Superconductivity / Influence of current and B-field

LEP 5.3.06

Related topics

Superconductivity, high temperature superconductor (HTSC), critical temperature, critical current, current-voltage characteristic of a superconductor

Principle and task

Disappearance of electric resistance in a high-temperature superconductor is observed when it is cooled to liquid nitrogen temperature. The disappearance of electric resistance becomes apparent during the experiment because even though alternating current flows through the sample, no alternating voltage can be detected across the sample. It is found that superconductivity vanishes when the so-called critical current density is reached. A thin film sample is used in order to reach this current density with small low current intensities which can be achieved with relatively low expenditure.
The critical current of the superconductor is determined by the four wire method. The influence of a magnetic field on a superconducting state is observed by measuring the current-voltage characteristics for various external magnetic field intensities, and by evaluating the dependence of magnetic field from the critical current.

Equipment

Superconductivity, power supply	13780.93	1
Superconductivity probe U(I)	13780.02	1
Superconduct.-storage/access.	13780.04	1
Pair of Helmholtz coils	06960.00	1
Bar magnet, l 72 mm	07823.00	1
Barrel base	02006.10	1
Stand tube	02060.00	1
Table top on rod	08060.00	1
Power supply 0-12 V DC/6 V, 12 V AC	13505.93	1
Digital multimeter	07134.00	1
Connecting cord, 500 mm, red	07361.01	1
Connecting cord, 500 mm, blue	07361.04	1
Connecting cord, 750 mm, red	07362.01	1
Dewar vessel, 500 ml	33006.00	1

Problems

1. Measuring and plotting the voltage drop between the superconducting $U(I)$ sample electrodes as a function of the current flowing across the probe.
2. Measuring and plotting of graphs according to problem no. 1 for different exterior magnetic fields.
3. Determination of the superconducting critical current I_c.
4. Determination of the dependence of critical current I_c from the external magnetic field intensity Hext.

Set-up and procedure

– Set up the circuit shown in Fig.1. Connect the $U(I)$ sample to the superconductivity control unit.
– Carefully fill the polystyrene vessel with liquid nitrogen and immerse the probe into the nitrogen. The probe must be immersed in the nitrogen during the whole measurement, i.e. its temperature must be equal to 77K. Displays on the superconductivity control unit should indicate no current whilst voltage drop is indicated to be 10 mV, and then slowly decreases to zero. Press the START/STOP button again; current now changes very slowly and values appear on both

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

Fig. 2: Experimental set-up: Influence of current and B-field.

displays. Press the START/STOP button again - current now rises with the same slope as previously. This allows to measure the $U(I)$ curve point by point increasing and decreasing current. The $U(I)$ curve is plotted for the superconducting $U(I)$ sample.

– Lay the rod magnet on the table in such a way that one of its poles is oriented towards the sample. The distance between magnet and sample is about 30 cm. Plot the $U(I)$ curve. The magnetic field intensity is now increased by decreasing the distance between the magnet and the sample. Repeat the measurement of the $U(I)$ curve for different external magnetic field intensities. Plot the $U(I)$ curves.

– A pair of Helmholtz coils in the set-up shown in fig. 2 is used to apply a definite exterior magnetic field H_{ext}. The Helmholtz coils are connected to the power supply in such a way that their fields are superposed additively. This is achieved for example connecting the two pairs of sockets marked “1” to the continuous current supply and the sockets marked “2” with one another. The lower spacer of the Helmholtz coils is removed and in the barrel base with clamped rod column holding the small table is set in its place. The polystyrene vessel is set on the table. The $U(I)$ sample, which is completely immersed in the liquid nitrogen, must be approximately at the centre of the Helmholtz coils. The perpendicular line to the surface points towards the axis of the coils. The critical current intensity Ic is measured while the field Hext increases in steps, and then plotted as a function of Hext.

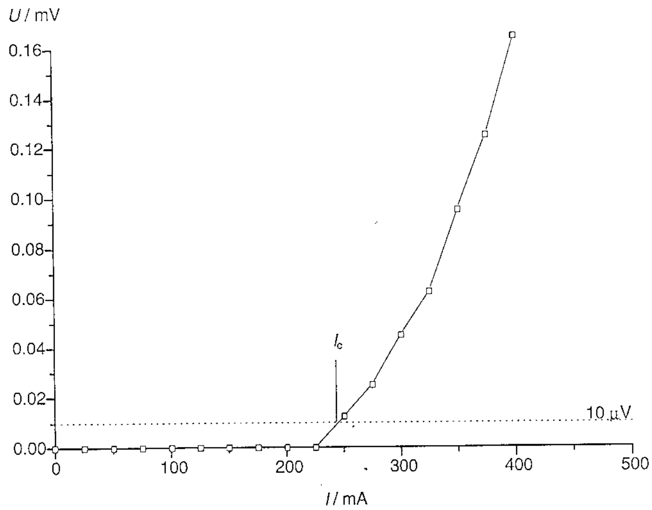


Fig. 3: Evaluation of the critical current.

Theory and evaluation

The critical current I_c is the maximum superconducting current the sample can withstand. Its evaluation depends on the choice of the “zero” resistance or voltage criterion. For the present purpose, the “zero” voltage can be set to 10 µV (Fig. 2), using the four wire method. When the critical current is exceeded, a resistive state appears in the superconductor. Resistance increases with the current, until it approaches its normal state value. The shape of the current-voltage characteristic curve depends on the type of superconductor, its complicated determination is obtained by the penetration of the

Fig. 4: Influence of the magnetic field on U(*I*) curves.

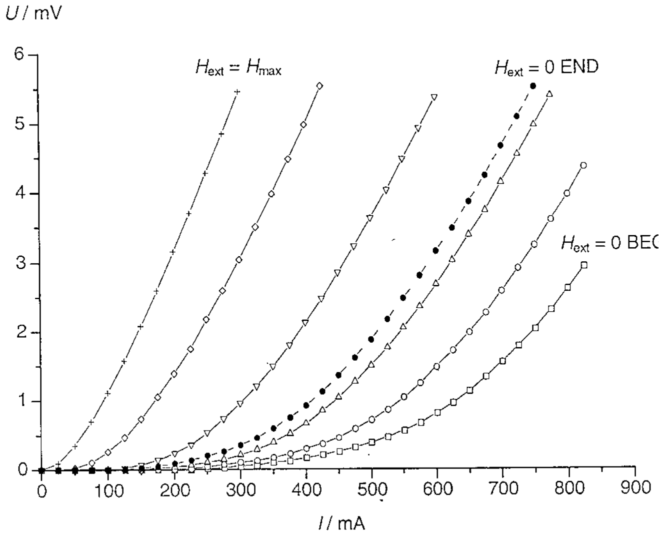
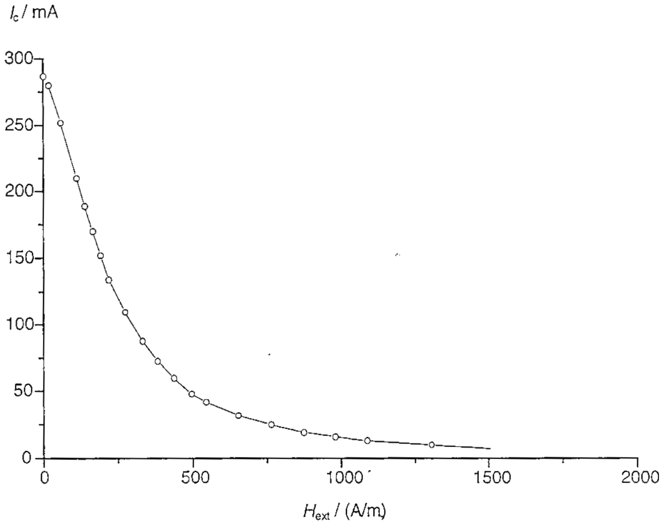


Fig. 5: Dependence of the critical current from the external magnetic field.



magnetic field produced by the current itself into the interior of the superconductor and the resulting destruction of superconductivity.

In type II superconductors (including high-temperature superconductors), a sufficiently strong magnetic field penetrates the sample, suppresses the critical current, and increases resistance, yielding different *U*(*I*) graphs for different external fields (fig. 4). The magnetic flux can remain frozen in the interior of the type II superconductor, even though the external field is removed. Therefore, the shape of the *U*(*I*) curve is not given by the applied field only. If one starts e.g. with an external field H_{ext} = 0, then increases it somewhat and lets it come back to H_{ext} = 0, the shape of *U*(*I*) for H_{ext} = 0 BEGIN will in general be different from the shape for H_{ext} = 0 END.

The dependence of Ic from the applied external magnetic field (fig. 5) can be determined, point by point, from the set of *U*(*I*) curves. However, it can also exhibit hysteresis features, caused by the flux trapped within the superconductor. In this case, a homogeneous magnetic field *H* is generated with the pair of Helmholtz coils, which can be calculated with the assistance of the current I circulating through the coils.

$$H = 0.715 \cdot \frac{n \cdot I}{r}$$

Where n = 154 (number of turns of each coil); r is the radius of the coils and is 0.20 m in this case.

Notes

One should be aware of the fact that temperature and magnetic field are not measured inside the superconductor, but rather on its surface. The real interior value and the value at the surface may principally differ, and in some cases, they really do.

Due to the above mentioned hysteresis phenomenon, the same exterior magnetic field may correspond to different values of the internal field. This ambiguity can be eliminated by heating the sample to room temperature and repeating the whole measurement from the beginning.