Influence of Pressure on the Superconductivity of Some High-Field Superconductors

C. B. MÜLLER and E. J. SAUR

Institute of Applied Physics, University of Giessen, Germany

I. INTRODUCTION

The influence of pressure on superconductors has been intensively studied in the past.[1] Olsen *et al.*[2] have recently summarized the results. One finds a linear relationship between $\partial \ln(T_c/\theta)/\partial \ln v$ and $\ln(\theta/T_c)$ ($v \equiv$ volume) for soft superconductors, except thallium, where an electron–phonon interaction leads to superconductivity. The transition metals do not obey this relationship, and the named authors conclude that for these elemental superconductors the electron–phonon interaction is not the only one leading to superconductivity.

We have studied the change in the transition temperature and in the critical currents of the high-field superconductors Nb_3Sn, V_3Ga, and V_3Si in transversal magnetic fields up to 10 kOe in the pressure range 0 to 1650 kg cm^{-2} by using the ice-bomb technique.[3]

II. EXPERIMENTAL

The cylindrical specimens were 30 mm long and 0.5 mm in diameter. The first class of samples have a thin layer of Nb_3Sn, V_3Ga, and V_3Si on the surface of niobium and vanadium wires, respectively. This layer can be prepared by diffusion of tin into niobium,[4] and of gallium or silicon into vanadium[5] at elevated temperatures. The second type of samples contain these superconductors inside a niobium jacket.[6]

The ice bomb, with the sample, is shown in Fig. 1. The bomb consists of the bomb body B, filled with distilled water, the bomb head H, which can be screwed firmly into B by using interposed washers W_1, W_2. The cooling capillary C runs through B. The water in this tube is first frozen by pouring liquid air into the German silver tube T, which may be raised through a sealing in the cover plate of the cryostat. By this arrangement it is possible to cool the bomb down slowly for obtaining hydrostatic pressure in it. Further, the bomb can be lifted to rewarm it. The bomb is made from copper–beryllium bronze strengthened by precipitation hardening. One end of the sample is fixed axially to the bomb head, which serves as one current lead. The other current lead and the potential wires are fixed to the sample with silver paste or indium, and run upwards through the capillary. Superconducting transition was detected by resistance measurement (current 1 mA) with a galvanometer sensitivity of 10^{-8} V. The temperature was measured by using the vapor pressure of the liquid hydrogen and this could be kept constant to

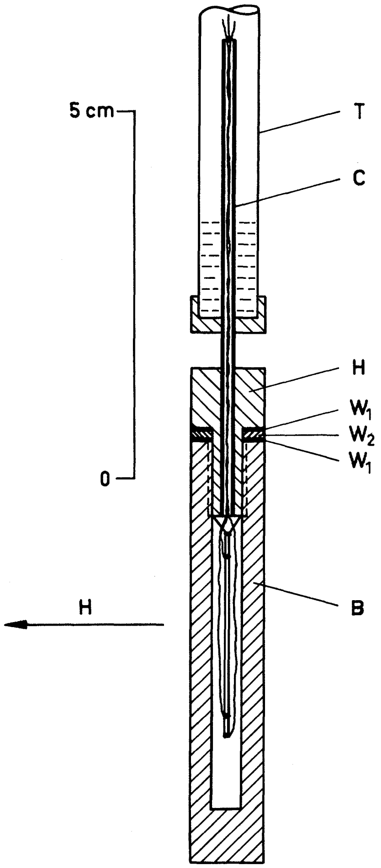

FIG. 1. The ice bomb.

---

[1] See, e.g., C. A. Swenson, Solid State Phys. **11**, 109 (1960).

[2] J. L. Olsen, K. Andres, H. Meier, and H. de Salaberry, Z. Naturforsch. **18a**, 125 (1963).

[3] B. Lazarev and L. S. Kan, J. Phys. (USSR) **8**, 193 (1944).

[4] E. J. Saur and J. P. Wurm, in *Proceedings of the International Conference on High Magnetic Fields, Cambridge, Massachusetts 1961* (John Wiley & Sons, Inc., New York, 1962, p. 589); Naturwissenschaften **49**, 127 (1962).

[5] D. Koch, G. Otto, and E. Saur, Phys. Letters **4**, 292 (1963).

[6] J. E. Kunzler, E. Buehler, F. S. L. Hsu, and J. H. Wernick, Phys. Rev. Letters **6**, 89 (1961).

0.005°K with a manostat.[7] The critical current was measured in the usual way, namely by increasing the current at fixed magnetic field just until normal conductivity sets in. The pressure in the bomb could be varied by using water–ethyl alcohol mixtures.[8] Pressure calibration was done by measuring the variation in resistance of a thin, very pure copper wire.[9] The reproducibility of pressure was correct to about 10%.

III. PRESSURE EFFECT ON TRANSITION TEMPERATURES

The critical temperature is reduced for all samples when these are under pressure. The relationship between decrease of critical temperature and pressure is a complicated one (Fig. 2). One knows that indium, with its simple Fermi surface, shows a linear reduction of critical temperature with increasing pressure.[10] Tantalum also shows a linear reduction,[11] whilst tin (with a complicated Fermi surface) has a complicated correlation between pressure and decrease of critical temperature.[10] In our experiments it seems more likely that the irregular relationship is caused by physical and symmetrical inhomogeneities in the superconducting layer, which, in addition, has a higher modulus of elasticity than the base material, resulting in an anisotropic compression.

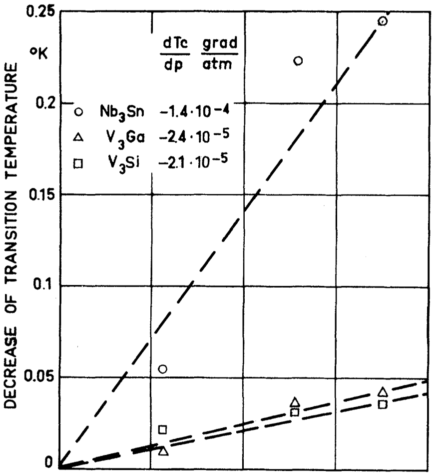

FIG. 2. Decrease of transition temperature with hydrostatic pressure.

Further, in principle it should be possible to find out, by using the Debye temperatures of Nb_3Sn, V_3Ga, and V_3Si[12] (and if the compressibility were known), whether the results obtained from these layers fit into the above-mentioned relationship.

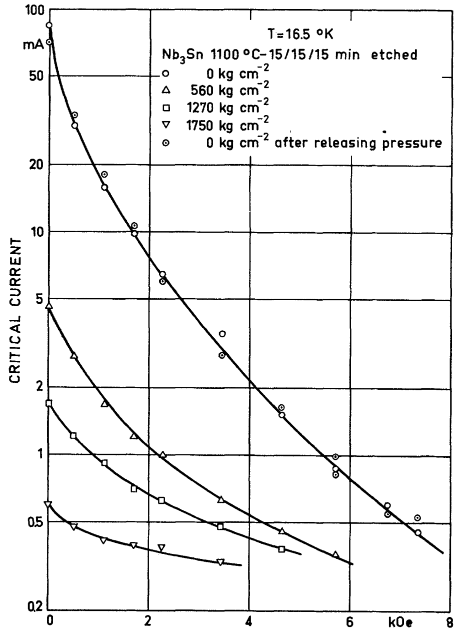

FIG. 3. Change of critical currents in transversal magnetic field with pressure.

Unexpectedly, the value of the pressure coefficient for Nb_3Sn is higher than that for V_3Ga and V_3Si. The negative sign of the pressure coefficient of the latter is in accordance with measurements from elsewhere.[13] Measurements on the second type of samples (core wires) turned out to be less reproduceable. The experimental error amounts to approximately 25%, and therefore no results will be given here.

IV. PRESSURE EFFECT ON CRITICAL CURRENTS

Finally, we measured the critical currents of the samples in transversal magnetic fields not far below the transition temperature. For all samples they are

---

[7] H. S. Sommers, Rev. Sci. Instr. **25**, 793 (1954).

[8] N. B. Brandt and A. K. Tomashchik, Instr. Exptl. Techn. USSR **2**, 113 (1958).

[9] J. S. Dugdale and D. Gugan, Proc. Roy. Soc. (London) **A241**, 397 (1957).

[10] L. S. Kan, B. G. Lazarev, and V. J. Makarov, Zh. Eksperim. i Teor. Fiz. **40**, 457 (1961) [English transl.: Soviet Phys.—JETP **13**, 317 (1961)].

[11] D. H. Bowen, in *Proceedings of the Fifth International Conference on Low-Temperature Physics and Chemistry, Madison, Wisconsin, August 30, 1957*, edited by J. R. Dillinger (University of Wisconsin Press, Madison, 1958), p. 337.

[12] F. J. Morin and J. P. Maita, Phys. Rev. **129**, 1115 (1963).

[13] N. E. Alekseevskii, E. M. Savitskii, V. V. Baron, and Y. V. Efimow, Dokl. Akad. Nauk SSSR **145**, 82 (1962) [English transl.: Soviet Phys.—Doklady **7**, 648 (1963)].

remarkably reduced. One example is given in Fig. 3. For the results of measurements of critical current and field characteristics there exists as yet no well-defined theoretical relationship. A possible explanation would be as follows. Suppose one filament in the weakest part of the superconducting sample has a certain cross section and has maximum current density; because of the compression, which reduces the value of this cross section, the current becomes supercritical. This has the effect that normal conductivity sets in at lower critical current values.

V. CONCLUSION

It seems worthwhile to investigate the pressure dependence of critical temperature, critical current, and critical field in smaller pressure steps up to very high pressures for clean, homogeneous specimens. This would result in a more detailed knowledge of the intrinsic properties of high-field superconductors.

ACKNOWLEDGMENTS

We would like to thank the Deutsche Forschungsgemeinschaft for support of this work.

Discussion 14

B. T. MATTHIAS, *University of California:* The change of T_c with pressure of Nb_3Sn as reported in JETP gives values that are smaller than yours by a factor of 2 from what I remember.

C. MÜLLER, *University of Giessen:* This would be in accordance with what I just mentioned. Our Nb_3Sn values are very much out of line, and perhaps there is something wrong in the whole structure we don't know about yet.

GERHART K. GAULÉ, *U. S. Army Electronics Research and Development Laboratory:* You mentioned in the abstract and you said here that the soft superconductors behave differently from those which you have investigated, by a factor of 2. I pointed out this morning the parameter for a fair comparison should be the atomic volume and not the pressure. Considering that your materials are much harder, I think that you get lesser volume change. If you plot atomic volume vs critical temperature you might find a better agreement.

THERMAL PROPERTIES

CHAIRMAN: *K. Mendelssohn*

Magnetic and Thermal Properties of Second-Kind Superconductors. I. Magnetization Curves[*,†]

T. KINSEL,[‡] E. A. LYNTON, and B. SERIN
Rutgers, The State University, New Brunswick, New Jersey

INTRODUCTION

We have measured, as a function of temperature, the magnetization curves of specimens which formed a group of solid solutions of bismuth in indium. The nominal concentrations ranged from 1.5 to 4.0 at.%. Each sample except the most dilute one was a superconductor of the second kind at its transition temperature T_c. This set of alloys has values of T_c in the liquid-helium temperature range, so that we were able to make a detailed comparison of our results with the predictions of the Ginzburg–Landau–Abrikosov (GLA) theory[1,2] which is derived to be valid near T_c.

The specimens were in the form of long, thin

---

[*] This work has been supported by The National Science Foundation and the Rutgers University Research Council.

[†] Based in part on a dissertation submitted by T.K. to the Graduate Faculty of Rutgers University in partial fulfillment of the requirements for the Ph.D. degree.

[‡] Socony-Mobil Fellow, 1961–63. Present address: Bell Telephone Laboratories, Whippany, New Jersey.

[1] V. L. Ginzburg and L. D. Landau, Zh. Eksperim. i Teor. Fiz. **20**, 1064 (1950). Cf. also V. L. Ginzburg, Nuovo Cimento **2**, 1234 (1955).

[2] A. A. Abrikosov, Zh. Eksperim. i Teor. Fiz. **32**, 1442 (1957) [English transl.: Soviet Phys.—JETP **5**, 1174 (1957) and J. Phys. Chem. Solids **2**, 199 (1957)].