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Thermodynamics and Phase Structure of Strongly-Interacting Matter

At high densities and/or temperature the theory of the strong interaction between elementary particles (QCD) can be solved perturbatively. But phenomena like chiral symmetry breaking and confinement are shielded from these calculations due to the divergence of the perturbative coupling constant. Alternatively, lattice calculations are a well-established non-perturbative method. However, these are constrained to vanishing or small baryonic densities preventing investigations of the whole phase diagram. Therefore, effective models that capture the major properties of QCD are an important companion tool to investigate properties of the strong interaction which can be probed in relativistic heavy ion collisions and by observations of compact stars. A Polyakov-loop quark-meson model will be motivated that is capable to reproduce the temperature dependence of results with non-perturbative calculations at vanishing density. Crucial ingredients for this are to include the quark back-reaction on the gauge-field dynamics and quantum and thermal fluctuations of quarks and mesons. After adjusting all parameters to reproduce lattice results at zero density, the framework is tested against the curvature of the phase transition line with increasing baryonic density as extracted from lattice calculations. It agrees with the latter as well as with chemical freeze-out data from particle yields of relativistic heavy ion collisions. The situation is different in the test against the isospin dependence of the pseudo-critical temperature where the model is in tension with lattice data which are away from the physical point and which indicates the need of further ingredients. Finally, the phase structure of the three-dimensional temperature - isospin - quark density phase diagram is investigated. A first order phase transition region remains at large baryonic density and small temperature and which shrinks with increasing isospin density. The equation of state at zero temperature is applied to calculate the mass-radius relation of compact stars. It allows within a restricted parameter range for pure quark stars with masses of up to two solar masses as those of recently observed pulsars. The process of nucleation in the first order region is investigated and the surface tension for the phase transition calculated. The consequences of its results for the early Universe, proto-neutron stars and heavy-ion collisions are discussed.

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