Experiment 12: Superconductivity

Using a superconducting ceramic disk (composition: $YBa_2Cu_3O_7$), you will demonstrate the Meissner effect (by magnetic levitation) and measure its critical temperature.

CAUTION:

1. The superconductor (the black material) is toxic if ingested. Do not touch it. If you do, wash with soap and water before touching your eyes or mouth.

2. Liquid nitrogen can cause "burns" due to its extreme coldness (77°K, or -321°F). A small droplet on your hand won't hurt, but don't touch significant amounts. Wear glasses or goggles in case it splashes. (Others have used these; alcohol wipes are available.) Do not touch anything which has been in it, especially metal, until you're sure it's warm.

3. Allowing this superconductor to absorb water will make it crumble. At the end of the experiment, remove all frost with a hair dryer. Puddles of melted frost can be removed more quickly by also dabbing with a paper towel.

Also, try not to bend the wires sharply on the end near the sample; they are easy to break loose from it.

SETUP:

Your kit contains a superconducting disk, mounted in brass with wires sticking out. Place this, black disk on top, in the <u>rectangular</u> cavity of its Styrofoam container, and make the electrical connections shown. The meter for V_{Ω} must be readable to a hundredth of a millivolt. On the newer kits, blue and red are more like purple and copper, sticking out of brown insulation. The connections to the red and blue wires should be on blocks or books, above cold drafts from the boiling nitrogen. (This junction needs to be at room temperature for the thermocouple to be accurate.)



Establish a quarter of an amp or so flowing through the sample. Notice that this causes a millivolt or two of potential difference across it, due to Ohm's law. Record V and I. Calculate the resistance at room temperature.

Turn the current off until you need it again - it will tend to heat the sample.

Part I: Meissner Effect.

The Meissner Effect is the expulsion of a magnetic field from the interior of a superconductor. It does this by developing current on its surface whose field cancels any external field. So, if you place a small permanent magnet over a superconductor, a magnetic "image" of it forms directly below it, which repels the magnet and makes it float.

One would expect from Faraday's Law that placing a magnet near a perfect conductor would have this sort of effect: As the magnet approached it, the strength of its field there would be changing, which would induce currents; these currents would persist after the magnet arrived due to the lack of resistance. However, experiment shows that if the magnet is already present when the superconductor loses its resistance, it will still be levitated. Since Faraday's law predicts no induced current because the magnet's field is not changing, this demonstrates that the Meissner effect is a separate phenomenon, distinct from electromagnetic induction.

PROCEDURE:

1. With tweezers, place the small square magnet on top of the superconducting disk. (It seems to work a little better than the round one.)

2. Carefully pour liquid nitrogen into the dish, until the level is roughly even with the top of the superconductor.

3. The manufacturer's calibration information for the thermocouple is included in the data table. (Actual experience is that V_T in the nitrogen is sometimes 6.3 mV rather than 6.4 mV, so the temperatures listed may be a few degrees off.) As you approach the temperature of the nitrogen, watch for levitation of the magnet: It only gets a millimeter or two above the superconductor, but if you try to gently spin it with the tweezers, it will be quite apparent when it's floating. (One proposed application of the Meissner effect is for magnetic bearings.) Record your observations, and comment on how this demonstrates the Meissner effect, as described above.

Part II: Critical Temperature:

You will determine the transition temperature between the superconducting and normal states for this material.

1. With tweezers, remove the device from the nitrogen so it can gradually warm up.

2. Carefully watch the levitated magnet. First one corner will touch down, then one edge, then finally the whole bottom. Record the temperature, from the thermocouple, at which it completely comes to rest on the superconductor. Estimate an uncertainty.

3. Remove the magnet. Put the superconductor back in the nitrogen.

4. Turn the current on (about a quarter of an amp) and observe the Ohm's law voltage. Watch it for a little while to be sure it's stable before recording it. Estimate an uncertainty in V_{Ω} based on how much the meter fluctuates; probably a few hundredths of a millivolt. Within the sensitivity of your meters, what does the sample's resistance appear to be?

5. Remove the sample from the nitrogen, and take data for a graph of resistance as a function of temperature. This will be easiest if you keep the current the same for each reading: By Ohm's law, the voltage across the sample will then be proportional to its resistance, and you will get the same graph if you just plot V_{Ω} versus T without bothering to divide by I. Remember to include error bars the size of your estimate from step 4. Draw a smooth curve that hits the error bars somewhere, not a choppy one that hits them all in the center.

6. Read the critical temperature from your graph. Unlike traditional materials, these "high temperature" superconductors do not have sharply defined critical temperatures. Rather, the transition takes place over a range of a few degrees. Use this range of a few degrees as your range of uncertainty, and use the center of it as your critical temperature.



7. Compare T_c from your graph to the value you got from watching the magnet. Also comment on whether the resistance well below T_c agrees with zero.

After you get it dry, put the superconductor back in the plastic bag with the desiccant, and close it with a twist tie. (The way you hopefully found it.)

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At room temperature:

 V_{Ω} = _____ ± ____, I = ____ → R = ____ ± ____

PART I:

Behavior of magnet as disk approaches 77°K:

PART II:

Magnet comes to rest at T = _____

In the nitrogen,

 V_{Ω} = _____ \pm _____, I = ____ \rightarrow R = _____ \pm ____

T (°K)	V _T mV)	$V_{\Omega} mV$)		
77	6.4			
80	6.3			
82	6.2			
85	6.1			
87	6.0			
90	5.9			
93	5.8			
951/2	5.7			
98	5.6			
1001/2	5.5			
103	5.4			
106	5.3			
109	5.2			
112	5.1			
117	5.0			

From graph, $T_c =$ _____

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