Hadron properties at finite density and temperature

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In non-central heavy-ion collisions, huge magnetic fields are believed to be produced, estimated to be of the order of $eB \sim 15m_\pi^2$ (5×10^{19} gauss) at LHC, $eB \sim 2m_\pi^2$ (6.5×10^{18} gauss) at RHIC. Such a strong magnetic field leads to interesting physical phenomena, such as (inverse) magnetic catalysis of chiral symmetry breaking. In (inverse) magnetic catalysis, the chiral condensate populates with the increase in magnetic field and critical temperature T_c (decreases) increases. Besides magnetic field, the strangeness, isospin asymmetry and temperature of the hadronic medium also play an important role in the modifications of condensates which results in the modification of in-medium properties of mesons [1].

In the present thesis, we investigated the modifications of different mesons properties in dense asymmetric baryonic medium at finite temperature using an effective chiral hadronic mean-field model along side QCD sum rules, $^3P_0$ model, and chiral perturbation theory. Within the chiral model, the effect of isospin asymmetry has been incorporated by the δ and ρ fields. We solved the coupled equations of $\sigma, \zeta, \chi, \delta$ and ρ, ω, ϕ fields under the influence of different medium attributes such as isospin asymmetry, strangeness, magnetic field, and temperature carried by the scalar and vector densities of baryons. The in-medium scalar fields are utilized to compute the light quark condensates and gluon condensates which are incorporated in QCD sum rules to compute medium influenced attributes of open charm D mesons and quarkonia.

At first, we investigated the in-medium mass of charmonia and bottomonia in dense magnetized nuclear matter at finite temperature employing the joint approach of chiral SU(3) model as well as QCD sum rules and observed greater mass shift of P-wave (χ_{c0}, χ_{c1}) charmonia than S-wave ($J/\psi, \eta_c$). We observed very less mass shift of bottomonia (η_b, Υ, χ_{b0} and χ_{b1}) as well [1, 2]. Further, we observed that from both Borel and moment QCD sum rules, the effective mass of quarkonia decrease with an increase in the nucleon density and magnetic field, however, found less magnitude of mass shift in the Borel sum rule than in the moment sum rule. The Borel sum rule is more reliable than the moment sum rule due to the inclusion of deeper perturbative expansion terms and hence have a better region of OPE convergence.

We have further investigated the medium modified isospin averaged masses of spin 0 and spin 1 D mesons under the effect of an external magnetic field at non-vanishing temperature and asymmetry of the nuclear medium by employing QCD sum rules and chiral hadronic model [3, 4]. The prominent effects of magnetic field was found on the charged D mesons, whereas for neutral D mesons, the effects are less. We found a negative (pseudoscalar and vector) and positive (scalar and axialvector) mass shift for D mesons. The intervention of Landau quantization depletes the effect of isospin asymmetry effects for the charged one but for uncharged mesons, it is quite appreciable with crossover effects. We calculated the medium modified decay width of higher charmonia decaying to pseudoscalar $D\bar{D}$ in $^3P_0$ model and observed appreciable changes in the decay width of excited charmonia ψ but less in χ. The calculated decay width of heavy charmonia mass may suppress the J/ψ production and hence its yield decreases.

We further investigated the effective mass of η-meson in zero and non-zero magnetized asymmetric hot nuclear matter using the chiral perturbation theory and chiral hadronic model [5, 6]. The in-medium effects were in-

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troduced through the nucleon scalar density which is computed in the chiral model and found a substantial decrease in the mass of η-meson concerning the magnetic field and nuclear density which is much deeper than the observations of the solo chiral model approach. The effects of isospin asymmetry and temperature are also incorporated and found to be a little repulsive. In both approaches, we observe a direct dependence of negative mass-shift with $a^{\eta N}$ scattering length. Furthermore, due to zero charge on the η meson, we do not observe Landau quantization therefore no additional energy levels were discovered. At finite momentum, the η optical potential in the hadronic matter can be used to study the experimental properties such as momentum dependence and η-meson production rate in the hadronic medium.

At last, using an effective Lagrangian approach we calculated the medium modified mass and decay width of the ϕ-meson by employing the in-medium K and $\bar{K}$ masses from the chiral SU(3) model [7]. At finite temperature, we observed the appreciable effect of the strangeness on the in-medium K and $\bar{K}$ mesons. The kaon baryon interactions in the strange medium lead to a decrease in the K and $\bar{K}$ mass. Despite a significant drop in the K and $\bar{K}$ mass, we observed a small downward mass shift in the in-medium mass of ϕ-meson. The impact of temperature becomes less in the asymmetric baryonic medium whereas becomes high in the symmetric medium. On the other hand, in the same medium, the decay width shows broadening and it decreases with the increase in the strange content of the hadronic matter.

These in-medium properties calculated in the present work can be used in the transport models to evaluate the experimental observables such as invariant mass spectra, decay width, and cross section which can be directly compared with the experiments. The in-medium negative mass-shift of J/ψ, D, η, K and ϕ mesons shows the attractive interaction of these mesons with nuclear matter. The obtained optical potential can be used to understand the spectra of meson-nucleon bound states. Experimentally, the major obstacle is the large momentum transfer related to the charm production. High quality antiproton beams at PANDA will be suitable to instigate charmed mesic nuclei. In addition, at J-PARC E29 experiment with antiproton beam, proposal is to study ϕ-meson bound states. There is also a proposal at JLab (following the 12 GeV upgrade), to study the binding of Helium nuclei with ϕ and η meson. At PANDA, Jlab and J-PARC the outcomes from such experiments are eagerly awaited. Predominantly, we found a good agreement of our model predictions with the outcomes of other non-perturbative effective models such as QCD sum rules, QMC model, and coupled channel approach.

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