Superconductivity

1 Introduction

In this lab we will do some very simple experiments involving superconductors. You will not have to take much data; much of what you do will be qualitative. However, in order to understand *what* you are doing, and *why* it is important to read this lab carefully. There is one part of the lab which involves determining the resistance as a function of temperature for the superconducting sample. We only have one sample with the appropriate connections, so please take turns.

This is a new lab . your comments on how to improve it are welcome.

2 Safety:

While it may seem like a lot of fun to work with liquid nitrogen, you should remember that it is a dangerous substance. It is extremely cold, and can damage flesh by freezing it. Please keep the following safety rules:

- Do not move liquid nitrogen containers in a matter that causes splashing. Be careful when transferring from one container to another.
- Never store liquid nitrogen in a container with a tight fitting lid.
- You may have seen people briefly dip their hands into liquid nitrogen: their skin is protected by a layer of nitrogen that flash-boils, blowing the bulk liquid back. It is therefore very dangerous to spill significant quantities of liquid nitrogen onto your clothing, which will hold the cold fluid close to your skin.
- While nitrogen gas is non-toxic, it can asphyxiate through displacement of oxygen. Make sure the room is well ventilated when you are using liquid nitrogen.
- Do not touch anything metal or ceramic that has been cooled down to liquid nitrogen temperatures. Use the tweezers provided.
- Do not pour liquid nitrogen onto any surface except those designed to hold it. The extreme cold can cause glass to shatter.

3 Theory:

Superconductivity was discovered in 1911, by H. Kamerlingh-Onnes in Holland (see Appendix 1). Its hallmark was the abrupt disappearance of electrical resistance at a critical temperature, T_c.

Superconductors possess many other unusual properties, such as perfect diamagnetism (they expel magnetic fields from their interior, causing magnets to “levitate” above them) and high thermal conductivity.

For a while it was thought that a superconductor was merely a material that somehow became a “perfect conductor” at low temperatures. Magnetic levitation was explained in the following fashion: when you bring a magnet up to the surface of a conductor, you are creating a time dependent magnetic field within the conductor as the magnet approaches the surface. You will learn/have learned that a time dependent magnetic field can create an electric field in a conductor. This electric field in turn creates currents that oppose the original magnetic field. The magnitude of these currents should depend on the resistivity of the material. If the material has *no* resistance, the currents are very large; large enough to entirely cancel out the magnetic field from within the sample. These surface *screening currents* are something like the screening charges that cancel a static electric field inside a conductor. The currents create a counter magnetic field that repels the approaching magnet.

Actually the story is more complicated than that, as you may see in this lab. A superconductor is *different* from a perfect conductor. It is more that just the absence of resistivity - it is another state. The transition to this new state occurs at a specific temperature much like the boiling of a liquid or the melting of a solid. In this lab you will determine this transition temperature.

4 Equipment

In order to investigate superconductivity you will need the following equipment:

- a superconductor in a brass housing with red and blue wires.
- a small disk of ceramic superconductor.
- two tiny, rare earth magnets: one cubic and one cylindrical.
- plastic tweezers.
- styrofoam cups
- liquid nitrogen
- digital multimeters and several wires.

Note that there are several tiny parts to this lab (such as the magnets) and several fragile ones (the superconductors). You will be held responsible for taking care of your equipment!

5 Care and Feeding of High T_c Superconductors

These high T_c materials are delicate and easily damaged. They are ceramic materials, like porcelain or china. **You must obey the following rules while handling these samples.**
You should obtain your samples from your TA at the beginning of lab, and return them to the TA at the end of lab.

1. Do not expose your superconducting samples to water. These means you should not touch them with your fingers.

2. When you are finished with the samples, be sure to wipe off the condensation on them using paper towels. Return them to the container with the dessicator (silica gel).

3. Do not drop, saw or pound the superconductors. They will shatter.

4. Do not heat them up to a temperature above 110F.

6 The Meissner Effect:

The expulsion of magnetic fields from a superconductor is called the Meissner effect. You will observe this both quantitatively and qualitatively.

1. Cut the bottom 3-4 cm off a styrofoam cup so that you have a shallow container in which to hold your samples. Fill a second, intact cup with liquid nitrogen from the TA's dewar.

2. Place a superconducting sample in the shallow cup and fill it with liquid nitrogen. (Use the large sample that is not bound in a brass casing.) Wait until the sample comes into equilibrium with the liquid. Pour off any excess until the sample is just in a shallow puddle.

3. Place the cylindrical magnet on top of sample using the tweezers. It should levitate. (You can also do this with the cubic magnet.)

4. Give the magnet a tap and set it rotating. Is the rotation damped? Make rough measurement of the number of rotations the magnet makes in 5 seconds. Wait at least a minute, and repeat the measurement. Wait an equivalent interval and repeat the measurement a third time.

Trial	Time	Rotations/5 sec	Period
1			
2			
3			

5. Tap the levitating magnet. Does it skitter about without friction, or does it seem stuck in place? Describe:

6. Carefully remove the sample from the cup with the magnet still suspended. Place the sample on the table and allow it to warm up. Describe your observations.

7. Place the small cylindrical magnet on the warm sample so that its flat end is on the bottom (so the magnet will not roll). Fill your shallow "dish" with liquid nitrogen. Using the tweezers, carefully place the sample in the liquid nitrogen with the magnet still balanced on top. When the sample is cooled, give it a slight tap. Does the magnet stay on the surface of the sample, or does it levitate slightly? Repeat until you are sure of your observations.

8. Again immerse the sample in the shallow styrofoam "dish", and cool it down with liquid nitrogen. Place one of the small magnets on top of the sample so that it levitates. Borrow a superconducting sample from another group (or obtain a second one from the TA) and place it in the dish beside the first, and let it cool down also. Using the tweezers, lift the sample with the magnet and place it atop the second sample. Does the magnet lift higher, or stay the same height?

7 Measuring the Transition Temperature:

In this section you will use the Meissner effect to measure the transition temperature. You will let the sample warm up and measure the temperature at which the magnet is no longer suspended. Repeating this several times will give you an estimate of the transition temperature.

You will measure the temperature of the sample using a thermocouple. A thermocouple consists of two different metals that, when placed in contact, develop a small voltage difference across their interface. This voltage is dependent on temperature and can be used to measure low temperatures. However, this voltage is extremely small (about 5mV). You must have accurate voltage readings in order for this to work.

1. Obtain from the TA a small superconducting sample in brass case. The case should have two wires attached to it: a blue one and a red one. Clip your digital multimeter to these wires, and set the scale for millivolts (mV).

2. Fill your shallow cup with liquid nitrogen and immerse this sample. You should see a voltage develop across the wires. When the nitrogen stops boiling, the voltage should read 6.4mV. If your result is slightly low, make sure the connections between the multimeter wires and the sample wires are at room temperature. Pinch each connection between your fingers to warm it up slightly. You should read 6.3-4mV. If you do not, try a different meter. If the result still does not change, try a different sample.

3. Place the small cylindrical magnet on top of the superconducting sample so that it levitates in place. Now carefully remove the sample from the liquid nitrogen using the tweezers, and place it on the table. The magnet should still be levitating. Center it with the tweezers, if necessary.

4. As the sample warms, the voltage will drop. One person should carefully watch the magnet and wait for it to completely fall in contact with the sample. Balancing on one end is not complete contact. When the magnet is no longer levitating, record the voltage across the thermocouple. Using the table in the appendix, convert this to a temperature.

5. Repeat this experiment at least 5 times. Calculate the average transition temperature and the standard deviation of the mean.

8 Resistance

The canonical indicator of superconductivity is an abrupt change in the sample resistance. In this experiment you will measure the resistance as a function of temperature for a high T_c superconductor. We only have one sample with the appropriate leads. Your TA should have this sample wired appropriately. Make sure that the connections are correct, and that you understand what you are measuring. You will need to work in a group of four in order to record the data.

In this part you will make a four point electrical probe in order to determine the sample resistance. When a simple measurement of the electrical resistance of a test sample is performed by attaching two wires to it, one inadvertently also measures the resistance of the contact point of the wires to the sample. Typically the resistance of the point of contact (the “contact resistance”) is far smaller that that of the sample and can be ignored. However, when one is measuring a very small sample resistance that is varying, the contact resistance can dominate and even obscure the changes in the sample resistance.

The effects of contact resistance can be eliminated with the use of a four point probe. A sketch of a four point probe is shown below. A constant current is made to flow the length of the wire sample through wires 1 and 4. If the sample has any resistance, then there will be a voltage drop as the current flows along the sample. Thus there will be a voltage drop between wires 2 and 3 in the figure. The voltmeter has a high internal resistance, and thus very little current flows across the contacts between wires 2 and 3 and the sample. This means that the voltage drop due to the contact resistance will be vanishingly small, and can be ignored.

1. Make sure the power is turned off in the voltage source before checking the circuit.

2. Hook the voltage supply up to the black wires coming from the sample. Set the meter on the voltage supply to measure amperes. This is both your power supply and your two current probes.

3. Hook up a multimeter to the yellow wires. Set the multimeter to measure millivolts (mV). These will be your voltage probes.

4. Hook up a second multimeter to the red and blue wires. These are your thermocouple leads.

Your circuit should look something like the following diagram:

5. Immerse the sample in liquid nitrogen. It is larger than the other samples, and will take a minute or two to cool down. Again wait for your thermocouple voltage to read 6.4mv. If it is slightly low, make sure the wire connections are warm. If you do not read 6.4mV, switch to better multimeter.

6. Remove your sample from the liquid nitrogen and allow it to warm up. Make sure it is not superconducting by checking it with a magnet.

7. Turn on the voltage supply and increase the power output to about 0.5 amps. (You may have to adjust the current control knob, which sets the maximum current the supply can produce). You should read 2-5mV on the voltage probes. If you do not, check your contacts and meter.

8. Ok! You are now ready to start. Immerse the sample in liquid nitrogen. At regular intervals (5 or 10 seconds) one person should call off the thermocouple reading, a second should call off the voltage on the voltage probes, a third should call off the current on the current supply meter, and the fourth should be recording all of this in table format. At some point you should see an abrupt drop in the voltage across the sample. When the voltage reaches zero, you can stop taking data.

9. Remove the sample from the liquid nitrogen and quickly place a magnet on top of it so that it levitates. Record the thermocouple voltage when the magnet ceases to levitate and when the voltage across the voltage probes is no longer zero. Are these events correlated?

10. If time allows, repeat the above experiment.

11. From your date plot the sample resistance (V/I) as a function of the temperature. Mark on your plot the temperature at which the magnet no longer levitated. Also mark the approximated temperature of the resistive transition.

9 Clean-up

Let your samples warm up, and then dry them off with paper towels. Return the samples to their storage containers. Return both small magnets. Dispose of the remaining liquid nitrogen in a safe fashion.

10 Questions

Please answer the following questions on a separate sheet of paper. Use complete sentences, and diagrams when appropriate. Refer to your calculations or measurements where appropriate.

1. From your Meissner effect measurements, what is the transition temperature of your high temperature superconductors? How does it compare with the transition as determined by the resistive transition?

2. Imagine you placed a magnet on top of some conductor with a non-zero resistivity. You cool the sample and for some reason its resistivity vanishes. Should the magnet levitate? Should there be any screening currents? (Hint: is there a time dependent magnetic field?) Relate this to your observations when you performed a similar experiment on these superconducting samples.

3. Give specific comments on this lab, the instructions, and any suggestions for improvement.