Exploring the effect of magnetic field on the liquid-gas phase transition in a hadron resonance gas approach with van der Waals interactions

Bhagyarathi Sahoo,* Kshitish Kumar Pradhan, Dushmanta Sahu, and Raghunath Sahoo
[1] *Department of Physics, Indian Institute of Technology Indore, Simrol, Indore 453552, India*

INTRODUCTION

It is assumed that a strong transient magnetic field ($eB \sim m_\pi^2 \sim 10^{18}$ G) is produced in ultra-relativistic heavy ion collisions due to the motion of the charged spectators. This magnetic field affects the thermodynamic, transport properties, conserved charge fluctuations, polarization of hadrons, QCD medium evolution, and phase diagram of QCD matter [1–3]. Recently, much attention has been given to understanding the QCD phase diagram in the presence of the magnetic field (eB), medium rotation (Ω), isospin chemical potential (μ_I), etc. Obtaining the location of the QCD critical end point (CEP) and understanding the nature of phase transition at CEP in the presence of such dissipative forces is still unclear. In this study, we attempt to study the liquid-gas phase transition in the presence of the magnetic field in a hadron resonance gas (HRG) model with van der Waals interactions among the hadrons.

FORMALISM

The thermodynamic pressure in ideal hadron resonance gas (IHRG) with Grand Canonical Ensemble (GCE) in the presence of a magnetic field is given as

$$P(T,\mu_i,eB) = P_{c,i}^{id,z}(T,\mu_i,eB) + P_i^{id}(T,\mu_i), \quad (1)$$

where, $P_{c,i}^{id,z}(T,\mu_i,eB)$ is the pressure for charged particles in the presence of a magnetic field, and is given by

$$P_{c,i}^{id,z}(T,\mu_i,B) = \pm\frac{Tg_i|Q_i|B}{2\pi^2}\sum_k\sum_{sz}\times \int_0^\infty dp_z\ ln\{1\pm\exp[-(E_{c,i}^z-\mu_i)/T]\} \quad (2)$$

with,

$$E_{c,i}^z(p_z,k,s_z) = \sqrt{p_z^2+m_i^2+2|Q_i|B(k+\frac{1}{2}-s_z)} \quad (3)$$

The $P_i^{id}(T,\mu_i)$ is the pressure for neutral particles, which are unaffected due to the magnetic field, and is given by

$$P_i^{id}(T,\mu_i) = \pm Tg_i\int\frac{d^3p}{(2\pi)^3}\times ln\{1\pm\exp[-(E_i-\mu_i)/T]\} \quad (4)$$

with $E_i = \sqrt{p^2+m_i^2}$ is the energy of i^{th} hadron, T and V represents the temperature and volume of the system. The notations g_i, m_i, and μ_i are for the degeneracy, mass, and chemical potential of the i^{th} hadron, respectively. Here, id denotes to the ideal. The plus and minus signs (±) correspond to baryons and mesons, respectively.

The thermodynamic pressure due to the van der Waals interaction is modified because the chemical potential is changed in the van der Waals HRG (VDWHRG) model, which is given in Ref. [1]. The details regarding the VDWHRG model are given in Ref [1, 4].

RESULTS AND DISCUSSION

The critical point of the phase transition is expected to vary with different types of chemical potential added into the system. We explore the

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* Bhagyarathi.Sahoo@cern.ch

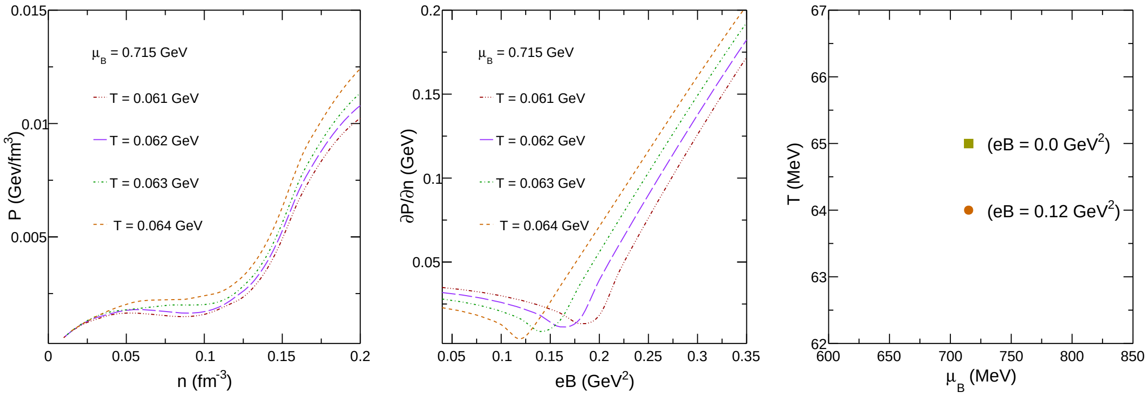

FIG. 1: The variation of pressure (P) as a function of number density (n) (left panel), the variation of $\frac{\partial P}{\partial n}$ as a function of magnetic field eB (middle panel), and the critical point of the liquid-gas phase transition in the QCD phase diagram in the presence of a magnetic field (right panel) [1].

effect of the magnetic field on the critical point and study the liquid-gas phase transition in the $T - \mu_B - eB$ plane using the VDWHRG model. The inclusion of interaction parameters a and b in the VDWHRG model allows us to study the liquid-gas phase transition in the hadronic phase. Using the van der Waals parameters mentioned in Ref. [1], it is observed that the critical point is found around T ≈ 65 MeV, and $\mu_B \approx$ 715 MeV. Taking the same baryochemical potential, we explore the effect of the magnetic field to see its effect on the critical temperature.

The left panel of Fig. 1 shows the variation of the pressure with number density for various values of magnetic field and at a fixed chemical potential, $\mu_B = 715$ MeV. Each curve is for different temperatures taken for the calculation. It is observed that the pressure as a function of number density seems to be constant for temperature T ≈ 64 MeV. To understand this effect more clearly, the slope of the left panel of Fig. 1 is plotted as a function of the magnetic field in the middle panel. It is observed that the $(\partial P/\partial n)_T$ tends to zero at $T = 64$ MeV and μ_B =715 MeV for $eB = 0.12$ GeV^2. This marks the critical temperature below which the number density varies discontinuously, showing the 1st-order liquid-gas phase transition. In the right panel of Fig. 1 the role of the magnetic field is investigated on the critical point in the $T - \mu_B$ plane. The square marker shows the critical point in the absence of the magnetic field, whereas the circle marker shows the critical point in the presence of a magnetic field. We found that in the presence of the magnetic field, the critical point shifts towards lower temperatures, i.e., at $T = 0.064$ GeV, $\mu_B = 0.715$ GeV and eB = 0.12 GeV^2. This indicates that the magnetic field delays the liquid-gas phase transition. Furthermore, considering medium rotation into account, similar phenomena on liquid-gas phase transition is observed in Ref. [4]. Thus, it can be concluded that the critical point depends on parameters, such as, temperature, T, baryochemical potential, μ_B, the magnitude of the magnetic field, eB, and medium rotation, Ω. Hence one can in principle be able to study the four-dimensional variation of the critical point in the $T - \mu_B - eB - \Omega$ plane.

Reference

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