Shear Viscosity in antikaon condensed matter

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Shear viscosity plays an important role in neutron star physics. It is essential in understanding the pulsar glitches and free precession of neutron stars. So far all the calculations of shear viscosity are done in neutron star matter composed of neutron, proton, electron and muon [1]. However, exotic forms of matter such as hyperon and antikaon condensates might be present in the interior of neutron star [2] and that could affect the electron shear viscosity appreciably. At $2-3$ times normal nuclear matter density(n_0), K^- condensates appear and replace electrons and muons. In the presence of K^- condensates, proton fraction becomes comparable to that of neutrons at higher densities.

As antikaons form s-wave($\mathbf{p} = \mathbf{0}$) condensates, they do not transfer any momentum during collisions with other particles. Therefore, they have no direct contribution to the shear viscosity. However, their influence on the proton fraction and the equation of state (EoS) have important consequences for the total shear viscosity. Hence, the total shear viscosity has contribution only from neutron, proton, electron and muons and is given by

$$\eta_{total} = \eta_n + \eta_p + \eta_e + \eta_\mu \tag{1}$$

where $n_{i(=e,\mu)} = \frac{n_i p_{F_i}^2 \tau_i}{5m_i^*}$, $\eta_n = \frac{n_n p_{F_n}^2 \tau_n}{5m_n^*}$ and $n_p = \frac{n_p p_{F_p}^2 \tau_p}{5m_p^*}$. Here m_i^* and p_{F_i} are effective mass and Fermi momenta of the i-th particle. The effective relaxation times ($=\tau$) for n, p, e and μ are obtained by solving a matrix equation that follows from

$$\sum_{j=n,p,e,\mu} (\nu_{ij}\tau_i + \nu'\tau_i) = 1 \tag{2}$$

where ν_is are the collision frequencies of ith particles, given by

$$\nu_e = \nu_{ee} + \nu'_{ee} + \nu_{e\mu} + \nu_{ep} \tag{3}$$
$$\nu_\mu = \nu_{\mu\mu} + \nu'_{\mu\mu} + \nu_{\mu e} + \nu_{\mu p} \tag{4}$$
$$\nu_p = \nu_{pp} + \nu'_{pp} + \nu_{pn} + \nu_{pe} + \nu_{p\mu} \tag{5}$$
$$\nu_n = \nu_{nn} + \nu'_{nn} + \nu_{np} \tag{6}$$

It is to be noted that the proton-proton interaction has contributions from electromagnetic as well as strong interactions. As there is no interference between them, the collision frequencies ν_{pp} and ν'_{pp} are simply sum of electromagnetic and strong contributions [1].

We adopt the plasma screening of the interaction due to exchange of longitudinal and transverse plasmons as described in [3, 4] to calculate the collision frequencies of charged particles (e, μ, p) due to electromagnetic interactions. The collision frequencies of n-n, p-p, n-p scattering due to strong interactions are calculated adopting the prescription of Ref [5] and exploiting the vacuum nucleon-nucleon scattering cross sections of Ref. [6, 7].

The calculation of shear viscosity involves the EoS as an input, that we construct within the framework of relativistic field theoretical model [2]. We consider a first order phase transition from nuclear matter to K^- condensed matter. Both the phases maintain charge neutrality and are in β equilibrium. Using the mean field approximation and solving equation of motions self-consistently, we calculate the effective nucleon mass and Fermi momenta of particles at different baryon densities. Finally total shear viscosity is calculated using Eq.1.

We find that the electron and muon shear viscosities drop steeply after the formation of K^- condensates in the neutron stars. On the other hand, the proton shear viscosity, whose contribution was negligible in nucleon-only matter calculations, now becomes significant in the presence of K^- condensates. The proton shear viscosity exceeds the neutron as well as lepton shear viscosities beyond $3n_0$. The total viscosity is dominated by contributions due to proton and neutrons.

We also study the temperature dependence of shear viscosity and note that the lepton shear viscosities ($\sim T^{\frac{5}{3}}$), differs from the standard Fermi-liquid nature. This deviation may be attributed to the collisions of charged particles through the exchange of transverse plasmons [3]. It is also noted that shear viscosity increases as temperature decreases.

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