially the ratio of "average" potential energy per particle to the average kinetic energy. Thus, as for the electrodynamic plasma parameter, it may also be related to the plasma parameter i.e $\beta = \dfrac{1}{n\ \Lambda^3}$. If we take Debye length $\Lambda_D \sim 1/4$ - 1/3 fm and a typical energy density ~ 2-5 Gev/fm^3 of the QGP then $\beta \sim 10^{-1} - 10^{-2}$ The parameter $\alpha = \dfrac{g\ a_o\ \Lambda_D}{V_0}$ characterizes the strength of the non-abelian terms in Eq (11a-b). We express it in terms of other physical quantities that we are familiar with, i.e. $\alpha = \dfrac{g a_0 \Lambda_D}{n_0 V_0} = g\beta(\ \sigma\ \Lambda_D^4\ \varepsilon_{th})^{1/2}(\frac{1}{V_0})$, where σ is the mass density and ε_{th} is the thermal energy of the plasma particles. In order to have an estimate about the range of values that α can take, let us assume (arbitrarily) that the test source which moves with non-relativistic velocity V_0, has value V_0 (max)= 0.4. We then get $\alpha > g\ 10^{-2}$.

Eq.(4.7b) has the following obvious constant of motion $I_1^2 + I_2^2 + I_3^2 =$ constant (4.7c)

We first demonstrate that, in the limit V_1, $V_2 \to 0$, the above equations reduce to the usual static test source problem. From equation (4.4) we note that, since n_1 and n_2 are finite even when $V_o \to 0$, V_o/V_A must also stay finite in this limit.If we now multiply Eq. (4.5) and Eq. (4.7b) either by V_1 or V_2 and take the limit V_1, $V_2 \to 0$ we get the following constraint conditions on I_a, A_a and $\frac{d}{dx} A_a$,

$$\varepsilon_{abc} A_b \frac{d}{dx} A_c = 0 \tag{4.8a}$$

$$\varepsilon_{abc} A_b I_c = 0 \tag{4.8b}$$

Eqs. (4.7a)-(4.7b) together with the subsidiary conditions Eqs. (4.8a) and (4.8b) describe screening of a static infinite sheet source in QGP. We note that all the non-abelian terms disappear from the equations and the screening is essentially abelian. Note also that Eq. (4.7b) is redundant since I_a ($a = 1,2,3$) become constant. This shows that for a static source A, $\frac{d}{dx}$ A and I are vectors parallel in color space, while for a moving test source there will be a non-zero angle between them. Thus for a static source all the non-abelian terms from in Eqs(4.7a-b) will vanish and the screening behavior becomes similar to that in the case for Coulomb plasma. Hence one can expect that with increasing α screening behavior should become more abelian (as that is the case with a static source).

We, thus, know the equations that need to be integrated, to study the screening in the plasma when $V_o = 0$ and $V_o \neq 0$. For both the cases they are difficult to solve analytically. We have therefore solved them numerically and the results are presented in the next section However, without solving the equations, we first show the non-abelian effects, in the screening of a moving test sheet source, in the plasma. Eqs. (14a-b) may be combined to generate an equation for $I_a A_a$, viz

$$\frac{d^2}{dx^2}(I_a A_a) = \left[\left(I_a^2 - 6\alpha\theta\, I_a{}' \varepsilon_{abc} A_b \frac{d}{dx} A_c\right)\left(1 + \theta^2/3(I_b A_b)^2\right)\right] \times \left(I_a A_a\right) + \text{source term} \quad (4.9)$$

where $\theta = \beta\, d_s/4\, h_s$.

In the static ($\partial/\partial t = 0$) situation, the "potential" energy $I_a A_a$ is gauge invariant quantity and the equation above shows that it is screened by a non-abelian Debye length Λ_{DNA}, which is a dynamical quantity given by the gauge invariant expression,

$$\Lambda_{DNA} = \left[\left(I_a^2 - 6\alpha\theta\, I_a\, \varepsilon_{abc} A_b \frac{d}{dx} A_c\right)\left(1 + \theta^2/3(I_b A_b)^2\right)\right]^{-2} \quad (4.10)$$

The above equation shows that screening of a moving sheet source in QGP is strongly influenced by dynamical non-abelian effects. From this we define a gauge invariant charge $Q^2_{inv} = I_a^2 - 6\alpha\theta I_a \varepsilon_{abc} A_b \frac{d}{dx} A_c$ which takes into account exchange of color charge with the gauge fields. It ought to be mentioned that the expression for the gauge invariant charge that we have obtained is similar to that obtained in the study of color screening in classical Yang-Mills theories with a single external source.[7] To fully investigate the novel qualitative and quantitative features of this we must solve Eqs.(4.7a,b)numerically. These are presented in the next section.

4.3 Numerical Results and Discussion :

In addition to Eq.(4.7c),we find from Eqs. (4.7a-b) the following conservation laws

$$\sum_a \left(\frac{dA_a}{dx}\right)^2 - \left(I_b A_b\right)^2 - \frac{\theta^2}{6}\left(I_b A_b\right)^4 = \text{constant} \qquad (4.11a)$$

and

$$\sum_a \alpha^2 M_a^2 - \frac{\alpha}{3\theta} I_b M_b = M \qquad (4.11b)$$

where, $M_a = \varepsilon_{abc} A_b \frac{d}{dx} A_c$ and M is a constant.

Eq. (4.11a) has a clear physical interpretation in terms of conservation of the sum of field energy and interaction energy of the particles and fields. Note from Eqs.(4.7a-b) that M_1,$M_2$and $M_3$are related to color charge fluctuations of the Yang-Mills field. The second term on the R H.S of Eq.(4.11b) is a consequence of the exchange of color charge between the fields and the material particles. Eq(4.7c) implies that the magnitude of the color charge is constant and only its precession is permitted by Eq. (4.7b).

The numerical approach, adopted to solve the differential equations for screening, described in the previous section, is the fourth order Runge-Kutta method, with variable step size. We also use, the conserved quantities (Eqs. (4.11a-b) and Eq.(4.7c)) as checks on our numerical work The results of numerical solutions are depicted in Figs 1-2. In these figures, we plot the force $I_a E_a \equiv IE$, on a color charged QGP fluid element, due to the infinite test sheet, as a function of the distance from the source. As $I_a E_a$ is a gauge invariant quantity (this is clear from the gauge transformation property of Eq. (4.1b)), we find such a plot more physical than the conventional plots of potential vs. distance

To obtain solutions of Eqs.(4.7a-b) we need to specify the boundary conditions on the variables A_a, $\frac{d}{dx}A_a$ and I_a (a=1, 2, 3) at some distance away from the source. However, all these variables are gauge dependent. To study the screening in gauge independent way, we construct useful gauge invariant physical quantities from A_a, $\frac{d}{dx}A_a$ and I_a such as — potential energy I_aA_a ,force IE, the gauge invariant charge Q^2_{inv} and the three conserved quantities as defined by Eqs.(4.7c,4.11a-b). For a screening solution the non-abelian field strength should vanish exponentially at distances greater than the Debye length. Therefore, it is necessary to have $Q^2_{inv} \to I^2_b$ as $x \to \infty$ i.e. at very large distances from the source, the gauge invariant charge is the invariant color charge carried by the fluid alone whereas the charge carried by the gauge field is vanishingly small.

Before we present the numerical results, a brief discussion about the choice of boundary conditions is in order. Our objective is to study the effect of change in velocity of the moving test charge, on its screening. For this we must vary the parameter α. However, the values of gauge invariant charge Q^2_{inv} and M are seen to depend upon the value of α. Therefore we must vary the parameter α (keeping β fixed)and the boundary conditions on the variables A_a, $\frac{d}{dx}A_a$ and I_a in such a manner that all the six physical quantities, considered above, remain fixed at the boundary.

Fig.(1a) represents the non-abelian screening when the test source is moving. The upper curve corresponds to value α = 15, while the lower curve depicts the case α = 5 (having higher velocity compared to the case with α = 15). If one considers e^{-1}fall off of IE one finds that the screening length is larger for the smaller value of α. Thus the screening is weaker for the smaller values of α. Fig (1b) shows the non-abelian screening for a different set of boundary conditions (compared to Fig.(1a)) and for two different values of α, α =10.(upper curve) and α = 5.(lower curve). Again we consider e^{-1} fall of the force, and we find that the screening length is larger for lower α values.

Note that the force IE now exhibits, novel oscillatory behavior, over and above the usual mean screening effects. Physically, the oscillatory behavior arises, because of the response of non-abelian plasma, to a moving test source. If we compare, the exponential decay length of the "mean" force in the non-abelian case with the abelian case, we find that the former is significantly larger i.e. the mean non-abelian screening is weaker. This feature arises, due to the fact that, color dynamics is involved in the non-abelian screening. The color charge vector of the fluid element precesses, so that, it is not always possible for it to have an opposite orientation, to the color vector of the test charge. Hence it requires a longer distance to screen the field of the test charge. When we change the parameters α and the boundary conditions, qualitative features of screening remain the same, but some details change.

Our results show that if we increase the value of α, screening becomes abelian and oscillatory behaviour slowly diminishes. Moreover, our study shows that non-abelian screening is sensitive to the value of gauge invariant charge Q^2_{inv}. Indeed, the lower curve in Fig.(2) depicts the screening when the boundary conditions on $A_a, \frac{d}{dx}A_a$, and I_a are the same as that of the upper curve in Fig.(1b) but the value of α is changed to 100. Hence the value of gauge invariant charge at the boundary(and also M) is changed. The upper curve in this figure is the same as that in Fig(1b). This figure shows that when the gauge invariant charge is more at the boundary the force become more oscillatory. and the screening is weaker in this case.

It should be emphasized that over many different sets of boundary conditions the numerical solutions have been studied and it was found that the qualitative features of the solutions remains the same. Hence, the general features of our results are independent of any specific choice of the parameters and the boundary conditions. The numerical results presented here are merely representatives of a larger set of parameter choices and boundary conditions.

4.3 Summary and Conclusions :We have studied the dynamic screening, of an infinite color sheet source, moving in quark matter. We find that, due to the motion of the test sheet, the screening behaviour is modified significantly. Further, it is clear from the equations that this is entirely due to the non-abelian nature of the plasma. The new features, we observe are,

1) non-abelian effects come into play only if the test source is moving.

2) increase in the mean screening length - or weakening of screening - due to dynamic non-abelian effects.

3) oscillations in the screening behaviour.

It is hard to see how perturbation theory can reveal these features of the non-abelian screening. The second feature may be understood in a qualitative manner as follows. The orientation (in color space), of the color charge vector $\vec{I}_f$ of the fluid element is not, due to precession, always exactly opposite to that of the color vector of the test source It, therefore, takes a larger distance, to shield the charge on the test source. The third feature of oscillations, appears to be similar in nature, to the non-abelian longitudinal plasma oscillations, discussed in the previous chapter. Also, it ought to be stressed that, non abelian screening is dependent on the value of gauge invariant charge Q^2_{inv} specified at the boundary.

We have not carried out, the two-dimensional calculations of dynamic screening of a point test charge. However, it appears plausible on physical grounds that, the various aspects of screening, found by us in slab geometry, would very likely persist in the full calculation. We believe, therefore, that the contribution of screening of QGP, to J/ψ suppression in ultra-relativistic heavy ion collision, would become quite complex, and needs very detailed investigation for realistic experimental situations.

APPENDIX-A

If two species interpenetrate, there would be some transfer of momentum from one specie to another. In this situation, the equation of motion for the two species can be (phenomenologically) written as

$$m \frac{\partial \mathbf{V}_1}{\partial t} + m\mathbf{V}_1.\nabla\mathbf{V}_1 = gI_{1a}(E_a+V_1xB_a) - \frac{\nabla P_1}{n_1} - \upsilon_m(\mathbf{V}_1-\mathbf{V}_2) \quad (A.1)$$

$$m \frac{\partial \mathbf{V}_2}{\partial t} + m\mathbf{V}_2.\nabla\mathbf{V}_2 = gI_{2a}(E_a+V_2xB_a) - \frac{\nabla P_2}{n_2} + \upsilon_m(\mathbf{V}_1-\mathbf{V}_2) \quad (A.2)$$

Here υ is the collision frequency, which is related to the mean free path[8] and the thermal velocity $<V_o>$ by the formula $\upsilon = \frac{<V_o>}{\ell}$. In the equations above, one can take the length scale for the pressure gradient term to be of the order of screening length Λ_D. Thus, we may neglect the collision term if $P/n\Lambda_D >> \frac{m<V_o>}{\ell}V_h$ where, V_h is hydrodynamic velocity.

We take the Debye length $\Lambda_D \approx 1/4 - 1/3$ fm, and the mean free path[8] $\ell = 0.5$ fm for a QGP with energy density $\varepsilon = 2$ GeV/fm^3, so that $\frac{\Lambda_D}{\ell} \sim 1$. Now for a high temperature plasma, in which the test particle has a large rest mass ($m_q >> T$) we have $<V_o>/V_h >> 1$. Thus, for the model studies discussed in this work the neglect of the collision term is justified.

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Figure Captions

Fig. 1 The screening of the force IE($\equiv I_a E_a$) acting on a fluid element at a distance x from the infinite sheet charge. x is in units of "perturbative" Debye length. The value of the parameter β is 0.1

a) The upper curve represent α = 15 case with the boundary conditions:

A_1 = 0.796827, A_2 = 0.3580845. A_3 = 0.2082261, $\frac{d}{dx} A_1$ = -0.696827, $\frac{d}{dx} A_2$ = -0.2580841, $\frac{d}{dx} A_1$ = -0.4302261, I_1 = 0.81, I_2= 0.3, I_3= 0.5.

The lower curve has α = 5 and the boundary conditions:

A_1 = 0.996827, A_2 = 0.5580841, A_3 = -0.2357739 and the rest of the boundary conditions are the same as the upper curve. Q^2_{inv} = 0.996109 for both the curves.

b) The upper curve represents the case α= 10, with A_1 = 0.9, A_2 = 0.09, A_3 = 0.27, $\frac{d}{dx} A_1$ = -0.741428 $\frac{d}{dx} A_2$ = -0.0741428, $\frac{d}{dx} A_3$ = -0.22485, I_1 = 1.0, I_2 = 0.1, I_3 = 0.3.

The lower curve corresponds to α =5,and the boundary conditions:

A_1 = 0 8007785, A_2 = 1.090078, A_3 = 0.2679821 and the rest of the boundary conditions are the same as the upper curve Q^2_{inv} = 1.1056254 for both the curves.

Fig 2 Caption same as Fig(1) Two cases with different value of Q^2_{inv} are compared

The upper curve is the same as that in Fig (1b).The lower curve corresponds to α = 100. All the boundary conditions are the same as the upper curve and Q^2_{inv} = 1.13488.

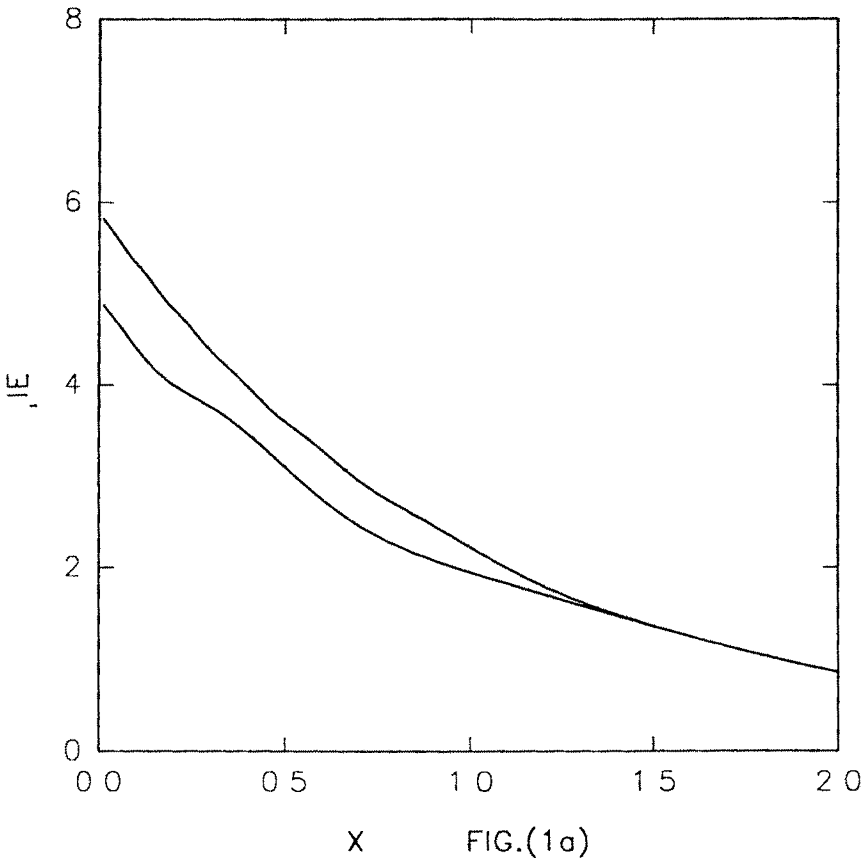

FIG.(1a)

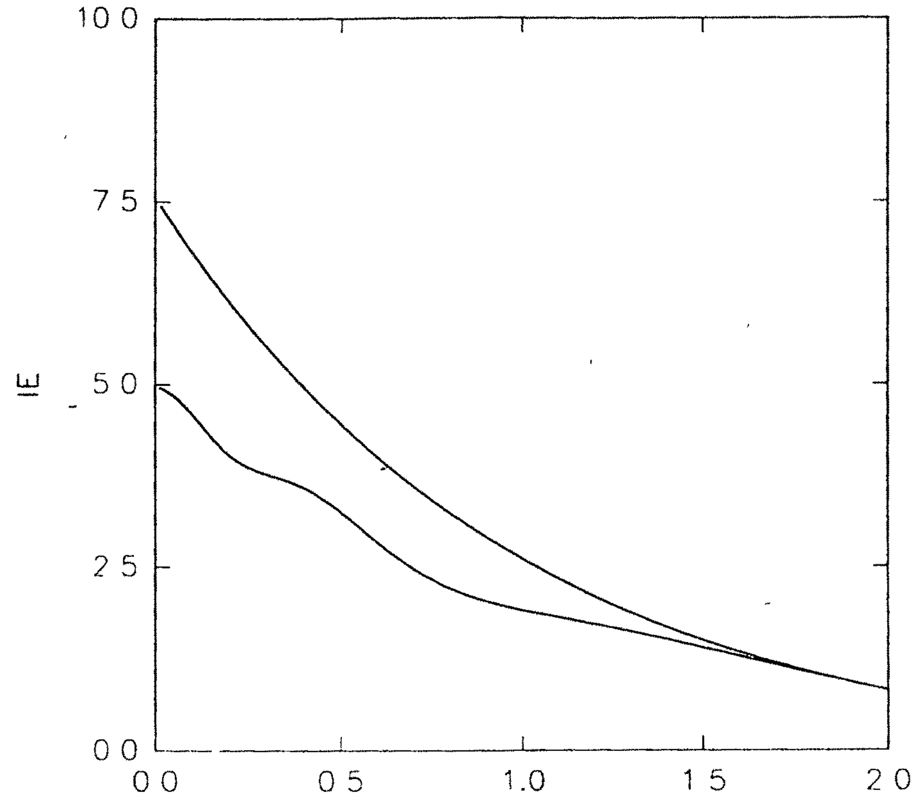

FIG.(1b)

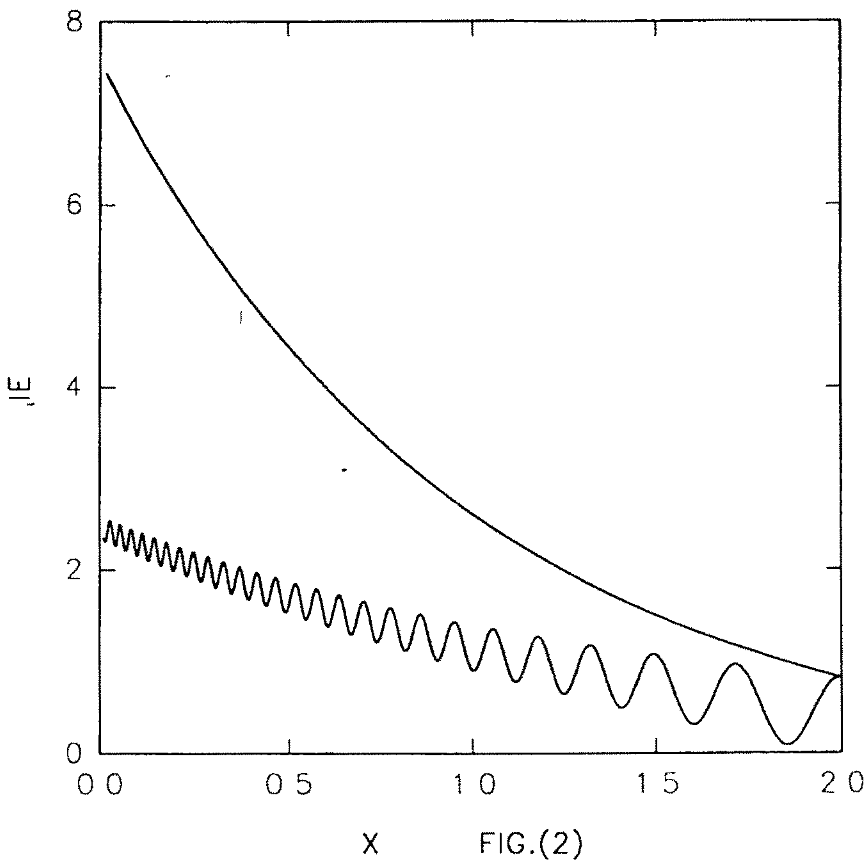

FIG.(2)