論文の内容の要旨

Schwinger Mechanism in QCD and its Applications to Ultra-relativistic Heavy Ion Collisions

(QCDにおけるSchwinger機構と，その超相対論的重イオン衝突事象への応用)

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In the presence of strong classical gauge fields, one encounters essentially new phenomena that are not observed in the vacuum. Such phenomena are collectively called "strong-field physics", which has been attracting attention of many researchers in various fields in physics. One of the most intriguing examples of the strong-field physics is spontaneous particle production from strong classical gauge fields, i.e., the *Schwinger mechanism*. The Schwinger mechanism has a long history especially in the context of the Quantum ElectroDynamics (QED), however, there still remains a number of unsolved problems. Formulation of the Schwinger mechanism in Quantum ChromoDynamics (QCD) and its application to the pre-equilibrium stage dynamics of ultra-relativistic heavy ion collisions are examples of the problems.

In the first half of this thesis, we formulate the Schwinger mechanism in QCD based on quantum field theory, including backreaction effects from quark, gluon, and ghost fluctuations. To be more specific, we consider quantum fluctuations of quarks, gluons, and ghosts on top of a classical color gauge field. By adopting mean field approximation for the quantum fluctuations appearing in the QCD Lagrangian, we derive a set of linear differential equations for the fluctuations, which accounts for particle production, backreaction, and (partial effects of) scatterings. Within the mean field approximation, we extensively study the Schwinger mechanism in QCD both analytically and numerically. For instance, we discuss finite pulse effects for particle production; the plasma oscillation induced by the backreaction; quantum interferences among created quarks and gluons; chemical composition of produced matter; and an evolution towards isotropization of the system.

In the last half of thesis, we apply the formalism to the pre-equilibrium stage dynamics of ultra-relativistic heavy ion collisions by modeling initial color flux tubes existing just after a collision with a boost-invariantly expanding, and spatially uniform classical electric field. By numerically tracing the time-evolution of the classical field strength, quark and gluon distribution functions, and thermodynamic quantities such as pressure and energy density, we reveal how the system evolves towards a formation of quark-gluon plasma in ultra-relativistic heavy ion collisions. In particular, we show (i) the classical electric field decays quite fast ~ 3 fm/c because of the decoherence of the classical field into quantum quark and gluon particles and the longitudinal expansion of the system; (ii) huge number of quarks ~ 1000 per unit rapidity are produced very quickly ~ 1 fm/c; and (iii) because of the decoherence and the longitudinal expansion, the system becomes less anisotropic as $\langle : \hat{P}_z : \rangle / \langle : \hat{P}_\perp : \rangle \sim 0.5$ within a few fm/c.