Fortgeschrittenenpraktikum

Experiment: Superconductivity

The goal of the experiment is to determine the critical temperature T_c and the critical magnetic field H_c of a tin sample in a magnet cryostat.

Measurement setup

The sample consists of a tin wire that is wound on long, cylindrical former parallel to the axis of the cylinder. The cryostat is fitted with a variable temperature insert (VTI, flow-through cryostat insert). Our tin sample and an Allen-Bradley carbon resistor are placed inside the VTI. The VTI is fit inside a magnet coil. The field center is at the position of the sample, and the field axis is parallel to the cylinder axis of the cylindrical former and thus approximately parallel to the windings of the tin wire.

Experiment

We use a constant current source to pass a current of 100 mA through the tin wire. The voltage drop across the sample is measured using a commercial Digital-Multimeter (DMM). The Allen-Bradley carbon resistor thermometer is located in close proximity to the tin sample inside the VTI. We supply a constant current of 10 uA by placing a commercial voltage source with 10 V output voltage and a 1 MΩ resistor in series. The voltage drop across the carbon resistor is measured using a commercial DMM. All measurement quantities are recorded using a Labview™ program.

First, we calibrate the carbon resistor as a thermometer. We do this by recording the voltage drop U_{AB} across the resistor and the helium vapor pressure p simultaneously as we cool the sample slowly from 4.2 K to base temperature, i.e., the lowest temperature we can achieve. The accuracy of the manometer is written in the manual of the instrument (available at the measurement setup). Additionally, we consider a calibration error of $\Delta p/p$ = 3%. The pressure is recorded using an output voltage signal of the manometer that is proportional to the reading. The output voltage is measured by a commercial DMM.

Next, we use the copper coil to apply a magnetic field to the sample. The field strength is determined by the geometry of the coil and the current supplied to the coil by the magnet current source. The coil current is measured by recording the voltage drop across a small series resistor with a commercial DMM.

<u>Note:</u> Do not surpass a coil current of 600 mA.

Preparation

The field in the center of the copper coil is given by the expression:

$$H(I) = \frac{1}{2}\frac{NI}{r_o - r_i} \ln \frac{r_o + \sqrt{r_o^2 + (\frac{L}{2})^2}}{r_i + \sqrt{r_i^2 + (\frac{L}{2})^2}}$$

Here N denotes the number of windings, I the current, r_o and r_i the outer and inner radii, respectively, and L is the length of the coil. The coil dimensions are available with the documentation of the measurement setup in the laboratory. Check the validity of formula eq. (1) by calculating the field inside the coil numerically. Model the coil as a stack of current loops, and plot the field profile along the axis of the coil. Use the result of this calculation to estimate the error when determining H_c and compare it to the error obtained by error propagation with eq. (1). (Which method is more accurate? Why?)

Measurements

Students will receive a short training regarding the operation of the VTI. When in doubt, please consult the supervisor!

A. *Fill the VTI with liquid helium:*

1. Start the pump.
2. Close the bypass valve on the helium recovery line.
3. Open the needle valve of the VTI a few turns.
4. Lower the pressure in the VTI by opening the bypass valve at the pump slightly.
5. Monitor the resistance of the carbon resistor until you register a strong increase in resistance.
6. Open the bypass valve at the helium recovery line and close the needle valve immediately. Don't apply excessive force to the needle valve mechanism!

B. *Calibration of the carbon resistor as a thermometer*

1. Close the bypass valve on the helium recovery line.
2. Open the regulator valve at the pump slowly. The pressure should decrease at a rate of 1-2 mbar/s at high pressures. You will have to adjust the regulator valve as you go.
3. When the regulator valve is fully open, gradually open the bypass valve at the pump. Keep pumping until you reach base temperature (i.e., the lowest pressure).

You may use the ITS-90 formulas or the vapor pressure table to convert the measured He-4 vapor pressures into temperature values. Determine suitable fit functions $T(U_{AB})$ for $T < 2.1768$ K and $T > 2.1768$ K, where U_{AB} is the voltage drop across the Allen-Bradley carbon resistor and T is the temperature. <u>Note:</u> We expect an exponential relationship for $U_{AB}(T)$. (Why? How do you propagate the error of the vapor pressure measurements?)

C. *Measurement of the critical magnetic field H_c*

1. Start your measurements at base temperature. Ramp the magnetic field using the Labview™ interface. Observe the jumps in the sample voltage and adjust the upper and lower bounds of the magnet field ramp to cover the transition feature at the critical magnetic field. Reduce the field step size and record several transitions. Convert the coil current reading at the superconducting transition into a magnetic field value using the formula eq. (1) or the conversion factor you obtained from your numerical calculation of the field of the coil.
2. Close the valves at the pump and open the needle valve of the VTI a few turns. Observe that the pressure rises in the VTI as warm liquid is drawn into VTI space. When you reach a pressure of 1 bar, open the bypass valve at the recovery line and close the needle valve of the VTI immediately. Do not apply too much force to the needle valve mechanism!
3. When you are ready to continue the measurements, close the bypass valve on the recovery line and open the regulator valve at the pump slowly.
4. Lower the pressure and stabilize the temperature at the desired value.

5. Take critical field measurement following the procedure under point 1. Keep in mind that the critical field is smaller at higher temperatures.
6. Repeat multiple times to obtain enough data to trace H_c(T).

Fit your data using the expression for H_c(T) and obtain values for H_c(T=0) and T_c. (How do you estimate the errors for these quantities?)

D. Direct measurement of the critical temperature T_c

1. Determine the critical temperature by sweeping the temperature multiple times across T_c.
2. Record and plot the voltage drop across the sample, U_{sample} , as a function of T. You need to sweep the temperature slowly to avoid thermal hysteresis. (What is the origin of the thermal hysteresis? What determines the accuracy of your measurement of T_c? Comment!)

Discussion

Compare the values you obtained for H_c and T_c with values you found in the literature. Comment on the advantages and disadvantages of each measurement method.