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Transport properties of a charged hot spot in an external electromagnetic field

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Abstract

We investigate adiabatic expansion of a charged and rotating fluid element consisting of weakly interacting particles, which is initially perturbed by an external electromagnetic field. A framework for the perturbative calculation of the non-equilibrium distribution function of this fluid volume is considered and the distribution function is calculated to the first order in the perturbative expansion. This distribution function, which describes the evolution of the element with constant entropy, allows to calculate momentum flux tensor and viscosity coefficients of the expanding system. We show, that these viscosity coefficients depend on the initial angular velocity of the spot and on the strength of its initial perturbation by the external field. Obtained results are applied to the phenomenology of the viscosity to the entropy ratio calculated in lattice models.

Keywords: Shear viscosity; Electromagnetic plasma; Quark–gluon plasma; Non-equilibrium process; Dense matter

1. Introduction

Collisions of relativistic nuclei in the RHIC and LHC experiments at very high energies led to the discovery of a new state of matter named quark–gluon plasma (QGP). At the initial stages of the scattering, this plasma resembles almost an ideal liquid which microscopic structure is not yet well understood [1–9]. The data obtained at the RHIC experiments is in a good agreement

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with the predictions of the ideal relativistic fluid dynamics, [10–12], that establish fluid dynamics as the main theoretical tool to describe collective flow in the collisions. As an input to the hydrodynamical evolution of the particles it is assumed that after a very short time, $\tau < 1$ fm/c [12], the matter reaches a thermal equilibrium and expands with a very small shear viscosity [13,14].

Different models of QGP were proposed in order to describe its fluid behavior. Among other there are strongly coupled Quark Gluon Plasma (sQGP) model, see [1] and references therein, different non-perturbative and lattice models [15–18]. In our approach we will model a QGP system created in the process of high-energy scattering as a system of weakly interacting particles where the thermal equilibrium is achieved for a small elements of the colliding matter [3,8,14, 19,20] separately at some initial moments of time. Namely, we assume, that the whole colliding system is not in a global equilibrium state, see [3,21], and therefore, at the initial stages of the evolution, only local equilibrium may be achieved for the small fluid elements of the matter, independently on each other in the first approximation, see [22]. We can call these elements as hot spots, considering them as local initial fluctuations of the density, see for example [23–27], and which can be related with the physics of saturation, [28–32], as well. Consequently, accordingly to [33], the expansion of the dense initial fluctuation occurs with the constant entropy which justifies the applicability of the hydrodynamical description of the process. This adiabatic expansion continues till the value of the particle's mean free path inside the expanding hot spot becomes comparable to the size of the whole system. At this stage, instead of liquid, there appears a gas of interacting particles with rapidly decreasing density, see for example [34].

In kinetic approach the process of the dense system expansion, i.e. hydrodynamics flow, is described by the Vlasov's equation. This equation determines a microscopic distribution function for the fluid element which depends on time in the case of non-equilibrium processes. For the very dense system the applicability of Vlasov's equation is determined by the value of plasma parameter, the dynamical constraints on the value of this parameter coincide with the requests of the mean free path smallness introduced in [33]. Additionally, an application of the fluid dynamics to the process of the hot spot expansion requires some initial conditions among which the most intriguing one is a condition of a small value of the shear viscosity/entropy ratio. For the collective flow, described by Vlasov's equation, usual perturbative mechanisms, see [35], responsible for the shear viscosity value are absent. Indeed, in the Vlasov's equation framework, in the first approximation in the plasma parameter, the collision term is zero implying an entropy conservation and collective flow of the particles without rescattering. To resolve this problems of the collective flow of an almost ideal fluid with very small viscosity coefficients some new mechanisms of the shear viscosity smallness were proposed, see [36–40]. Additionally, for the non-isotropic initial conditions, the connection between stress–energy tensor and viscosity is more complicated than in the case of isotropic initial state, see [34] for example, that means an existence of a family of different viscosity coefficients in the expanding system, for example see [36] or [49].

Referring to Vlasov's equation as to the equation which describes equilibrium state only, the viscosity coefficients will be equal to zero by definition. Therefore some time-dependent fluctuations around the equilibrium must be considered in the approach in order to generate the viscosity coefficients. The mechanisms behind these fluctuations may be, for example, some instabilities generated in the plasma, see [37–40] and references therein. The viscosity obtained by this way is called "anomalous" one, in contrast to viscosity coefficient created by the perturbative rescattering mechanisms as in [35]. The proposed generation of "anomalous" viscosity and corresponding solution of Vlasov's equation, in turn, requires an existence of some equilibrium state which is perturbed by fluctuations, but in the case of very fast expanding hot spot such set-up may be questionable.