Study of criticality in Hadron Resonance Gas Model with van der Waals interaction

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Introduction

The ideal or non-interacting Hadron Resonance Gas (HRG) model is quite successful in reproducing the zero chemical potential LQCD data of bulk properties of the QCD matter at low temperatures $T < 150$ MeV. However, disagreement between LQCD data and ideal HRG model calculations have been observed at higher temperatures. Considering excluded volume correction, which mimics repulsive interaction, in HRG model, one can improve the picture in the crossover temperature region $T \sim$ 140-190 MeV [1]. Recently Van der Waals (VDW) type interaction with both attractive and repulsive parts have been introduced in HRG model [2]. Interestingly VDWHRG model shows first order liquid-gas phase transition in nuclear matter at large chemical potentials and small temperatures which was not observed in other HRG models like ideal HRG or EVHRG models.

The motivation of the present work is to find out van der Waals attractive and repulsive parameters a and b that gives the best description of LQCD data at zero chemical potential using VDWHRG model and then extend this work to the finite chemical potential and try to locate the existence of a critical point in the QCD phase diagram.

HRG model with van der Waals interaction

The van der Waals equation of state in the Grand canonical ensemble can be written as

$$p(T, \mu) = p^{id}(T, \mu^*) - an^2,$$

$$\mu^* = \mu - bp(T, \mu) - abn^2 + 2an,$$

where n is the particle number density of the van der Waals gas:

$$n \equiv n(T, \mu) \equiv \left(\frac{\partial p}{\partial \mu}\right)_T = \frac{n^{id}(T, \mu^*)}{1 + bn^{id}(T, \mu^*)},$$

and p^{id}, n^{id} are the pressure and number density in ideal HRG model:

$$p^{id} = \sum_i (\pm) \frac{g_i T}{2\pi^2} \int_0^\infty p^2\, dp \; \ln[1 \pm \exp(-(E_i - \mu_i)/T)],$$

$$n^{id} = \sum_i \frac{g_i}{2\pi^2} \int_o^\infty \frac{p^2 dp}{\exp[(E_i - \mu_i)/T \pm 1}.$$

We assume that baryons are interacting whereas mesons are non-interacting.

Results

We have used LQCD data of $p/T^4, \varepsilon/T^4, s/T^3, C_V/T^3$ and χ_B^2 at $\mu = 0$ [3, 4] to extract the van der Waals parameters in the VDWHRG model. We get $a = 1250 \pm 150$ MeV fm^3 and $r = 0.7 \pm 0.05$ fm in our present work which best describes the LQCD data at $\mu = 0$ within the temperature range $130 - 180$ MeV. The values of the VDWHRG model parameters are obtained using a chi-square minimization procedure. Errors on the parameters are obtained by knowing their values at $\chi^2_{min} + 1$. Figure 1 shows variation of different thermodynamical quantities with the temperature at $\mu = 0$. It can be seen that VDWHRG model can describe Lattice QCD data [3, 5] of different thermodynamical quantities satisfactorily.

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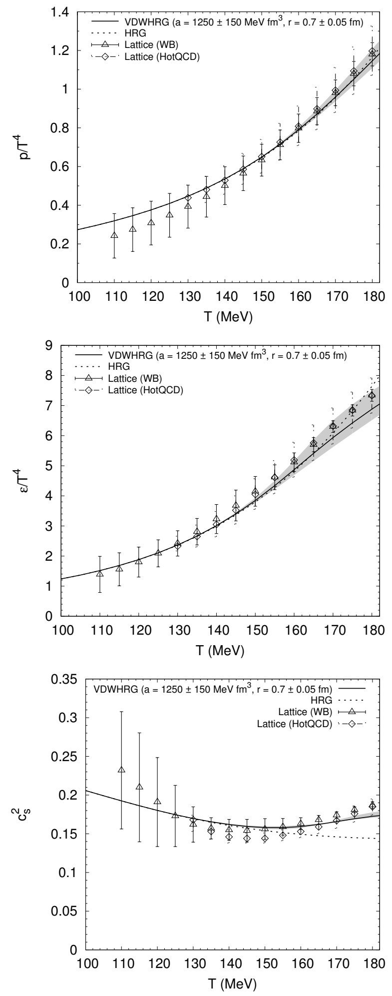

FIG. 1: The variation of different thermodynamical quantities with the temperature at $\mu = 0$. Points are LQCD data and lines are HRG model results.

Top panel of Fig. 2 shows variation of pressure with number density at a fixed temperature in VDWHRG model. Above T = 62.1 MeV, n changes continuously while below this temperature discontinuity in n is observed which might be due to the hadron-liquid first order phase transition. We also show variations of $(\partial p/\partial n)_T$ with respect to μ_B at the bottom of this plot. One can see that at $T = 62.1$ MeV and $\mu_B = 708$ MeV,

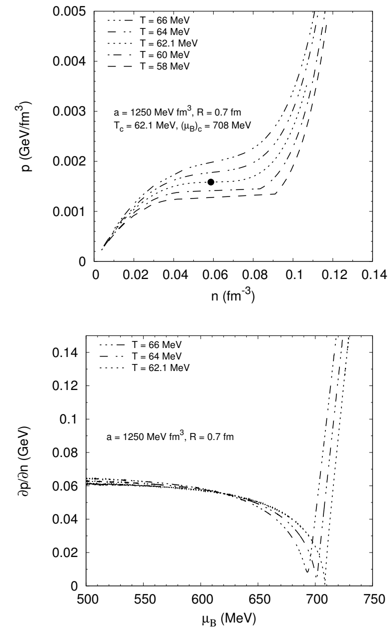

FIG. 2: The variation of pressure with number density (Top panel) and the variation of $\partial p/\partial n$ with μ_B (Bottom panel).

$(\partial p/\partial n)$ becomes zero and above $T = 62.1$ MeV, $(\partial p/\partial n)$ is always greater than zero. So in present work we observe a critical point at $T = 62.1$ MeV and $\mu_B = 708$ MeV.

Acknowledgments

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