ENGR 240 – Science of Materials Laboratory

LAB K
EXPLORING SUPERCONDUCTIVITY

Background

The existence of superconductors, materials that conduct electricity without resistance, was first observed in the early 1900's, shortly after helium was successfully liquefied, which made it possible to attain temperatures in the laboratory of less than 10 K. A number of metals were found to become superconducting at these temperatures, and the temperature below which superconductivity is achieved is called the material's *critical temperature*, T_c. In the late 1980s, scientists formulated certain ceramic materials, mixtures of metals and a non-metal (usually oxygen), which exhibited T_c's above 80K. This jump was most significant, as now superconductivity was obtainable at temperatures above that of liquid nitrogen (77K), which is much cheaper and more easily attainable than liquid helium. This has moved superconductivity from a laboratory curiosity to a potentially practical phenomenon with a number of envisioned applications, such as cheap and efficient power transmission, magnetic levitation, ultrafast computers, medical imaging, and more.

Why do materials superconduct? At low temperatures, electrons with opposite spins become paired because of mutual attraction to a positive charge within the crystal structure. At T_c, the vibrational frequency of these pairs becomes synchronized with the vibrational frequency of the atoms in the lattice. Unlike normal conducting electrons that bump into vibrating atoms, these pairs, vibrating themselves in sync with the atoms, can pass through the solid virtually uninterrupted.

Two ceramic superconductors in use today with T_c's above 77K have the following chemical formulas:

$YBa_2Cu_3O_7$	$Bi_2Sr_2Ca_2Cu_3O_9$
(123 superconductor)	(2223 superconductor)

Because of the relative proportion of the *metal* atoms (everything but O) in these materials, they are often referred by the 123 and 2223 nicknames as indicated.

Procedures

A. Meissner Effect

All conductors shield their interior from externally applied fields by setting up surface currents, whose associated magnetic field exactly cancels the external field. Due to resistance in most conductors however, these currents die out almost instantaneously, and the external magnetic field penetrates the substance. In superconductors with no resistance however, these surface currents persist, and the external field continues to be expelled from the material, resulting in a strong repulsive force between the magnet and superconductor.

Place a plain (without any wires attached) superconducting pellet into a shallow styrofoam well. Carefully fill the well with liquid nitrogen, which is below T_c for the superconductor. When the pellet is below its critical temperature, you will find it possible to levitate and rotate a small magnet above it. If you carefully start the magnet rotating, you will see that it continues to rotate for a long while, slowed only by friction from the surrounding air.

B. Critical Properties

Use a superconducting pellet containing three pairs of embedded wires. One pair (red/blue) gives a voltage reading from an embedded thermocouple, which measures the temperature of the pellet. The black pair allows application of a current, and the yellow pair allows measurement the voltage drop associated with the applied current. This setup allows measurement of temperature and resistance (R=V/I).

When making measurements of resistance, use applied currents of 0.5 A or less!

1. As the sample warms from liquid nitrogen temperature, measure the resistance as a function of temperature for both the 123 and 2223 superconductors. Plot R vs. T for each, and determine each material's critical temperature.

2. Although current is carried with no resistance in superconductors, an unlimited amount of current cannot be carried in this fashion—as current is increased, a limit will be achieved at which the material no longer superconducts. This limiting current depends on the temperature (below T_c) of the material, with more current able to be conducted at lower temperature. Of interest is the *limiting current at 77K*, which represents the greatest practical current transmission (at liquid nitrogen temperature). Unfortunately, we cannot directly measure this, because currents above 0.5A will damage the probe setup. Because the limiting current and temperature are related however, we can estimate it by measuring T_c as a function of applied current—when T_c is reached at a given current, that also means that you have found the limiting current at that temperature.

   On multiple runs at different applied currents ranging from 0.1 to 0.5 A (do not exceed 0.5 A!), measure the resistance vs. temperature of a superconducting sample as it warms from liquid nitrogen temperature. For each current, plot R vs. T and determine the critical temperature. Plot log(current) vs. T_c. This is expected to give a linear relationship, and by extrapolating to 77K, estimate the *limiting current at 77K*.

Reference

Callister, Section 21.11

NOTE: Bring a 3.5" diskette (IBM formatted) to copy your experimental data.