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Zubarev's Nonequilibrium Statistical Operator Approach –Applications to Chemical Freeze-out

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The exploration of the phase diagram of quantum chromodynamics (QCD) is performed in ultrarelativistic heavy-ion collision experiments, whereby the LHC and SPS facilities at CERN Geneva and the RHIC at Brookhaven National Laboratory provide high-quality data on the production of particles (hadrons and nuclei). While for the interpretation of the data a statistical equilibrium approach (hadron resonance gas) is generally accepted, a quantum statistical description of these strong nonequilibrium processes is needed, based on the time-dependent statistical operator $\rho(t)$.

In this talk, we outline Zubarev's method of the nonequilibrium statistical operator (NSO) [1,2] as a fundamental approach to describe nonequilibrium processes and present recent applications to understand chemical freeze-out in the QCD phase diagram. We trace the origin of the freeze-out lines to their correlation with the Mott lines for the dissociation of bound states in a hot and dense medium [3-6].

[1] Zubarev, Morozov, Röpke, Statistical Mechanics of Nonequilibrium Processes II, Wiley (1997)

[2] D. Blaschke et al. (Eds.), Nonequilibrium Phenomena in Strongly Correlated Systems, Particles (2020)

[3] Dönigus et al., PRC 106 (2022) 044908

[4] Blaschke et al., PLB 860 (2025) 139206

[5] Vitiuk et al., arXiv:2409.09019, PRC (2025)

[6] Röpke et al., arXiv:2411.00535

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