High-temperature superconductors are interesting metamaterials currently being researched around the world. Given students easy access to an education-rich superconductivity experiment was the project goal. After over a year of hard work, the experiment will be available for the Fall 2015 Semester.

**Materials**

Materials can be classified as (1) conductors or metals, (2) non-conductors or electrical insulators, (3) semiconductors or (4) superconductors according to their ability to move charge. **Superconductors** are solid elements, inter-metallic alloys or compounds that reach a superconducting phase transition at a specific **critical temperature** $T_c$. Below this temperature, the superconductor’s electromagnetic properties are altered appreciably without change in the crystal structure. While superconducting, they are known for (1) **Zero-Resistance**, no resistance to direct current (DC), allowing charge to flow without hindrance and (2) **Meissner-Ochsenfeld Effect**: expulsion of magnetic flux from the superconductor’s interior.

Superconductivity was discovered in 1911 by Heike Kamerlingh Onnes when he cooled a mercury sample and caused it to superconduct. He used liquid helium as the coolant which has a boiling point temperature of $-268.95\,\text{K}$ ($-452.11\,\text{F}$). This was an important discovery, but much excitement was renewed in 1986 when Swiss scientists discovered that certain ceramics would superconduct around $4.2\,\text{K}$.

Starting in 1987, several groups discovered materials that would superconduct at temperatures over 77K. These new materials are called **high-temperature** or **high-$T_c$** superconductors. Their discovery was a major breakthrough because liquid nitrogen could be used as the coolant which has a boiling point temperature of $77K = -196.15\,\text{C} = -321.07\,\text{F}$. Liquid nitrogen can be distilled from air, and is relatively cheap.

**Methods**

An autotuning temperature controller (Model 330) was used to control the temperature of the sample in this experiment. **Liquid nitrogen** was used as the coolant and heater coils were used to control the cooling and set the temperature at a specific value.

An electromagnet produced uniform external magnetic field of $\approx 90\,\text{mT}$ for the cryostat to sit in. The sample was inserted into the cryostat and helium gas was used to exchange thermal energy between the sample space and liquid nitrogen.

**Data**

- **Sample Resistance vs. Temperature**: The sample's resistance $R_S$ decreases as the magnetic field $B_0$ increases, a superconductor’s critical temperature $T_c$ increases. As the current density in the superconductor $J$ increases, its critical temperature $T_c$ decreases.

**Conclusion**

- The four point probe method with the appropriate equipment and approximations allowed an accurate determination of the YBCO sample’s decreased resistance with temperature.
- Attaching the current and voltage leads to the sample was extremely sensitive. If the surface degraded, measurements actually displayed semiconducting properties and resistance increased with temperature.
- The YBCO sample had its superconducting phase transition between 89 K and 92 K. The resistance falls to near-zero as it enters the superconducting state. Any residual resistance represents the experiment’s measurement limitations.
- An external magnetic field shifts the superconducting phase transition to a lower temperature, but does not significantly affect the superconducting or normal region.

**Further Work**

- Resistivity calculations
- Magnetic susceptibility measurements
- Current density effect on critical temperature
- Improved method of attaching current and voltage leads

**References**