Abstract

Heavy quarks (HQs) like charm (c), bottom (b), and their bounds states such as $J/\psi, \Upsilon$, etc. provide a unique framework and tool to systematically investigate the in-medium properties of strong interaction in high energy nuclear-nuclear collisions. This uniqueness is firstly because of the large masses (M) of the HQs compared to the inherent QCD scale (Λ_{QCD}) as well as the emergent scales such as temperature (T) in the thermalized medium that is believed to be created in these nuclear collisions. Indeed, due to a large mass threshold, HQs are not produced in the thermal medium for the temperature range achieved in nuclear collision experiments. Thus, both the production mechanism and number of HQs are controlled by the hard scatterings, mainly gluon-gluon fusion during the initial stages of the collision. Secondly, the vacuum properties of HQs and their bound states are quite well understood in pp collision. Therefore, any modification on HQ observables such as jets and quarkonia properties signals the presence of a thermalized bulk medium consisting of light quarks and gluons.

In nuclear collision experiments, the accelerated beam of charged ions is also responsible for the magnetic field generation. Indeed the strongest field in nature, i.e., $\sim 15m_\pi^2$ at LHC with Pb-Pb nuclei at $\sqrt{s} = 2.75$ TeV/A and $\sim m_\pi^2$ at RHIC Au-Au nuclei at $\sqrt{s} = 200$ GeV/A. Even though this magnetic field decreases rapidly in a vacuum, it may be possible that it stays reasonably strong for a longer time and directly affects the dynamics of light partons and HQ through its interaction with the light partons in a magnetized thermal medium as well as in pre-equilibrium phase. This situation may arise in the case when the system develops a finite electrical conductivity during the thermalization process. There have been many efforts to estimate electrical conductivity both in QGP as well as hadronic medium and its effects on the strength of the magnetic field and its phenomenological implications both theoretically as well as experimentally.

In order to characterize the in-medium properties of strong interaction at RHIC and LHC energy scales, perturbative QCD (pQCD) based analysis are not enough.

Since the non-perturbative nature of QCD arising from confinement and chiral symmetry is dominant near $\Lambda_{QCD} \sim 200$ MeV, one needs to go beyond perturbative analysis. Indeed, at finite temperature, this situation arises near a transition temperature of $T_c \approx 155$ MeV.

In this thesis, we study the magnetic field and non-perturbative effects on the in-medium binding potential of HQ and its anti-quark, collisional energy loss, and transport coefficients, namely the drag and diffusion coefficient. In order to see the magnetic field effect on quarkonia decay width, we first estimate modifications of the real and the imaginary part of quarkonia potential. An increase in the imaginary part of the potential with an increase in the magnetic field suggests that quarkonia dissociate earlier in a magnetic medium compared to its counterpart purely thermal medium.

For single HQ, the collisional energy loss in a magnetized medium suggests that the magnetic field may significantly contribute to the jet quenching. This is because the magnetic field contribution to the energy loss is of similar order as to the case of vanishing magnetic field, at least in the strong field limit where HQ is not directly affected by the magnetic field, i.e., $M \gg \sqrt{eB} \gg T \gg g\sqrt{eB}$. Further, in the low momentum regime, the magnetic field gives rise to anisotropy in the diffusion coefficient. In fact, depending on the relative direction of HQ velocity and magnetic field, one can define five diffusion coefficients. For HQ moving parallel to the magnetic field, diffusion in the transverse direction is larger than that of the longitudinal direction, i.e., $\kappa^{\parallel}_{TT} \gg \kappa^{\parallel}_{LL}$. However, for HQ moving perpendicular to the magnetic field, diffusion along the direction of HQ velocity and perpendicular to the magnetic field is gets, and dominant contribution and diffusion perpendicular to both magnetic field and HQ velocity get the least one, i.e., $\kappa^{\perp}_{TL} \gg \kappa^{\perp}_{LT} \gg \kappa^{\perp}_{TT}$. Out of these five diffusion coefficients, $\kappa^{\parallel}_{TT}$ is the dominant one. Similarly, the transverse drag coefficient $\eta^{\parallel}_{D;TT}$ is the largest one out of five drag coefficients. These estimations suggest that the magnetic field can significantly contribute to the elliptic and directed flow of heavy flavor mesons.

In addition to the magnetic field effects, we investigate the non-perturbative contributions that are significantly large near transition temperature on HQ transport coefficients. This is done withing the matrix model of semi-QGP with input parameters as the expectation value of the Polyakov loop and constituent quark mass. It is observed that with the inclusion of constituent quark mass and Polyakov loop, the drag coefficient is significantly large compared to the one estimated within the pQCD framework. On the other hand, the diffusion coefficient decreases with the momentum. Furthermore, with the inclusion of shear and bulk viscosities, it is observed that the momentum diffusion coefficient increases. This, in turn, gives a small value of the spatial diffusion coefficient. The consistency in the results of various models suggests that the non-perturbative effects on HQ transport are indeed very important for heavy ion collision phenomenology.

Keywords: Quark gluon plasma, Thermal field theory, magnetic field, Quarkonia suppresion in QGP, HQ transport coefficient.