HEAVY QUARKONIA UNDER EXTREME CONDITIONS

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Abstract

The present thesis primarily focuses on the investigation of in-medium properties of various light and heavy flavor mesons (HFMs) in the extreme environments of baryon density and/or strong magnetic fields. In low-energy regime of quantum chromodynamics (QCD), the strong coupling constant is large and perturbative approaches are not valid. An effective field theory (EFT) approach is employed, which is inspired from the symmetries and symmetries breaking effects of low energy QCD, to describe the strongly interacting matter. An effective chiral Lagrangian is constructed based on the principles of chiral symmetry and scale symmetry along with their symmetry breaking effects. The scalar (σ, ζ, and δ) fields are introduced within the context of chiral $SU(3)$ model to imitate the scalar quark condensates which arise in the QCD vacuum due to spontaneous breaking of chiral symmetry. The effects of scale symmetry breaking, which leads to trace anomaly of QCD, are considered through a scalar dilaton (χ) field. We use a mean field approximation of the chiral Lagrangian and derive the equations of motion for scalar fields. The effects of baryon density (ρ_B), isospin asymmetry (η), and magnetic field are incorporated through number (ρ_i) and scalar densities (ρ_i^s) of the ith baryons. The medium modifications of the QCD condensates (scalar quark and gluon condensates) are thus calculated.

We further introduce the QCD sum rule (QCDSR) approach to relate the parameters of high energy regime of QCD (in terms of quark and gluon degrees of freedom) with the low-energy QCD quantities (in terms of hadronic parameters). The correlator functions are the quantities, in QCDSR approach, which can be calculated reliably in both high energy perturbative regime

of QCD as well as in hadronic framework. The finite energy sum rules (FESRs) are solved to find in-medium masses of light vector mesons (ρ, ω, and ϕ) from medium modified QCD condensates. These light vector mesons can lead to e^+e^- production in heavy ion collision (HIC) experiments, and hence the dilepton pairs can serve as good experimental probes to observe their mass variations. The in-medium characteristics of vector mesons can affect dilepton creation in the invariant mass range of these LVMs.

We also discuss the open strange mesons (vector K^* and axial vector K_1) in (magnetized) isospin asymmetric hadronic matter. The in-medium masses are calculated within the QCDSR approach and the effects of baryon density and isospin asymmetry are studied. The effects of strong magnetic field, like Landau quantization and PV mixing, are also investigated on the masses of vector K^* mesons. The in-medium $K^* \to K\pi$ and $K_1 \to K^*\pi$ decay widths are studied from the mass variations of K_1, K^* and K mesons, using the $^3P_0$ model. The decay width for the K^* and K_1 meson is also determined using a phenomenological Lagrangian approach. This present analysis of open strange particles might find relevance in HIC experiments in the Relativistic Heavy Ion Collider (RHIC) low-energy scan programme and the High Acceptance DiElectron Spectrometer (HADES) Collaboration at GSI, Darmstadt.

We also investigate the in-medium masses of charmonium and bottomonium states in isospin asymmetric nuclear matter in presence of an external magnetic field within a chiral effective model. These mass modifications are obtained from the medium modified dilaton field. The values of the dilaton field (χ) along with the scalar (σ, ζ, and δ) fields are solved within the chiral $SU(3)$ model by accounting for the effects of Dirac sea (DS) as well as anomalous magnetic moments (AMMs) of nucleons. When AMMs are neglected, both at zero density and at nuclear matter saturation density, ρ_0, the Dirac sea contributions are found to result in enhancement of the quark condensates (through σ and ζ fields) with increase in magnetic field, an effect called the 'magnetic catalysis (MC)'. However, the inclusion of AMMs is observed to lead to the opposite trend of 'inverse magnetic catalysis (IMC)' for $\rho_B = \rho_0$. Further, the magnetic field leads to PV mixing and these effects are quite notable for larger magnetic field. This might have observable consequences on the creation of the heavy quarkonia and open HFMs, resulting from ultra-relativistic peripheral HIC experiments, where the created magnetic field can be huge.

We further study the production cross-sections of heavy quarkonium states (HQS), such as $\psi(3770)$ and $\Upsilon(4S)$, from the scattering of $\bar{D}D$ and $\bar{B}B$, respectively, in magnetized nuclear medium. These are studied from the medium modifications of the masses and partial decay widths to open charm (bottom) mesons of these HFMs. The contributions of PV mixing, Dirac sea (DS), and the AMMs of nucleons are also considered. The radiative decay widths of vector (V) HQS to pseudoscalar (P) mesons $(J/\psi \rightarrow \eta_c(1S)\gamma, \psi(2S) \rightarrow \eta_c(2S)\gamma$ and $\psi(1D) \rightarrow \eta_c(2S)\gamma$ for the charmonium sector and $\Upsilon(NS) \rightarrow \eta_b(NS)\gamma, N = 1, 2, 3, 4$, for the bottomonium sector) are also investigated, from the medium modified masses of involved mesons. The PV mixing induces a mass difference in the transverse and longitudinal component of vector meson, which is seen as a double peak structure in the invariant mass spectrum of the production cross-section of $\psi(3770)$. The modifications of the production cross-sections as well as the radiative decay widths of HQS, in magnetized nuclear matter, might have observable consequences on the creation of these HFMs resulting from ultra-relativistic peripheral HIC experiments.