

Superconductivity

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(Dated: December 17, 2014)

Abstract

I. INTRODUCTION

II. EXPERIMENT

Temperature and resistance are measured for two different materials: $YBa_2Cu_3O_7$ (YBCO) and $Bi_2Sr_2Ca_2Cu_3O_9$ (BISCO). The experiments are done in two different ways for different materials.

A. YBCO

The setup of YBCO experiment is shown in the Fig. 1. The device (Fig. 2), including the YBCO sample, a thermocouple, a current probe and a voltage probe, is put in a plastic-foam cup and immersed in sands, which serve as insulator. The box variable resistor in Fig. 1 is only used for keeping the free wires at a fixed place.

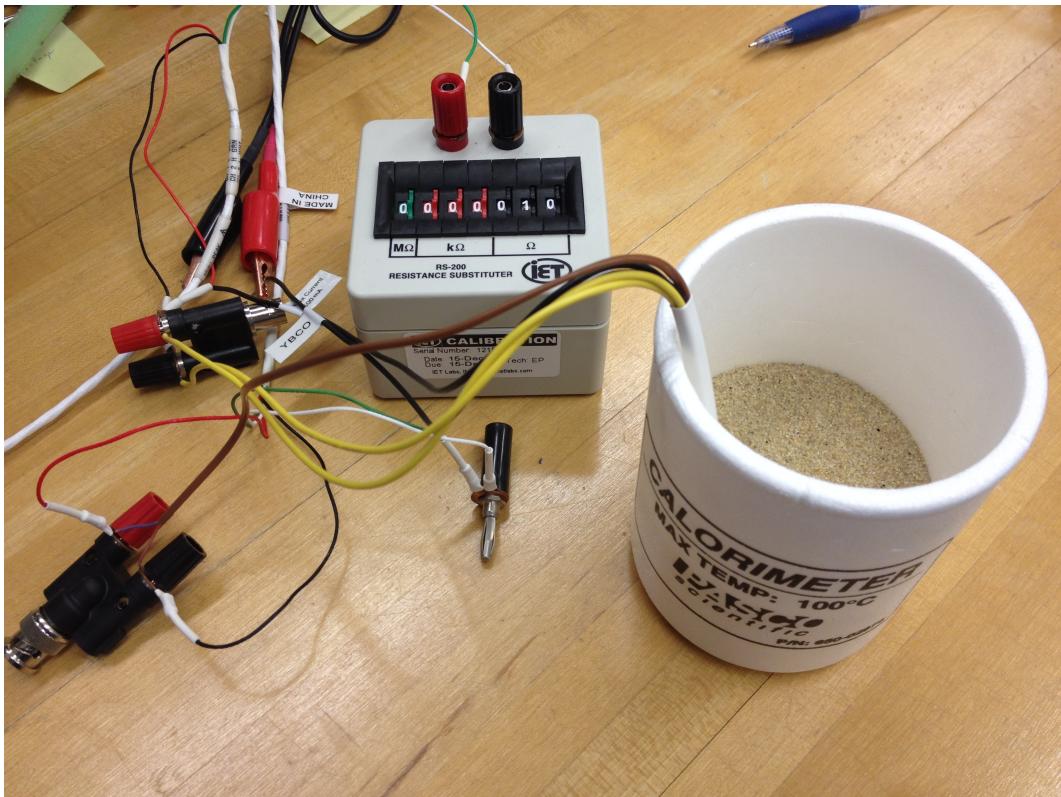


FIG. 1. Picture of the experiment setup

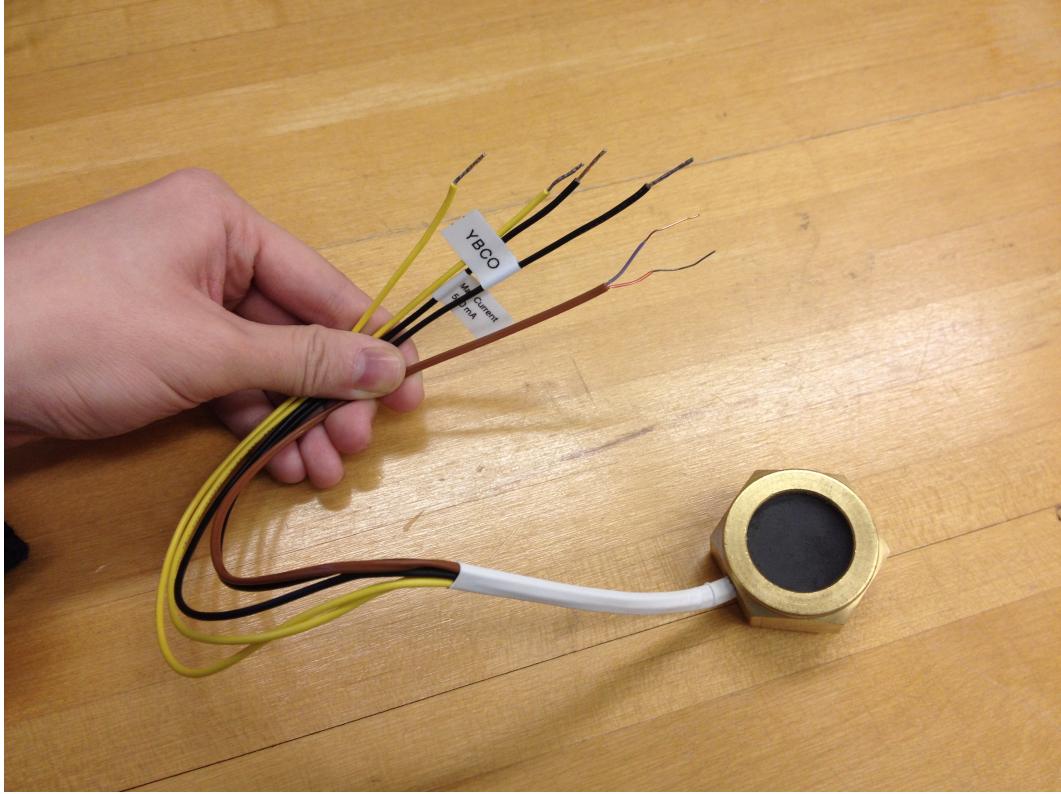


FIG. 2. Picture of the device, including YBCO sample (the black disk on top), thermocouple (brown lead), current (black leads) and voltage probes (yellow leads)

When superconducting, the material has a very low resistance, which means the resistance of the leads of the probes becomes non-negligible. Therefore a method called four point probe is employed so that only the resistance of the material is measured, not that of the leads. The circuit is shown in Fig. 3. The black rectangle at the bottom represents the YBCO sample, an ammeter is connected in series with the sample through leads 1 and 4, and a voltmeter is connected in parallel with the sample through leads 2 and 3. Then the resistance of the sample could be calculated using Ohm's Law:

$$R = \frac{V}{I} \quad (1)$$

where V and I are readings of the voltmeter and ammeter respectively. The key point here is that leads 2 and 3 have to be inside leads 1 and 4, in terms of position on the sample. Picture the meters as ideal meters plus lead resistance. The advantage of doing so is that the ammeter approximately measures the current through the sample, because the resistance of the voltmeter is so much bigger than that of the superconductor that the current through

the voltmeter is very close to zero; and the voltmeter only measures the voltage across the sample. However, if the position of the ammeter and voltmeter were switched, as the second circuit shown in Fig. 3, the voltmeter would measure the voltage across the lead resistance of the ammeter and the sample resistance connected in parallel. The total resistance of the two in parallel would differ from the sample resistance a lot because when superconducting, the resistance of the sample is comparable to the resistance of the lead.

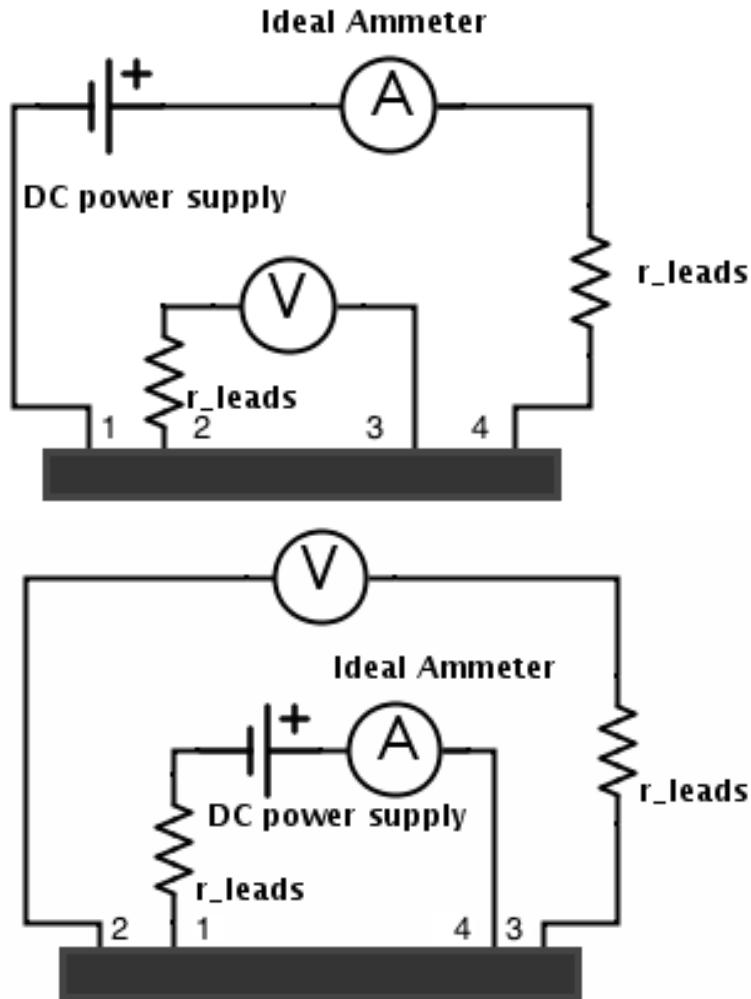


FIG. 3. Schematic of four point probe. The second is the bad configuration.

The sample is connected to two digital multimeters (DMM) (top two in Fig. 4) and one power source bottom one in Fig. 4. The top one is measuring the voltage across the thermocouple, and the voltage can be translated into temperature according to the table in Fig. 5.

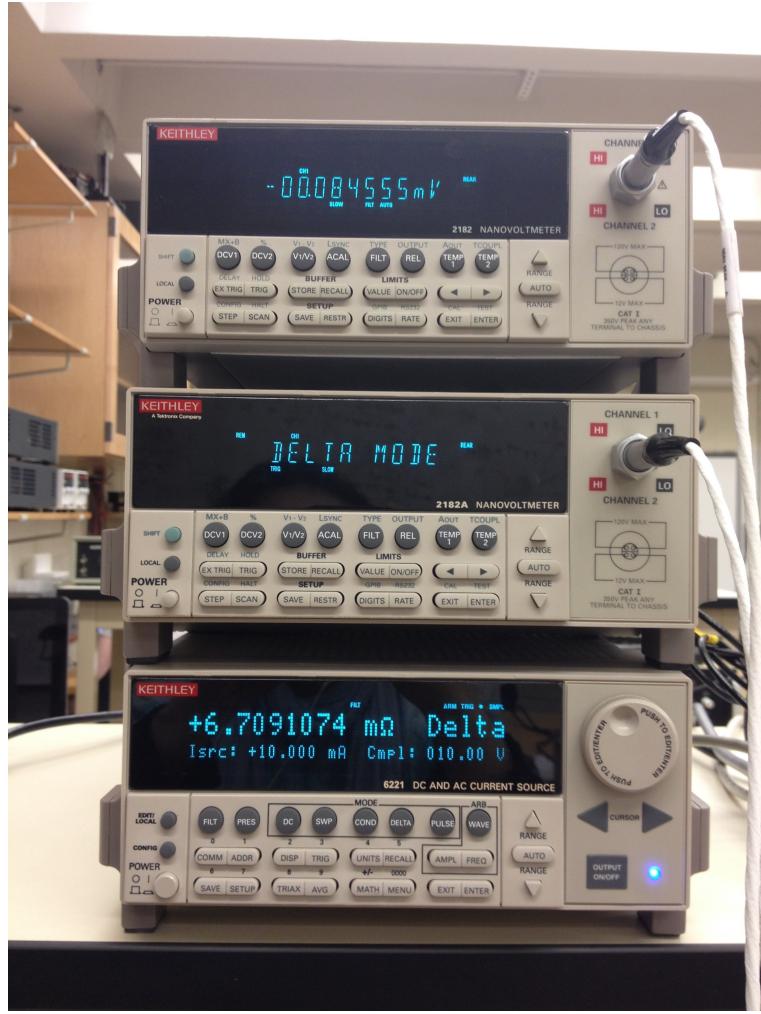


FIG. 4. The DMMs and power supply used. The top one measures the voltage of the thermocouple, the middle one measures the voltage across the sample, but the value is not shown on the screen under delta mode. And the bottom one is a power source that is in delta mode, and it reads the resistance of the YBCO sample.

The source is the "DC power supply" in Fig. 3 and Fig. ???. Although it is labelled as DC power source, it is actually in delta mode, which means it is outputting a current alternating between positive and negative. The advantage of delta mode is that it can eliminate the affect of offsets measured by the voltmeter. When a positive current is passing through the sample, the voltmeter measures an offset and the real voltage signal across the sample, $V_+ = V_{offset} + V_{signal}$; if the current is reversed, the voltage across the sample would also flip sign, but the offset would remain the same, $V_- = V_{offset} - V_{signal}$. From V_+ and V_- , the

Conversion from mV to Kelvin												%K
%K	0	1	2	3	4	5	6	7	8	9	10	
60	7.60	7.53	7.46	7.40	7.33	7.26	7.19	7.12	7.05	6.99	6.92	60
70	6.92	6.85	6.78	6.71	6.64	6.56	6.49	6.42	6.37	6.33	6.29	70
80	6.29	6.25	6.21	6.17	6.13	6.09	6.05	6.01	5.97	5.93	5.90	80
90	5.90	5.86	5.83	5.79	5.75	5.72	5.68	5.64	5.60	5.56	5.52	90
100	5.52	5.48	5.44	5.41	5.37	5.34	5.30	5.27	5.23	5.20	5.16	100
110	5.16	5.13	5.09	5.06	5.02	4.99	4.95	4.91	4.88	4.84	4.81	110
120	4.81	4.77	4.74	4.70	4.67	4.63	4.60	4.56	4.53	4.49	4.46	120
130	4.46	4.42	4.39	4.35	4.32	4.28	4.25	4.21	4.18	4.14	4.11	130
140	4.11	4.07	4.04	4.00	3.97	3.93	3.90	3.86	3.83	3.79	3.76	140
150	3.76	3.73	3.69	3.66	3.63	3.60	3.56	3.53	3.50	3.47	3.43	150
160	3.43	3.40	3.37	3.34	3.30	3.27	3.24	3.21	3.18	3.15	3.12	160
170	3.12	3.09	3.06	3.03	3.00	2.97	2.94	2.91	2.88	2.85	2.82	170
180	2.82	2.79	2.76	2.73	2.70	2.67	2.64	2.61	2.58	2.53	2.52	180
190	2.52	2.49	2.46	2.43	2.40	2.37	2.34	2.31	2.29	2.26	2.23	190
200	2.23	2.20	2.17	2.14	2.11	2.08	2.05	2.02	1.99	1.96	1.93	200
210	1.93	1.90	1.87	1.84	1.81	1.78	1.75	1.72	1.69	1.66	1.64	210
220	1.64	1.61	1.59	1.56	1.54	1.51	1.49	1.46	1.44	1.41	1.39	220
230	1.39	1.36	1.34	1.31	1.29	1.26	1.24	1.21	1.19	1.16	1.14	230
240	1.14	1.11	1.09	1.07	1.04	1.02	0.99	0.97	0.94	0.92	0.89	240
250	0.89	0.87	0.84	0.82	0.79	0.77	0.74	0.72	0.69	0.67	0.65	250
260	0.65	0.62	0.60	0.58	0.55	0.53	0.50	0.48	0.45	0.42	0.40	260
270	0.40	0.38	0.36	0.34	0.32	0.30	0.28	0.26	0.24	0.22	0.20	270
280	0.20	0.18	0.16	0.14	0.12	0.10	0.08	0.06	0.04	0.02	0.00	280
290	0.00	-0.02	-0.04	-0.06	-0.08	-0.10	-0.12	-0.14	-0.16	-0.18	-0.20	290
300	-0.20	-0.22	-0.24	-0.26	-0.28	-0.30	-0.32	-0.34	-0.36	-0.38	-0.40	300

FIG. 5. The correlation between the temperature and the voltage across the thermocouple

voltage due to the sample can be calculated. The middle DMM reads the two voltages and calculates V_{signal} automatically. The middle DMM is also connected to the power supply at the back. The power source reads V_{signal} from the middle DMM and then divides it by the current to get the resistance of the superconductor, which is shown on the screen in unit of $\text{m}\Omega$. By observing the temperature dependence of the resistance, the critical temperature of the superconductor could be found out.

However, the drawback of this setup is that we could not make computer record the data. So we videotaped the DMMs while the sample was cooled down by liquid nitrogen, and then transcribed the thermocouple voltage and superconductor resistance into analysis tool, i.e. Igor Pro, by hand. To test the current dependence of the critical temperature of the material, four sets of data are collected, with current output of the power supply being 0.1mA, 1mA, 10mA and 100mA respectively.

B. BISCO

The setup of the experiment on BISCO is shown in Fig. 6. The device is also put in a plastic-foam cup and covered by sands. This device is designed in the same manner as the YBCO sample using four point probe.

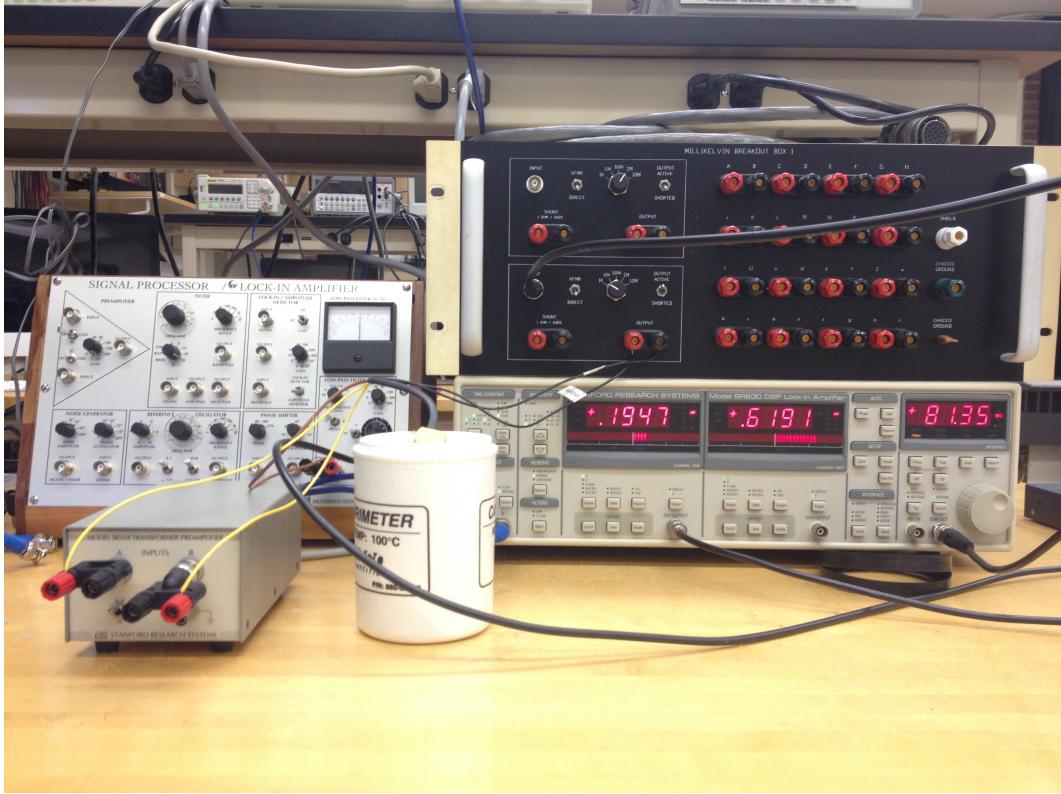


FIG. 6. The setup of experiment of BISCO

The thermal couple is connected to the left lock-in amplifier in Fig. 6, which has a time constant of 1s and a gain of 1000. The output is fed to a DMM which is read by the computer.

A Model SR830 DSP lock-in amplifier (simplified as SR830 lock-in amplifier, gray equipment on the lower right in Fig. 6) is employed in this experiment. The most important feature of this lock-in amplifier is that it feeds the sample a sine signal and then it detects the in-phase and out-of-phase feedbacks from the sample separately, with in-phase feedback shown in channel 1 (left) and the out-of-phase one shown in channel 2 (right).

When wires are close together, they form a capacitor. When they curl, they become

inductors. In both situations the wires bring in noise if we only want to know the voltage across the resistor. Normally the noise would be so small that it could be safely neglected. However, the resistance of the superconductor drops to such a low level that that noise becomes dominant. To distinguish between signal and noise, a sine input is introduced. The resistor outputs a voltage that is in-phase with the input, while the "capacitors" and "inductors" formed by wires yield voltage that has a $\pi/2$ phase delay. We could filter out the noise by only taking the in-phase voltage.

SR830 lock-in amplifier has a sine voltage output, whose peak to peak value is measured to be $2.8 \pm 0.02V$. This output is fed to the input of a breakout box (the black box in the upper right in Fig. 6), and then converted to a current through a resistor of $1k\Omega$. This current now acts as the "DC power supply" in Fig. 3, and is introduced into the circuit through the black wires (the current probe). The yellow leads (the voltage probe) are connected to a transformer preamplifier with a gain of 500, which is then connected back to the SR830 lock-in amplifier. The in-phase channel (CH1) is read by another DMM which ultimately communicates with the computer. LabView is used to collect the readings from the two DMMs: the voltage from the thermal couple and the in-phase voltage signal from the SR830 lock-in amplifier.

The resistance of the superconductor can be calculated by

$$R_{superconductor} = \frac{V_{in-phase}/g}{I} \quad (2)$$

where

$$I = \frac{V_{max}}{R_{breakout}} \quad (3)$$

and $V_{in-phase}$ is the in-phase voltage measured, $g = 500$ is the gain of the transformer, $V_{max} = 1.4 \pm 0.01V$ is the maximal input sine voltage from SR830 lock-in amplifier and $R_{breakout} = 1k\Omega$ is the resistance in the breakout box. And the temperature of the sample could be converted from the voltage across the thermal couple using the table in Fig. 5.

III. RESULTS

A. YBCO

B. BISCO

IV. DISCUSSION

V. CONCLUSION

ACKNOWLEDGMENTS

We gratefully acknowledge Nathanael Fortune and Dana Parsons, who helped with the experimentation and editing of this experiment. This work was supported by the Smith College Physics Department.

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¹ Scheme-it, <http://www.digikey.com/schemeit>

² Optical Pumping, <http://internal.physics.uwa.edu.au/~stamps/2006Y3Lab/SteveAndBlake/theoretical.html>