Temperature dependence of shear viscosity in SU(3)-gluodynamics

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One heavy ion collision produces a huge number of final particles

Large number of particles ⇒ hydrodynamical description can be used

In hydrodynamics transport coefficients control flow of energy, momentum, electrical charge and other quantities
Elliptic flow at STAR (Nucl. Phys. A 757, 102 (2005))

\[
\frac{dN}{d\phi} \sim (1 + 2v_1 \cos(\phi) + 2v_2 \cos^2(\phi)), \phi \text{-scattering angle}
\]

QGP close to ideal liquid \( \left( \frac{\eta}{s} = (1 - 3) \frac{1}{4\pi} \right) \)

Comparison of different liquids

QGP the most superfluid liquid

The aim: first principle calculation of transport coefficients
Viscosity is small, this means that the plasma is strong-interacting.
Lattice simulation of QCD

- Allows to study strongly interacting systems
- Based on the first principles of quantum field theory
- Acknowledged approach to study QCD
- Very powerful due to the development of computer systems
Shear viscosity and lattice calculations

- Lattice measurement of the Euclidean correlator
  \[ C(t) = \langle T_{12}(t) T_{12}(0) \rangle \]

- Calculation of spectral density \( \rho(\omega) \) from the correlator
  \[
  C(t) = T^5 \int_0^\infty d\omega \rho(\omega) \frac{ch(\frac{\omega}{2T} - \omega t)}{sh(\frac{\omega}{2T})}
  \]

  In the hydrodynamical approximation \[ \rho(\omega)_{\omega \to 0} \sim \frac{\eta}{\pi} \omega \]

- Calculation of viscosity \[ \eta = \pi \lim_{\omega \to 0} \frac{\rho(\omega)}{\omega} \]

Details of the calculation

- SU(3) gluodynamics
- Two level algorithm for generation of gauge field configurations
- Lattices \( 32^3 \times 16 \)
Correlation function

![Graph showing correlation function](image)
Determination of the spectral function

\[ C(t) = T^5 \int_0^\infty d\omega \rho(\omega) \frac{ch\left(\frac{\omega}{2T} - \omega t\right)}{sh\left(\frac{\omega}{2T}\right)} \]

Properties of the spectral density:

- \( \rho(\omega) \geq 0, \rho(-\omega) = -\rho(\omega) \)
- Asymptotic freedom: \( \rho(\omega)|_{\omega \to \infty}^{NLO} = \frac{1}{10} \frac{d_A}{(4\pi)^2} \omega^4 \left(1 - \frac{5N_c \alpha_s}{9\pi}\right) \)
  
  7/8 of the total contribution at the point \( t = \frac{1}{2T} \)
- Hydrodynamics: \( \rho(\omega)|_{\omega \to 0} = \frac{n}{\pi} \omega \)
Ansatz for the spectral density

\[ \rho(\omega) = \frac{n}{\pi} \omega \theta(\omega_0 - \omega) + \theta(\omega - \omega_0) A \rho_{\text{asym}}(\omega) \]

\[ \rho(\omega) = \frac{n}{\pi} \omega + \theta h^2 \frac{\omega}{\omega_0} A \rho_{\text{asym}}(\omega) \]
Ansatz for the spectral density

\[ \rho(\omega) = \frac{n}{\pi} \omega \theta(\omega_0 - \omega) + \theta(\omega - \omega_0) A \rho_{asym}(\omega) \]

\[ \rho(\omega) = \frac{n}{\pi} \omega + \text{th}^2 \frac{\omega}{\omega_0} A \rho_{asym}(\omega) \]

Other variants

- \( \text{th}^2 \frac{\omega}{\omega_0} \rightarrow \sum A_k \text{th}^{2k} \frac{\omega}{\omega_0} \) ✓
- Transport peak ✗ → Strong Interaction
- Backus-Gilbert method ✓
$\eta/s$ versus $T$, $SU(3)$ gluodynamics

$$\eta/s = \frac{\eta}{s}$$

$$\frac{\eta}{s} \omega (\omega_0 - \omega) + A \theta (\omega - \omega_0) \rho_{\text{lat}} (\omega)$$

$$\frac{\eta}{s} \omega + A \tanh^2 (\omega/\omega_0) \rho_{\text{lat}}$$

Backus - Gilbert
The results of the calculation ($T/T_c = 1.2$)

- $\frac{\eta}{s} = 0.178 \pm 0.06$ (V.V. Braguta et al.)
- $\frac{\eta}{s} = \frac{1}{4\pi} \approx 0.08$ N=4 SYM $\lambda = \infty$ (Phys. Rev. Lett. 87 (2001) 081601)
- $\frac{\eta}{s} = (1 - 3)\frac{1}{4\pi} \approx 0.08 - 0.24$ Experiment (Phys. Rev. C 78, 034915 (2008))
- $\frac{\eta}{s} \sim 2$ Perturbative result (JHEP 11 (2000) 001)
- $\frac{\eta}{s} = 0.102 \pm 0.056$ (Phys. Rev. D76 (2007) 101701)
Conclusion

- Lattice calculation of viscosity in $SU(3)$ gluodynamics was performed.
- The result of the calculation is in agreement with heavy ion collisions.
- QGP is strongly correlated system which is close to SYM and far from to weakly interacting plasma.