Experimental Methods II

Villanova University, Department of Physics
PHY 4303-002, Spring 2014: Tuesday, 4:00-7:20 PM

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Dr. G. C. Papaefthymiou-Davis

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Dr. Davis will provide the rest of her information later.

Overview: The purpose of this course is to introduce you to some experimental methods used by physicists, and involves work in the research labs of two faculty members. As such, the work you will perform will be more in-depth than what you've encountered in previous laboratory courses, and you will be expected to make independent and original efforts to achieve results in open-ended inquiry, rather than following "cookie-cutter" procedures toward an expected result.

Organization / Scheduling: The first module will be conducted by Dr. Carlo, and will concentrate on the phenomenon of superconductivity (described on the next page), and the remainder of the semester by Dr. Davis. Dr. Davis' portion will focus on gamma-ray resonance measurements and the interaction of electromagnetic radiation with matter, hyperfine interactions and magnetism in bulk and nanoscale materials containing iron. In some cases we will have to deviate from the Registrar's course schedule, due to availability of equipment and storage requirements of cryogens. Any such changes will be arranged by mutual agreement of the instructor(s) and students.

Attendance: As laboratory courses are participatory and involve work in groups, attendance during scheduled laboratory periods is essential. Makeups will be arranged if and only if attendance at scheduled sessions is impossible due to sickness or an emergency.

Grading: Your final grade will be based on a weighted average of your work in both parts of the course.

Safety: In this course you will perform work in the laboratory, using scientific equipment. While none of the work you will perform is particularly hazardous, we will be dealing with various chemicals and compounds, liquid nitrogen and other cryogens, electronic equipment, and sources of ionizing radiation. Your instructors will provide information about these in the laboratory as they are used, and it is vital to be aware of any necessary precautions (both for your own safety, and to prevent damage to expensive equipment!). Above all, *always use common sense: if you're not sure what you're doing is safe and appropriate, stop and get clarification!*

Information for first module

This module of PHY 4303 will concentrate on the phenomenon of superconductivity.

Superconductivity, a phenomenon whereby a material's electrical resistivity drops abruptly to zero below a "critical temperature" T_C, was first discovered just over 100 years ago, and has been a topic of intensive research ever since. Superconductivity manifests in a wide range of materials, ranging from

-elemental metals such as lead and mercury in which it was first discovered, to
-metallic alloys, including the niobium alloys used in many superconducting magnets, to
-intermetallics, including the very recently-discovered iron-based superconductors, to
-ceramic oxides, such as the famous "high-temperature" cuprate superconductors.

Even some organic compounds, and compounds based on C_{60} "buckyballs," exhibit superconductivity!

Superconductivity is a fascinating example of an *emergent property*. It cannot be understood simply as an interaction between two isolated particles, but is a demonstration that the whole is greater than the sum of its parts. Fundamentally, it happens when conduction electrons pair up inside the material (known as "Cooper pairs"), enabling them to travel without resistance. But exactly *how* this pairing happens is only understood in a few of the simplest superconductors; in others the origin of SC is still a mystery being investigated by thousands of researchers worldwide, involving experts in fields as diverse as structural analysis, magnetism, optical properties, and even theoretical particle physics.

Potential applications of superconductivity range from lossless energy storage and transport, to powerful magnets for MRI machines and other research instruments, to exquisitely sensitive magnetic field detectors employing superconducting junctions (SQUIDs), to magnetic levitation of trains for high-speed transportation. One of the principal impediments to practical applications has been the fact that all known superconductors exhibit superconductivity only at temperatures significantly below ambient room temperature (300K); even the so-called "high-temperature" superconductors all have T_C's below 100-150K, requiring liquid nitrogen for cooling (versus "regular" superconductors which generally have T_C's below 30K, requiring the much more expensive liquid helium).

In this module, we will study the properties of two copper-based "high-temperature" superconducting materials, $YBa_2Cu_3O_x$ (YBCO) and $Bi_2Sr_2CaCu_2O_x$ / $Bi_2Sr_2Ca_2Cu_3O_x$ (BSCCO).

We will measure resistivity as a function of temperature, to verify the headline result: $\rho \rightarrow 0$ abruptly as T drops below T_C in these two superconducting systems.

We will observe the Meissner effect, whereby a superconductor exhibits perfect diamagnetism, completely expelling magnetic field lines. (This is what makes magnetic levitation possible!)

Depending on available time, there are other measurements that can be made, including estimates of how applied fields reduce T_C, measurements of persistent supercurrents, observation of magnetic flux pinning, structural measurements with x-ray diffraction, and measurements of magnetic susceptibility.

We will also learn a little about the theories which have been developed to understand superconductivity: the London model, the Ginzburg-Landau model, the Bardeen-Cooper-Schrieffer (BCS) theory, and some of the current ideas about high-temperature superconductors.