Shear viscosity of rotating, hot, and dense spin-half fermionic systems using Kubo formalism

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Motivation & Ingredients

Motivation: Derive shear viscosity using Kubo formalism and study the impact of finite rotation on shear viscosity in a fermion-dominated medium subject to high angular velocity?

The metric tensor in a rotating setting at an angular velocity Ω is

$$g_{\mu\nu} = \begin{pmatrix} 1-\left(x^2+y^2\right)\Omega^2 & y\Omega & -x\Omega & 0 \\ y\Omega & -1 & 0 & 0 \\ -x\Omega & 0 & -1 & 0 \\ 0 & 0 & 0 & -1 \end{pmatrix}.$$

And, in curved spacetime the energy-momentum tensor is expressed as

$$T^{\mu\nu} = \frac{i}{4}\left(\overline{\psi}\widetilde{\gamma}^{\mu}\widetilde{D}^{\nu}\psi + \overline{\psi}\widetilde{\gamma}^{\nu}\widetilde{D}^{\mu}\psi\right) + \text{h.c},$$

where ψ and $\overline{\psi}$ are the Dirac field operator and its conjugate, respectively, and h.c denotes the Hermitian conjugate. In a uniformly rotating frame, $\widetilde{D}^{\mu}$ is

$$\widetilde{D}_{\mu} = \left(\partial_t - i\frac{\Omega\Sigma_3}{2}, -\partial_x, -\partial_y, -\partial_z\right),$$

where $\Sigma_3 = (i/2)\left[\gamma^1, \gamma^2\right]$. The spacetime dependent gamma matrices $\widetilde{\gamma}^{\mu}$ in tetrad system are

$$\widetilde{\gamma}^0 = \gamma^0, \quad \widetilde{\gamma}_0 = \gamma^0 - x\Omega\gamma^2 + y\Omega\gamma^1, \quad \widetilde{\gamma}^1 = \gamma^1 + y\Omega\gamma^0, \quad \widetilde{\gamma}_1 = -\gamma^1,$$
$$\widetilde{\gamma}^2 = \gamma^2 - x\Omega\gamma^0, \quad \widetilde{\gamma}_2 = -\gamma^2, \quad \widetilde{\gamma}^3 = \gamma^3, \quad \widetilde{\gamma}_3 = -\gamma^3,$$

where γ^{μ} are the gamma matrices in Minkowski space. The final piece is the Kubo formula for shear viscosity

$$\boxed{\eta = -\frac{1}{10}\lim_{q_0\to 0}\frac{\rho_{\eta}(q_0)}{q_0}},$$

Effect of angular velocity on shear

$$\eta(T,\mu,\Omega) = \frac{1}{240}\int \frac{d^3p}{(2\pi)^3}\left(\frac{1}{4E_p^2\Gamma T}\right)\times\Bigg\{\Big\{160p_z^4 + 4p_\perp^2\Omega^2 + (\Omega - E_p - 3p_z)\Omega^3 + 8p_\perp^2 p_z(\Omega - 4E_p) + 32p_z^3(\Omega + 5E_p) - 8p_z^2\Omega(2E_p + 3\Omega)\Big\}\mathcal{N}_{\pm\mu,\mp\Omega/2}$$
$$+\Big\{160p_z^4 + 4p_\perp^2\Omega^2 + (\Omega - E_p - 3p_z)\Omega^3 + 8p_\perp^2 p_z(\Omega - 4E_p) + 32p_z^3(\Omega - 5E_p) - 8p_z^2\Omega(2E_p - 3\Omega)\Big\}\mathcal{N}_{\pm\mu,\pm\Omega/2}\Bigg\}$$