Dragging D by hot hadrons

Sabyasachi Ghosh,* Santosh K Das, Sourav Sarkar, and Jan-e Alam
Theoretical Physics Division, Variable Energy Cyclotron Centre, 1/AF, Bidhan Nagar , Kolkata - 700064

The aim of nuclear collisions at Relativistic Heavy Ion Collider (RHIC) and Large Hadron Collider(LHC) energies is to create a phase where the bulk properties of the matter are governed by a deconfined state of (light) quarks and gluons known as Quark Gluon Plasma (QGP). The study of the transport properties of QGP is a field of great contemporary interest and the heavy flavors, namely, charm and bottom quarks, play a crucial role in such studies. The interaction of heavy quarks with the QGP can be used to estimate the value of the transport coefficients. A large amount of works have been done on the heavy quarks diffusion in QGP [1](and the references therein) but the diffusion of heavy mesons in hadronic matter has received much less attention so far. The drag coefficient of QGP may be determined from the experimental data on nuclear suppression of heavy flavours. To make the estimate of the drag of the QGP reliable from the analysis of the data the role of the hot hadrons formed from the hadronization of QGP should be taken into consideration and its contributions from the observables must be subtracted out.

In the present work, we demonstrate the importance of the drag of charmed meson (D) in the hadronic sector. We evaluate the drag and diffusion coefficients of a D mesons interacting with thermal pions, nucleons, kaons and η for temperature range relevant for heavy ion phenomenology. The interaction of D with the hadronic matter has been considered within the framework of chiral perturbation theory in which the leading term allows for D scattering via D^* meson exchanges in addition to a contact interaction. The leading order chiral Lagrangian describing the interaction of Goldstone bosons (π,K,η) with the charmed pseudoscalar (P) and vector (P^*_μ) mesons is given by [2]

$$\mathcal{L}_{PP^*\Phi} = \langle(\partial_\mu P - P\Gamma_\mu)(\partial^\mu P^\dagger + \Gamma^\mu P^\dagger)\rangle + ig\langle P^*_\mu u^\mu P^\dagger - P u^\mu P^{*\dagger}_\mu\rangle \quad (1)$$

The vector (Γ_μ) and axial-vector (u^μ) currents contain the Goldstone boson fields. The value of the heavy-light pseudoscalar-vector coupling constant g is obtained by reproducing the experimental $D^* \to D\pi$ decay width of $\sim$ 65 keV with the above interaction Lagrangian. In this work we have also obtained the DN scattering amplitudes proceeding via Λ_c and Σ_c exchanges using the Lagrangian of Ref. [3]. To calculate drag and diffusion coefficients of the D meson from those Lagrangian we have taken the possible elastic D-h (π,K,η,N) scattering processes assuming that the relaxation time for heavy mesons are larger than the corresponding quantities for light hadrons. The details formalism are given in Ref. [4]. We have included form factors in each interaction vertices to take into account the finite size of the hadrons.

In Fig. 1 the variation of drag coefficient with T has been depicted for D-meson. The drag coefficient is the measure of the thermal average of the the momentum transfer weighted square of the invariant amplitude. Therefore, as the temperature of the thermal bath increases the hadrons move faster and gain the ability to transfer larger momentum during their interaction with the D mesons - resulting in the increase of the drag coefficient. We have observed that the pion-D meson interaction plays the most dominant role in the drag coefficients primarily because of the larger phase space density of the pions.

*Electronic address: sabyasachighosh@veccal.ernet.in

However, at higher T the contributions from the nucleons become significant.

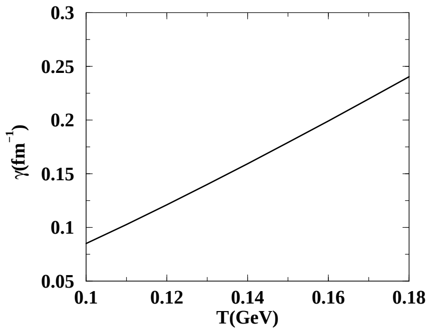

FIG. 1: The variation of drag coefficients with temperature due to the interaction of the D with thermal pions, nucleons, kaons and eta.

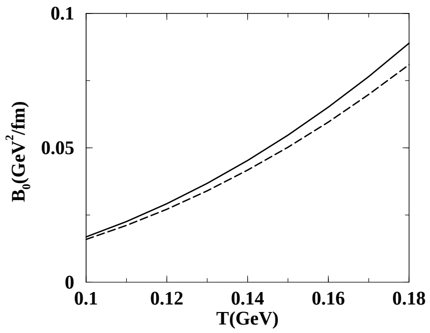

FIG. 2: Variation of diffusion co-efficient as a function of temperature. The slod line indicates the variation of the diffusion coefficient from our calculation. The dashed line stands for the diffusion coefficient obtained from the Einstein relation (Eq. 2).

The large value of the drag coefficient indicate that the interaction of the D meson with the thermal medium is quite significant - such that the the D meson may get thermalize in the system and flow with the bulk matter, which may be examined by analyzing the transverse momentum spectra of the D mesons produced in heavy ion collisions. We find that the typical value of the relaxation time ($\sim \gamma^{-1}$) is about 4-5 fm/c. Therefore, if the life time of the hadronic phase is more than this time scale then the D meson may get thermalize indeed.

We have also evaluated the diffusion coefficient (B_0) of hot hadrons as probed by D meson. The dominant contribution in B_0 comes from the interaction of D mesons with pions. The temperature variation of B_0 obtained from Eq. 2 is depicted in Fig. 2. We observe that B_0 increases with T, this behaviour may be understood from the fact that the diffusion coefficient involves the square of the momentum transfer - which should also increase with T.

The drag and the diffusion coefficients are related through the Einstein relation as:

$$B_0 = M_D \gamma T. \tag{2}$$

where M_D is the mass of the D-meson. The small difference between the results obtained from our calculation and Einstein's relation illustrate the validity of the Einstein relation in the current situation. The value of the spatial diffusion coefficients, D_x may be expressed in terms of drag coefficients as $D_x = T/(M_D\gamma)$. The value of D_x at $T = 180$ MeV is $\sim 2.5/(2\pi T)$.

The value of γ obtained in the present calculation indicate substantial loss of energy of the D meson in the medium, which might have observable effects on quantities such as the nuclear suppression factor of single electrons originating for the decays of heavy mesons. The effect of these transport coefficient on the nuclear suppression (R_{AA}) will be presented at the symposium.

References

[1] S. K Das, J. Alam and P. Mohanty, Phys. Rev. C **80**, 054916 (2009);

[2] L.S. Geng, N. Kaiser, J.Martin-Camalich and W.Weise, Phys. Rev. **D82**, 054022 (2010)

[3] W.Liu and C.M.Ko, Phys. Let. **B533**, 259 (2002).

[4] S. Ghosh, S. K. Das, S. Sarkar and J. Alam, Phys. Rev. D(R) **84**,011503(R) (2011)