

Critical Temperature of YBCO and BSCCO Superconductors

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Abstract

Superconductors are materials that lose their electrical resistance when they fall below a certain temperature. This is called the critical temperature. We determine the critical temperatures of two superconductors, $\text{YtBa}_2\text{Cu}_3\text{O}_{7-\delta}$ and $\text{Bi}_2\text{Sr}_2\text{Ca}_{n-1}\text{Cu}_n\text{O}_9$, by measuring the voltage across the resistor as a function of temperature.

I. INTRODUCTION

In 1911, Kamerlingh Onnes discovered superconductivity in mercury. Instead of a gradual decrease in the electrical resistance as the temperature decreased, he found a sudden loss of resistance when the temperature went below 4.2 K. The temperature at which the resistance disappears is called the critical temperature. In addition to having no resistance, superconductors also exhibit perfect diamagnetism, which means they exclude all magnetic field flux from their interior. This property, called the Meissner effect, was discovered in 1933.¹ A common demonstration of the Meissner effect is to place a magnet on top of a superconductor above its critical temperature. When the superconductor is cooled to become superconducting, the magnet will start to levitate above the superconductor. This phenomenon can be used to make levitation trains. Superconductors are also used to create magnetic fields used in magnetic resonance imaging and in high energy physics to accelerate and control the path of particles.²

Superconductivity has been found to occur in elements, alloys, binary compounds, and other materials. Roughly 70 years after superconductivity was discovered, ceramic materials with critical temperatures above the liquid nitrogen temperature of 77 K were found.³ These “high temperature” superconductors were made up of alternating layers of rare earth atoms and copper and oxygen atoms.² In our experiment, we look at two high temperature superconductors, $\text{YtBa}_2\text{Cu}_3\text{O}_{7-\delta}$ and $\text{Bi}_2\text{Sr}_2\text{Ca}_{n-1}\text{Cu}_n\text{O}_9$, where $n = 1, 2$, or 3 . The amount of oxygen in $\text{YtBa}_2\text{Cu}_3\text{O}_{7-\delta}$ determines if the material will be superconducting. For $\text{Bi}_2\text{Sr}_2\text{Ca}_{n-1}\text{Cu}_n\text{O}_9$, the critical temperature is depends on the value of n .

II. AIMS

1. To determine the critical temperature of YBCO and BSCCO.

III. PROCEDURE

The YBCO and BSCCO superconductors were obtained from Colorado Superconductor Inc. Each superconductor is contained in a brass casing with three pairs of leads. One pair was for attaching to the current source, another pair was used to measure voltage across the superconductor, and the last pair that of the thermocouple inside the casing.

The thermocouple has a resistance that varies with temperature, so we can determine the temperature of superconductor by measuring the voltage across the thermocouple.

We used different methods to measure the critical temperature of the two superconductors. For the YBCO, we connected it to a source with an alternating current of ± 1 mA. The voltage across the YBCO sample, V_{YBCO} , and the voltage across the thermocouple, V_T were measured with two nanovoltmeters. We placed the superconductor inside a styrofoam cup filled with sand. The sand reduces the rate at which the superconductor heats up, which allows us to gather more data points. We cooled the YBCO sample by pouring liquid nitrogen into the styrofoam cup. We waited for the superconductor to settle to a minimum temperature. Then we recorded V_{YBCO} and V_T as it warmed up to above its critical temperature.

We used a two-phase lock-in amplifier for the BSCCO experiment. In an AC circuit, the measurement of resistance includes contributions from capacitors and inductors. Although there are no explicit capacitors or inductors in our circuit, they are effectively present due to the electrical cables used. The lock-in amplifier allows us to extract the resistance of superconductor from the other contributions because the resistance will be in phase with the signal, while the contributions of capacitors and inductors will be out of phase. Since the resistance of the BSCCO at room temperature is on the order of $\text{m}\Omega$ s, we can get approximately ± 1 mA in the circuit by connecting the BSCCO in series with a $1\text{ k}\Omega$ resistor, and with a AC voltage source of 1 V.

IV. RESULTS AND ANALYSIS

First, to convert our thermocouple voltage into a usable temperature, we transcribed the chart provided in the Teachspin manual that came with the YBCO and BSCCO samples and plotted temperature vs voltage (see Fig. 1). While it was best fit piecemeal, a single curve was able to cover our temperature range, and we used that function to convert our thermocouple voltages in later fits.

We gathered data across two warm-ups of the YBCO sample, the first at equal time intervals between points (see Fig. 2) and the second focusing on taking more points during the transition period than elsewhere (see Fig. 3). In order to determine the critical temperature, we found the point along the transition period that was exactly in between the trend line

[h!]

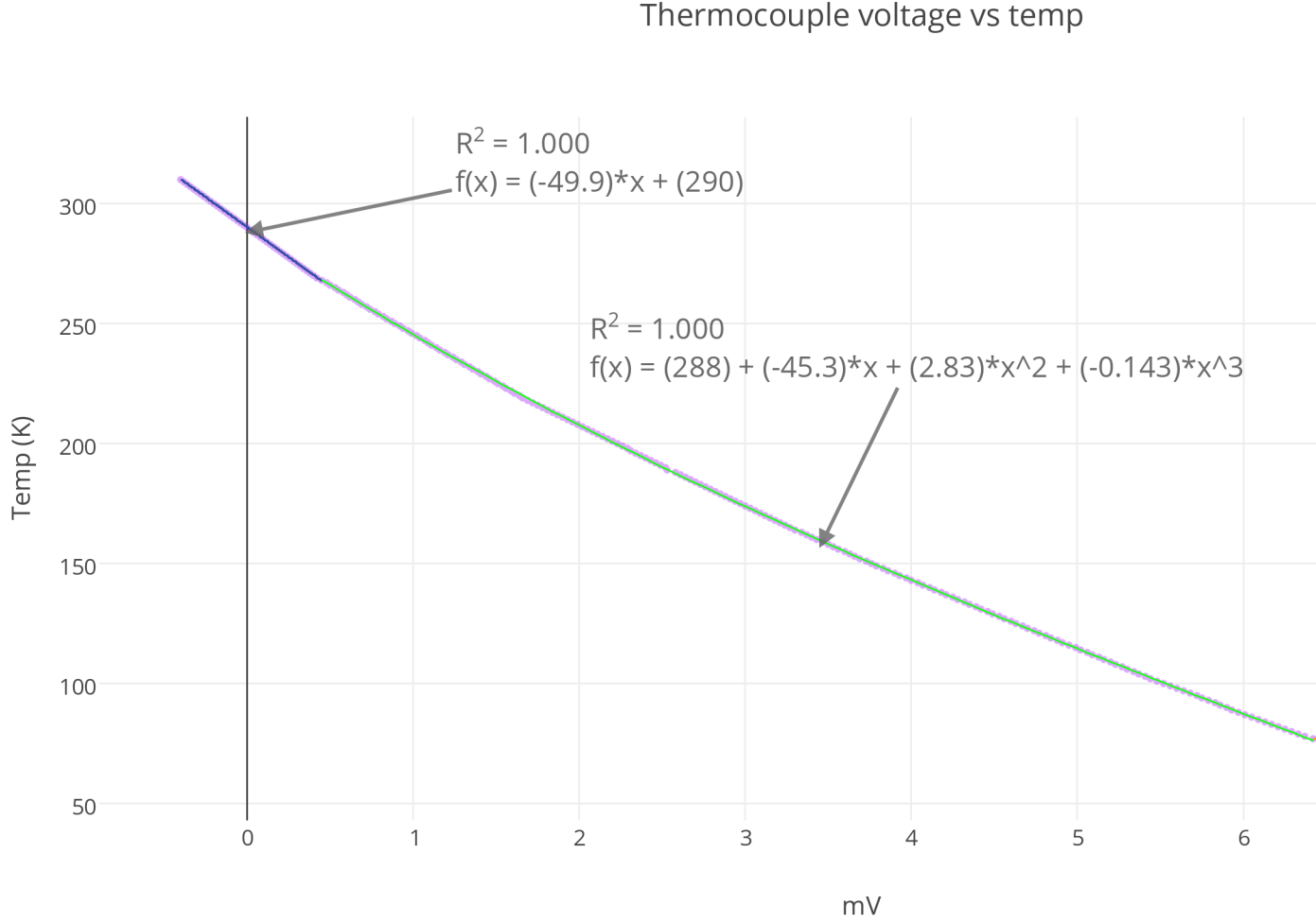


FIG. 1. Figure 1: Plot of Temperature and thermocouple voltage transcribed from the Teachspin manual, with fit lines across different sections.

for resistance during non-superconductivity and the trend line for resistance during superconductivity, and noted the corresponding temperature. The error in our voltage readings was very low (on the order of 0.000005mV), so the larger element of error is looking at the width of the transition zone, which was defined between the first points to clearly deviate from the trend lines. This yielded results of a T_C of 98.03K and 98.67K per trial, with a range of 91K to 100K and 94K to 101K , respectively.

Next we looked at a sample of BSCCO gathered through the two-phase lock-in amplifier. Only one trial was performed, though data was gathered every 3 seconds for 3 hours. Once

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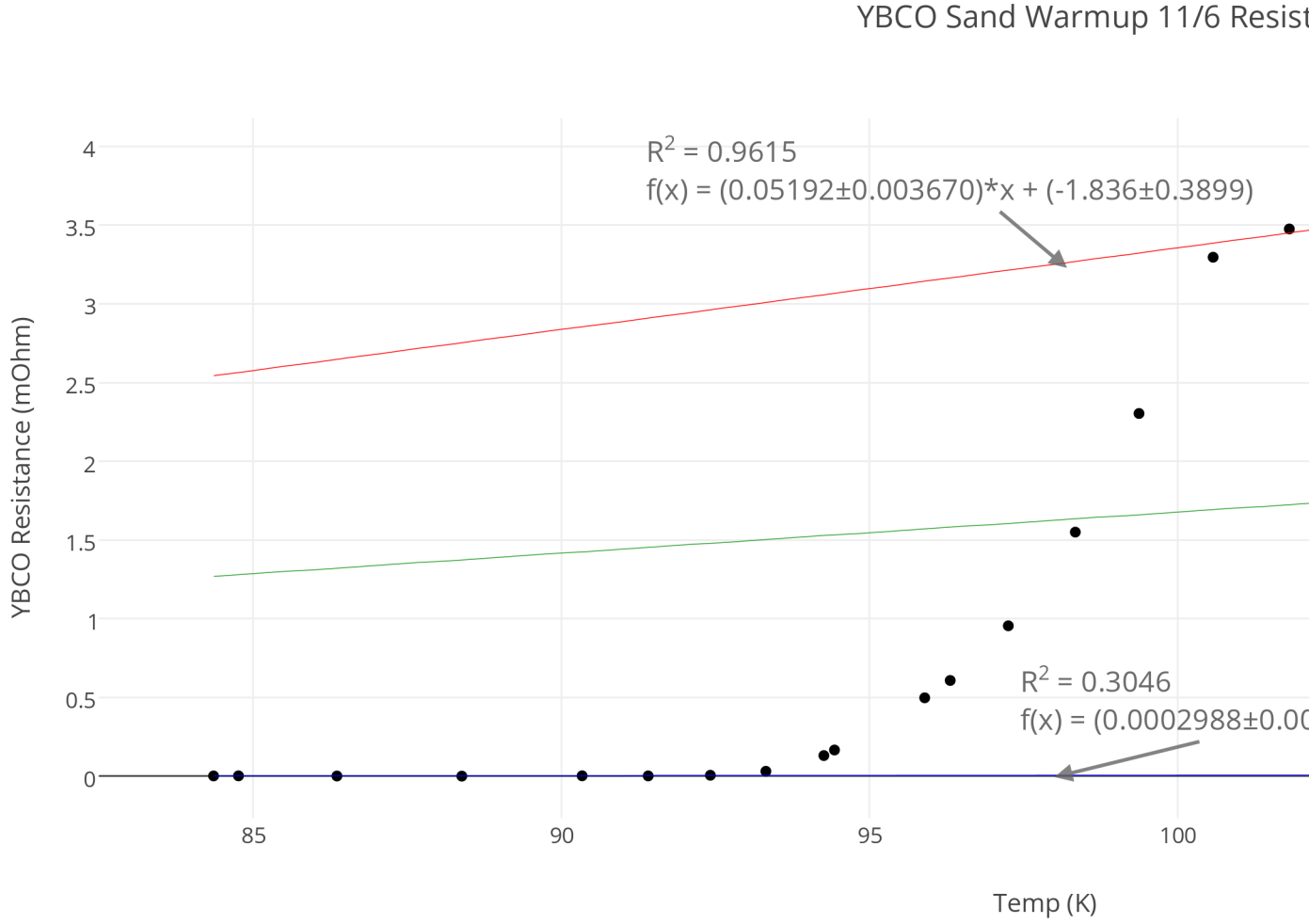


FIG. 2. Plot of resistance vs temperature for YBCO sample, with best fit lines during normal conductivity and during superconductivity, with a third line showing the space equidistant between. Data was gathered every 20 seconds during warm-up.

the data was plotted, the same procedure was used as with the YBCO sample to determine the critical temperature (see Fig. 4). The critical temperature T_C here was 110K, with a range of 101K to 119K. Of particular interest was the trend during the early pre-superconducting period. While certainly not truly ceasing to superconduct, there appeared to be some jumps in resistance during the superconductive phase, shown closely in Fig. 5. On closer inspection, while there is clearly some upward trend and movement not seen in the YBCO sample, it is not clear enough to pinpoint any specific jumps.

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YBCO Sand Warmup 11/11 Resis

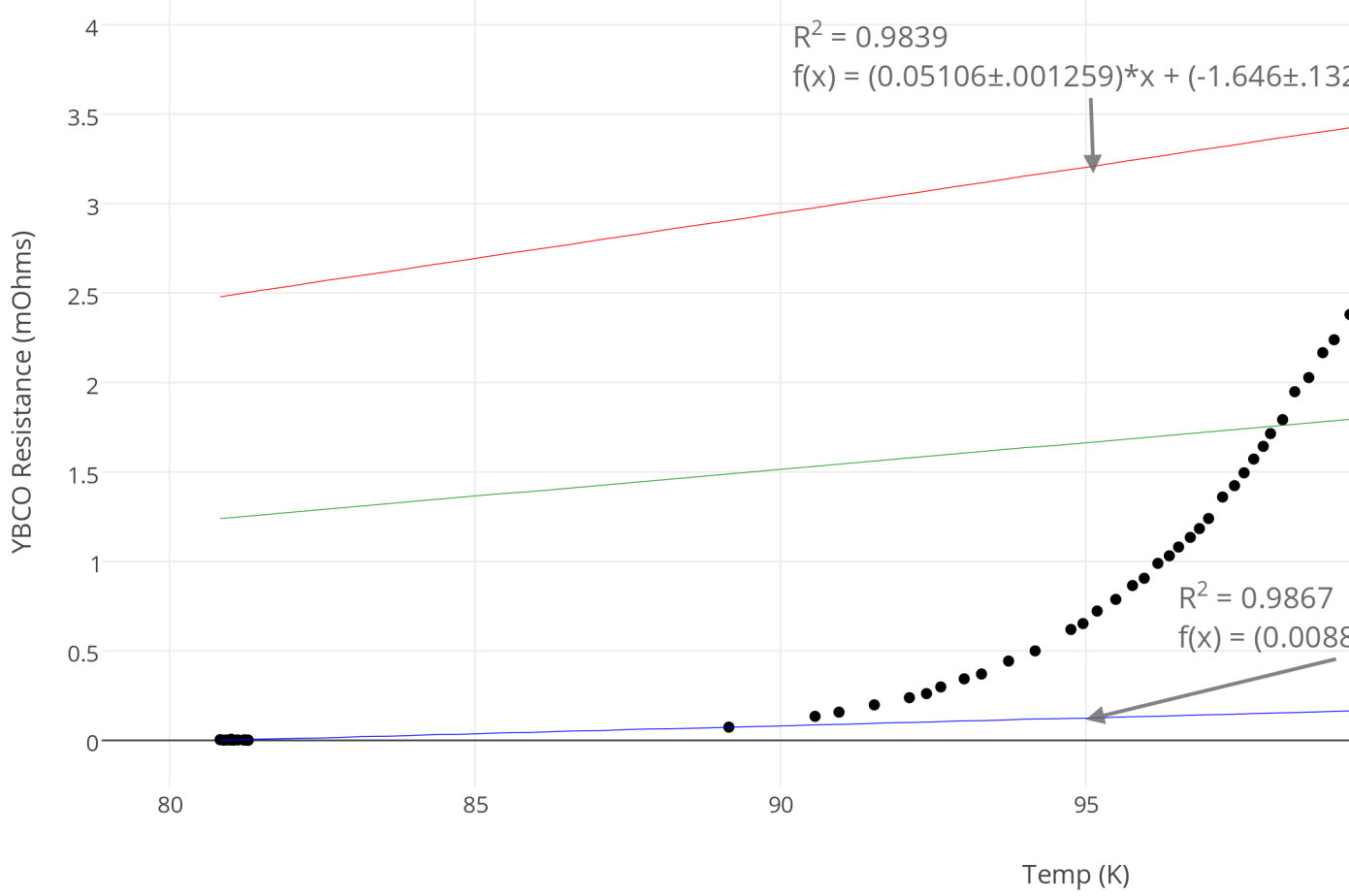


FIG. 3. Plot of resistance vs temperature for YBCO sample, with best fit lines during normal conductivity and during superconductivity, with a third line showing the space equidistant between. Data was gathered every 30 seconds until onset of superconductivity, then every couple seconds throughout the transition period.

V. CONCLUSION

Superconductivity was clearly achieved in both the YBCO and the BSCCO samples, and their transition to being non-superconductive as their temperature increased was recorded. Graphical analysis yielded a critical temperature for YBCO of 98.35K \pm 7K and for BSCCO

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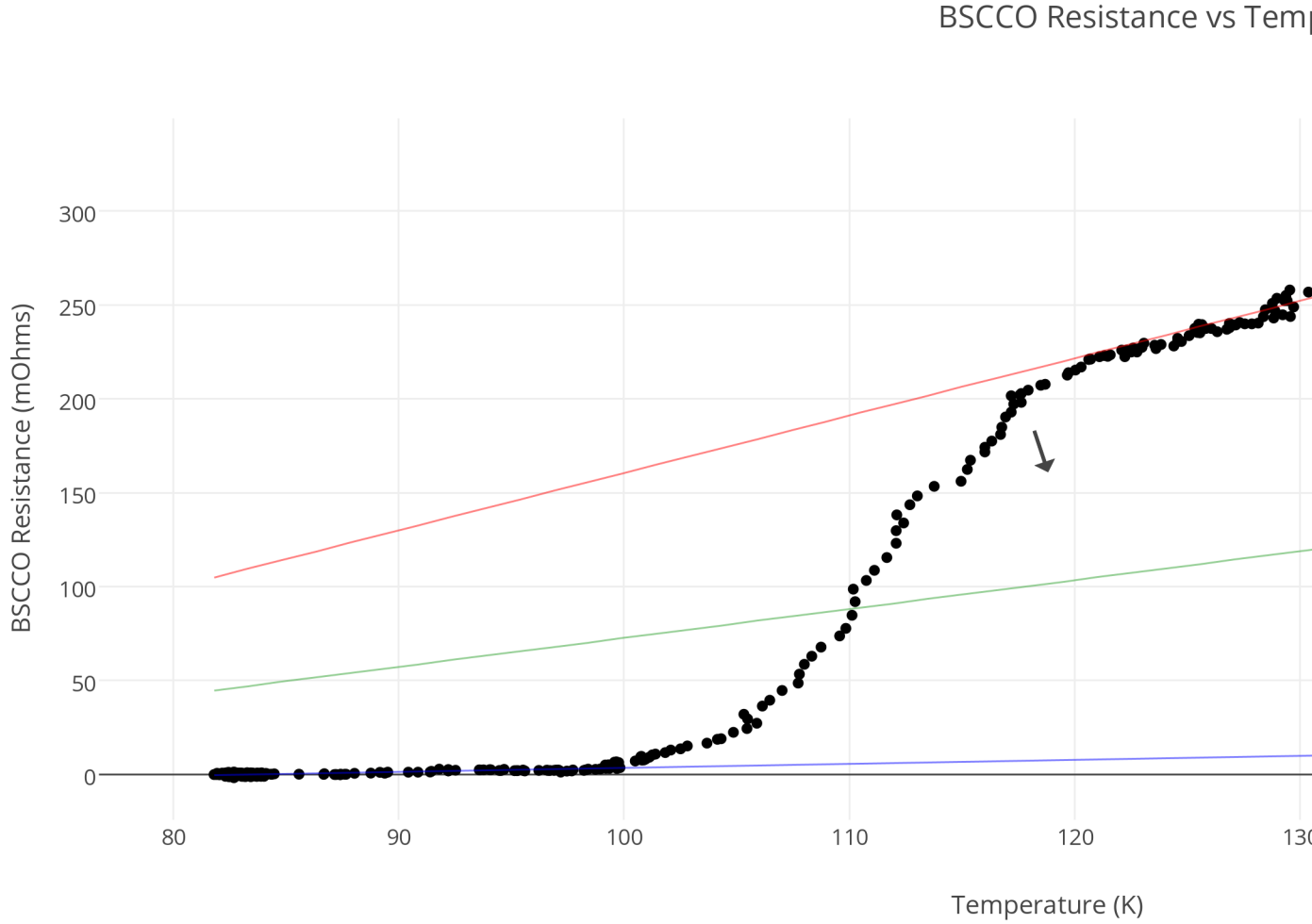


FIG. 4. Plot of resistance vs temperature for BSCCO sample, with best fit lines during normal conductivity and during superconductivity, with a third line showing the space equidistant between.

of 110K \pm 9K. According to the Teachspin manual, YBCO has a critical temperature of 92K, which is within our margin of error; similarly, the BSCCO sample was noted as having a critical temperature of 105K, again within our margin of error. The strange behavior seen during the end of the superconducting phase of the BSCCO sample may also have had to do with the fact that BSCCO can have two other critical temperatures. The general formula is $\text{Bi}_{2,1}\text{Sr}_{n+1}\text{Ca}_{n-1}\text{Cu}_n\text{O}_{2n+4+\delta}$. While the sample we had was specified for $n = 3$, it is quite possible that other variations were present in our sample, each with their own critical temperature: T_C for $n = 1$ is 80K and T_C for $n = 2$ is 90K. While we did not get as

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BSCCO Superconductivity close-up

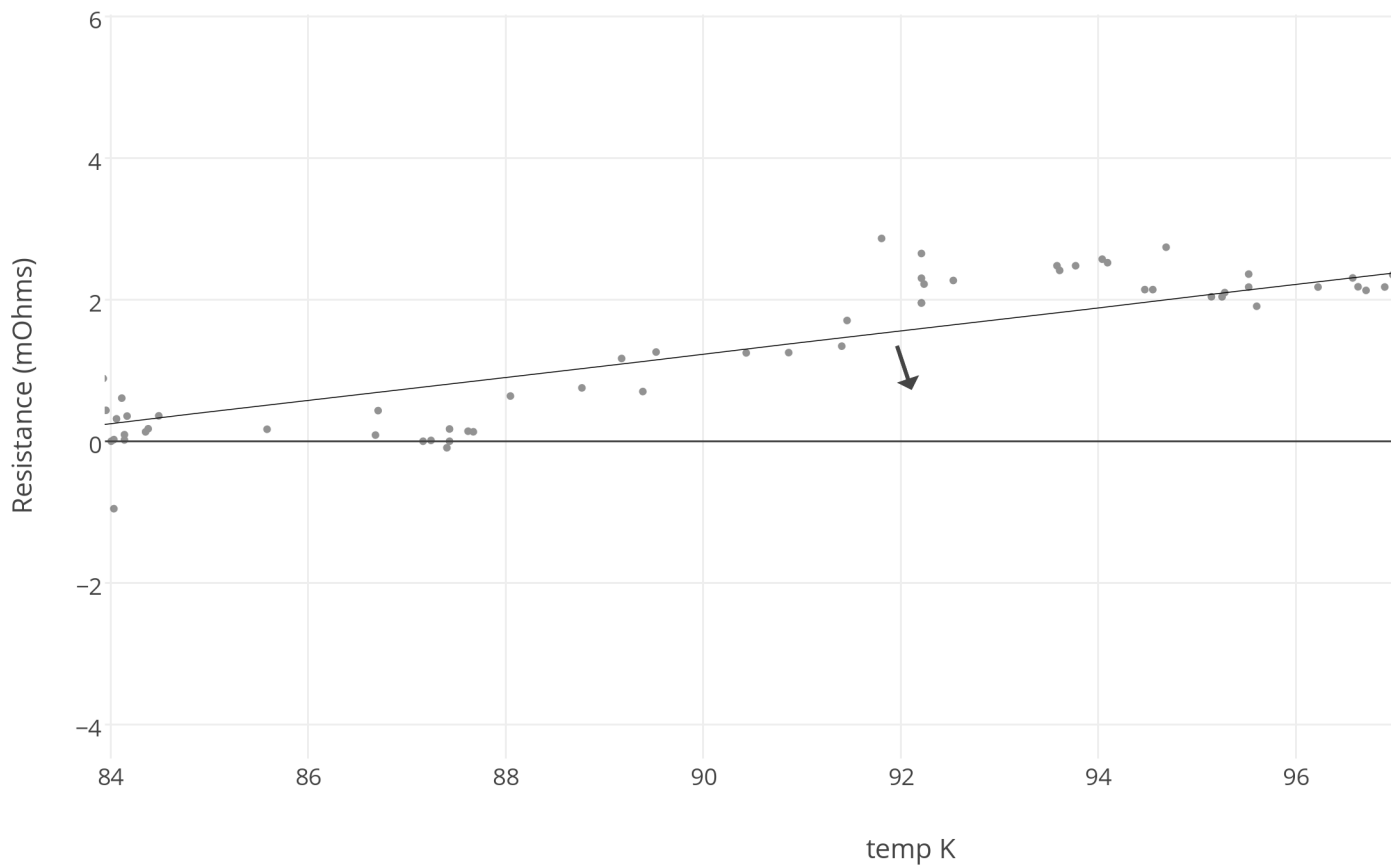


FIG. 5. Close up of the BSCCO sample warm-up during its superconductive phase. Irregularities are definitely present, but jumps are not clear.

cold as 80K, we could be seeing some sections stop superconducting around 90K, alongside the already non-superconducting $n = 1$ material, giving us a not truly flat superconducting zone.

¹ Charles Poole, Horacio Farach, and Richard Creswick, *Superconductivity* (Academic Press, 2007).

² Ajay Kumar Saxena, *High-Temperature Superconductors* (Springer Berlin Heidelberg, 2010).

³ Experiments in Modern Physics. Adrian Constantin Melissinos and Jim Napolitano. Gulf Professional Publishing, 2003