1 Abstract

It is a well known fact that quarks and gluons are confined in colorless particles, called *hadrons*. However, at high temperature and densities, a new state of matter emerges, where quarks and gluons are free to occupy color states: the *quark gluon plasma* (QGP). Many theoretical and experimental attempts have been done in searching for this state. It is believed that up to a few milliseconds after the Big Bang, the Universe was in a quark-gluon plasma state [1], whence the strong interest in this state of matter.
Important experimental efforts have been set up to look for signatures of the QGP phase and to study the properties of this new state of matter at the Large Hadron Collider (LHC) and at the Relativistic Heavy Ion Collider (RHIC). One of the possible signature could be given by suppression and enhancement of quarkonia states (mainly J/Ψ). Then it is natural to look for models which describe heavy quark diffusion in QGP.
In the first chapter of this thesis we briefly review few facts about QGP, which motivate this study. Then we discuss the problems that may arise using usual perturbation theory for QGP, and more in general for an hot gauge theory [2]; this leads to the introduction of the so called *hard thermal loops* (HTL), which we briefly review.

This work emerges as a natural continuation of previous works [3, 4, 5]; these introduce and study a model for heavy quarks propagation in the plasma. The model consists of an Abelian QED plasma where only Coulomb interactions are retained; heavy quarks are treated as non relativistic particles. The Abelian nature of the plasma simplify computations; through the analogy of the HTLs in QED and QCD the results are related to the non-Abelian case. The final result of these works is the derivation, through an open quantum system approach, of a Langevin diffusion equation in the classical limit and the numerical study of the latter [4].
In the second chapter we introduce the model and we discuss the relevant approximations, in particular the weak coupling limit and the quasi-instantaneous approximation. We do not take the classical limit, but we keep track of the quantum nature of the heavy particles. The final result of this procedure is a path-integral expression for the density matrix of the heavy particles, with the associated Feynman rules for the perturbative evaluation of the latter. This represents the first and probably the most important result of this work. Many of the techniques used are taken from similar problems in other fields of physics, in particular in soft matter physics [6].

In the last chapter we study the first simple application of the result obtained for the density matrix. We focus on one particle diffusion; this simple case enables us to show how to use simple computations with the Feynman rules derived and to discuss the validity of the perturbative expansion. Furthermore, it makes possible to apply a standard diagrams resummation technique, which, with the instantaneous approximation, leads to the derivation of a Linblad equation for the density matrix of one heavy particle. However the study of the latter forces us to retract the assumption made in the derivation. Finally we discuss the results and we state an integral Bethe-Salpeter equation, which may possbly solve the problems found in the study of the Linblad equation.

References

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