Vol. XXXVI (1969) ACTA PHYSICA POLONICA Fasc. 5 (11)

DETERMINATION OF THE ELECTRICAL RESISTANCE OF A SUPERCONDUCTOR IN THE INTERMEDIATE STATE ON THE BASIS OF ITS MAGNETIC INDUCTION DISTRIBUTION

By R. Freud

Low Temperature Laboratory, Institute of Low Temperatures and Structural Research, Polish Academy of Sciences, Wrocław*

(*Received January 30, 1969*)

The geometry of the distribution of superconducting and normal domains found by the bismuth probe technique, with a known specific resistance of the bulk sample in the normal state, can be utilized for determining the value of the sample's electrical resistance unperturbed by the shortening of the free path of conduction electrons due to their reflection at the surfaces of the superconducting domains.

As is well known, the shortening of the free path of conduction electrons due to their reflection at the boundaries of superconducting domains leads to augmented values in potentiometric determinations of electrical resistance. Among other things, attempts are made to explain by this effect the jump of electrical resistance at the transition of a superconducting cylinder with current to the intermediate state, which is experimentally found to be bigger than 0.5 R_n as predicted by London's theory. However, should the distribution of normal and superconducting domains in a given state of the sample be known from another source, then it would be possible in principle to calculate the value of the electrical resistance of the sample in that state from the geometry of the distribution of the two phase and the specific resistance of the bulk sample in the normal state. The value of the electrical resistance calculated thus would be unperturbed by the shortening of the free path lenght of conduction electrons owing to reflections at the surfaces of the superconducting domains.

The determination of the distribution of normal and superconducting domains in the intermediate state by the bismuth probe technique [1] does not depend on any possible shortening of the free path of conduction electrons. Hence, in every case when the distribution of the two phases can be determined by this technique, it is possible at the same time to determine the unperturbed value of the sample's resistance.

We shall illustrate this procedure with the example of the intermediate state of a superconducting cylinder.

* Address: Instytut Niskich Temperatur i Badań Strukturalnych PAN, Wrocław, ul. Próchnika 95, Polska.

By means of a long bismuth probe (approx. 2 mm) moving in a narrow slit in the central part of the cylinder and running symmetrically with respect to the axial plane (Fig. 1; also see Makiej [2]), the mean value of the magnetic induction $B(r) = H_c x(r)$ at a distance r from the cylinder axis is determined. H_c stands for the critical value of the magnetic field

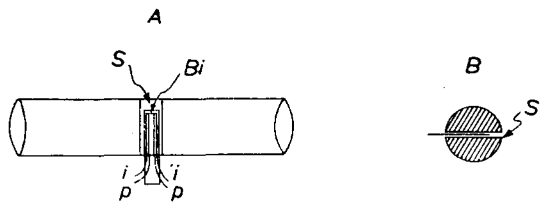

Fig. 1. Bismuth probe *1* mounted between two mica foil layers, current leads *2* and potential leads *3* in the slit of a superconducting cylinder

for a given temperature T of the helium bath, and $x(r)$ is the relative content of the normal phase at a distance r from the sample axis. From this empirical curve of the induction $B(r)$ as a function of distance r from the cylinder axis we determine the relative content of the normal phase $x(r)$ as a function of distance from the sample axis: $x(r) = B(r)/H_c(T)$.

If we imagine the core to be divided into a number of hollowed-out concentric cylinders, then the electrical resistance per unit length of the part of the core bounded by cylindrical surfaces of radii r and $r+dr$ will be $\varrho \dfrac{x(r)}{2\pi r dr}$, where ϱ denotes the specific resistance of the bulk sample in the normal state. Thence the reciprocal of the electrical resistance of the entire core equals $\dfrac{2\pi}{\varrho} \displaystyle\int_0^{r_0} \dfrac{rdr}{x(r)}$. Here, r_0 is the radius of the core. Since the electrical resistance of the normal state sheath per unit length is $\varrho \dfrac{1}{(a^2-r_0^2)\pi}$ (a being the cylinder radius), the reciprocal of the electrical resistance of the entire cylinder $1/R$ is equal to $\dfrac{\pi}{\varrho}(a^2-r_2^2) + \dfrac{2\pi}{\varrho} \displaystyle\int_0^{r_0} \dfrac{rdr}{x(r)}$.

In order to determine R we must first find ϱ, H_c and r_0 for the same helium bath temperature T and current i flowing through the sample. For helium temperatures ϱ can be determined with satisfactory accuracy from the ratio of sample resistances at the helium temperatures (4.2°K) and room temperature, $R_{4.2}/R_{300}$, and the specific resistance of the sample at room temperature: $\varrho_{4.2}/\varrho_{300} = R_{4.2}/R_{300} \cdot T_c$ and the dependence of H_c on temperature are determined according to the known method from the experimental dependence of the critical current on helium bath temperature: $2i_c/a = H_c(T)$. For temperatures sufficinetly near to T_c this dependence is linear.

At the boundary between the core and normal state sheath we have $r = r_0$ and only the normal phase remains, $x(r_0) = 1$; hence, $B(r_0) = H_c$. Thus, from the empirical curve depic-

ACTA PHYSICA POLONICA Vol. XXXVI (1969) Fasc. 5

ting the dependence of the mean value of magnetic induction B on distance from the cylinder axis r we directly read the value of r_0 at the point $B = H_c$.

Next, from the same $B(r)$ curve we find the dependence $r/B(r)$, and then calculate $\frac{2\pi H_c}{\varrho} \int\limits_0^{r_0} \frac{rdr}{B(r)}$ by numerical integration. There is now no difficulty in calculating the resistance of the cylinder in the intermediate state.

Of course, in order to get sufficiently accurate values of sample resistance R the value of magnetic induction B as a function of distance from the sample axis r must be measured densely.

This method is particularly applicable for samples of large diameters.

REFERENCES

[1] D. Shoenberg, *Superconductivity*, pp. 103–110, Cambridge 1960.

[2] B. V. Makiej, *Zh. Eksper. Teor. Fiz.*, **34**, 312 (1958).