Scattering of Quark-Quasiparticles in the Quark-Gluon Plasma

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Employing a Brueckner-type many-body approach, based on a driving potential extracted from lattice QCD, we study light quark properties in a Quark-Gluon Plasma (QGP) at moderate temperatures, $T \simeq$ 1-2 T_c. The quark-antiquark T-matrix is calculated self-consistently with pertinent quark self-energies. While the repulsive octet channel induces quasiparticle masses of up to 150 MeV, the attractive color-singlet part exhibits resonance structures which lead to quasiparticle widths of ∼200 MeV.

1. Introduction

Over the past few years the properties of the Quark-Gluon Plasma (QGP) at moderate temperatures have received renewed interest. On the one hand, experimental evidence from the Relativistic Heavy-Ion Collider (RHIC) suggests the formation of a "strongly interacting QGP" to reconcile the phenomenological success of hydrodynamic approaches with the inherent short thermalization times of ∼0.5 fm/c. On the other hand, lattice QCD (lQCD) computations [1,2] indicate the formation of mesonic bound (and/or resonance) states, which are also supported by applications of lQCD-based potentials [3] in a Klein-Gordon equation [4]. To better understand the scattering aspects of this problem, we have recently implemented lQCD-based potentials into a selfconsistent scheme of quark-antiquark T-matrix and quark selfenergies [5], which we will report on in this talk.

2. Brueckner Approach

To obtain a driving term (potential) for a q-$\bar{q}$ scattering equation we take recourse to lQCD calculations of the static free energy for a (heavy) Q-$\bar{Q}$ pair. For temperatures $T\simeq$ 1.1-2 T_c, the unquenched singlet free energy [3] can be reasonably well reproduced by

$$F_1(r,T) = -\frac{\alpha}{r}e^{-a\mu(r,T)r} + \frac{\sigma}{\mu(r,T)}(1-e^{-\mu(r,T)r})\,, \quad (1)$$

where $\mu(r,T) = \frac{\sigma}{b}\exp(-0.3/\mathrm{r})$ is a "screening mass", a and b are fitting functions (see [5] for details), and $\alpha = 0.4$, $\sigma = 1.2\,\mathrm{GeV}^2$, cf. left panel of Fig. 1. The internal energy is obtained by subtracting the entropy contribution to the free energy,

$$E_1 = F_1 - T\frac{dF_1}{dT} \quad (2)$$

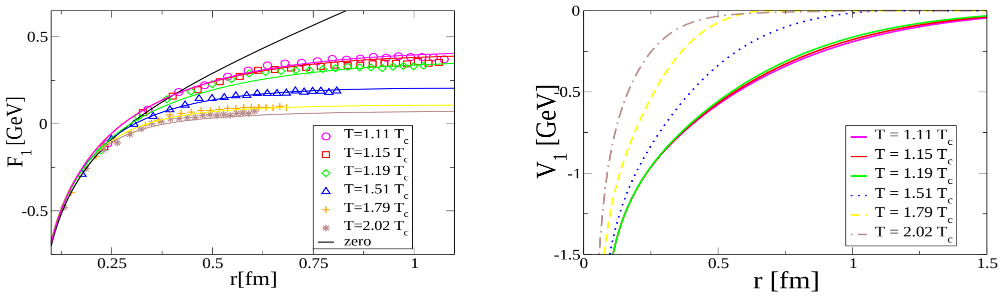

Figure 1. Left panel: color-singlet free energy from unquenched lQCD simulations for 6 different values of the temperature (symbols) compared to our fit function, Eq. 1, represented by the various curves. Right panel: corresponding potentials in the color-singlet channel obtained with Eq. 3 for the same values of the temperature.

and the potential is the defined by subtracting the asymptotic value of the internal energy (which is interpreted as a mass term),

$$V_1(r,T) = E_1(r,T) - E_1(\infty,T)\,. \tag{3}$$

cf. right panel of Fig. 1. We also consider the (repulsive) color-octet channel assuming that the potential follows the leading-order result of perturbation theory, $F_8 = -\frac{1}{8}F_1$. Relativistic corrections are included via a velocity-velocity interaction [6].

The quark-antiquark interactions in the QGP are evaluated in the T-matrix approach, as is well known from the nuclear many-body problem. In relativistic field theory, the starting point is a system of coupled equations,

$$T = K + \int KSST\,, \quad S = S_0 + S_0\Sigma S\,, \quad \Sigma = \tilde{\Sigma} + \int TS\,; \tag{4}$$

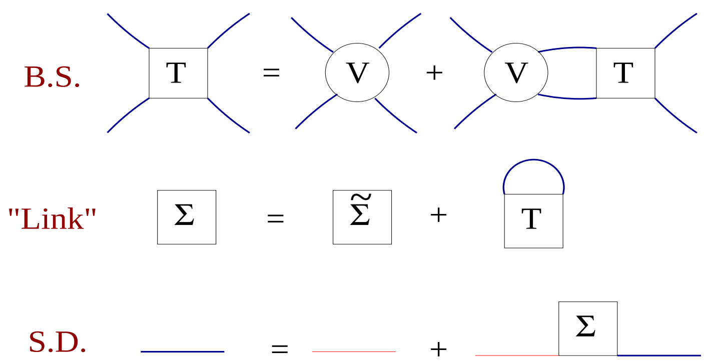

Figure 2. Schematic representation of the self-consistency problem, Eqs. (4). Upper panel (B.S.): Bethe-Salpeter equation, middle panel ("Link"): single-quark selfenergy, lower panel (S.D.): Schwinger-Dyson equation for the quark propagator; thick (blue) lines: full quark propagators, thin (red) lines: bare quark propagators.

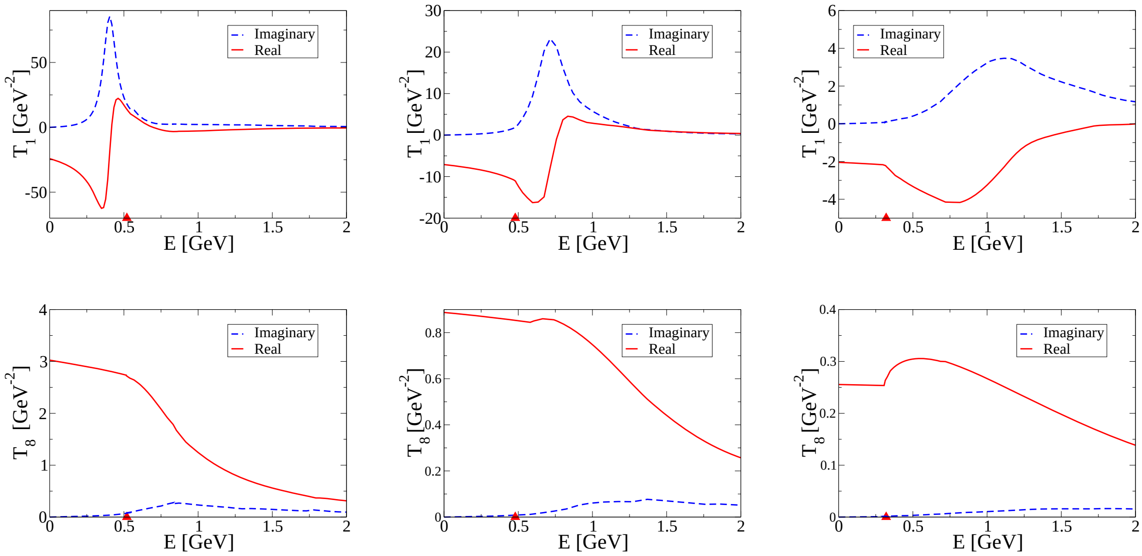

Figure 3. Real (full red line) and imaginary part (dashed blue line) of the T-matrix in the color-singlet (upper panel) and color-octet (lower panels) channels at temperatures T=1.2, 1.5 and 1.75 T_c (left, middle and right panel, respectively) as a function of $q\bar{q}$ CM energy E, with m=0.1 GeV. Red triangles on the x-axis indicate the threshold energy.

the first is a 4-dimensional Bethe-Salpeter equation (K: interaction kernel), the second a Schwinger-Dyson equation for the single-quark propagator, S (S_0: vacuum propagator), where the medium effects are encoded in a self-energy Σ, which, via the third equation, depends on the two-body T-matrix ($\tilde{\Sigma}$ represents a contribution due to quark interactions with thermal gluons which we treat as a "gluon-induced" mass m in the quark dispersion law [5]). Eqs. (4) constitute a self-consistency problem which is diagrammatically illustrated in Fig. 2. After employing an appropriate non-relativistic reduction scheme in line with the potential approximation, we have solved Eqs. (4) by numerical iteration for a vanishing baryon chemical potential implying identical results for quarks and antiquarks.

3. Selfconsitent Scattering Amplitudes and Selfenergies

Fig. 3 summarizes our results for the selfconsistent on-shell T-matrices (real and imaginary parts) with a "gluon-induced" mass term of m=0.1 GeV for 3 different temperatures. At T=1.2 T_c, the color-singlet T-matrix (upper left panel of Fig. 3) exhibits a relatively narrow bound state located significantly below the q-$\bar{q}$ threshold energy, $E_{thr} \simeq 0.52$ GeV. With increasing temperature (middle and right panels), this state moves above threshold (i.e., becomes a resonance) and broadens substantially, being essentially melted at T=1.75 T_c. These results are in qualitative agreement with computations of mesonic spectral functions in (quenched) lQCD [1,2]. The color-octet T-matrix (lower panels of Fig. 3) depends rather smoothly on CM energy, decreasing in strength with temperature with the (repulsive) real part being much larger in magnitude than the imaginary part.

Fig. 4 displays the self-consistent on-shell quark self-energies for the same tempera-

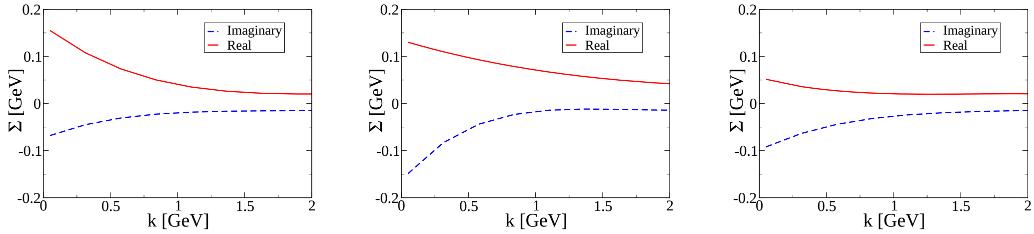

Figure 4. Real (solid line, red) and imaginary (dashed line, blue) part of the on-shell quark self-energy as a function of 3-momentum at temperatures T=1.2, 1.5 and 1.75 T_c (left, middle and right panel, respectively), with m=0.1 GeV.

tures as in Fig. 3. Both real and imaginary parts are smooth functions of the quark 3-momentum with maximal values at k=0. The positive real part mostly arises due to the repulsive color-octet T-matrix with a degeneracy factor of 8 times the singlet one. Pertinent (nonperturbative) thermal quark masses amount to 150 MeV at small momenta for T=1.2-1.5 T_c, decreasing to ∼50 MeV at 1.75 T_c. With the underlying "gluon-induced" mass term of m=100 MeV, the total thermal mass, $m + \Sigma_R$, adds to 150-250 MeV. The imaginary part is chiefly generated by resonant scattering in the color-singlet channel, translating into quasiparticle widths of ∼200 MeV at low momenta.

4. Summary and Conclusions

Anti-/quark self-energies and scattering amplitudes have been evaluated within a self-consistent Brueckner approach using temperature-dependent lQCD-based potentials. Our calculations support the notion of mesonic resonances in the QGP at temperatures below 2 T_c. Pertinent quasiparticles masses and widths are appreciable (∼100-200 MeV) and comparable, qualitatively suggesting that the QGP could be in a liquid-like regime [7].

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