Modelling of Hadronic Interactions and Study of Particle Ratios Using Van der Waals Type Equation of State

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We have incorporated the van der Waals interactions in the framework of a statistical thermodynamical model for a multi-component hadron resonance gas system which is expected to form in the ultra-relativistic nucleus-nucleus collisions. Using this approach we have obtained particle ratios and studied their dependence on temperature and baryon chemical potential of the system. These particle ratios are compared with the corresponding results of the point-like hadron case. It is found that the particle ratios get significantly modified by considering the van der Waals type interactions especially for a baryon rich system. In the van der Waals type equation of state (EoS) both the attractive and repulsive parts of interactions have been taken into account.

Introduction: The particle production in the hot and dense hadronic matter created in the ultra-relativistic heavy ion collisions enable us to understand the final stage properties of hadronic matter. The matter which existed at the very early stages of universe can also be recreated and studied in these collisions. It is believed that the matter created in such nuclear collisions in the laboratory can achieve reasonably high degrees of thermal and chemical equilibrium. The study of the *relative* hadronic yields at ultra-relativistic collision energies is an important tool to explore such properties of the strongly interacting matter produced in such collisions. In the framework of statistical thermal models applied to the hot and dense fireball formed in the ultra-relativistic nucleus-nucleus collisions one can study its final stage properties hadronic matter. The grand canonical ensemble approach can provide a reasonable thermodynamical picture of the hadronic system, because the number of particles in any such HRG system is usually not conserved in the real physical systems formed in the highly energetic nuclear collisions.

Model Calculations: We have developed the thermodynamically consistent Van der Waals type equation of state (EoS) for interacting hadronic matter. This is done by employing the grand canonical ensemble (GCE) formulation with both the attractive as well as repulsive interactions. The repulsive force is assumed to exist between pairs of two baryons and pairs of two antibaryons, while it is purely attractive between a baryon-antibaryon pair. The ideal (i.e. interaction free) grand canonical partition function is given by:

$$\mathcal{Z}(T,\mu,V) = \sum_{N=0}^{\infty} e^{\frac{\mu N}{T}}\, Z(T,N,V) \qquad (1)$$

Here $Z(T,N,V)$ represents the canonical partition function for N number of particles. T and V are the temperature and physical volume of the system, respectively.

By employing grand partition function formulism, we have derived the expression for effective baryon chemical potential (μ_j^*) and modified number density (n_j) for multi-component hadronic matter as:

$$\mu_j^* = \mu_j - \frac{b_j n_j T}{1-\sum_i b_i n_i} + 2a n_j \qquad \text{and}$$

$$n_j = \frac{n_j^{id}(T,\mu_j^*)}{1+\sum_i b_i n_i^{id}(T,\mu_j^*)} \qquad (2)$$

The excluded volume arising due to the jth hadronic species is $(b_j = \frac{16}{3}\pi r_j^3)$, where r_j represents the radius of the j^{th} hadronic species. The summation over the index i in the denominator also includes j.

Results and Discussion: In figure 1, we have plotted the variation of the particle ratios $\frac{\bar{p}}{p}$, $\frac{\bar{\Lambda}}{\Lambda}$ and $\frac{\bar{\Xi}}{\Xi}$ with temperature at fixed value of baryon chemical potential μ_B = 300 MeV, using two models that is Van der Waals type and point like models. We notice the first two particle ratios get enhanced as compared to point like model particularly at higher values of temperature while in the third case the $\frac{\bar{\Xi}}{\Xi}$ ratio gets slightly suppressed using van der Waals type model as compared to the point like model case.

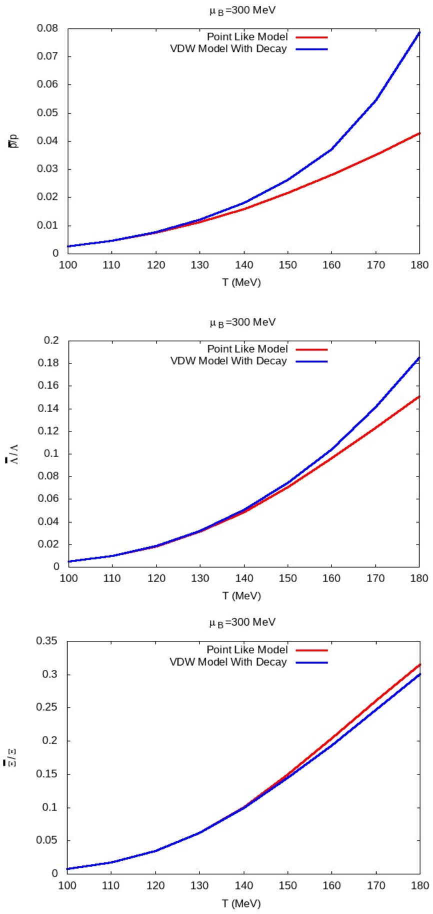

Figure 1: Variation of particle ratios $\frac{\bar{p}}{p}$, $\frac{\bar{\Lambda}}{\Lambda}$ and $\frac{\bar{\Xi}}{\Xi}$ with temperature at fixed baryon chemical potential μ_B = 300 MeV.

This seems to emerge from the fact that cascades (anti)particle consists of two strange (anti)quarks whose number in the system is governed by the strangeness conservation criteria, which is used to extract the value of the strange chemical potential (μ_s). To highlight this we have in the figure 2 plotted the variation of μ_s with μ_B at fixed temperature and vice-versa. The variation of μ_s in two cases shows significantly different behaviour. Consequently, the *relative* abundance of strange hadron is also significantly affected. To highlight this we have in figure 3 shown variation of $\frac{\Lambda}{p}$ ratio with T at fixed μ_B.

Conclusion: We have provided a modified grand canonical ensemble formulation for a multi-component hadronic resonance gas (HRG) system incorporating the van der Waals type interaction. We have considered the attractive as well as repulsive interaction among the constituent baryons (antibaryons). Using our formulation we have calculated several particle ratios and compared them with the case of interaction free point-like HRG system. We find that the inclusion of VDW type interaction can lead to significant modifications in the particle ratios for a baryon rich system at high T.

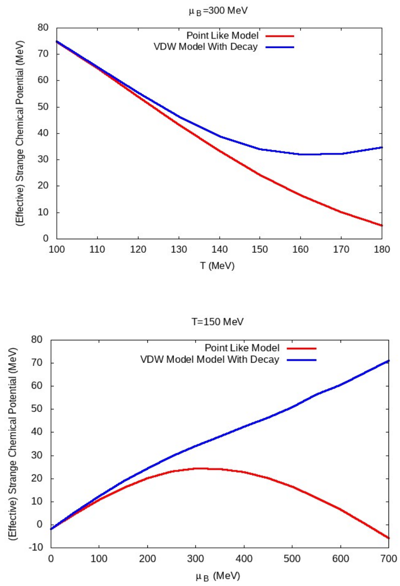

Figure 2: Variation of strange chemical potential (μ_s) with T and μ_B.

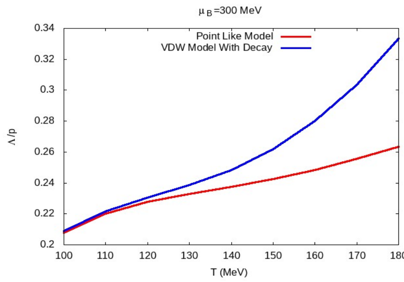

Figure 3: Variation of $\frac{\Lambda}{p}$ ratio with T at fixed μ_B

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