Dynamical Screening and Radiative Parton Energy Loss in a Quark-gluon Plasma *

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Radiative energy loss has been estimated in various approaches, from uncertainty principle analysis to calculation of induced radiation in a multiple scattering model. A very interesting feature of the radiative energy loss found by a recent study in Ref. [1], referred to as BDMPS in this paper, is that the energy loss depends quadratically on the distance that the parton travels through. BDMPS demonstrated that such a nonlinear dependence arises from the non-abelian gluon rescattering in the medium. Most of these studies used the screened static-potential model for multiple scattering in a hot medium as proposed by Gyulassy and Wang (GW). In the GW model for multiple scattering, the interaction suffered by the propagating parton is assumed to be by a static potential with Debye screening. Such a screened static potential model gives finite cross section and average transverse momentum broadening. Even though BDMPS and Zakharov later on generalized the study to other models of parton scattering, the problem of the magnetic part of one-gluon exchange interaction in a medium and its effect on the radiative energy loss remains unexplored.

In this paper we will study the radiative energy loss of a fast parton inside a quark-gluon plasma including both the electric and magnetic part of the strong interaction. The magnetic part of the one-gluon exchange interaction is not screened perturbatively in the static limit in a hot QCD plasma. One therefore has to introduce a non-perturbative magnetic screening mass $\mu_{\rm mag}$ in order to calculate the parton scattering cross section or the mean-free-path of a propagating parton similar to the calculation of the gluon damping rate. For the calculation of some transport quantities, like the average momentum transfer per interaction, the dynamical screening provided by the imaginary part of the self-energy in the magnetic interaction is enough to regulate the infrared behavior of the magnetic interaction and gives finite results. In both cases, correlation scales provided by the static and dynamics magnetic screening are somewhat different from the static electric screening. They should have significant effect on radiative parton energy loss in a quark-gluon plasma.

The radiative energy loss of a fast parton inside a medium with finite size L is

$$\frac{dE}{dz} = \frac{\alpha_s N_c}{4}\langle p_{\perp W}^2\rangle, \tag{1}$$

for any model of multiple parton scattering, where $\langle p_{\perp W}^2\rangle$ is the total accumulated momentum broadening during the parton's propagation inside the medium which grows linearly with the media length L, *i.e.*, $\langle p_{\perp W}^2\rangle = Ld\langle p_\perp^2\rangle/\mathrm{dL}$. The momentum broadening per unit distance is

$$\frac{d\langle p_\perp^2\rangle}{dL} = \rho\int_0^{\mu^2/B^2} dq^2 q^2 \frac{d\sigma}{dq^2}\,, \tag{2}$$

where ρ is the media parton density, $B = \lambda/L$ with λ being the mean-free-path of the propagating parton and μ is the typical momentum transfer in a parton scattering which is the Debye screening mass μ_D in the GW model of multiple scattering. In a hot quark-gluon plasma, one should include both the electric and magnetic interaction of one-gluon exchange. We have then the parton energy loss in a quark-gluon plasma,

$$\frac{dE_a}{dz} = 4\pi N_c\alpha_s^3 T^3 L C_a 1.42 \ln\left[\frac{9}{2}C_a L \ln\frac{1}{\alpha_s}\sqrt{2\pi\alpha_s ET}\right]. \tag{3}$$

For a fast quark with $E = 250$ GeV traveling through a hot quark-gluon plasma with $T = 250$ MeV and $L \simeq 10$ fm we have

$$\begin{aligned}\frac{d\langle p_T^2\rangle_a}{dL} &\approx 1.9\ \ \mathrm{GeV}^2/\mathrm{fm}\\ \frac{dE}{dz} &\approx 24\ \ \mathrm{GeV/fm}\left(\frac{L}{10\,\mathrm{fm}}\right).\end{aligned} \tag{4}$$

This is about 4 times larger than the original estimate by BDMPS [1].

Footnotes and References

*Phys. Lett. **B485**, 157 (2000).

*[1] R. Baier, et al., Nucl. Phys. B **483**, 291(1997)