

Name of Scholar: Iqbal Mohi Ud Din

Notification No.: F.NO. COE/Ph.D./(Notification)/602/2026

Name of Supervisor: Prof. Saeed Uddin

Date of Award: 14/07/2026

Name of Department: Department of Physics,
Jamia Millia Islamia

Topic of Research: A Thermal Model Based Study of Particle Production in Hadron Resonance Gas and Formation of Quark Gluon Plasma

Findings

Chapter 1: Introduction

The thesis begins with an introduction to strongly interacting matter and its study through relativistic heavy-ion collisions. The basic concepts of quantum chromodynamics, confinement, asymptotic freedom, quark–gluon plasma, and the QCD phase diagram are discussed. The chapter explains the physical motivation for studying matter under extreme temperature and baryon density and introduces the importance of particle production as an observable in heavy-ion collisions. The concept of chemical freeze-out is also discussed, together with its significance in determining the thermodynamic conditions at which the yields of produced particles become fixed. The chapter establishes the objectives of the research and provides the necessary background for the theoretical and phenomenological studies presented in the subsequent chapters.

Chapter 2: Hadron Resonance Gas Framework

The thermodynamic properties of hadronic matter are investigated using the Hadron Resonance Gas (HRG) model. The ideal HRG formulation is first developed by considering the hadrons and resonances as a gas of non-interacting particles. The framework is then extended to include excluded-volume effects and van der Waals interactions. The relevant thermodynamic quantities, including pressure, particle density, energy density, and entropy, are formulated within these approaches. The excluded-volume treatment accounts for repulsive effects associated with the finite size of hadrons, while the van der Waals formulation incorporates both attractive and repulsive interactions. The chapter establishes the theoretical framework used for the subsequent study of particle production and chemical freeze-out parameters.

Chapter 3: Particle Production and Chemical Freeze-out

The production of different hadrons is studied over a broad range of collision energies using thermal-model calculations. Experimentally measured particle ratios are compared with the predictions of the HRG models to determine the chemical freeze-out temperature and baryon chemical potential. The energy dependence of the extracted freeze-out parameters is investigated in detail. The analysis also examines the influence of different treatments of hadronic interactions on the obtained results. The calculated particle ratios provide a consistent description of several experimentally observed trends. The results demonstrate that the chemical freeze-out conditions vary systematically with collision energy and that the inclusion of interactions influences the extracted thermodynamic parameters.

Chapter 4: Particle Ratios and Phenomenological Analysis

A detailed phenomenological analysis of particle ratios is carried out within the thermal-model framework. Particle-to-antiparticle ratios, strange-to-pion ratios, and other relevant observables are investigated over different collision energies. The study includes the energy dependence of kaon and proton ratios and examines characteristic structures observed in strange particle production. The behavior of particle ratios is related to the changing baryon and strangeness chemical potentials of the system. Correlations between selected particle ratios are also studied to obtain further information about the chemical properties of the produced matter. The results show that particle ratios provide useful information about the freeze-out conditions and the role of hadronic interactions.

Chapter 5: Quark–Hadron Phase Transition

The quark–hadron phase transition is studied by combining the description of the hadronic phase obtained from the van der Waals HRG model with an equation of state for the quark–gluon plasma. The phase boundary is determined by applying Gibbs equilibrium conditions between the two phases. The resulting transition curve is studied in the (T, μ_B) plane over a range of temperature and baryon chemical potential. The analysis also incorporates the condition of strangeness neutrality, ensuring zero net strangeness in the system. The effect of the model parameters on the phase boundary is examined, and the resulting phase curve provides a description of the transition between the hadronic and deconfined phases of strongly interacting matter.

Final Findings

The thesis gives a thermal-model description of particle production, chemical freeze-out, and the quark–hadron phase transition. The study shows the relevance of hadronic interactions in describing particle ratios and freeze-out parameters and provides a consistent description over a wide range of collision energies. The phase-transition analysis connects the hadronic and QGP descriptions and gives the corresponding phase boundary in the (T, μ_B) plane. The overall findings provide a unified description of important thermodynamic properties of strongly interacting matter produced in heavy-ion collisions.