Formation of a Nematic Fluid at High Fields in $Sr_3Ru_2O_7$

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http://arXiv.org/cond-mat/0612599

Science 315, 158 (2007).

Recommended and a commentary by Catherine Kallin, McMaster University

One of the exciting forefront areas of condensed matter physics is the discovery and understanding of new electronic states of matter which might be stabilized by strong electron-electron interactions. This paper reports some extraordinary results of magneto-resistivity measurements in high-purity $Sr_3Ru_2O_7$. It is suggested that the properties may be that of a novel phase, discussed by Kivelson, Fradkin and Emery [1] and named by them an electron nematic phase. This phase has a spontaneously broken point group invariance but with full translational symmetry and could arise from a Pomeranchuk instability of a Fermi liquid. One can think of the electron nematic phase as a partially melted stripe phase, where in the stripe phase a direction is picked out and translational order is broken. Whether or not this interpretation of $Sr_3Ru_2O_7$ is correct, the experimental results are unusual and they invite further experimental and theoretical work.

$Sr_3Ru_2O_7$ is a layered material of tetragonal symmetry which exhibits a metamagnetic phase in an applied field. In earlier work, the group of Mackenzie *et al.* found the existence of a new quantum phase near the quantum critical point separating the magnetically ordered phase from the paramagnet. Very interestingly, the quantum criticality arises by tuning two-first order transitions in a magnetic field so that the critical point is near $T = 0$. In this paper, they report on magnetoresistance measurements in the intermediate region between the two first order transitions. With field applied along the c-axis, the resistivity is the same along the a-axis and the b-axis and much higher than outside the region between the two first order transitions. However when the field is tilted with respect to the c-axis, the resistivity remains the same in the direction of the tilt but shows no evidence of the high-field first order transition for the direction perpendicular to the tilt. The results are interpreted as evidence for a nematic electron fluid, where in zero in-plane field, the transport is isotropic because of domain formation, but a tiny in-plane component orients the easy transport direction perpendicular to the field.

The authors find through neutron scattering measurements that to a high accuracy (10^{-5}), the tetragonal symmetry is not broken in the intermediate phase. Consequently, given the large transport anisotropy, it seems very unlikely that this electronic behavior is driven by a structural transition. On the other hand, the lack of any observable orthorhomic distortion raises questions about the nematic phase which may be answered by further experiments. Electronic charge density is linearly coupled to the lattice charge density and one generally cannot develop anisotropy in one without developing a corresponding anisotropy in the other.

The authors also studied 20 different samples with a variety of shapes, and no change was found in the first order phase boundaries separating this novel phase from the paramagnetic and metamagnetic phases. This rules out demagnetization effects which would be expected in the formation of magnetic domains.

The observed magnetotransport anisotropy bears a striking similarity to that observed in GaAs fractional quantum Hall systems with two or more filled Landau levels, with the highest occupied level near half-filling.[2] The GaAs data has been interpreted as evidence for either a striped phase or an electron nematic phase. However, the energies associated with the magnetic fields are the largest energies in the quantum Hall effect problem in GaAs while the magnetic field energies are at least an order of magnitude below the Fermi-energy in $Sr_3Ru_2O_7$.

So far, there are no direct measurements giving the order parameter in the intermediate phase. The somewhat subtle nature of the nematic order or whatever order exists implies that the number of definite experimental probes of the order may be limited. In $Sr_3Ru_2O_7$ one might imagine probing the anisotropy of the Fermi surface in the presence of a small in-plane field or possibly probing the collective excitations associated with the order in Raman scattering experiments. Certainly, the striking results reported in this paper and the suggestion of novel electron order warrent further experimental and theoretical investigation. [1] S.A. Kivelson, E. Fradkin and V.J. Emery, Nature 393, 550 (1998).
[2] K.B. Cooper, M.P. Lilly, J.P. Eisenstein, L.N. Pfeiffer and K.W. West, Phys. Rev. B65, 241313 (2002).