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Modified Surface Tension of a QGP-Droplet Under One Loop Correction in Peshier Potential

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Under one loop correction in Peshier potential surface tension of a Quark-Gluon Plasma (QGP) droplet has been recomputed. The correction reduces the stable size of a QGP droplet. The value of surface tension obtained here is in better agreement with the current lattice result.

Key Words : Quark-Gluon Plasma; Quark-Hadron Phase Transition

Introduction

It is well known that under extreme conditions of hadronic density and/or temperature the hadronic system would split into its fundamental constituents, quarks and gluons, such that the bulk properties of the hadronic system would be governed by these degrees of freedom (Shuryak, 1973). Such a (locally) thermally equilibrated state of matter in which quarks and gluons are deconfined from hadrons, so that color degrees of freedom become manifest over inter nuclear distances rather than just intra nucleonic distances, is called Quark-Gluon Plasma (QGP) (Satz, 1978). The phase transition (Csernai *et al*., 2003; Mustafa *et al*., 1998; Ramanathan *et al*., 2007; Shukla and Mohanty, 2001) might be anticipated during Ultra Relativistic Heavy Ions Collisions (URHIC). So ongoing experiments related to URHIC at RHIC and LHC are much more concerned for the new state.

Under a phase transition, the critical free energy difference between the two phases with the help of liquid drop model is given (Kapusta *et al*., 1995) as:

$$\Delta F = -\frac{4\pi}{3}R^3[P_{had}(T) - P_{q,g}(T)] + 4\pi R^2\sigma + \tau_{crit}T\ln[1 + (\frac{4\pi}{3})R^3 s_{q,g}]. \quad (1)$$

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The surface tension is calculated by minimizing the expression (1) with respect to the droplet size. It is obtained as (Linde, 1983):

$$R_c = \frac{2\sigma}{\Delta p} \; or \; \sigma = \frac{3\pi\Delta F}{4\pi R_c^2}. \tag{2}$$

In this paper, we briefly revisit free energy incorporating one loop correction factor in the mean-field potential and compute, once again, the surface tension of stable droplets. The perturbative part modifies the density of state of the constituent particles of QGP.

Potential with one Loop Correction and DOS

The density of states (DOS) of QGP droplet is determined adapting a phenomenological confining potential $V_{conf}(k)$. The potential is evaluated by considering the interactions between the constituent particles. The calculation is considered with first order correction factor in the potential called mean field potential in phase space. The correction is done in such a way that the expansion of strong coupling constant is perturbed with a loop correction between quark-antiquark and quark-gluons (Ramanathan *et al.*, 2007; Shukla and Mohanty, 2001; Brambilla *et al.*, 2001). It is calculated through the Hamiltonian of system. So the interacting mean field potential is expressed as:

$$V_{\text{conf}}(k) = (2\pi/k)\beta\, \alpha_s(k) T^2 [1 + \frac{\alpha_s(k)}{4\pi} a_1] - \frac{m_0^2}{2k}, \tag{3}$$

where

$$\beta = \sqrt{2} \times \sqrt{(1/\beta_g)^2 + (1/\beta_q)^2} \tag{4}$$

called the effective rms value of parametrization factor of $\beta_q = 1/8$ and $\beta_g = \; (8-10)\; \beta_q$. These factors determine the dynamics of QGP flow and subsequent transformation to the confining colorless hadrons. $\alpha_s(k)$ is the coupling value of quark and gluon with degree of freedom n_f,

$$\alpha_s(k) = \frac{4\pi}{(33 - 2n_f)\ln(1 + k^2/\Lambda^2)} \tag{5}$$

in which QCD parameter is defined as $\Lambda = 0.15\; GeV$. The coefficient a_1 is one loop correction in the interactions (Fischler, 1977; Billoire, 1980) and it is given as:

$$a_1 = 2.5833 - 0.2778\, n_l\;, \tag{6}$$

where n_l is considered with the number of light quark elements (Smirnov *et al.*, 2008).

So the density of states in phase space with one loop correction factor in the potential is obtained through Ramanathan *et al.*, (Ramanathan *et al.*, 2007; Shukla and Mohanty, 2001; Ramanathan *et al.*, 2004) as:

$$\int \rho_{q,g}(k) dk = \frac{\nu}{\pi^2} [-V_{conf}(k)]^2 \frac{dV_{conf}}{dk} \tag{7}$$

or,

$$\rho_{q,g}(k) = \frac{\nu}{\pi^2}[\frac{\beta_{q,g}^3 T^2}{2}]^3 g^6(k) A \tag{8}$$

where,

$$A = \{1 + \frac{\alpha_s a_1}{\pi}\}^2 [\frac{(1 + \alpha_s a_1/\pi)}{k^4} + \frac{2(1 + 2\alpha_s a_1/\pi)}{k^2(k^2 + \Lambda^2)\ln(1 + \frac{k^2}{\Lambda^2})}], \tag{9}$$

ν is the volume occupied by the QGP and k is the relativistic four-momentum in natural units and $g^2(k) = 4\pi\alpha_s(k)$.

The Free Energy Evolution and Surface Tension

With the help of free energies (Peshier *et al*., 1994; Smirnov *et al*., 2008; Ramanathan *et al*., 2004; Neegaard and Madsen, 1999; Christiansen and Madsen, 1997; Balian and Block, 1970; Marder and Sretitsky, 1991; Singh and Ramanathan, 2013; Iwasaki *et al*., 1994) under the loop correction, the surface tension is computed as

Table 1: Surface tension of QGP droplet at $\beta_g = 8\beta_q$,$\beta_q = 1/8$;

T_c (MeV)	ΔF_c (MeV)	R_c (fm)	σ (MeV/fm^2)	$\frac{\sigma}{T_c^3}$
150	242.28	2.57	8.785	0.10
170	263.24	2.60	9.282	0.10
190	510.02	2.61	17.861	0.10
210	678.23	2.59	24.082	0.10
230	861.58	2.55	31.683	0.10
250	1053.00	2.49	40.709	0.10
270	1244.00	2.41	51.002	0.10
290	1430.00	2.32	63.265	0.10

Result and Conclusion

The surface tension at a suitable flow parameter such as $\beta_q = 1/8$, $\beta_g = 8\beta_q$ is evaluated through the expression (2). Now surface tension $\sigma(MeV/fm^2)$ is found to be increasing function with respect to the corresponding temperature of different droplet size in the both parameters. The increment is also observed with high gluon flow parameter at which the stability of QGP droplet is obtained near the hadronic phase. Moreover if we consider the ratio of surface tension to the cube of critical temperature, the result is found to be independent of the critical temperature and constancy is also observed in both cases of flow parameter. Thus surface tension σ is found to be $0.10T^3$ with the correction value in the potential. It increases from the earlier value $0.078\,T^3$ to $0.10\,T^3$. There is an improvement in the result and it becomes closer to lattice value $0.24\,T^3$. This means that result with the correction factor in the mean field potential increases the value of surface tension to a very close result of lattice QCD (Iwasaki *et al.*, 1994). It implies that the loop correction in the potential provides the stability of QGP dynamics with the appropriate flow parameters as well as the surface tension of the droplets with a good result.

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