Determining the transition temperature of a high-temperature superconductor

Objects of the experiment

- Record the voltage drop across a superconductor with varying temperature.

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 the discovery of the high-temperature superconductors with transition temperatures in excess of 90 Kelvin, and above the boiling point of liquid nitrogen (77 K), raised the interest in those substances.

The superconductor used consists of Yttrium-Barium-Copper-Oxide(Y Ba2 Cu3 O7).

The Experiment kit 667 552 is used to investigate the properties of a high-temperature superconductor in liquid nitrogen. At a temperature of approximately 93 K or –180 °C, it shows a sharp decrease in the voltage drop across the superconductor.

Safety notes

Just as a Thermos flask can burst if hot water is poured into it, a Dewar flask could implode when it is filled with liquid nitrogen. For this reason, always wear safety goggles when handling Dewar flasks. Nitrogen, the largest constituent of the air we breathe, is completely non-toxic. In spite of this, the evaporation of large quantities in closed spaces could pose hazards, e.g. if a full 25 l flask explodes. Such dangers can be easily avoided by ensuring adequate ventilation and using small Dewar flasks when performing the experiments. Proceed with caution, in view of the low temperatures involved. Never reach into liquid nitrogen or touch cooled objects with bare hands (wear protective gloves). Avoid skin contact.

Local regulations on hazardous materials apply otherwise.

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2 Integrated measuring module

The measuring head to be dipped into liquid nitrogen contains the Superconductor and a Platinum thermal resistor on board. The wiring of the superconductor and the Platinum resistor is shown in fig. 2. A highly stable current of approx. 140 mA is applied between points 1 and 4. The voltage drop is measured across contact points 2 and 3.

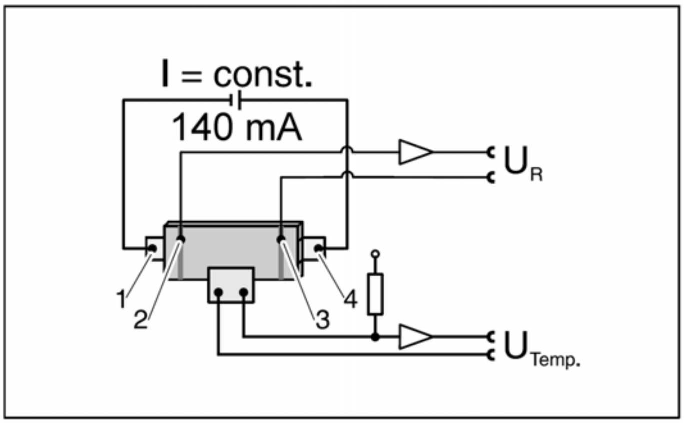

Fig 2: Measuring module circuit diagram

Measuring module technical specifications

Superconductor Type $YBa_2Cu_3O_{7-x}$

Temperature sensor Platinum-Iridium resistor

100 Ω at 0 °C

Connections Points 1 and 4 via copper plate

Points 2 and 3 via copper wire

Cable 6-core, with DIN plug

3 Adapter for data acquisition

Fig. 3 provides a schematic view of the adapter for data acquisition, which serves as a measuring device as well as a voltage supply.

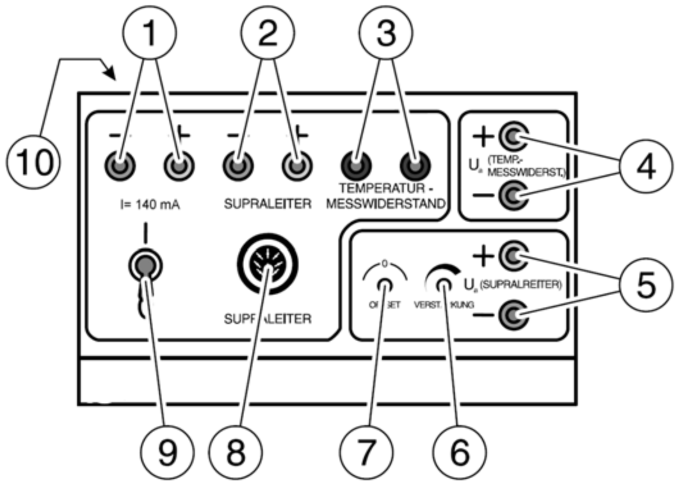

Fig 3: Measuring adapter

1 Output highly stable power supply

2 Input voltage measurement (external superconductor)

3 Input temperature sensor (external superconductor)

4 Output temperature measurement

5 Output voltage measurement (Ua)

6 Gain factor

7 Offset

8 Input measuring module

9 On-off switch

10 Jack socket for plug-in power supply

The temperature value measured by the Platinum-Iridium thermal resistor is linearized and converted into a voltage signal of 0 ... 200 mV, corresponding to a temperature range of 0 to -200 °C. Power is supplied by the plug-in power supply unit.

The device is calibrated. If, upon attaining the transition temperature, the value of the measured voltage is not exactly 0 volts, the offset voltage and the output voltage (Ua) can be corrected.

The offset voltage can be corrected with the potentiometer 7. For this, short-circuit the voltage measurement input 2 and set the voltage to 0 V.

The maximum output voltage Ua can be adjusted via the gain factor (potentiometer 6 - use a screwdriver for this purpose). The setpoint value at T = 25 °C is approx. 190 mV

Technical data: adapter for data acquisition

Output current 140 mA

Ua (Temperature resistor) –50 … 200 mV

-196 °C = +196 mV

Ua (superconductor) ≤ 200 mV

Voltage supply 12 V AC/580 mA via plug-in power

supply

4 Dish for liquid nitrogen

The plastic block serves firstly as a thermal vessel for the liquid nitrogen and secondly to accommodate the entire experiment set-up.

Material: high-density polyurethane

5 Experiment procedure

Either the superconductor in the integrated measuring module or an external superconductor can be used as the superconducting sample.

To obtain reproducible and comparable results when performing measurements with external superconductors, always use a temperature sensor with the same characteristics as those in the integrated measuring module.

The measurements are recorded by means of an x/y recorder or a PC. The CASSY interface is extremely suitable as an A/D converter. The required software functionality is contained in the CASSYLab software package.

5.1 Experiment with the integrated measuring module and CASSY-S

additionally required:

Sensor-CASSY (524 010 / 524 010 USB)

Software CASSYLab

A PC, running windows 98SE or better

Procedure:

1. Connect the measuring module with adapter for data acquisition (socket 8).

2. Connect the power supply: Insert the jack of the plug-in power supply into the socket 10 until it engages firmly.

3. Connect the adapter for data acquisition with the CASSY interface: Output 4 “Messwiderstand” (temperature sensing resistor) goes into Input A, connection U (not I). Output 5 “supraleiter” (superconductor) goes to input B.

4. Place the measuring module in the polyurethane block. Insert the module into the guide slot on the floor of the block only so far that liquid nitrogen can still flow beneath the bottom of the aluminium housing of the measuring module. Alternatively, a dewar flask can be used, where the measuring module can be inserted in step 9.

5. Start the program “CASSYLab”, activate Input A and B by clicking at them, for both select range –0.3V … 0.3 V, “Averaged values”. Set the “measurement interval” to 200 ms.

6. To display the temperature in degrees centigrade, create a “new quantity”, being a formula “-UA1*1000” and scaled from –200 to 30 °C.

7. Create a “new display”, with the temperature as x-axis and the voltage UB1 as y-axis, compare to figure 4.

8. Start recording the values.

9. Fill the polyurethane block with liquid nitrogen until the aluminum housing is covered. During the experiment keep the liquid level constant and add liquid nitrogen as needed.

10. When the voltage drop has been attained (at approx. -180 °C, see Fig. 4), end the experiment.

5.2 Experiment with integrated measuring module and x/y recorder

1. Connect the temperature output 4 of the adapter for data acquisition to the x-axis input of the recorder, and the voltage drop output 5 to the y-axis input of the recorder.

2. As described in 5.1, insert the measuring module into the polyurethane block and commence cooling.

5.3 Experiment with an external superconductor

1. Attach the Platinum-Iridium thermal resistor to the superconductor using superglue

2. Make the connections on the superconductor and the measuring module

3. Connect terminals 1 and 4 with the power supply output 1

4. Connect terminals 2 and 3 with the voltage measurement input 2

5. Connect the Platinum-Iridium resistor with the temperature measurement input 3

6. Connect the plug-in power supply with the adapter for data acquisition: insert the jack into socket 10 until it has engaged firmly

7. Connect the temperature 4 and voltage 5 outputs with the recorder or CASSY interface (see above

8. Insert the measuring module (see above)

9. Pour in liquid nitrogen

10. Record measured values

5.4 Experiment results

Fig. 4 shows the voltage drop as a function of the temperature. When the transition temperature is attained, the electrical resistance breaks down, causing the voltage drop to abruptly become 0.

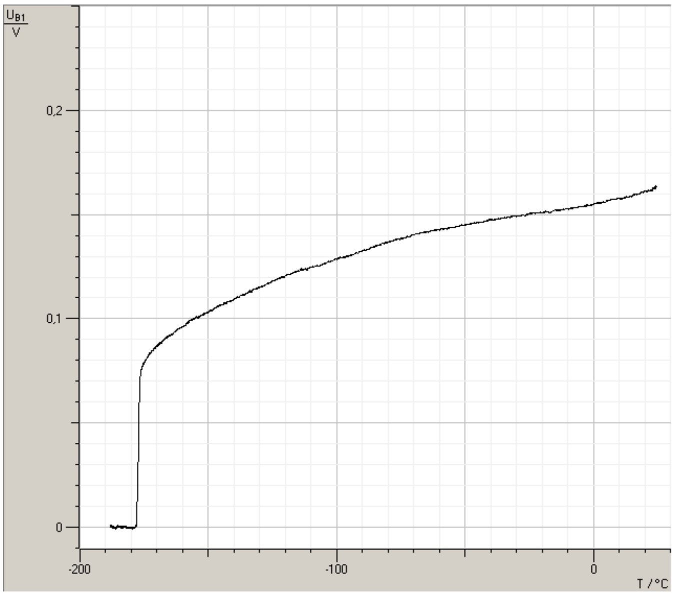

Fig. 4: Voltage drop at the transition temperature of approximately –180 °C.

Fig 5 shows the plot of temperature and voltage versus time, at t=0 the measuring module was inserted into the liquid nitrogen.

After nearly 600 seconds (10 minutes) the superconductor was cold enough to become superconducting.

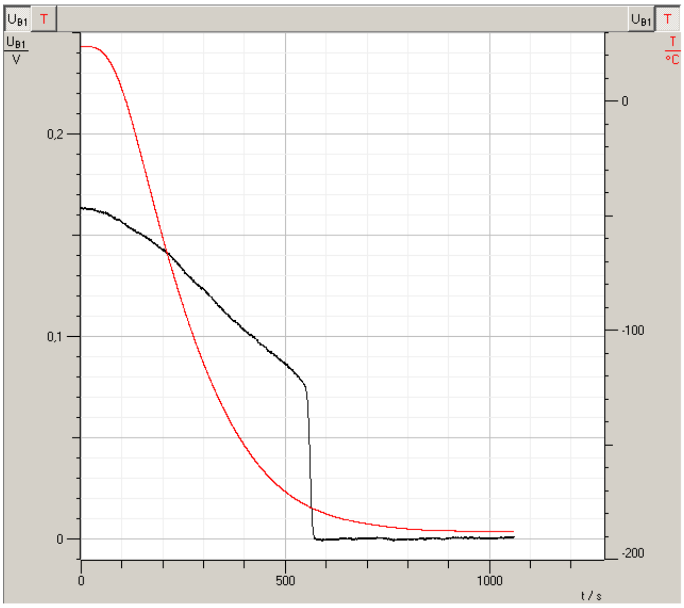

Fig 5: Temperature and voltage versus time

6 Liquid nitrogen storage

25 l Dewar flasks are most suitable for storage. They can be transported easily and hold the nitrogen for more than two weeks. Unfortunately, these flasks are quite expensive. 2 l Dewar flasks are considerably cheaper. However, the evaporation rate in them is relatively high, so that their contents last less than one day.

In principle, conventional Thermos flasks can also be used for the purpose of storage. The only disadvantage here is that the insulating vessel of a Thermos flask is embedded in a plastic housing which, upon coming into contact with liquid nitrogen, becomes brittle and very susceptible to breakage. On no account must a Thermos flask be sealed with a screw cap, as the nitrogen vapors will cause a tightly sealed flask to explode.