Related topics

Superconductivity, diamagnetism, critical temperature, temperature dependence of the resistivity of a superconductor, Meissner-Ochsenfeld effect, high temperature superconductor (HTSC), temperature dependence of the resistivity of a metal (i. e. copper)

Principle and task

Disappearance of electric resistance in a high-temperature superconductor is observed when it is cooled to liquid nitrogen temperature. The temperature dependence of the resistivity of the superconductor above liquid nitrogen temperature is compared to that of a good conductor, i. e. copper.
All resistance values are determined by measuring the drop of alternating voltage over the samples through which a constant alternating current flows. One only can be sure that the unavoidable thermal voltages will have no distorting influence on the results, and that the drop of voltage will be exactly zero in the superconducting state, by working with alternating current. The precise measurement of small resistances requires the four wire method, with separate couples of current and voltage leads. This method allows to avoid the influence of wire and contact resistances.
The diamagnetism of a superconductor is observed through the levitation of a small FeNdB magnet.

Equipment

Superconductivity power supply	13780.93	1
Superconductivity probe R(T)	13780.01	1
Superconductivity probe, copper	13780.03	1
Superconduct.-storage/access.	13780.04	1
Dewar vessel, 500 ml	33006.00	1

Problems

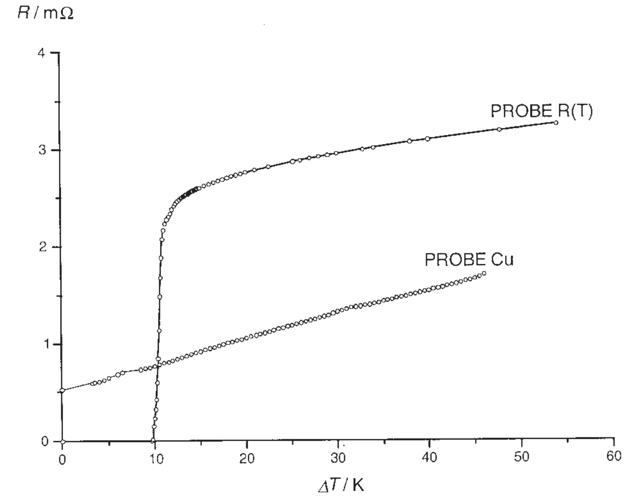
1. Observation of the Meissner-Ochsenfeldt effect in a superconductor.
2. Measuring and plotting the resistance between superconducting *R(T)* sample electrodes as a function of temperature. Temperature is measured as the difference between the temperature of liquid nitrogen (77 K) and the temperature of the superconducting sample. The critical temperature T_c of the *R(T)* sample must be determined.
3. Measuring the same characteristics as in 2 for the copper sample. The temperature coefficient of the resistivity of copper at the temperature of liquid nitrogen must be calculated.

Set-up and procedure

– The circuit shown in fig. 1 is set up. The *R(T)* superconducting sample is used.
– Carefully fill the polystyrene vessel with liquid nitrogen and wait for 5 minutes. Remove the sample from the liquid nitrogen and lay it horizontally. Let the FeNdB magnet hover above the centre of the sample to demonstrate the diamagnetism of the superconducting material.
– Fill the vessel again with liquid nitrogen. Immerse the sample into the liquid nitrogen and wait for 5 minutes. The displays on the control unit for superconductivity should indicate zero for both the difference of temperature and the sample resistance. Lay the sample horizontally and meas-

Fig. 1: Experimental set-up: Determination of the transition temperature of a HTSC.

Fig. 2: *R(T)* curves for superconductor and metal.



ure resistance as a function of the difference of temperature. Temperature must increase very slowly in order to obtain a reliable value of the critical temperature. Stop measurement once the difference of temperatures increases above 50 K. Plot the *R(T)* graph of the superconductor.

– Change the sample. Connect the copper sample to the superconductivity control unit and repeat the measurement as described in 3. Notice that in this case, a sample resistance which is not zero will appear when the temperature difference is zero. Plot the *R(T)* graph for copper.

Theory and evaluation

The superconducting states of solids manifests itself by the fact that electric resistance vanishes, and by diamagnetism, that is, the expulsion of the magnetic field from the inside of the superconductor. When an exterior magnetic field is applied, shielding currents are generated inside the superconductor, which tend to expel the field from the inside of the latter. The field may be completely expulsed (Type I superconductors) or incomplete (Type II superconductors). As a consequence, small magnets hover above the surface of the superconductor.

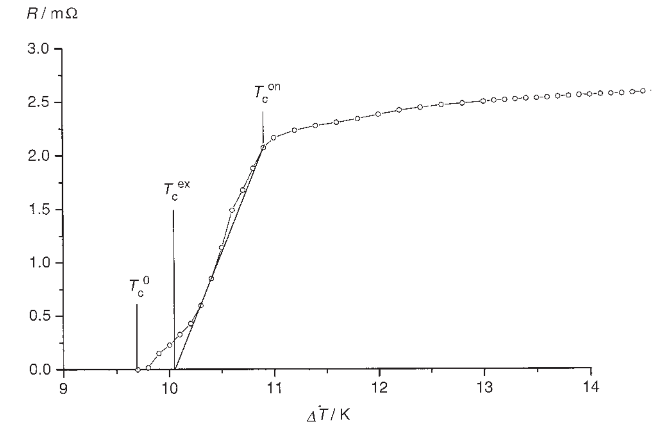


Fig. 3: Different definitions of T_c

The superconducting state can be observed if the material is cooled below the critical temperature T_c. For high temperature superconductors, the values of T_c exceed the temperature of liquid nitrogen.

Transition form the state of normal resistivity to that of zero resistivity occurs within a finite temperature range (fig. 2).

Thus, the critical temperature T_c is not determined unambiguously; it can be defined as follows:

- T_c^{on} corresponding to the transition onset – the point on the *R(T)* curve where resistance starts decreasing dramatically.
- T_c^0 corresponding to zero resistance - the point on the *R(T)* curve where resistance becomes so small, it can no longer be measured.
- T_c^{ex} corresponding to the extrapolation of the steep transition slope of the *R(T)* curve to zero resistance.

Transition width (T_c is defined as $T_{90\,\%} - T_{10\,\%}$, representing the points of the *R(T)* curve where resistance drops to 90 % and 10 %, respectively, of the normal state value immediately above T_c^{on} .

The normal state resistance of a superconductor usually displays metallic characteristics - it increases with temperature, with a constant slope.

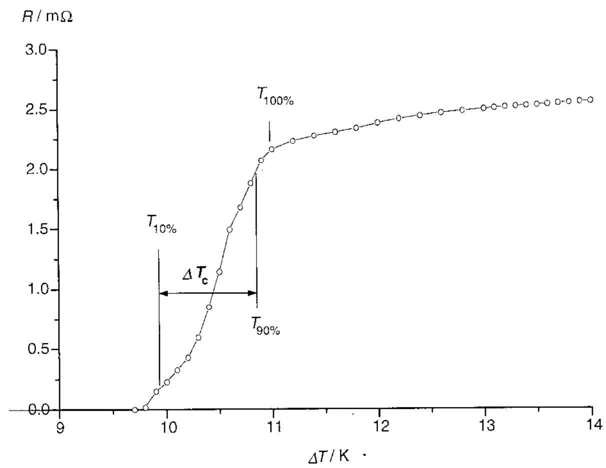


Fig. 4: Transition width ΔT_c.

The temperature coefficient of the metallic resistance is defined by $\gamma(T) = \Delta R/\Delta T$.

Notes

If the temperature of the sample changes fast, temperature is not the same everywhere inside the sample at a given time, and surface temperature may no be the best approximation of the average temperature. Thus, the safest way for measuring temperatures is to do this as slowly as possible (20…30 minutes should be sufficient).

Recording of the measurement values is easier if a XY-plotter is available. The plotter can be connected directly to the corresponding output sockets on the front plate of the operating unit. Instead of a plotter, a computer interface with the corresponding software may be used.