10/10

Building
A
Superconductor

By
Mark Young

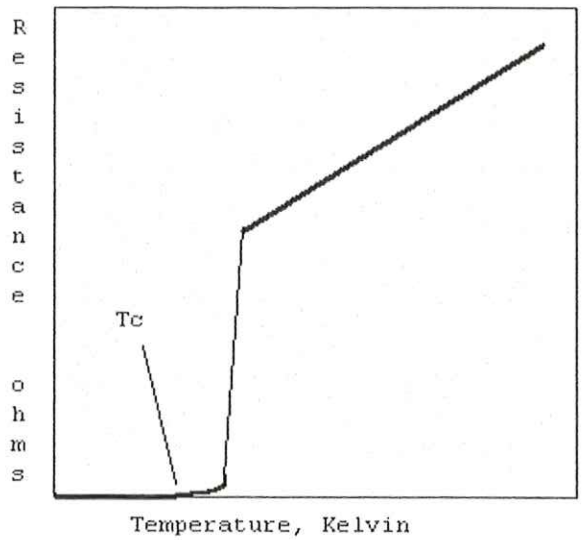
April 19, 2002

Purpose

The purpose of this lab is to build a working superconductor.

Introduction

Below a certain temperature for some metals and materials, it has been observed that their resistance goes to zero. That temperature is the "Critical Temperature", Tc, and the metal or material is then called a superconductor.



Between the temperatures 0 and Tc, the resistivity of this substance is very near zero.

Once Tc is surpassed, there is a jump in resistivity, and the substance yields a resistivity characteristic unique to that substance.

In the zero resistivity range, a current may be supplied to the superconductor, which may persist with no further applied voltage. Since the discovery of superconductivity in 1911, it was found that Tc was typically in the frigid 4K range.

In 1986 two scientists reported evidence of superconductivity in the 30K range. The discovery was unexpected and sparked excitement, as it hinted that superconductivity might be possible in more practical temperature ranges. Although superconductivity has since been observed in substances at temperatures as high as 125K, the cause remains unclear. [1]

A substance may be tested for superconductivity in two ways. First, of course, one may measure the resistance of the subject to see if it does approach zero. A second, more exciting test, is known as the Meissner Effect.

A circulating current in a superconductor causes there to be an absence of a magnetic field in the interior of the superconductor. It is thought that the magnetic field caused by this current opposes the magnetic field of the magnet, and a balancing in magnetic forces gives rise to levitation. Interestingly, a force is required for lateral movement.[2]

[1] Serway, Physics for Scientists and Engineers, p. 751
[2] Serway, Physics for Scientists and Engineers, p. 1328.

Experiment

This lab will involve the creation of a high temperature superconductor. Specifically, YBa_2Cu_3 with a Tc of approximately 92K. This compound must first be made from the mixtures of Y_2O_3, $BaCO_3$, and CuO. These substances come in powder form and must be mixed according to the stoichiometry ratio 1:4:6.

Procedures

Y_2O_3, $BaCO_3$, and CuO must each be weighed separately with caution, as they are toxic. Their molar masses are found to be 225.81, 197.34, and 79.55 in g/mol respectively. The powders are then to be mixed together thoroughly, and the mixture is then placed in a porcelain boat, ready to be placed in an oven. ✓

These powders are generally hydrated, that is, the molecules may include multiples of $\cdot H_2O$. The oven must reach a temperature of 400°C to, in a sense, boil away the water molecules. After a waiting period, the oven must climb to 950°C to provide sufficient heat energy to allow the compounds to combine. This process is to be undergone twice to ensure full reaction of the compounds. ✓

Results

After examination of the stoichiometry of the reaction, the following amounts were used:

Compound	Molar Mass (g/mole)	Amount Used (g)
Y_2O_3	225.81	2.20
$BaCO_3$	197.34	7.69
CuO	79.55	4.65[3]

These compounds were weighed and mixed under a fume hood. After being thoroughly mixed and being transferred to three porcelain boats, they were placed in an oven with the following heating schedule: ✓

<u>Cycle 1:</u>
Heat 10°/min until 400°C
Heat 5°/min until 950°C
Wait 480 minutes (8 hours)
Cool until 650°C
Wait 360 minutes (6 hours)
Cool until 100°C
End

[3] See calculation on page 6

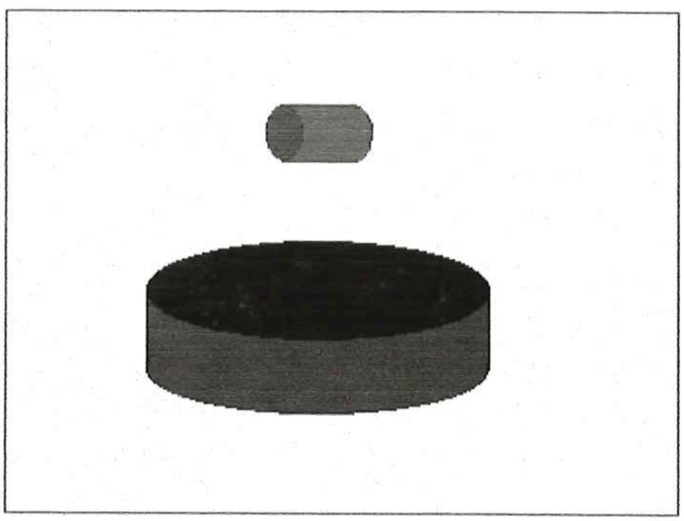
After this heating cycle completed, the samples were removed from the oven, remixed, and pressed into pellets. Some pellets disintegrated, but five, somewhat crumbly pellets were created. These were then placed back in two porcelain boats (as a porcelain plate was unavailable) and returned to the oven for one more heating cycle:

Cycle 2:
Heat 5°/min until 960°C
Wait 480 minutes (8 hours)
Cool until 650°C
Wait 480 minutes (8 hours)
Cool until 400°C
Wait 360 minutes (6 hours)
Cool until 100°C
End

After the second heating cycle, the pellets were ready to be removed from the oven, and tested for Superconducting capabilities. Two types of tests were conducted.

The Meissner Effect
The pellets were placed in a small tray, and then cooled to 70K with liquid nitrogen. A small magnet was placed over each pellet. The magnet levitated over each pellet at a height that seemed to increase as the thickness of the pellets increased. The simple fact that there was levitation is an indication of Superconducting, and therefore all five pellets may be called "superconductors".

The Meissner Effect:



Resistivity
An attempt was made to measure the resistance of a pellet below its critical temperature. Two wires were attached to the pellet to direct a constant current across it. An additional two wires were attached to the pellet to measure the voltage across the pellet, thereby

measuring its resistance, as V = IR. That is, R = V/I. At room temperature, the pellet had a resistance of around 400Ω. Once cooled with liquid nitrogen, this resistance dropped to around 40 to 50Ω. Although the pellet would appear to be Superconducting as a magnet levitated over it during this test, an expected zero resistance was not observed.

It was then decided to submerge the tray that held the pellet, as well as a good portion of the lead wires attached to it, in liquid nitrogen. It was suspected that the tray and lead wires were supplying enough heat to portions of the pellet to cause it to behave normally in these sections, that is, have sectional resistance, while it would be cold enough to superconduct in other regions, hence allowing the Meissner Effect to be seen. After the tray was submerged, the measured resistance fell to zero, but then to negative values ranging from –50 to -100Ω.

Discussion

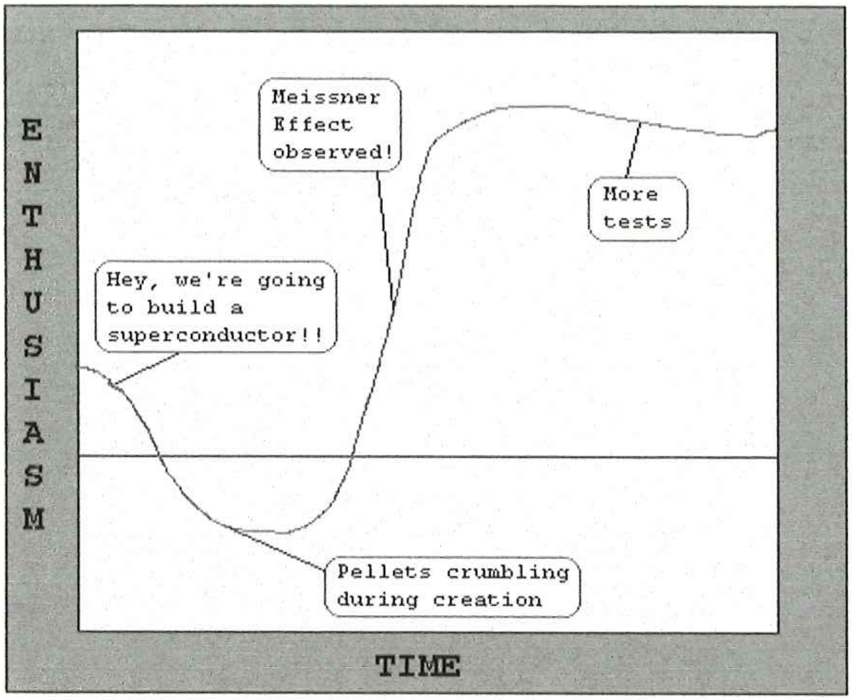
The procedures of this lab were relatively straight forward, with only a couple of difficulties. The first was the construction of the pellets from the fine black powder. Perhaps this is an aspect where "practice makes perfect", and more experience in pellet making might have helped. Despite a few completely disintegrated pellets, we were able to continue with five, somewhat crumbly pellets, that in the end were quite adequate.

The second difficulty leads to varying speculation. This was the difficulty of measuring the resistance of the superconductor. It was clear that the pellets could superconduct while at the same time have a resistance of about 50Ω, which seemed somewhat contradicting. While we also suspected that the lead wires were supplying heat causing normal areas to form on the pellets, Dr. Williams also suggested that perhaps the pellets were not quite homogeneous.

We also consulted Dr. Williams on the negative resistance readings, as his familiarity with the equipment might qualify him. He seemed as stumped as we were, but reminded us that the machine measures resistance by reading a voltage potential, and that this could be due to a contact potential between metals.

One might also think that as the machine supplies the superconductor with a current, the current in the pellet may soon balance the input current, and perhaps current feedback could cause a negative reading. It is felt that the resistance of the pellet did approach zero. The negative readings are then either a result of equipment malfunction due to zero resistivity, or another unknown phenomenon.

The drive in this experiment was not only the anticipation of building a high temperature superconductor, but also in reproducing a more modern scientific achievement. Until now, it seemed that all the experiments I have participated in were reproducing results that were known long before I was born. The idea of reproducing an achievement that before 1986 was not thought possible adds extra excitement to the experiment. It seems to, more than any other lesson, point out that this is still a very active subject, with much still to be discovered. A fine note on which to finish a drawn out science degree.



Conclusions

A high temperature superconductor was successfully created, restoring experimental enthusiasm.

References

Latta, Dr. Bryan, Acadia University

Serway, Raymond, Physics for Scientists and Engineers, 3rd edition, Saunders College Publishing, Toronto, 1990.

Williams, Dr. Peter, Acadia University

Calculations

Mass of CuO:

The molar mass of CuO was determined to be 79.55g/mole. From the stoichiometry ratio, 1:4:6, we know that we need 6 moles of CuO for every mole of Y_2O_3 used. 2.20g of Y_2O_3 was used,

$$\therefore (2.20g)/(221.81g/mole) = 9.74mmol\ Y_2O_3$$
$$9.74mmol(6)(.07955g/mmol) = 4.65g\ CuO \text{ needed}$$