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Investigation of the Thermophysical Behavior of Quark-Gluon Plasma

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Abstract

At very high temperatures and energy densities, a deconfined state of highly interacting matter called Quark-Gluon Plasma (QGP) is created, in which quarks and gluons are no longer bound inside hadrons. Relatistic heavy-ion collisions at CERN and Brookhaven National Laboratory experimentally reproduce this state, which is thot to have existed microseconds after the Big Bang. Thermophysical characteristics of QGP are studied in this work, which include its collective flow behavior, viscosity, thermal conductivity, equation of state, and transport coefficients. In order to comprehend the almost perfect fluid character of QGP, we will go over both experimental findings and theoretical models, including hydrodynamic modeling and lattice Quantum Chromodynamics (QCD). The work emphasizes the importance of thermophysical analysis in understanding the early cosmos and the basic characteristics of strong interactions.

Keywords: *Plasma, Thermophysical, Nuclear, Property, Quantum Chromodynamics*

Introduction

A major focus of contemporary nuclear and high-energy physics is the investigation of material systems with strong interactions in very hostile environments. Quantum chromodynamics (QCD) describes the essential characteristic of color confinement, which states that at standard temperatures and densities, hadrons like protons and neutrons permanently contain quarks and gluons. Nevertheless, theoretical studies conducted in the 1970s postulated that nuclear matter could transform into quark-gluon plasma (QGP) when heated or baryon densities reach a certain threshold, allowing quarks and gluons to move over larger distances than a hadron. Decades of theoretical and experimental endeavors to comprehend the behavior of matter controlled by strong interaction at extreme energy scales were laid down by this prediction. It is thot that QGP exists because it represents a natural phase of matter that filled the universe soon after the Big Bang, rather than just being a theoretical creation. Hadrons could not exist as bound states in the early microseconds of the universe's development because temperatures were higher than trillions of degrees Kelvin. Hadronic matter, which predominates in the observable world today, is the result of the combination of quarks and gluons as the cosmos cooled and expanded. Thanks to ultra-relativistic heavy-ion collisions carried out at large research facilities like the Relativistic Heavy Ion Collider and the Large Hadron Collider, it is now feasible to recreate and investigate this primordial phase under laboratory settings. These experiments produce small droplets of QGP that quickly expand and cool by colliding heavy nuclei at almost light speed, providing extraordinarily high energy densities over very short time intervals.

Thermophysical behavior of highly interacting matter is a major driving force behind QGP research. Learn all you need to know about plasma formation, evolution, and hadronization from the thermodynamic quantities: temperature, pressure, energy density, entropy density, and transport coefficients. The strong force, which is asymptotically free at short distances and strongly coupled at longer scales in QGP, predominates over ordinary plasmas controlled by electromagnetic interactions. The complicated collective events caused by this duality need non-perturbative techniques like lattice QCD and relativistic hydrodynamics, since they provide a challenge to perturbative methods. The view of high-temperature QCD matter has been drastically altered by the finding that QGP acts as an almost perfect fluid with very low viscosity, showing that it is tightly linked instead of weakly interacting. Evidence of QGP in experiments may be seen in phenomena such as jet quenching, accelerated generation of weird hadrons, suppression of quarkonium, and collective flow patterns. The intense collective motion corresponding with fast thermalization and hydrodynamic expansion has been seen in the medium produced in heavy-ion collisions, according to measurements from detectors like ALICE and STAR. Since the system's development is highly dependent on its state equation and transport coefficients, these data have direct bearing on the plasma's thermophysical characteristics.

As a result, QGP provides a unique chance to understand how collective behavior emerges from basic interactions by connecting microscopic quantum field theory with macroscopic fluid dynamics. The study of QGP has ramifications for astrophysics and the study of compact objects like neutron stars, where unusual phases of dense QCD matter may exist, in addition to its importance for early-universe cosmology. Experimental programs are being conducted to look for a critical end point and to study areas of high baryon density, and the mapping of the QCD phase diagram as a function of temperature and baryon chemical potential is an important field of research. Consequently, it is crucial to comprehend the thermophysical behavior of QGP in order to define matter at very high temperatures and to provide a consistent description of highly interacting matter in many physical settings. Examining the collective dynamics, transport processes, and equation of state of quark-gluon plasma are the main foci of this study on its thermophysical features. The goal of the work is to explain why QGP is one of the most extraordinary states of matter ever found and how it behaves under severe circumstances by combining theoretical knowledge from QCD with practical data from heavy-ion collision programs.

A Quasi-Particle Bag Model with a Thermomagnetic Coupling

The development of short-lived powerful magnetic fields is a potential outcome of heavy-ion collisions, and several observables are being considered and researched to gage the influence of these fields on the QGP's development. A weak magnetic field where qB. T 2 could cause changes in the way quarks and gluons propagate in the heat bath at temperature T, but only if the strong magnetic fields don't last too long. The authors determined the effective thermo-magnetic quark-gluon connection by calculating the thermo-magnetic correction to the quark-gluon vertex in the presence of a weak magnetic field inside the HTL approximation. One important aspect of the inverse magnetic catalysis phenomena that they demonstrated is that this coupling reduces with increasing magnetic field intensity. Our goal in this study is to make small adjustments to the thermal quasi-particle model discussed in Section 2 so that it can account for the influence of a magnetic field on the evolution of the QGP system's longitudinal and transverse pressures. The bare minimum to include the effects of the magnetic field via the quark effective mass is to use the author's findings. Additionally, this may be accomplished directly by using a novel dimensionless coupling that is built upon the thermo-magnetic coupling described in Reference [1]. To get the QGP system's longitudinal and transverse pressures, one may leverage recent results from Lattice QCD with magnetic fields present [2] to limit the thermo-magnetic bag function.

Next, we'll examine the QGP's thermo-magnetic pressure when a magnetic field is present,

$$p(T,\mathcal{B}) = \frac{\nu_g}{6\pi^2}\int_0^\infty \mathrm{d}k\, C(T)\, f_B(E_k^g)\,\frac{k^4}{E_k^g}$$

$$+\frac{2N_c}{3\pi^2}\sum_{q=1}^{N_f}\int_0^\infty \mathrm{d}k\, C(T)\, f_D(E_k^q)\,\frac{k^4}{E_k^q},$$

Where the magnetic field dependence enters through the single particle energy for quarks only, and is given by

$$E_k^q = \sqrt{k^2 + m_q^2(T,\mathcal{B})}.$$

For this minimally modified quasi-particle model, we shall retain the gluon mass with just the thermal correction, even tho Eq. (4) might additionally get magnetic corrections via fermion loops. The effective thermo-magnetic mass of the quarks in this simplified version of the thermal quasi-particle model is denoted by

$$m_q^2(T,\mathcal{B}) = m_q^2(T) + C_F\,\frac{T^2}{4}\mathcal{G}_q^2(T,\mathcal{B}),$$

Where we now propose and use the following dimensionless coupling

$$\mathcal{G}_q^2(T,\mathcal{B}) = \frac{g_0^2}{32\pi}\frac{|q\mathcal{B}|}{T^2}\left(\frac{2\ln(2)}{\pi} - \frac{T}{m_q(T)}\right)^{2\beta},$$

Where the parameters are determined for the purely thermal coupling provided by Eq. and the characteristic exponent ṛ is included. The ability to optionally include a bag function B(T, B) into Eq. above is a benefit of this little expansion to the thermal quasi-particle model, as will be shown in the next section. An efficient method of include the linear terms in the magnetic field, as would be anticipated from a real treatment of the Landau level resummation (for example, see the references therein), is shown above Eq.

Thermophysical Properties of Qgp

A remarkable finding in contemporary high-energy nuclear physics is the thermophysical characteristics of quark-gluon plasma (QGP). A deconfined phase of strongly interacting matter, QGP is created at very high temperatures and energy densities, in contrast to conventional matter where quarks and gluons are always contained within hadrons. Relativistic heavy-ion collisions at facilities like the Relativistic Heavy Ion Collider and the Large Hadron Collider reproduce circumstances that occurred naturally in the early cosmos a few microseconds after the Big Bang. The interaction between pressure, energy density, and temperature is described by the equation of state, which is one of the most basic thermophysical features of QGP. Hadronic matter smoothly transitions into QGP at low baryon chemical potential when the temperature rises above a threshold range of around 150-160 MeV, according to Lattice Quantum Chromodynamics simulations. Here, the energy density is rising at a faster rate than the pressure, which indicates that the color degrees of freedom have been released. This less-than-ideal behavior shows that QGP is not a free gas of quarks and gluons but instead maintains strong correlations throughout the transition temperature. When heavy ions collide, the plasma expands and cools in response to the equation of state, which in turn affects the empirically observable patterns of particle creation and collective motion.

The propagation of pressure disturbances throughout plasma is characterized by the speed of sound in the medium, which is closely related to the equation of state. A phenomenon often known as the "softening" of the equation of state occurs when the speed of sound drastically drops close to the transition temperature. Longer lives and stronger collective effects are the result of this softening's influence on the hydrodynamic expansion of the fireball formed in collisions. Although it does not completely approach the ideal limit owing to persisting interaction effects, the speed of sound approaches the value predicted for an ultrarelativistic gas when temperatures rise far beyond the transition area. The number of accessible microscopic states is reflected in the entropy density of QGP, another important thermodynamic metric. The tremendous increase in active degrees of freedom when quarks and gluons become deconfined is shown by the quick rise in entropy density over the transition. The strong collective flow patterns shown in tests, which point to early thermalization and efficient redistribution of energy, are also compatible with high entropy density.

Because it measures the medium's internal friction, shear viscosity has drawn a lot of interest among transport characteristics. Interestingly, higher-order flow harmonics and elliptic flow experiments show that QGP is a nearly perfect fluid with a very small shear viscosity in relation to its entropy density. Findings from the PHENIX and STAR collaborations brought attention to this finding, which showed that plasma moves collectively with little resistance, efficiently transforming initial spatial anisotropies into momentum-space anisotropies. First predictions that QGP would behave as a weakly interacting partonic gas were thwarted by the tiny viscosity, which suggests substantial coupling among components. Rather, its behavior is more like to that of a liquid with strong correlations. It seems that QGP is located near to the lower bound for the ratio of viscosity to entropy density, which has been postulated based on theoretical insights from gauge-gravity duality approaches. Because of this quality, QGP is considered one of the most ideal fluids known to exist, with fluidity similar to that of ultracold atomic gasses yet present at temperatures that are trillions of degrees higher. Another significant transport coefficient, bulk viscosity describes how resistant a material is to homogeneous compression or expansion. In contrast to shear viscosity, bulk viscosity is a major factor close to the phase transition, when conformal symmetry is severely disrupted. Dissipative effects linked to changes in volume are amplified in this area by departures from ideal scale-invariant behavior. Final particle spectra and flow observables are affected by bulk viscosity, which in turn impacts the plasma's rate of expansion. Theoretically, it reflects the medium's changing structure as it goes from hadronic to partonic degrees of freedom, and its temperature dependency is thot to peak close to the critical temperature. While shear viscosity is easier to measure experimentally, bulk viscosity is essential for accurate hydrodynamic modeling of heavy-ion collisions.

A material's thermal conductivity indicates how well it can transfer heat in reaction to changes in temperature. Thermal conductivity is less important than viscous effects in high-energy collisions with low net baryon density. Nevertheless, when investigating collision energies at lower levels using beam energy scan programs, the significance of limiting baryon density becomes apparent, and heat transport may impact the system's development. Modest thermal conductivity is predicted for QGP by theoretical models, which is consistent with its tightly interacting nature. The effective use of relativistic hydrodynamics to represent experimental data requires efficient heat redistribution, which leads to quick equilibration. Local thermal equilibrium is attained in a very short amount of time after the impact, on the order of a fraction of a femtosecond per unit of time, so hydrodynamic models may replicate particle yields and flow patterns. The opacity of QGP to energetic probes, which is another thermophysical feature of QGP, is often investigated by studying jet quenching processes. Interactions with the plasma cause high-energy partons to lose energy as they travel across it. The duration of color screening and momentum diffusion are two transport characteristics that affect this energy loss. The ALICE and CMS collaborations' observations show that high-momentum particles are strongly suppressed in nucleus-nucleus collisions as opposed to proton-proton collisions, suggesting that QGP is dense and very interacting. When the suppression level is high enough, we may infer, indirectly, thermodynamic parameters such as temperature and energy density, which can reach levels that are several times greater than the deconfinement critical threshold. The binding of heavy quarkonia states is altered by color screening in plasma, which in turn causes sequential suppression patterns that act as medium thermometers.

Thermophysical description of QGP is further enhanced by fluctuations and correlations. Variations in conserved charges, including baryon number and electric charge, become sensitive to critical behavior and the fact that the QCD phase diagram could have a critical termination point as we approach the transition area. Signs of such crucial events are sought for by measuring higher-order cumulants in heavy-ion studies. The susceptibilities calculated in lattice QCD are linked to these fluctuations, which relate microscopic thermodynamics to observable values. The transition also shows typical behavior in the system's specific heat, which measures the change in energy density with temperature; this is a reflection of the fast growth in the number of degrees of freedom and the intensity of the interactions. A tightly linked, quickly equilibrating, and highly collective form of matter is revealed by the thermophysical features of quark-gluon plasma. A softening around the transition temperature is seen in its equation of state, which also displays a smooth but quick departure from hadronic matter. According to transport factors like shear and bulk viscosity, QGP is one of the most ideal fluids ever seen since it moves with very little resistance. Its internal dynamics and reaction to perturbations may be further characterized by its thermal conductivity, energy loss mechanisms, and fluctuation observables. The combination of these characteristics not only enhances our knowledge of the intense interaction in harsh environments, but also sheds light on how matter behaved during the Big Bang and in the centers of massive astronomical objects.

Conclusion

Research into the thermophysical characteristics of quark-gluon plasma has shown that, when created in environments of very high temperatures and energy densities, it is a fluid that is both highly interacting and almost flawless. Collective behavior, low viscosity, and non-ideal equation of state have been confirmed by experiments at the Relativistic Heavy Ion Collider and the Large Hadron Collider. The early cosmos, the basic characteristics of matter under severe circumstances, and strong interaction physics are all better understood as a result of these results.

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Conflicts of interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

References

1. B. Aboona *et al.*, "Temperature measurement of quark-gluon plasma at different stages," *Nature Communications*, vol. 16, 2025, doi: 10.1038/s41467-025-63216-63225.
2. J. Churchill, L. Du, C. Gale, G. Jackson, and S. Jeon, "Virtual photons shed light on the early temperature of dense QCD matter," *Physical Review Letters*, vol. 132, p. 172301, 2024.
3. J. Churchill, L. Du, C. Gale, G. Jackson, and S. Jeon, "Dilepton production at next-to-leading order and intermediate invariant-mass observables," *Physical Review C*, vol. 109, p. 044915, 2024.
4. S. McDonald, S. Jeon, and C. Gale, "3 + 1 D initialization and evolution of the glasma," *Physical Review C*, vol. 108, no. 6, p. 064910, Dec. 2023.
5. W. Busza, K. Rajagopal, and W. van der Schee, "Heavy ion collisions: The big picture, and the big questions," *Annual Review of Nuclear and Particle Science*, vol. 68, pp. 339–376, 2018.
6. P. Braun-Munzinger, V. Koch, T. Schäfer, and J. Stachel, "Properties of hot and dense matter from relativistic heavy ion collisions," *Physics Reports*, vol. 621, pp. 76–126, 2016.
7. R. Rapp and H. van Hees, "Thermal dileptons as fireball thermometer and chronometer," *Physics Letters B*, vol. 753, pp. 586–590, 2016.
8. C. Shen, U. W. Heinz, J. F. Paquet, and C. Gale, "Thermal photons as a quark-gluon plasma thermometer reexamined," *Physical Review C*, vol. 89, p. 044910, 2014.
9. J.-P. Blaizot, J. Liao, and L. McLerran, "Gluon transport equation in the small angle approximation and the onset of Bose–Einstein condensation," *Nuclear Physics A*, vol. 920, pp. 58–77, 2013.
10. E. Elizalde, A. J. Lopez-Revelles, S. D. Odintsov, and S. Yu. Vernov, "Cosmological models with Yang–Mills fields," *Physics of Atomic Nuclei*, vol. 76, pp. 996–1003, 2013.
11. R. Pasechnik, V. Beylin, and G. Vereshkov, "Dark energy from graviton-mediated interactions in the QCD vacuum," *Journal of Cosmology and Astroparticle Physics*, vol. 06, p. 011, 2013.
12. M. L. Miller, K. Reygers, S. J. Sanders, and P. Steinberg, "Glauber modeling in high energy nuclear collisions," *Annual Review of Nuclear and Particle Science*, vol. 57, pp. 205–243, 2007.