An inexpensive and easy experiment to measure the electrical resistance of high-T_c superconductors as a function of temperature

L. M. León-Rossano
Departamento de Física, Facultad de Ciencias, Universidad Nacional Autónoma de Mexico (UNAM), A.P. 70-542, 04510 Mexico D.F., Mexico

(Received 24 December 1996; accepted 6 May 1997)

I. INTRODUCTION

Since the discovery of high-temperature superconducting ceramics in 1986 by Bednorz and Müller,[1] physicists have actively studied the behavior of these new materials. As a result of these studies, some properties of such materials are now measured in the undergraduate laboratory. A superconductor may be characterized by two important properties: the expulsion of magnetic field (Meissner effect) and zero electrical resistance.[2,3]

In some educational and scientific laboratories, it is not easy to measure electrical resistance as a function of temperature, because it is necessary to build[4] or to buy expensive[5] devices that control the temperature from room temperature to 77 K. For example, Fortin built an easy and cheap cryostat,[6] but it requires making some parts with machine tools, while Chen *et al.* introduced the ceramic sample slowly and directly into the open Dewar that contains liquid helium or liquid nitrogen,[7] but his method only allows one to check if the sample becomes a superconductor, furthermore, the sample holder is difficult to build.

In the present work, a simple method was used to vary the temperature of high-T_c superconductors from room to liquid

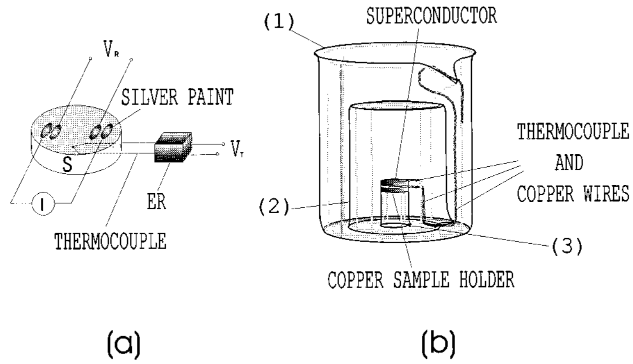

Fig. 1. (a) Superconducting sample (S) and electrical leads. (b) Diagram showing the position of the three Pyrex beakers (1), (2), (3), and the sample.

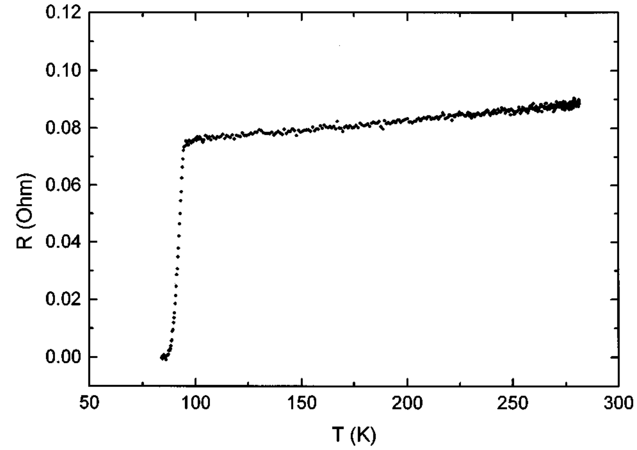

Fig. 2. Curve of resistance as a function of temperature for $Y_1Ba_2Cu_3O_7$; the transition temperature of the high-T_c superconductor occurs at about 91 K. Above T_c the behavior is metallic and below T_c the resistance is zero.

nitrogen temperatures. The electrical resistance was measured as a function of temperature using a standard four-point technique.

II. EXPERIMENT

A superconducting $Y_1Ba_2Cu_3O_7$ sample was made from Y_2O_3, $BaCO_3$, and CuO powders.[8] Powders were mixed and then calcined at 900 °C. Thereafter, they were reground, compacted, and sintered at 950 °C in air for 24 h. The sample was further oxygenated in air at 450 °C for 12 h.

To measure the electrical resistance, electrical contact leads made of 34 AWG copper wire[9] were attached to the sample (S) with silver paint [Fig. 1(a)].[10] The temperature was measured with a copper-constantan type ''T'' thermocouple,[11] which was attached with Crycon grease between the sample and the copper sample holder disks.[12] The thermocouple voltage, compensated with an electronic reference (ER),[13] was transformed into temperature units through the controlling personal-computer (PC) software. The 10-mA current source (I) was homebuilt. The voltage drop across the sample (V_R) and the thermocouple voltage (V_T) were measured with two Keithley-177DMM microvoltmeters connected with an IEEE-488 protocol to the controlling PC. For each temperature, the electrical resistance V_R/I was calculated.

The system that controls the sample temperature [Fig. 1(b)] consisted of three Pyrex beakers: beaker (1) was a 500-ml liquid nitrogen container, beaker (2) was a 150-ml beaker for heat exchange between the sample and the liquid nitrogen bath,[14] and beaker (3), which had a volume of 5 ml, supported the sample and the copper sample holder. The superconductor sample and the copper sample holder disks, with dimensions of 12 mm diam and 4 mm thickness, were in good thermal contact.

The controlling PC was programmed to measure the sample resistance and the temperature every 10 s. After initiating the PC, liquid nitrogen was poured into beaker (1) until beaker (2) was covered. When liquid nitrogen went into beaker (2), part of it evaporated generating an over-pressure that limited the amount of liquid in this beaker, and favored the heat exchange between the sample and the wall of beaker (2). Beaker (3) avoided the thermal contact between the sample and the liquid nitrogen deposited at the bottom of beaker (1). The low thermal conductivity[4,15] of Pyrex ensured slow sample temperature changes. This experimental arrangement hinders the formation of ice on the sample.

III. RESULTS

Figure 2 shows the electrical resistance of a superconducting sample as a function of temperature measured with the experimental arrangement described above. The curve was similar to that reported by Ellis[3] and Wu *et al.*[16] From room temperature to 95 K, the sample had metallic behavior. The superconducting transition temperature T_c was around 91 K; below this temperature the electrical resistance was zero. For all temperatures, electrical resistance and temperature values had absolute uncertainties less than 2%.

IV. CONCLUSIONS

An easy and inexpensive method to measure electrical resistance as a function of temperature is shown. In this method, using no more than 2 ℓ of liquid nitrogen, the metal–superconductor transition of high-T_c superconductors can be measured. This experiment was developed to enrich the laboratory associated with teaching a course on modern physics.

ACKNOWLEDGMENTS

I would like to thank B. E. Fuentes for her comments and R. Ortega for his technical assistance. This work was partially supported by the PAPIME Program, UNAM, Mexico.

[1]J. G. Bednorz and K. Müller, ''Possible High T_c Superconductivity in the Ba-La-Cu-O System,'' Z. Phys. B **64**, 189–193 (1986).

[2]C. Kittel, *Introduction to Solid State Physics* (Wiley, New York, 1976), 5th ed., pp. 357–358.

[3]Arthur B. Ellis, ''Superconductors,'' J. Chem. Educ. **64**, 836–841 (1987); Frederick H. Juergens, Arthur B. Ellis, Gunther H. Dieckman, and Ronald I. Perkins, ''Levitating a Magnet Using a Superconductive Material,'' J. Chem. Educ. **64**, 851–853 (1987).

[4]B. A. Hands, *Cryogenic Engineering* (Academic, London, 1986), Chap. 4; Martin Nikolo, ''Superconductivity: A guide to alternating current susceptibility measurements and alternating current susceptometer design,'' Am. J. Phys. **63**, 57–65 (1995).

[5]K. E. Oldenburg and W. A. Morrison, ''Critical current density of $Y_1Ba_2Cu_3O_{7-x}$,'' Am. J. Phys. **61**, 832–834 (1995).

[6]E. Fortin, ''Portable Metallic Cryostat for Optical Measurements at 77 K,'' Rev. Sci. Instrum. **41**, 1252–1252 (1970).

[7]Xiao-Dong Chen, Sang Young Lee, John P. Golben, Sung-Ik Lee, R. D. McMichael, Yi Song, Tae W. Noh, and J. R. Gaines, ''Practical prepara-

tion of copper oxide superconductors,'' Rev. Sci. Instrum. **58**, 1565–1565 (1987).
[8] Y_2O_3, 99.99%, cat. No. 20, 516-8; $BaCO_3$, 99.98%, cat. No. 32, 943-6; CuO, 99.99%, cat. No. 32, 545-7. *Catalog Handbook of Fine Chemicals (1990–1991)* (Aldrich Chemical Company, Milwaukee, 1990).
[9] L. J. Van der Pauw, ''A Method of Measuring Specific Resistivity and Hall Effect of Disks of Arbitrary Shape,'' Philips Res. Rep. **13**, 1–9 (1958); K. G. Vandervoort, J. M. Willingham, and C. H. Morris, ''Simple, inexpensive probe for resistivity measurements above 77 K on metals and superconductors,'' Am. J. Phys. **63**, 759–760 (1995).
[10] Silver paint, cat. No. 16031, Ted Pella, Inc., P.O. Box 492477, Redding, CA 96049.
[11] Thermocouple Reference Tables, Omega Press, Omega Engineering, Inc. 179-206, April 1975; models TFCP-003 and TFCC-003; *The Temperature Handbook* (Omega Engineering, Inc., Stamford, CT, 1995), Vol. 29, p. H-17.
[12] Cry-Con conductive grease, model GCC-28, Lake Shore Cryotronics, Inc., 64 East Walnut Street, Westerville, OH 43081.
[13] Miniature Electronic Ice Point, model MCJT, *The Temperature Handbook* (Omega Engineering, Inc., Stanford, CT, 1995), Vol. 29, p. K-8.
[14] T. Zakrzewski and Z. Dzcuba, private communication with A. C. Rose-Innes; A. C. Rose-Innes, *Low Temperature Laboratory Techniques* (The English Universities Press, Liverpool, 1973), 2nd ed., pp. 161–162.
[15] D. A. Wigley, *Mechanical Properties of Materials at Low Temperatures* (Plenum, New York, 1971), pp. 304.
[16] M. K. Wu, J. R. Ashburn, C. J. Torng, P. H. Hor, R. L. Meng, L. Gao, Z. J. Huang, Y. Q. Huang, and C. W. Chu, ''Superconductivity at 93 K in a New Mixed-Phase Y-Ba-Cu-O Compound System at Ambient Pressure,'' Phys. Rev. Lett. **58**, 908–910 (197).

WHY I BECAME A SCIENTIST

The first reason why I am a scientist is that I have parents who believed I could do anything. ... The second reason I became a scientist was that I loved doing the science. ... That brings me to the third reason that I am a scientist, which is that I was allowed to experience laboratory research relatively early in my career as an undergraduate student. ... The fourth reason why I am a scientist is that I was always a very good student. ... The reason I survived as a scientist is that I don't mind a good fight.

Shirley M. Tilghman, ''Why I became a scientist,'' AWIS Magazine **24**(1), 10–11 (1995).