Labreport solid-state physics

Resistivitymeasurement of a HTSC-Metal

Modul:
Solid state physics PHY210

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1 Introduction

Superconductivity in metals and alloys is characterized by a sudden disappearance of resistance for temperatures lower than a certain transition temperature, T_c. Not all materials can become superconducting and if they do, the temperature at which they do is not the same for different materials. Some only become superconducting at less than 5K (Mercury for example) while some can still be superconducting above 130K (Hg-Ba-Ca-Cu-O).
In our experiment, $YBa_2Cu_3O_{7-\delta}$ was used. This material has a transition temperature of around 92K.

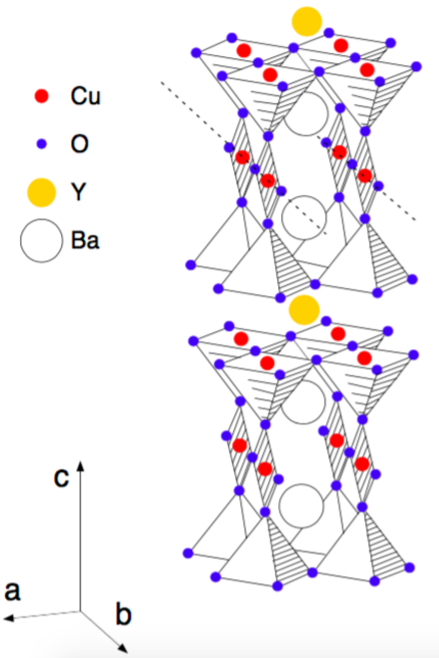

Figure 1: Crystal structure of $YBa_2Cu_3O_{7-\delta}$

2 Experimental setup and Procedure

The setup consists of four main parts [1]

- The specimen holder.
  This is the container where the superconductor is placed. There are connections for the temperature sensor, the heating foil and for the resistance measurement.

- The cryostat.
  This part serves as a temperature regulator. The sample is enclosed in a tube, which is submerged in liquid nitrogen. To keep the sample at a certain temperature, a heating foil is attached behind the sample. This heating foil is needed, as liquid nitrogen has a constant temperature of around 77K at atmospheric pressure.

- The vacuum system.
  A vacuum of $2.8 \cdot 10^{-3}$mbar was created inside the tube. This vacuum helps to reduce the heat transfer between the probe and its surroundings, as heat is primarily exchanged through convection.

- The electromagnet.
  The tube with the sample is placed inside an electromagnet. Therefore the experiment can be repeated with different magnetic fields up to a field of 0.8T .

Procedure

The first step in the measuring process is the cooling. The sample and the apparatus are cooled by liquid nitrogen which gets pumped into the system. With the heating foil and the PID-controller a arbitrary temperature within the apparatus working range can be achieved. In the experiment the starting temperature was set to 82K. When this temperature was reached and stabilized the heating and cooling got turned off and the experiment started. While the samples temperature slowly increased due to the temperature difference to the room temperature, we measured the resistivity. Since the sample is in a vacuum, the rise in temperature happens very slowly and we can assume the sample to be in thermal equilibrium.

[1] `http://www.physik.uzh.ch/data/peter/FestkoerperPhysik/InfoPraktFestkoerperphysik.shtml`

The resistivity measurement got realised in a four point measuring circuit. This setup is usually used when a resistance has to be measured precisely.

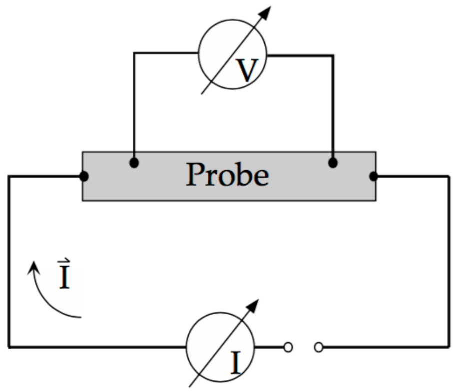

Figure 2: The four-point measuring technique

Another measuring technique got used which at first glance may seem rather unusual. The direction of the current got reversed after each measurement. We can think of this as running the current in figure 2 first in clockwise direction and than in counterclockwise.

The reason behind this procedure are the contact potentials (also known as *Volta potential*) of the plugs. Every connection between two different metals leads to such a potential and therefore creates a systematic error. To reduce this systematic error we computed the final resistivity as the mean between the clockwise-resistance and the counterclockwise-resistance.

3 Results

$B[T]$	0	0.42	0.7
$T_c[K]$	94.3 ± 0.4	94.0 ± 0.4	94.1 ± 0.5

Table 1: Results

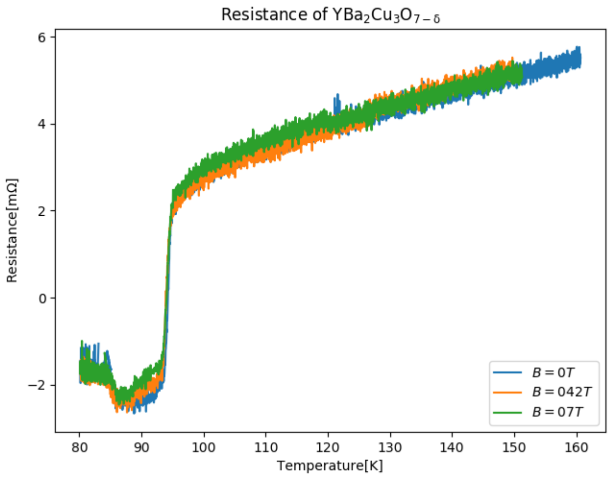

Figure 3: Measurement of the mean resistance.

3.1 Questions

1. Does $YBa_2Cu_3O_{7-\delta}$ behave like a metal above the transition temperature? Describe the temperature dependence qualitatively.

   In the measured region just above the transition temperature, the resistance increases linearly with respect to the temperature. This corresponds to the expected behaviour of a metal.

2. What is the expected dependence of the resistance of a metal (no superconductivity) due to an external magnetic field (for small magnetic fields)?

For small magnetic fields, the resistance of a metal is independent due to an external magnetic field. The reason behind this is the Hall-effect. The magnetic field causes a Lorentz-force, acting on all moving electrons, perpendicular to the magnetic filed and the direction of the electrons velocities. Therefore the electrons concentrate on one side of the metal and an electric field, in the direction of the Lorentz-force is set up. This causes a force on the electrons, in the opposite direction. As soon as the equilibrium is reached, where the two forces are equal, the electrons are able to move like if there was no magnetic field. Therefore, the resistance is the same.

3. Determine the transition temperature, T_c. How do you do this?

   Hauptidee Bericht

4. Why is the resistance measurement carried out twice with a reversion of the polarity?

   The reason behind this procedure are the contact potentials (also known as *Volta potential*) of the plugs. Due to the different Fermi-energies in the different metals, in the region near the connection, some electrons move from the material with higher Fermi-energy to the other one. Thus every connection between two different metals creates a potential, with a fixed direction. This leads to a systematic error, which shifts all measured voltages (positive and negative) to the same direction. So the voltage was measured, and the resistance calculated in both directions. Finally the mean value of the two resistances was taken to reduce the systematic error. The result of this procedure can be seen in figure 4.

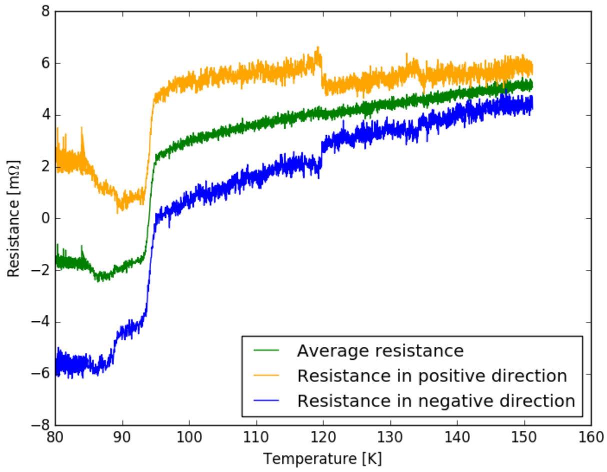

Figure 4: Resistances in different directions at 0.7T

4 Error calculus

4.1 Derivative

Since the measurement more or less looks like a step-function one can get the error of T_c by looking at the width of the derivative-curve. In an ideal case the derivative of a step-function would give a δ-function which is localised in one point. Since the measured data has a lot of noise on top of the underling curve, we had to use the so called *five-point-stencil method* [1] to compute the derivative. Otherwise we wouldn't see the peak we are looking for.

The *five-point-stencil method* takes not only the next date point into account but also the 4 surrounding values. With this method we get a more smooth and useful curve.

$$f'(x) \approx \frac{-f(x+2h) + 8f(x+h) - 8f(x-h) + f(x-2h)}{12h}$$

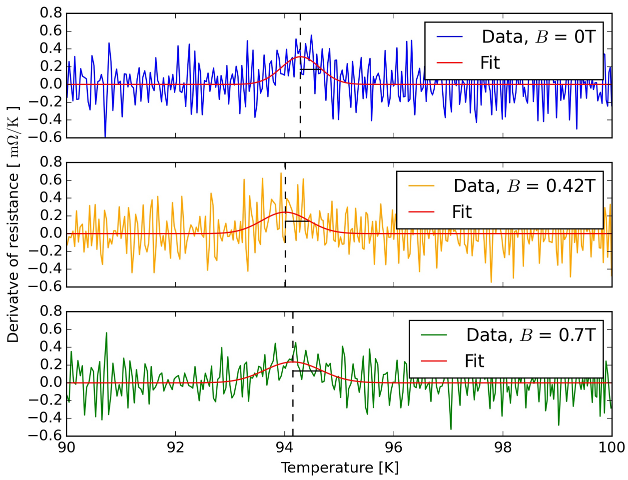

Figure 5: Derivative calculated using the five-point stencil method and considering the direct neighbours (h=1).

[1] `https://en.wikipedia.org/wiki/Five-point_stencil`

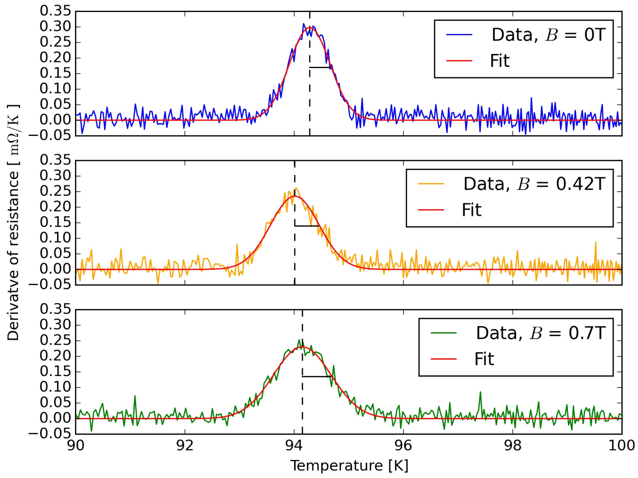

Figure 6: Derivative calculated with h=10.

The five-point-stencil method with $h = 10$ gives a clearer indication to where the jump in resistance is located. This is due to the fact that in taking larger steps (making h bigger) the noise has less of an impact. Even though successive measures oscillate quite a lot, the general behavior of the measurements is given by figure **??**. A larger step size will on average suppress the fluctuations.