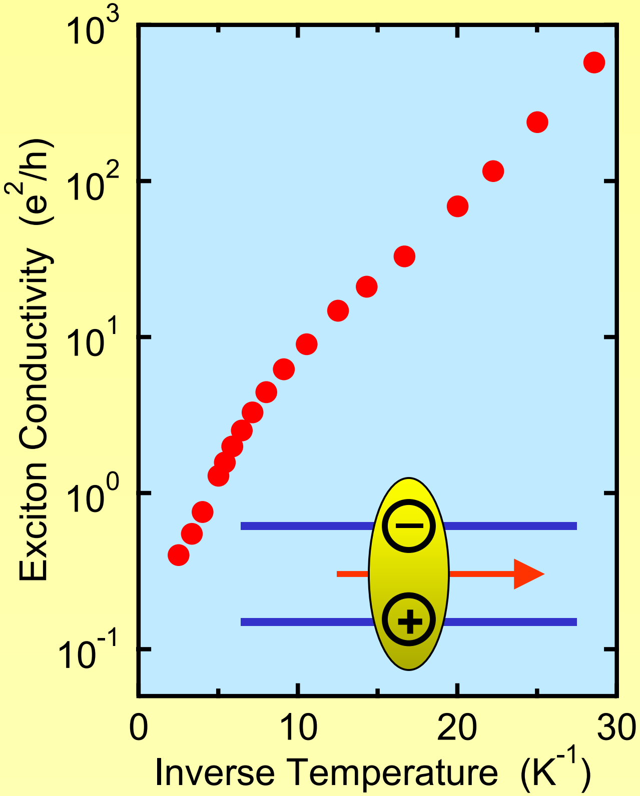
Nature of Excitonic Superfluidity

J.P. Eisenstein, Caltech, DMR-0242946

Superconductors are metals which lose all electrical resistance at low temperatures. This phenomenon occurs when electrons join up in "Cooper pairs". Physicists have long speculated that a similar effect could occur in semi-conductors. The idea is that electrons should form pairs not with other electrons, but with "holes". Holes are empty electron states which masquerade as particles much like electrons, but with opposite charge. Alas, the expected electron-hole, or "excitonic", superfluid resisted discovery for forty years. Our recent research has shown that such a state does indeed appear in specially designed double layer semiconductor structures subjected to an intense magnetic field.

Last year we reported convincing evidence for exciton condensation based on the vanishing of the Hall resistance when counterflowing electrical currents are driven through the two layers. This year we carefully studied this effect and found the conductivity of the exciton system does indeed head to infinity as the temperature is reduced, but only *gradually*. The apparent lack of a clear-cut transition temperature is a significant puzzle and has spurred considerable interest in both the experimental and theoretical physics communities.



Exciton conductivity versus inverse temperature. Conductivity *gradually* tends to infinity as the temperature falls. No evidence of a sharp transition temperature is seen. Inset depicts exciton motion in a double layer structure.

A fundamental goal of condensed matter physics the discovery of "emergent" phenomena. An emergent phenomenon is something exhibited only by *very large collections of particles* (atoms, electrons, etc). It cannot be predicted on the basis of the understanding of the individual particles in the system. For example: We know most everything about the properties of a single electron. Its mass, charge and spin are all recorded in textbooks. Its interactions with the other sub-atomic particles have been thoroughly investigated. And yet large collections of electrons continue to startle us. For example, the electrons in aluminum become superconducting at temperatures close to absolute zero. All resistance to the flow of electricity vanishes. Although we now understand this phenomenon (in terms of a bizarre pairing of the electrons), it could never have been predicted in advance. Electrons in iron produce magnetism, another example of emergent behavior. Magnetism and superconductivity are both technologically exceedingly important (data storage in computers and MRI imaging in medicine spring immediately to mind). The study of emergent behavior of many-body systems is thus an extremely important scientific discipline.

In our recent research we have discovered a new example of an emergent many-electron state. A semiconductor structure containing two sheets of electrons, cooled down to nearly absolute zero and placed in a big magnetic field, exhibits "exciton condensation". Electrons in one layer pair up with the voids between electrons in the other layer! The result is a new kind of superfluidity. Our NSF funding has enabled this discovery.

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Graduate Students: Melinda J. Kellogg and Ian B. Spielman

Undergraduate Students: Laura Sinclair

Collaborators: Loren Pfeiffer and Ken West, Bell Labs

Related Manuscripts:

"Vanishing Hall Resistance at High Magnetic Field in a Double Layer Two-Dimensional Electron System", *Physical Review Letters* **93**, 036801 (2004).

"Onset of Interlayer Phase Coherence in a Bilayer Two-Dimensional Electron System: Effect of Layer Density Imbalance", accepted by *Phys. Rev. B*, Rapid Communications.

"Bose Einstein Condensation of Excitons in Bilayer Electron Systems", *Nature* (accepted pending final editorial review).

Of Special Note:

Our work on exciton condensation is the subject of a *Search and Discovery* article by Barbara Levi in the July 2004 issue of *Physics Today*.

In addition, a solicited *Perspective* by the P.I. reviewing the recent developments, will appear in *Science* very soon.

Selected Invited Presentations:

"Vanishing Hall and Longitudinal Resistances in a Bilayer 2D Electron System", Int'l Conf. on High Magnetic Fields in Semiconductor Physics, NHMFL, Tallahassee, Aug. 2004 (**Kellogg**)

"Josephson-like Tunneling in a Quantum Hall Exciton Condensate", European Physical Society Meeting, Prague, July 2004 (**Spielman**).

"Experiments on a Quantum Hall Bilayer Exciton Condensate", March 2004 APS meeting, Montreal, (**Eisenstein**).