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Topic of Research: A Theoretical Study of Hot and Dense
Matter Produced in Ultra-Relativistic Heavy-Ion Collisions

Findings

The first part of the thesis focuses on chiral dynamics within the Nambu–Jona-Lasinio (NJL) model, which provides an effective description of low-energy QCD by encoding the essential symmetry properties of the theory. Within this framework, spontaneous chiral symmetry breaking is realized through the formation of quark condensates in both 2 and 3 flavor model, leading to the generation of constituent quark masses that are significantly larger than the corresponding current quark masses. The temperature (T) and quark chemical potential ($3\mu_q = \mu_B$) dependence of the quark condensates is studied by solving the gap equations self-consistently. The restoration of chiral symmetry is analyzed by tracking the behavior of the order parameter as a function of T and μ_B , and the corresponding reduction of the constituent quark masses is quantified. The resulting chiral transition is characterized in terms of its crossover or first-order nature depending on the region of the phase diagram under consideration.

Building upon the medium-dependent constituent quark masses obtained from the NJL model, the second part of the thesis addresses the calculation of baryon masses in hot and dense matter. A mass formula of the constituent quark model is employed, in which the baryon mass is expressed as a function of the effective masses of its valence quarks along with appropriate interaction terms. This approach allows for a transparent connection between chiral symmetry restoration at the quark level and modifications of hadronic properties in the medium. The temperature- and baryon chemical-potential-dependent baryon masses are evaluated over a wide range of thermodynamic conditions, with particular emphasis on their deviation from the corresponding vacuum masses defined at $T = 0$ and $\mu_B = 0$. The analysis demonstrates that baryons composed predominantly of light quarks exhibit a stronger sensitivity to medium effects, while strange baryons show a comparatively milder dependence, reflecting the explicit breaking of chiral symmetry in the strange sector.

In the third part of the work, the calculated medium-dependent baryon masses are incorporated into the excluded-volume hadron resonance gas (EVHRG) model. The EVHRG framework extends the ideal hadron resonance gas by accounting for repulsive interactions among hadrons through finite-size effects, which become increasingly important at high densities. By replacing vacuum baryon masses with their T and μ -dependent counterparts, the thermodynamic pressure, number densities, and particle yields are recalculated in a manner that consistently reflects chiral medium effects on the hadronic spectrum. Using this modified EVHRG model, relative hadron yields and particle ratios are evaluated and compared with experimental data. The correlation between K^-/K^+ & $\bar{P}/P$ is also studied.

The chemical freeze-out conditions are subsequently extracted by imposing standard thermal criteria within the modified EVHRG framework, such as fixed energy per particle. The re-

sulting freeze-out parameters (T_{ch}, μ_B) are systematically compared with those obtained in other phenomenological studies and statistical models. The comparison demonstrates that the inclusion of medium-dependent baryon masses leads to noticeable shifts in the freeze-out curve, especially at lower collision energies where baryon density effects are significant. These findings suggest that chiral dynamics plays a non-negligible role in determining the chemical freeze-out conditions of strongly interacting matter.

In the final part of the thesis, the results obtained for the hadronic phase are combined with a description of the quark gluon phase (QGP) in order to construct the QCD phase diagram. The quark–gluon plasma is modeled using kapusta’s equation of state that incorporates constituent quark masses and perturbative expansions in the coupling constant upto 3^{rd} order. The phase boundary between the hadronic and deconfined phases is determined by applying the Gibbs criteria for a first-order phase transition, which requires the equality of temperature, chemical potential, and pressure in the two phases. By matching the modified EVHRG equation of state to that of the quark–gluon plasma, the transition line separating confined hadronic matter from deconfined quark matter is obtained in the (T, μ_B) plane. The influence of medium-modified masses on the location and shape of the phase boundary is analyzed, and the resulting phase diagram is discussed in the context of existing theoretical and phenomenological studies. Moreover the implications of strict strangeness conservation in HRG on quark-hadron phase transition is discussed in detail.

Overall, this thesis establishes a coherent link between chiral symmetry breaking at the microscopic level and observable thermodynamic properties of strongly interacting matter. By consistently incorporating temperature- and chemical-potential-dependent constituent quark and baryon masses into the hadronic equation of state, the work provides new insights into particle production, freeze-out conditions, and the nature of the QCD phase transition from confined to deconfined matter.