3 Hard thermal loops

3.1 Introduction

Around 1988 the following problem arose in thermal field theory: one-loop calculations of the gluon damping rate in the high-temperature limit turned out to be gauge dependent, see e.g. [38] and references therein, although it was generally believed that this physical quantity should be gauge independent (as was proven later [72]). The problem was even more accentuated by the fact that in certain gauges the damping rate turned out to be negative, which would indicate the instability of the quark gluon plasma. The cause of the problem is that at one-loop the dominant contribution to the integration over soft momenta is of order $gT$. For these momenta there are higher-loop corrections that are not suppressed. This situation is similar to the one in section 2.3 (as discussed particularly in remark 1. in section 2.4), where for a small mass $m << T$ loop corrections exist that are unsuppressed also. The solution to the damping rate problem is that these unsuppressed contributions need to be resummed. The resummed one-loop contribution to the damping rate is gauge independent and positive [32].

The terms that need to be resummed to obtain a consistent perturbation theory are called hard thermal loops (HTL's). By definition the hard thermal loops are loop-contributions from the integration region $K \sim T$ that are as large as the tree-level contribution for (external) momenta $P \sim gT$ [31].

We have encountered already an example of a hard thermal loop, namely the tadpole self-energy in $\lambda \phi^4$-theory, see section 2.3. We recall that the tadpole self-energy is of order $\lambda T^2 \sim g^2 T^2$, setting $\lambda \sim g^2$. The tree-level part of the two-point vertex function is $P^2 - m^2$. For $P, m \sim gT$, the tadpole self-energy is as large as the tree-level part. Hence, it is a hard thermal loop. This is the only hard thermal loop that occurs in $\lambda \phi^4$-theory. The need for resummation of this contribution was already discussed in section 2.4; see remark 1.