Physics Colloquium

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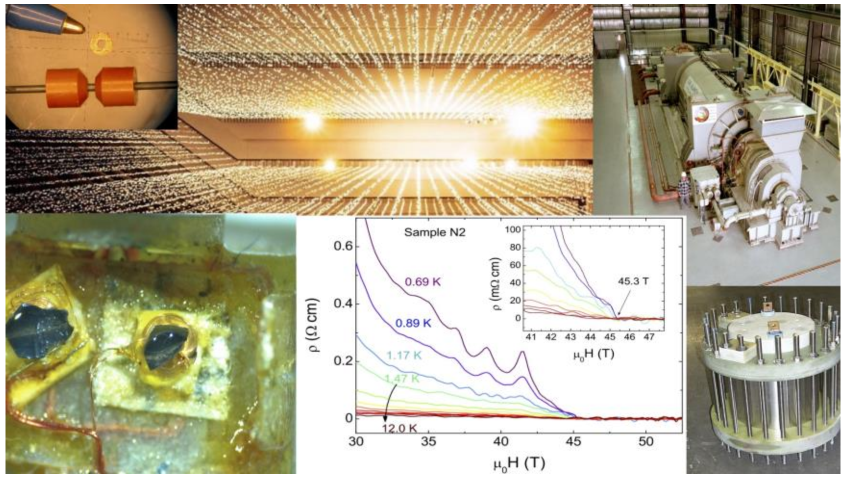
Electrons behaving badly: electrical insulators and neutral fermions

ABSTRACT

From an early age, we are taught that metals are good conductors of electricity and heat but that insulators are not. At High School we learn that metals contain vast numbers of charged electrons that are free to move and carry heat and current, whereas insulators do not. At College, we find out that electrons are fermions, and perhaps comprehend Fermi-Dirac statistics, leading to the well-known definition that “a metal is a solid with a Fermi surface”. The Fermi surface is the constant-energy surface which at zero temperature separates the occupied electron states from the empty in momentum space; if we know the size and shape of a metal’s Fermi surface, we understand how its free electrons behave and hence can account for almost all its electrical, thermal and magnetic properties.

Over the past decade, this comforting picture of well-behaved electrons has been upset by experiments on various materials at high magnetic fields and low temperatures. Though these substances are electrical insulators, they exhibit an oscillatory effect in magnetic field that is smoking-gun evidence for a Fermi surface; i.e., it is usually seen only in metals. Equally striking are the low-temperature heat capacities of these materials, which look as though they come from large concentrations of free electrons. Somehow, mobile fermions are present, but are unable to conduct electricity!



In this talk, I will describe our recent data on two of these insulating compounds in magnetic fields of up to 75 Tesla. The experiments reveal that the insulators are stuff full of electrons *behaving badly*-pretending to be something else. In one of the insulators, YbB_{12}, the electrons rearrange themselves into Majorana fermions, particles that are their own antiparticle, hypothesized by Ettore Majorana in 1937. In the other insulator, YCOB ($YCu_3(OH)_6Br_2[Br_{1-y}(OH)_y]$), the electrons undergo a process called *spin–charge separation*, which results in them behaving like three separate particles: (i) the *spinon*, which carries the spin of the electron; (ii) the *orbiton*, which carries its orbital location; and (iii) the *holon*, which carries its charge. In YCOB, the holons do not move (so it is an electrical insulator), but the spinons form a liquid of mobile neutral fermions that account for our data.

1:30-2:45 p.m., Friday, January 31st, 2025

In-person in McLane Hall 162