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Hadronic and partonic composition of QCD matter across the crossover

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We construct a simple equation of state of strongly interacting matter at zero chemical potentials that provides a unified description of lattice QCD thermodynamics in terms of hadronic and partonic degrees of freedom. The hadronic phase is described by the quantum van der Waals hadron resonance gas, extended by excluded-volume repulsion between mesons, while the quark-gluon plasma is modeled as an ideal gas of quarks and gluons supplemented with a phenomenological interaction term proportional to T^3. The two regimes are connected by a smooth crossover switching function. The three model parameters - the meson hard-core radius, the strength of the partonic interaction term, and the switching temperature - are determined from a fit to lattice QCD results for the trace anomaly. The resulting equation of state reproduces the lattice data on the pressure, entropy density, energy density, and speed of sound in the temperature range $T = 100 - 500$ MeV. The fit yields a meson hard-core radius $r_M \simeq 0.2$ fm, a partonic interaction scale $A \simeq 600$ MeV, and a switching temperature $T_0 \simeq 216$ MeV, substantially exceeding both the pseudocritical temperature of the QCD chiral crossover and the chemical freeze-out temperature. This finding suggests that the transition from hadronic to partonic degrees of freedom is considerably more gradual than indicated by the chiral pseudo-critical temperature alone, with hadronic states remaining an important component of strongly interacting matter up to temperatures of about 250 MeV, well above the QCD chiral crossover.

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