Nematic Quantum Hall Fluid Without Stripes

Pomeranchuk instability of composite Fermi liquid
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arXiv:1802.08261

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The two-dimensional electron gas (2DEG) in a transverse magnetic field is about the simplest experimentally realizable highly correlated electron fluid, and has thus played a central role in the subject generally. In addition to having been the foundational system in which topological order – as reflected in various quantum Hall liquid states – was first explored, it has also proven to be an ideal laboratory for the investigation of the emergence of various forms of spontaneously broken symmetries. In particular, it has been observed under a wide variety of circumstances[2, 3, 4, 5, 6, 7, 9, 10] – perhaps universally in conditions in which the chemical potential lies in a partially filled higher Landau level – that states form that spontaneously break the rotational symmetry down to a residual C_2.

An important conceptual issue is that it is unclear when this is the full extent of the symmetry breaking – i.e. if the phase giving rise to the macroscopically observed anisotropy is a nematic state – or if this anisotropy arises as a component of a more complex pattern of translation and rotational symmetry breaking, e.g. some form of stripe ordered density wave phase. Often, there is no direct evidence of any form of density wave order in the experimental observations. None-the-less, it is frequently assumed that such density-wave order exists to the extent that any system exhibiting such anisotropies is often described in the literature as a "stripe phase." One reason for this is that it is straightforward to visualize how rotational symmetry breaking can arise from stripe order, and indeed in many cases it is possible to write a Hartree-Fock wave-function for a stripe phase, while a purely nematic phase resists characterization in such a classical sense.

Still, there are at least two ways one can get a theoretical handle on a purely nematic electron fluid in this problem: i) One is to imagine a melted stripe phase – a "nematic close to a smectic" in the language of classical liquid crystals.[11] Such a description is natural[12] at non-zero temperature, where the proliferation of dislocations inevitably destroys stripe order, but can leave (quasi-long-range) orientational order intact. It is, however, much more difficult to treat the problem of the partial quantum melting of a stripe phase to obtain an understanding of a T=0 nematic Fermi fluid. ii) The other approach is to start from a Fermi liquid in which a $l = 2$ Pomeranchuk instability leads to an elliptical distortion of the Fermi surface. In the quantum Hall context, especially in conditions of a nearly half-filled Landau level, such a nematic Fermi fluid presumably involves a Pomeranchuk instability of

a composite Fermi liquid. Such a state is easy to visualize intuitively,[13] but extremely difficult to handle in any quantitative fashion. For this reason, it has remained unclear whether such a state is a physically plausible candidate to account for the anisotropic states observed in experiment.

In this context, the recent paper of Lee *et al* represents not just a notable calculational advance,[14] but also a conceptually important contribution to the field. The explicit calculations exploit advances that have been made in writing composite Fermion wave-functions projected onto a single Landau level. Variational energies can then be numerically computed for a large enough number of particles that finite size effects can plausibly be neglected. No attempt was made to construct an actual nematic state – rather, energies of various small deformations of the isotropic composite Fermi liquid state were computed from which the values of the various Fermi liquid parameters, F_l, could be extracted. The pseudo-potentials used in the variational calculation not only depend on the assumed Landau level index, n, in the usual way, but on the short-distance behavior of the Coulomb interaction as well. This the authors characterize by introducing a dimensionless parameter, η, which loosely can be thought of as the thickness of the 2DEG in units of the magnetic length.

Carrying the usual considerations of Fermi liquid theory over to the composite Fermi liquid, the isotropic state is assumed to be stable so long as $F_l > -1$ for all $l > 1$, while a Pomerancuk instability occurs whenever $F_l \leq -1$. (In general, and in the composite Fermi liquid in particular, special considerations apply to F_0 and F_1.) Strikingly, the variational calculations show that F_2 is a strongly decreasing function of Landau level index (at least for $0 \leq n \leq 2$) and of decreasing η. In particular, for $n = 2$, F_2 computed in this way is less than -1 for small enough η, implying the existence of a nematic instability. No other angular momentum channel comes close.

While compelling arguments[16, 17] can be made that stripe phases are likely the true ground-states for half-filled Landau levels with large enough Landau index, and while it seems likely that an isotropic composite Fermi liquid of one sort or another is typically the ground-state for $n = 0$, the present results lend considerable weight to the proposition that under many circumstances (e.g. for small enough η) and for intermediate n, the ground state is a nematic composite Fermi fluid.

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