Departamento de Física
Laboratorio de Electricidad y Magnetismo

DETERMINING THE TRANSITION TEMPERATURE OF A HIGH-TEMPERATURE SUPERCONDUCTOR

1 Objetives

- To measure the critical temperature, TC, of the superconductor $YBa_2Cu_3O_7$
- To obtain the electrical potential between the end of a superconductor and plot it versus the temperature
- To visualize some characteristics phenomena related to the superconductivity

2 Theoretical background

2.1 Principles

Superconductivity was discovered in 1911, when Kamerlingh Onnes found that the electric resistance of mercury dropped to zero at cryogenic temperatures. The so called transition temperature when a conductor becomes superconducting depends on the material used. For the next 75 years, the transition temperatures were just in the 10 to 20 K range.
In 1986, Georg Bednorz and Karl Alex Müller discovered the first high T_C superconductor. It was an oxide of lanthanum, barium and copper (Ba-La-O-Cu) that is superconductor at around 30 K. Since then, new high-T_C superconductors have been discovered and with higher transition temperatures. These new high-T_C superconductors exhibit a critical temperature which is above the Nitrogen boiling temperature, so it is possible to use liquid nitrogen for arriving to the region in which these materials are in a superconductor state.

The electrical conductivity of metals at low temperature depends on the scattering of the free electrons with the lattice phonons and with the impurities and defects which are present in the material. According to the Matthiesen's rule, the conductivity of the metals at low temperature can be written as:

$$\rho = \rho_{st} + \rho_{ph} \quad (1)$$

The first term, ρ_{st}, is independent of the temperature and it is due to the interaction of the electrons with the impurities and defects present in the metals. The second term, ρ_{ph}, comes from the scattering of the electrons with the phonons and it depends on the temperature. At very low temperature, when T << θ_D, where θ_D is the Debye temperature, it is expected a dependence with the temperature as $\rho_{ph} \propto T^5$, although the exponent can be between 4 and 5. In case the temperature approaches to zero. However, in most cases the resistivity tends to a constant value, because of the presence of impurities in the material.
In a superconductor, on decreasing the temperature below a critical temperature, T_C, the electrical resistance drops to zero. The goal of this practice is to determine the transition temperature for Yttrium-Barium-Copper-Oxide($YBa_2Cu_3O_7$).

3 Bibliography

- **Charles Kittel, "Introduction to Solid state Physics", Chapter 10, pp. 257. 8th Edition, John Wiley & Sons, Inc, 2005.**

- **L. Solymar, D. Walsh, "Electrical properties of materials", Chapter 14, pp. 361, Oxford Universitary Press. 2010.**

En internet

https://www.energy.gov/science/doe-explainssuperconductivity
http://www.superconductors.org/INdex.htm

4 Equipment

1. Integrated measuring module with a sample of $YBa_2Cu_3O_7$
2. Measurement adapter for superconductor
3. Adapter for data acquisition
4. Dish for liquid nitrogen (material high-density polyurethane
5. Software CASSYLab installed in a computer
6. Connection cables

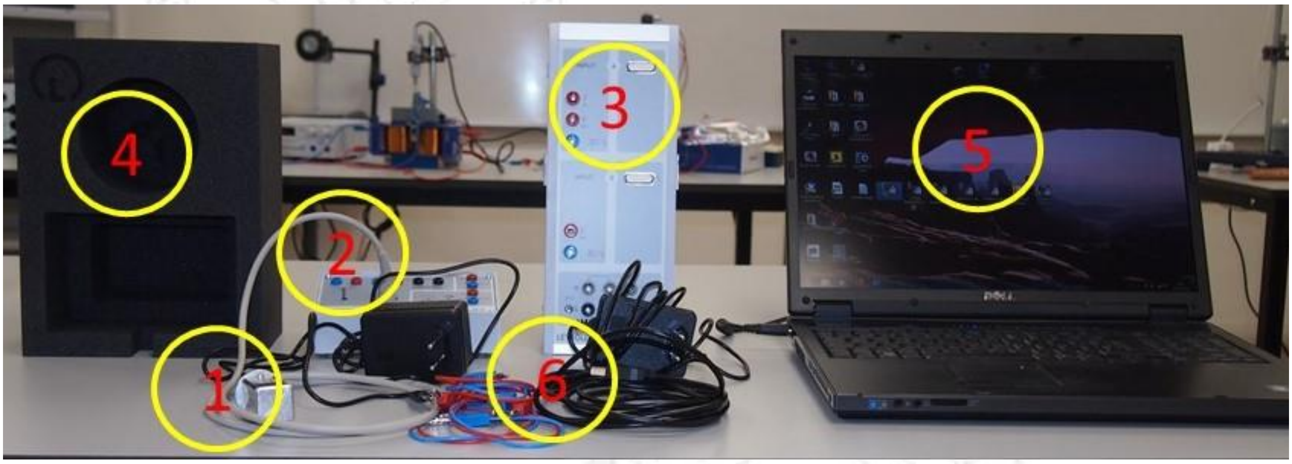

Figure 1. Equipment of the practice.

5 Equipment description

5.1 Integrated measuring module with a sample of $YBa_2Cu_3O_7$

The integrated measuring module, (1) in Figure 1, contains the superconductor ($YBa_2Cu_3O_7$) and a platinum thermal resistor to measure the temperature. A highly stable current of 140 mA is applied between the ends of the superconductor. During the experiment the voltage drop between the ends of the superconductor is measured. According to the Ohm's law, the voltage is proportional to the electrical resistance of the superconductor sample.

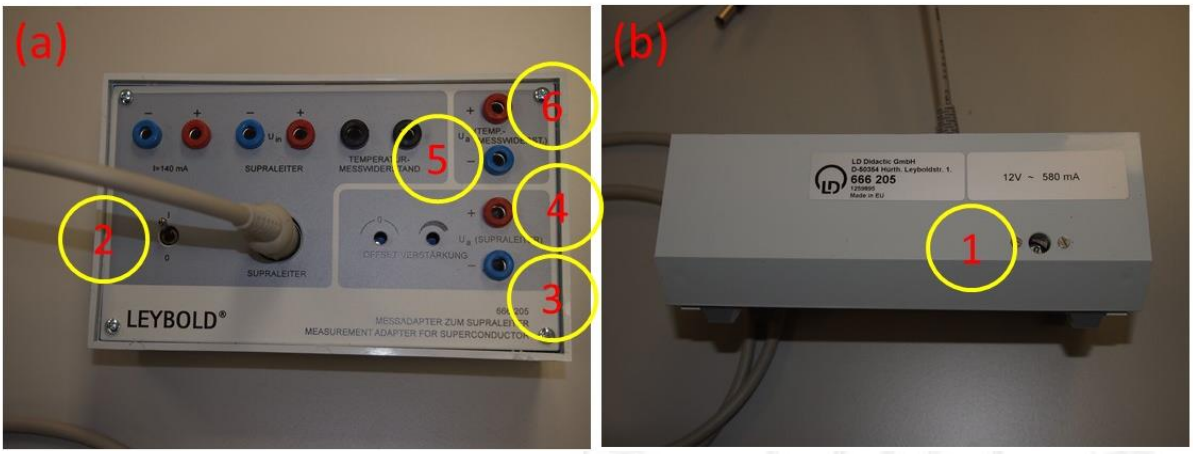

Figure 2. Measurement adapter for superconductor. (a) Front of part. (b) Back part.

5.2 Measurement adapter for superconductor.

The Measurement adapter for the superconductor is shown in Fig. 2. The point (1) is the jack socket for plug-in power supply; it must be connected to the net through an adaptor (12 V AC). The point (2) is the on-off switch. The points (3) and (4) are the output for the measurement of the voltage drop at the ends of the superconductor sample. The points (5) and (6) are the output for the measurement of the temperature of the superconductor sample.

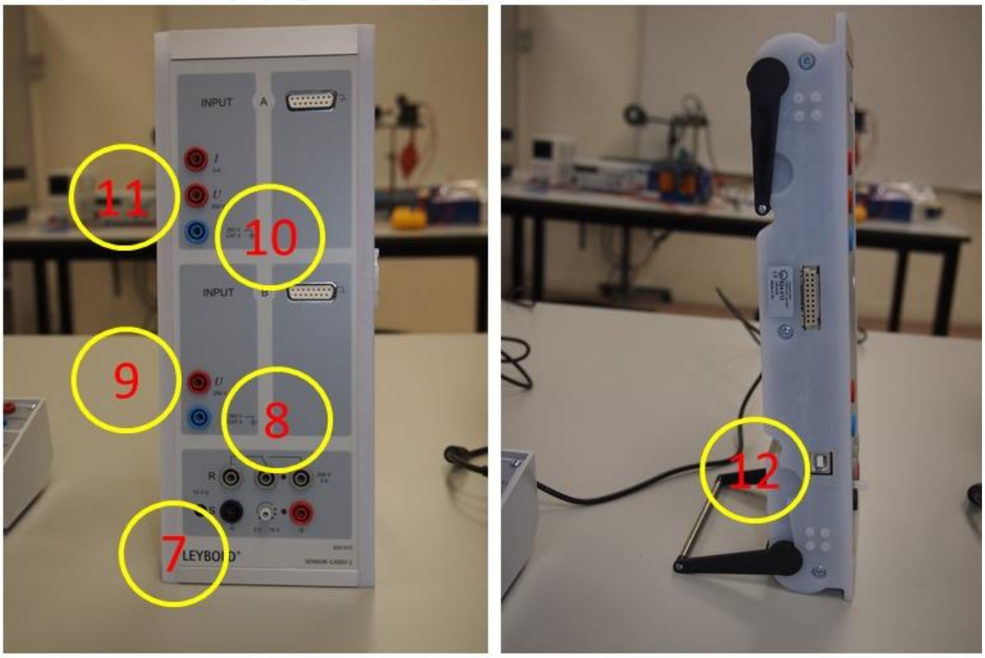

Figura 3. Front (left) and back (right) of the adapter for data acquisition

5.3 Adapter for data acquisition.

The adapter for data acquisition is presented in Fig. 3. The point (7) is the jack socket for plug-in power supply. It is connected to the net through an adapter (12 V AC). The points (8) and (9) are the in-put for measuring the voltage drop at the ends of the superconductor sample. The points (10) and (11) are the input for measuring the temperature of the superconductor sample. The point (12) is the connection for the USB cable that connects the adapter for data acquisition to the computer.

Figura 4. Dish for liquid nitrogen.

5.4 Dish for liquid nitrogen.

The dish for the liquid nitrogen is shown in Fig. 4. The integrated module is fixed in the point (13) of the dish for liquid nitrogen. Before pouring the liquid nitrogen the dish must be leaned on the table, with the point (13) in the up position looking at the ceiling. The liquid nitrogen is used to cool the superconductor sample.

Connection of the equipment

1. Fix the integrated measuring module to the point (13) of the dish for liquid nitrogen. The Dish for liquid nitrogen must be leaned on the table looking at the ceiling
2. Connect the measurement adapter for the superconductor to the net. Connect point (1) to the net through the corresponding adapter
3. Connect the point (3), negative pole, of the measurement adapter to the point (8), negative pole of the adapter for data acquisition. Connect the point (4), positive pole, of the measurement adaptor to the point (9), positive pole of the adapter for data acquisition. These connections are for measuring the voltage drop in the superconductor (module B of the adaptor for data acquisition)
4. Connect the point (5), negative pole, of the measurement adapter to the point (10), negative pole of the adapter for data acquisition. Connect the point (6), positive pole, of the measurement adapter to the point (11), positive pole of the adapter for data acquisition. These connections are for measuring the temperature of the superconductor (module A of the adaptor for data acquisition)
5. Connect the point (12) of the adapter for data acquisition to the computer by using a USB cable
6. Connect the adapter for data acquisition to the net. Connect point (7) to the net through the corresponding adapter

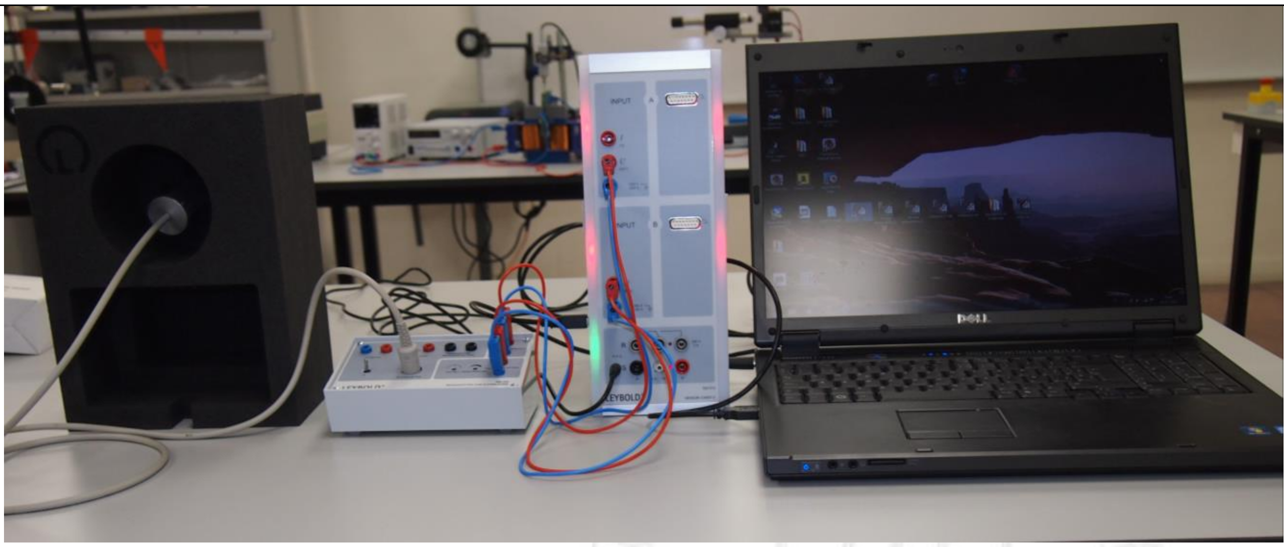

Figure 5. Experimental set-up for the determination of the TC of $YBa_2Cu_3O_7$.

6 PROCEDURE

6.1 Check that all the connections are properly performed (see Fig. 5). Check that the computer is switched on. If it is off, you must switch on.
6.2 Switch on the power supply to the measurement adapter for the superconductor. Put point (2) of the measurement adapter to the position "On"
6.3 In the computer open the program CASSYLab
6.3 Before starting the experiment you must get familiar with the program.

Getting familiar with the program CASSYLab
On opening the program it is very possible that all the points of the menu are not accessible. Firstly, the different buttons that appear in the menu (up-left of the screen) will be described. We will start from the left to the right (see figure 6).

1. Erase measurements (F4)
2. Load measurements (F3). You can load a file with the measurements
3. Save measurements (F2). You can save a file with the measurements. You can chose the format of the program or a text format (.txt)
4. Print the data
5. Start/Stop measurements (F9)
6. Change the preferences (F5)
7. Activate/Disactivate (F6). With this button you can modify the small screen that appear in the screen with the values of different magnitudes
8. Help (F1)
9. Information (symbol of Leybold)
10. Activate/Disactivate the buttons that appear to its right. This buttons are related to the different physical quantities that the program is measuring: UA1 (voltage temperature), UB1 (voltage superconductor), R1, S1, X1, (x-axis of the figure), Y1 (y-axis of the figure), T (temperature).

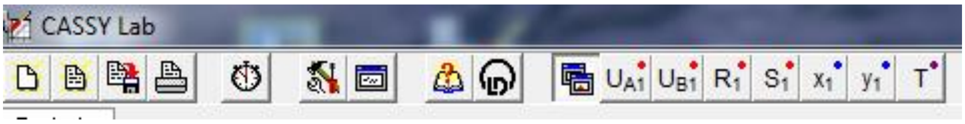

Figure 6. Options of the program CASSYLab.

After open the program you must change certain things in the menu "preferences". Push the button 6 with the mouse. A screen will appear in the screen with different options. Here you must carry out some changes.

- **First**, in the option CASSY, click in the three images of the left, (A), (B) and (C) of Figure 7 (UA1, UB1 and data). This will activate all the buttons that were not active in the menu (up-left of the screen)
- **Second**, click in the menu: Parámetro/Formula/FFT: select "Nueva magnitud". Click in formula (it must appear time, date, n,t,UA1,…) and write: -UA1*1000 (see Figure 8).
  On doing this the voltage for the temperature is transformed in the value of the temperature
- Below, write: 10 in valor medio; 1 in histograma; T in simbolo; ºC in Unidad; -200 in "desde"; 30 in "hasta"; an 1 in decimales.
- **Third**, In the option "Representación" (figure 9). First, clic in "nueva representación" and chose "estándard". Then write: Eje x: select T; Eje y: select UB1; Select x and y.
- **Fourth,** In the option "generación de modelo", (figure 10). First click in "nuevo modelo" and then check : in Simbolo x_1 desde -1 1; in Simbolo y_1 desde -1 1
- **Firth,** Close the screen, but keeping all the changes

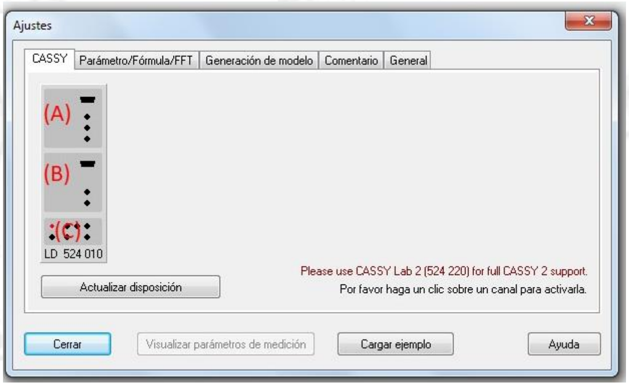

Figure 7. "Ajustes" of CASSY.Click on (A), (B) and (C)

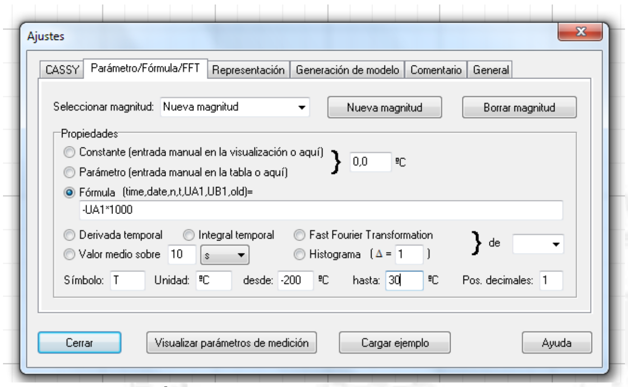

Figure 8. "Parámetro/formula/FTT" of CASSY.

After doing all these changes in the menu "preferencias", you must have in the screen a graphic, and two small screen with the data of the voltage UB1 and the temperature. Check that the x-axis of the graphic is the temperature and the y-axis is UB1. With the button 7 and the button that appear after 10, you can change the small screens variable and also the variables of the axis.

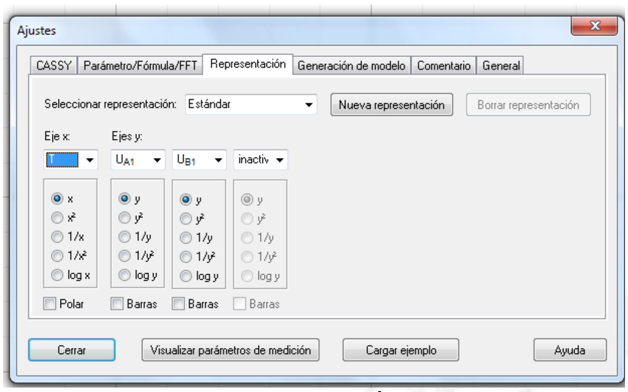

Figure 9. “Representación” of CASSY.

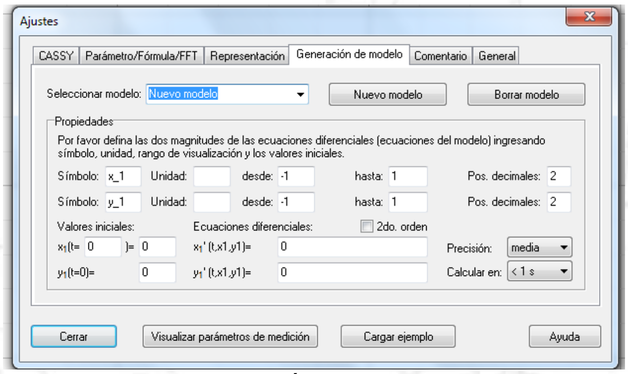

Figure 10. “Generación de modelo” of CASSY.

START THE EXPERIMENT

Once you have got familiar with the program, you can start the experiment. For it you must perform the following steps:

1. Tell to the teacher of the laboratory or to the technician that you are ready to start the experiment
2. The teacher or the technician will pour liquid nitrogen in the dish for cooling the superconductor. DO NOT INTRODUCE YOUR FINGERS OR TOUCH THE LIGUID NITROGEN, YOU WILL GET SERIOUS INJURED (If you finger is frozen in liquid nitrogen, later if you hit your finger against something your finger will break into many pieces like a glass !!!!)
3. Click in the button 5 (start the measurements). In the plot of the screen you will start to see the values of the voltage drop versus the temperature. The data are taken during the cooling process.
4. Once the temperature of the superconductor achieves the liquid nitrogen temperature, you will realize that the temperature of the superconductor is stable, and of course the sample has been in the superconductor state during a certain period of time, you can stop the measurements clicking in the button 5.
5. You must save your data. First you must save them with the format of the program CASSYLab, and later you save the data again with the format .txt
6. DO NOT LOAD THE FILE with the data (.txt) with a pendrive, you must use the internet connection of the computer to connect to your e-mail account of the uc3m and send the file to you by the e-mail.

ANALYSIS OF THE RESULTS

-Plot the experimental results on a curve, Voltage versus the temperature.
-Determine the value of the Transition temperature T_C
-Plot also temperature and voltage versus time.
-Compare the critical temperature with the values of the bibliography
-Perform a discussion about the results of the experiment
Try to observe another phenomenon related to the superconductivity as the Meissner effect.