Graphene Motivated 2+1D generalised Gross-Neveu Model

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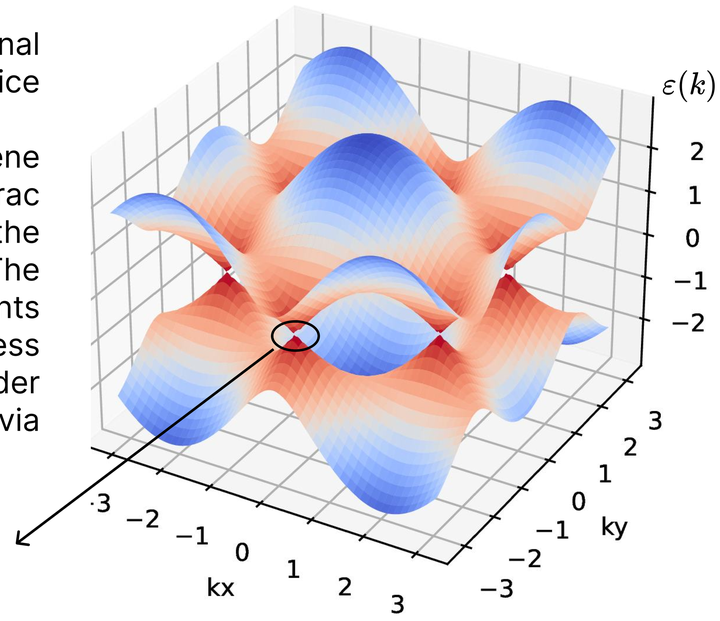
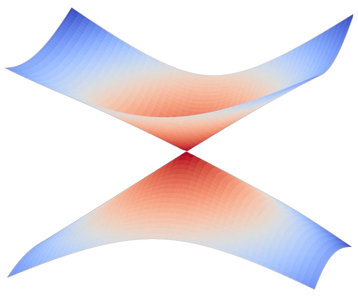
Introduction

Graphene is a two dimensional material with hexagonal lattice structure.
The band structure of graphene contains special points (Dirac Points), near which the dispersion becomes linear. The theory near those points resembles of two massless Dirac fields. Here we consider free dirac fields interacting via contact interaction.





Model

Fermions Interacting via four point contact interaction same as NJL and GN model

$$\mathcal{L} = \bar{\psi}(\gamma_\mu \partial_\mu - \mu\gamma_3 + m_0)\psi - \sum_{i=1}^{4} \frac{G_i}{2N}(\bar{\psi}\Gamma_i\psi)^2 \qquad \Gamma_i = \{I, \gamma_{45}, i\gamma_5, i\gamma_4\}$$

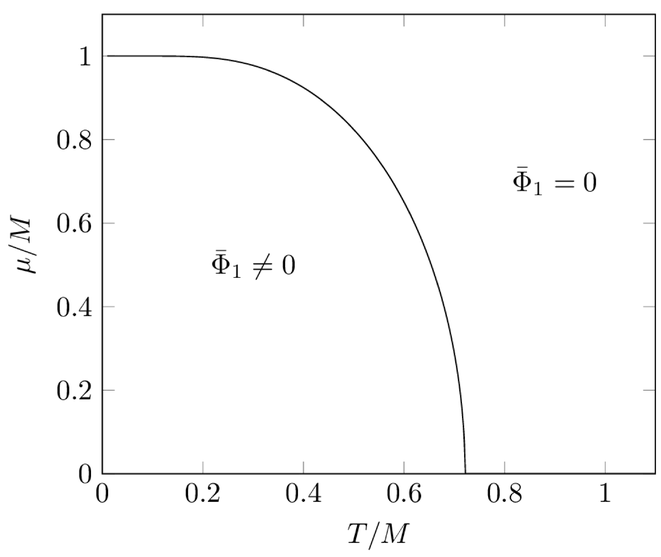
We are only considering the model with $G_i = G$ which respects the Coulomb symmetry in case of Graphene.

Method

- Introduce auxiliary fields to bosonize the theory $\Phi_i = -G_i(\bar{\psi}\Gamma_i\psi)$
- Mean field approximation: assume a space-time independent expectation value for the auxiliary fields $\Phi_i \to \bar{\Phi}_i + \delta\Phi_i$
- The expectation value can be fixed by extremising thermodynamic potential. $\frac{\partial\Omega}{\partial\bar{\Phi}_i} = 0$
- Theory has two parameters, cutoff Λ for regularisation and renormalised coupling $g^{-1} = G^{-1} + \Lambda/\pi$
- Theory is not sensitive to cutoff if it is large enough.
- A mass scale can be obtained from the coupling. $M = \frac{\pi}{|g|}$
- To go beyond mean field we calculate the polarisation loop. $\Pi_i(q,\omega)$
- Excitonic states lies in the poles of spectral function. $\frac{N}{G} - \Pi_i(q=0, \omega = M_i) = 0$
- Beth-Uhlenbeck Approach to calculate phase shifts $\phi_i(q,\omega) = \mathrm{Im}\left[\log\left(\frac{N}{G} - \Pi_i(q,\omega)\right)\right]$

Results

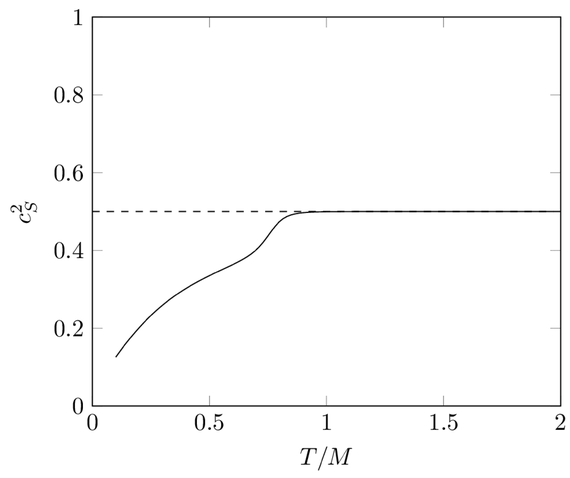
For the case $G_i = G$ there are two phases separated by second order phase transition

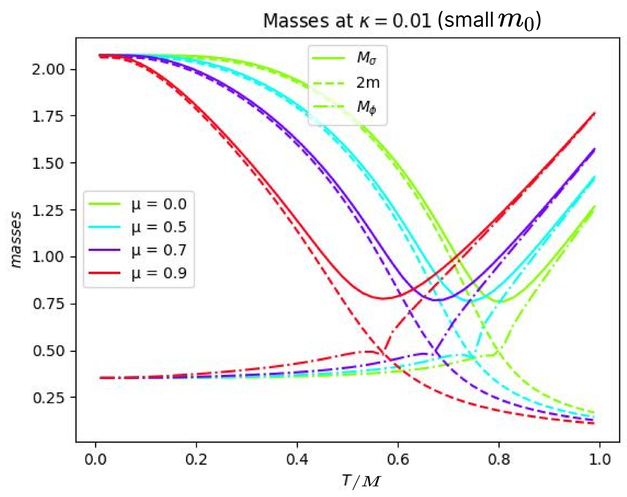


Speed of sound calculated from

$$c_s^2 = \frac{\partial\mathcal{E}}{\partial\mathcal{P}}$$

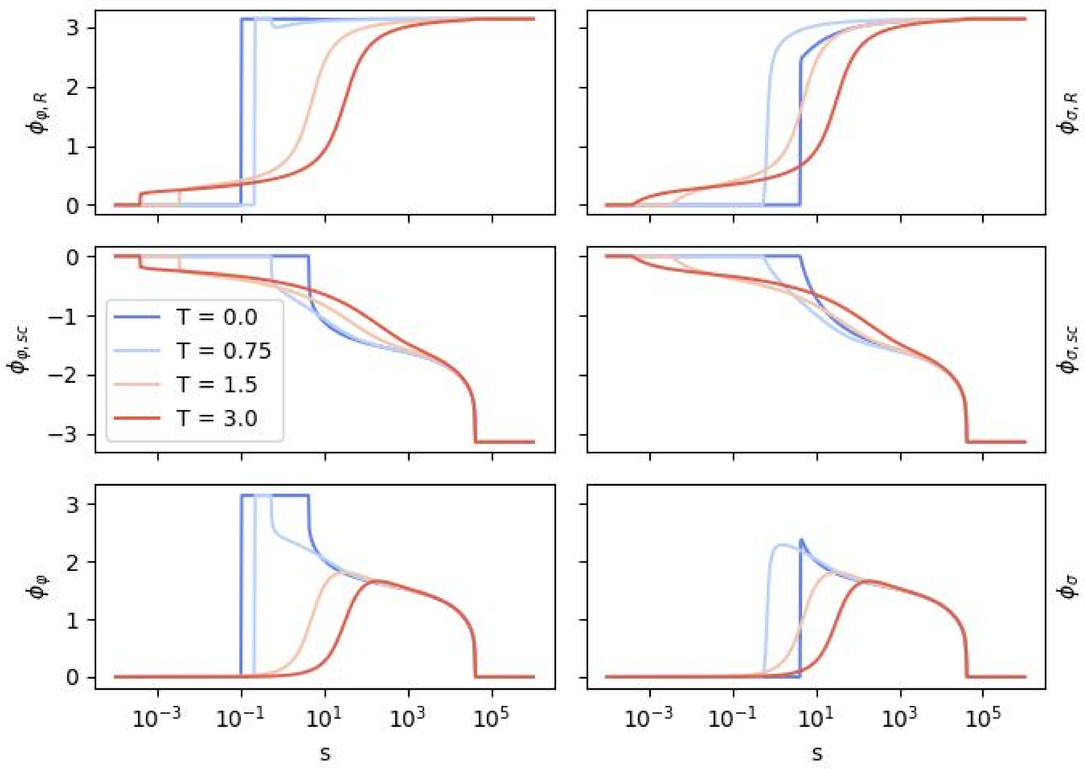
reaches the conformal limit $1/d$ at high temperature



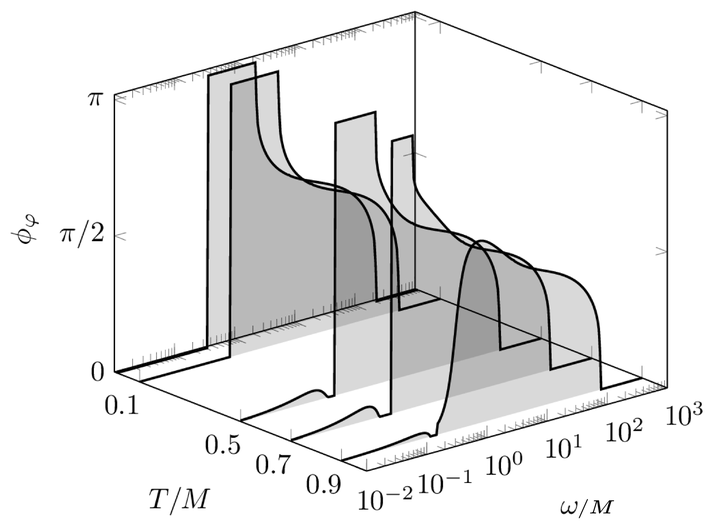


Excitonic bound states masses look very similar to meson spectra calculataed from NJL type models

Phase Shifts $\phi_i(q=0,\omega)$



Phase shifts at finite momentum shows a small bump below the critical value of frequency. The figure shows phase shift values at $q/M = 0.3$



References

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