Effect of magnetic field on jet transport coefficient $\hat{q}$ for quark and gluon jets

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Jets, produced from hard scattered partons in high energy hadronic and heavy ion collisions, lose their energy via elastic and inelastic interactions with the partons of the quark gluon plasma (QGP) formed in nucleus-nucleus collisions. This phenomena is known as jet quenching. In the heavy ion physics community, its measurement is well practiced through a quantity called jet transport coefficient $\hat{q}$, which is defined by the mean square of the momentum transfer between the propagating hard jet and the soft medium per unit path length. We present the effect of magnetic field on $\hat{q}$ using a simplified quasi-particle model introducing a temperature and magnetic field dependent degeneracy factor of partons, $g(T, B)$. From standard statistical mechanical description, entropy density s for massless QGP can be expressed as

$$s_{QGP} = \left[g_g + g_Q\left(\frac{7}{8}\right)\right]\frac{4\pi^2}{90}T^3 \approx 20.8\,T^3\ , \quad (1)$$

which is known as the Stephan-Boltzmann (SB) limit and lattice quantum chromodynamics (LQCD) data [1] shows that the value of $S(T)$ at eB = 0 will remain smaller than it's SB limit. In our quasi-particle model, we map this T dependent suppression of $s(T)$ by imposing a temperature-dependent fraction $g(T)$, multiplied with the total degeneracy factor of QGP. By matching LQCD data [1] of $s(T, B)$, we get the parametric form of $g(T, B)$ [2]:

$$g(T, B) = a_0 - \frac{a_1}{e^{a_2(T-0.17)} + a_3}\ , \quad (2)$$

where values of $a_{0,1,2,3}$ for different eB's are given in Table I. We assume that $\hat{q}$ is proportional to the effective density of the scatterers in the medium [3], which can be thought of as gluon dominated and expressed as

$$\hat{q}(T) = \frac{\hat{q_N}}{\rho_N}\rho_G(T), \quad (3)$$

where $\hat{q}_N \approx 0.02$ GeV^2/fm and $\rho_N = 0.17$ fm^{-3} is nuclear saturation density at the center of the cold nuclear matter. The $\rho_G(T)$ can be calculated by multiplying $g(T)$ at $eB = 0$ with massless value of gluon density $\rho_G(T) = g(T) \times g_g \times \frac{\zeta(3)}{\pi^2}\,T^3$ and using this in Eq. (3), we get [5]

$$\hat{q}(T) = \frac{\hat{q}_N}{\rho_N} \times g(T) \times g_g \frac{\zeta(3)}{\pi^2}\,T^3 = 3.03 \times \left[a_0 - \frac{a_1}{e^{a_2(T-0.17)} + a_3}\right] \times 1.94\,T^3 \quad (4)$$

Using corresponding parameters $a_{0,1,2,3}$ for finite magnetic field, we can get B dependent degeneracy factor $g(T, B)$, which can

TABLE I: Different values of $a_{0,1,2,3}$ given in Eq. (2) for different magnetic field strengths

$eB(GeV^2)$	a_0	a_1	a_2	a_3
0.0	-0.26	-1.49	-21.58	1.49
0.1	-0.16	-1.20	-22.61	1.33
0.2	-0.47	-2.82	-16.51	2.26

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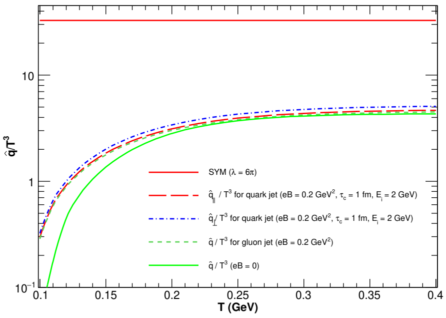

FIG. 1: Temperature (T in GeV) dependence of $\hat{q}_{\parallel,\perp}(eB = 2\text{GeV})/T^3$ (red long dash, blue dash-dotted lines) for quark jet with energy $E_i = 2$ GeV and relaxation time $\tau_c = 1$ fm; $\hat{q}(eB = 2\text{GeV})/T^3$ (green dash line) for gluon jet; $\hat{q}(eB = 0)/T^3$ (green solid line) for both quark and gluon jets; ADS/CFT value (red solid line).

provide us B dependent jet transport coefficient $\hat{q}(T, B)$. In this case, we don't get any anisotropy in $\hat{q}(T, B)$, which means that its parallel and perpendicular components remain same as it does for $B = 0$. Only its isotropic value is modified due to finite B. This picture is relevant for gluon jet due to its chargeless character but for quark jet, its parallel and perpendicular components will be different.

To get anisotropic jet quenching parameter, here we will go for an indirect estimation by using its connection with the ratio between shear viscosity (η) to entropy density (s), η/s [4]. In weakly coupled picture of QGP, an approximate relation $\frac{\hat{q}}{T^3} \approx \frac{s}{\eta}$ is expected. Based on the knowledge of shear viscosity components of quark matter in presence of magnetic field, we can guess the magneto-thermodynamical phase-space structure of parallel ($\hat{q}_{\parallel}$) and perpendicular ($\hat{q}_{\perp}$) jet transport coefficient. Shear viscosity coefficient is basically a proportionality constant between shear stress and velocity gradient. One can get its microscopic expression from relaxation time approximation of kinetic theory framework, where relaxation time τ_c scale will be the main controlling parameter for its numerical values. In presence of magnetic field, along with this τ_c, there will be another time scale τ_B, which will be appear due to cyclotron motion of the charged particle. Knowing the magneto-thermodynamical phase-space structure of parallel and perpendicular components of shear viscosity ($\eta_{\parallel,\perp}$), we can build the relations [5]

$$\frac{\hat{q}_{\parallel,\perp}/T^3}{\hat{q}/T^3} = \frac{s/\eta_{\parallel,\perp}}{s/\eta}\hat{q}_{\parallel,\perp} = \hat{q}\frac{\eta}{\eta_{\parallel,\perp}} ,$$

which give

$$\hat{q}_{\parallel}(T, B) = \frac{47.5}{\left[16 + \frac{7}{8}12\sum_{f=u,d,s}\frac{1}{1+(\tau_c/\tau_{Bf})^2}\right]} \times \left[g(T, B) \times 5.87T^3\right]$$

$$\hat{q}_{\perp}(T, B) = \frac{47.5}{\left[16 + \frac{7}{8}12\sum_{f=u,d,s}\frac{1}{1+4(\tau_c/\tau_{Bf})^2}\right]} \times \left[g(T, B) \times 5.87T^3\right] . \quad (5)$$

We have drawn the curves of $\hat{q}_{\parallel,\perp}/T^3$ (red dash line and blue dash-dotted line) for a quark jet in Fig. 1, where jet energy $E_i = 2$ GeV is entering into $\tau_{Bf} = \frac{E_i}{q_f B}$ for different quark flavors $f = u, d, s$. We have fixed $eB = 0.2$ GeV^2 and $\tau_c = 1$ fm. The green dashed line shows T dependence of $\hat{q}/T^3$ for gluon jet by using $g(T, B)$ in Eq. (4). Green solid line represents $\hat{q}/T^3$ at eB = 0 for both quark and gluon jets. We notice an enhancing trend of quenching parameter in the presence of the magnetic field. For quark jet, a small anisotropy with $\hat{q}_{\perp} > \hat{q}_{\parallel}$ with respect to horizontal red line in Fig. (1), indicating ADS/CFT value, we get very suppressed values of $\hat{q}/T^3$ within the range $1 - 5$ in quark temperature domain, which is in quite well agreement with existing references [3, 5].

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