Non-Fermi liquid behavior of energy and momentum relaxation in degenerate QED plasma

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Introduction

The low temperature fermi system in the high density region is commonly known as ultradegenerate plasma. For relativistic plasma this regime is less explored in comparison with the high temperature low density domain. In particular, we calculate fermionic drag (η) and longitudinal diffusion coefficients ($\mathcal{B}$) in this regime and eventually extend it to the limiting case of zero temperature. The salient feature here has been the inclusion of the higher order terms both in the transverse and longitudinal sector. The magnetic interaction in non-relativistic systems is suppressed in powers of $(v/c)^2$. But, in case of the relativistic domain, it becomes important. Hence, in dealing with the relativistic plasma one has to consider both electric and magnetic interactions. A fermionic system interacting via the exchange of transverse gauge bosons exhibit deviations from the normal Fermi liquid behavior. Such non-Fermi liquid behavior emerges from the vanishing of the Fermion propagator near the Fermi surface. Due to the small temperature expansion of the Fermion self-energy in ultradegenerate plasma the fractional power appears. Such a characteristic feature, for the first time was reported in case of low temperature specific heat of degenerate non-relativistic electron gas. Similar non-Fermi-liquid terms, for ungapped quark matter, also appear in the calculation of neutrino emissivity and its mean free path. We show that the same behaviour is also present in case of the fermionic drag and diffusion coefficients in the low and zero temperature region beyond the leading order and the next to leading order term in the transverse sector contributes more in comparison with the leading order electric sector in the mentioned domains.

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Formalism: In this section we calculate the drag and diffusion coefficients (η and $\mathcal{B}$) when $T \sim |E-\mu| \ll e\mu \ll \mu$, this is the region which is relevant for the astrophysical applications. The evaluation of η is plagued with infrared divergences. To remove this divergences, the region of integration has to be divided into two regions (intermediate cut-off q^*) distinguished by the momentum transfer *i.e.* the soft and the hard sector. For the former, one can use the one loop resummed propagator and for the latter the bare photon propagator. But, unlike high temperature plasma here we discuss that the entire contribution to η and $\mathcal{B}$ in the relevant domains *i.e.* for small and zero temperature, comes from the soft photon exchange. Following this prescription, the final expression

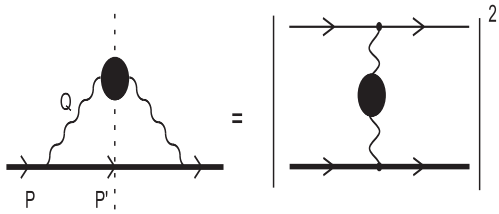

FIG. 1: Fermion-fermion scattering with screened interaction.

for drag-coefficient then becomes [1]:

$$\eta = \frac{e^2 m_D^2}{E}\left\{\frac{1}{48\pi}\left(\frac{T}{m_D}h_1(\alpha)\right)^2 - \frac{3\times 2^{1/3}}{72\pi^{7/3}}\left(\frac{T}{m_D}h_2(\alpha)\right)^{\frac{8}{3}} - \frac{6\times 2^{2/3}}{9\pi^{11/3}}\left(\frac{T}{m_D}h_3(\alpha)\right)^{\frac{10}{3}}\right\} + \frac{e^2 m_D^2}{96E}\left(\frac{T}{m_D}g_1(\alpha)\right)^3, \quad (1)$$

the h_1, h_2, h_3 and g_1 functions are defined in [1] and $\alpha = \frac{(E-\mu)}{T}$. In the zero temperature limit the functions behave as $h_i(\alpha) \to |\alpha|$ and $g_i(\alpha) \to |\alpha|$. In the extreme zero temperature limit η becomes [1],

$$\eta = \frac{e^2|E-\mu|^2}{48\pi E} - \frac{3\times 2^{1/3}e^2 m_D^2}{72\pi^{7/3}E}\left(\frac{|E-\mu|}{m_D}\right)^{\frac{8}{3}} + \frac{e^2|E-\mu|^3}{96 m_D E} + \cdots . \quad (2)$$

Both the first and the second term here comes from the transverse sector while the last piece is from the longitudinal interactions. The subleading term with fractional power in Eqs.(1) and (2) from the transverse sector is larger than the leading order contribution of the longitudinal sector. This observation, was first noted in [2] in connection to the evaluation of Fermion self energy and was overlooked in [3]. Such characteristic feature, also known as non-Fermi liquid behavior and can be attributed to the absence of the magnetostatic screening as noted in the introduction. The leading term of the hard sector fails to contribute to η and $\mathcal{B}$ at least upto our order of interest. Beyond the leading order in the soft sector, we see even after the inclusion of the correction terms no intermediate cut-off dependent term appear upto $O(e^2)$. Therefore, we conclude upto this order the entire contribution comes from the soft sector providing indirect justification of the omission of the next to leading order hard term [1].

The expression for $\mathcal{B}$ at low temperature becomes [1],

$$\mathcal{B} = e^2 m_D^3\left\{\frac{1}{72\pi}\left(\frac{T}{m_D}h_4(\alpha)\right)^3 - \frac{3\times 2^{1/3}}{99\pi^{7/3}}\left(\frac{T}{m_D}h_5(\alpha)\right)^{\frac{11}{3}} - \frac{20\times 2^{2/3}}{39\pi^{11/3}}\left(\frac{T}{m_D}h_6(\alpha)\right)^{\frac{13}{3}}\right\} + \frac{e^2 m_D^3}{128}\left(\frac{T}{m_D}g_2(\alpha)\right)^4, \quad (3)$$

where, the h_4, h_5, h_6 and g_2 functions are given in [1]. $\mathcal{B}$ in the extreme zero temperature limit becomes,

$$\mathcal{B} = \frac{e^2|E-\mu|^3}{72\pi} - \frac{2^{1/3}e^2 m_D^3}{33\pi^{7/3}}\left(\frac{|E-\mu|}{m_D}\right)^{\frac{11}{3}} + \frac{e^2|E-\mu|^4}{128 m_D} + \cdots . \quad (4)$$

Conclusion: In this work it is seen that the subleading term of the transverse sector, which appears with the fractional power, is larger than the leading term coming from the soft longitudinal photons. Both the appearance of the fractional power and dominance of the transverse sector are related to absence of the magnetostatic screening or the singular behavior of the fermion self-energy near the Fermi surface. Furthermore, we find that the entire physics is dominated by the soft excitations. This is a clear departure from the high temperature case where both the hard and the soft part contribute at the same order.

References

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