ABSTRACT

In high-energy heavy-ion collisions, two heavy nuclei, moving at relativistic velocities, undergo Lorentz contraction and collide onto one another. Within these collisions, certain nucleons, known as participants, contribute to the collision process, depositing a significant amount of energy within a small volume. This leads to the formation of hot, dense matter composed of a deconfined state of quarks and gluons, termed Quark Gluon Plasma (QGP). Initially, this matter exists in a highly non-equilibrium state, with its constituents colliding rapidly until reaching a near-equilibrium stage. This is then accurately described by relativistic viscous hydrodynamics formalism. The QGP subsequently expands and cools, transitioning back to colorless hadrons in a process known as hadronization. Even after hadronization, the hadrons continue to collide, both elastically and non-elastically, until reaching a point where all collisions cease, and the particles freely stream into the detector for detection. In addition to the QGP formed by the participants, there is also an intense transient magnetic field generated, primarily by the relativistically moving spectators who do not participate in the collision process. Theoretical calculations suggest that the initial magnitude of the magnetic field resulting from a non-central Au+Au collision at $\sqrt{s_{NN}} = 200$ GeV ranges from 10^{14} to 10^{15} Tesla. This intense magnetic field offers a unique opportunity to explore various novel phenomena such as Chiral Magnetic Effect (CME), Chiral Separation Effect (CSE), and Chiral Magnetic Wave (CMW). Since the QGP consists of freely moving charges, it exhibits finite conductance and is highly responsive to electromagnetic fields. Consequently, the QGP induces additional responses to the electromagnetic fields, thereby altering the fields themselves. This underscores the importance of studying the interplay between electromagnetic fields and fluid dynamics. The most effective approach to this study is through relativistic magnetohydrodynamics formalism.

During the cooling and expansion process, constituent degrees of freedom, namely quarks and gluons, collide with each other and transfer momentum, energy and mass. This is why the study of transport properties is crucial. In the first part of the thesis, we will primarily examine the impact of external electromagnetic fields, originating from spectators, on the transport coefficients and evolution equations of various dissipative stresses (shear, bulk, and diffusion). This is carried out by solving relativistic magnetohydrody-

namic (RMHD) equations and determining the transport coefficients through underlying microscopic theory, specifically from relativistic kinetic theory. We find here that second-order evolution equations pick up additional contributions due to external electromagnetic fields, and the Navier-Stokes relations change, making the primary transport coefficients (shear and diffusion) anisotropic. Additionally, we delve into how these additional transport coefficients arising from the external electromagnetic fields are influenced by variations in temperature, mass, and magnetic field. Understanding these dissipative stresses, such as shear, bulk, and diffusion, is critical in the context of high-energy collisions as they govern the non-equilibrium behavior of the QGP formed in these collisions.

Next, we study the generation of the electromagnetic fields in heavy-ion collisions. There are essentially two sources of electromagnetic fields: the spectators and the participants. Here, we will focus on contributions from participants only. We study here the full 3+1D spatio-temporal evolution of electromagnetic fields, taking into account the participants flowing with the fluid. We discuss the results for two specific cases: point charges and a more realistic scenario with transverse charge distribution. We found that unlike the electromagnetic field by the spectators, fields by participants increase and then decrease with time post collisions. Also, a naive comparison about the strength of the field from both sources suggests that the fields at a later stage are mainly due to the participant charges.

As we transition to low-energy heavy-ion collisions, experimental observations reveal the emergence of nuclear stopping, where an increasing number of nucleons congregate the mid-rapidity region. As there is a stopping we can affirm that there should be deceleration of the charges occuring. These deceleration should be taken into account while calculating the electromagnetic fields at the low centre-of-mass energies. This motivates us to investigate the effect of baryon stopping on the electromagnetic fields at low center-of-mass energy collisions. We do this by introducing a energy-dependent stopping power and hence parameterizing the participants velocity profile in a Monte-Carlo Glauber model. Here we see clear effects of stopping on the various components of EM fields at later times after the collisions.

Finally, in the last part of this thesis, we conduct a detailed investigation into the impact of electric fields on bulk observables such as spectra and flow harmonics. Here we consider four different configurations of electric fields on the transverse plane of the freeze-out surface (kinetic freeze-out) and analyze the bulk observables (spectra and flows). This analysis is performed using a blast wave model where we parameterize the flow velocity and temperature on the freeze-out hypersurface and incorporate Cooper-Frey prescriptions for the particlization process. One of the most important result is the effect of electric fields on the behavior of Δv_2 of the identified particles (proton and pion for our case) with respect to transverse momentum (p_T) of the particles. It initially increases and then nearly saturates at some higher p_T at around 3 GeV.