Materials at Low Temperatures

An offhand comment by a long forgotten colleague provided the impetus to develop one of the most comprehensive books available on the study of materials at low temperature. As the 30-year era of the NBS Cryogenics Division was coming to a close, it was remarked, perhaps more than once, that the accumulated expertise of the division should be gathered and preserved. Thus, the idea was born to pull together a tutorial text and apply the resident expertise to a critical evaluation of the existing data on cryogenic materials. It is rare enough that such an opportunity presents itself, but rarer still that 13 authors should work together to create such a text. That the result had widespread impact and influence on the low-temperature community, however, was no surprise.

The book, *Materials at Low Temperatures* [1], consists of 14 chapters, each a combination of tutorial text and critical data analysis for 14 different properties of materials at cryogenic temperatures. It was written during the years 1980-1982 by the staff members of the former Cryogenics Division while the Division was being disbanded during a major reorganization, with the staff being distributed throughout three different Centers that have since evolved into three laboratories: Electronics and Electrical Engineering Laboratory (EEEL), Materials Science and Engineering Laboratory (MSEL), and Chemical Science and Technology Laboratory (CSTL). The 590-page book represents the consolidation of an estimated 600 staff-years of experience accumulated by the Division staff while it led the world in research and development of cryogenic technology. The history of that experience can be traced from its beginning with nuclear weapons, through the rapid growth of the space age, and into the world of low-temperature physics and superconductivity.

The book contains nearly 3000 references to extensive collections of theoretical and experimental work, much of it data for the critical analyses. The book is organized into the following 14 chapters:

Chapter 1 – *Elastic Properties,* H. M. Ledbetter
Chapter 2 – *Specific Heat,* L. L. Sparks
Chapter 3 – *Thermal Expansion,* A. F. Clark
Chapter 4 – *Thermal Conductivity and Thermal Diffusivity,* J. G. Hust
Chapter 5 – *Electrical Properties,* F. R. Fickett
Chapter 6 – *Magnetic Properties,* F. R. Fickett and R. B. Goldfarb

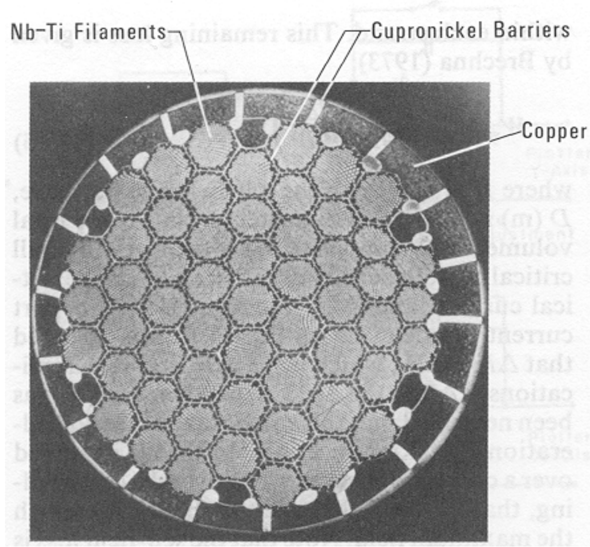

Fig. 1. Practical superconducting wires often are composite structures consisting of many fine superconducting filaments embedded in a matrix of normal metal to give the composite stability. When an ac current is passed through the superconductor, substantial energy losses can occur due to eddy currents. These losses must be minimized so that they do not heat the superconductor above its critical temperature. Subdividing the copper sheathing with sheets or fins of low conductivity Cu-Ni helps to reduce those losses. The figure shows a multifilamentary superconductor with cupronickel barriers (white areas) to prevent coupling currents from flowing around filament clusters and the outer copper stabilizing sheath. Copper areas are dark and the Nb-Ti filaments are gray. [Figure courtesy of Imperial Metal Industries.]

Chapter 7 – *Mechanical Properties,* D. T. Read
Chapter 8 – *Fracture Mechanics,* R. L. Tobler and H. I. McHenry
Chapter 9 – *Martensitic Phase Transformations,* R. P. Reed
Chapter 10 – *Compatibility of Materials with Cryogens,* J. C. Moulder and J. G. Hust
Chapter 11 – *Structural Alloys,* H. I. McHenry
Chapter 12 – *Composites,* M. B. Kasen
Chapter 13 – *Superconductors,* J. W. Ekin
Chapter 14 – *Temperature, Strain, and Magnetic Field Measurements,* L. L. Sparks

Each chapter is complete on its own, yet there is an interweaving that was done by the editors, drawing from the interactions of the authors, who were all colleagues and who compared notes and ideas as they were writing. The book is readable by the most inexperienced layman while remaining a valuable reference to even the old hands of cryogenics. This coherent presentation is exemplified by the chapter on thermal expansion by A. F. Clark. He begins with a simple observation: "Warming a solid body from absolute zero requires energy. In a free body, this energy manifests itself in two ways: an increase in temperature and a change in volume. Both of these are directly related to the additional vibrational energy of the individual atoms; the former simply because more atomic energy states are excited, the latter because the mean interatomic distance changes with energy. The ratio of the change in energy to the change in temperature is the specific heat. The ratio of the change in volume to the change in temperature is the thermal expansion." Thus, in this remarkably lucid introduction, Clark establishes the significant conceptual relation between two extremely important properties, specific heat and thermal expansion. He goes on to explain, " . . . the volume expansion is due to the anharmonic behavior of atomic vibrations and the specific heat is due primarily to the vibrations themselves . . . " From there, one quickly proceeds to learn about the wide-ranging importance of understanding the thermal properties, from the dimensional stability needed to maintain the critical alignment of a large telescope operating in the very cold environment of space while being warmed by the sun, to the earthbound commercial consequences of the thermal expansion or contraction of a low-temperature storage tank. In a commercial storage tank for liquefied natural gas (LNG), the tank itself cools as the LNG is added. The volume of the fully cooled storage tank may be as much as thirty thousand liters smaller than it was at the ambient temperature! Having explained the concepts and the consequences, Clark then proceeds to review the essential theoretical elements and the principal measurement methods, and concludes with an evaluation of the pertinent data.

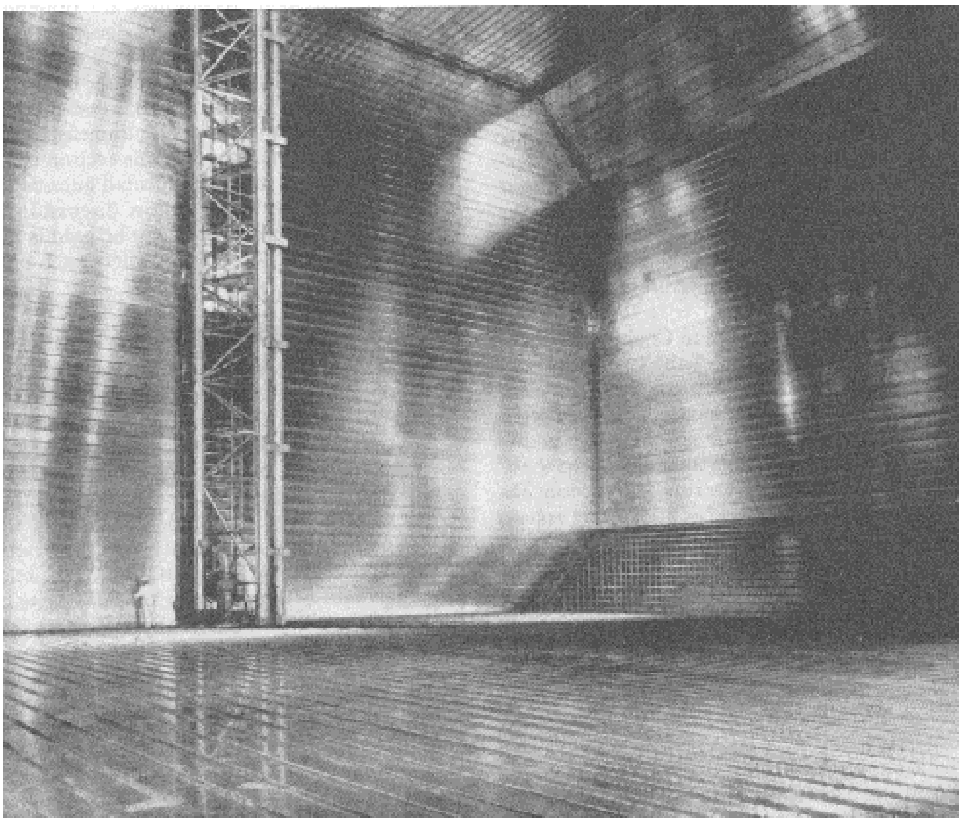

Fig. 2. An interior view of a liquefied natural gas tank lined with a low thermal expansion alloy. [Figure courtesy of McDonnell Douglas, Astronautics Laboratory and Gaz-Transport.]

The approach exemplified by Clark's chapter is followed throughout the book by a collection of authors who, at the time of writing, were considered by many to be the world's best experts on virtually all aspects of cryogenic technology. To have some of the best researchers in the field outline and explain the low-temperature behavior of materials creates an unusually complete reference. To have those same experts evaluate the available data, explain them, and indicate future research directions, creates a sound, thorough, and scientifically excellent work.

The book has been used as a text in courses on cryogenic technology and as a reference by cryogenic engineers and low-temperature physicists throughout the world. Book reviews of that time used such words as "extraordinarily useful," "extensive," "understandably written," and "indispensable reference." Personal feedback to the authors was, and some cases still is, always very positive. Two categories of users were often more lavish in their praise, those new to the field and those in the depths of low-temperature experiments, responding respectively to the tutorial text and the data evaluations, the two primary objectives of the book.

The volume, published by the American Society for Metals, sold out rapidly. Of the approximately 1000 books printed, none are still available for purchase. Copies are widely distributed in university, government, and industrial laboratories throughout the world. These books have been seen on shelves from New England to New Zealand, from China to Scotland, and from Argentina to Finland. Visits to the many laboratories that have copies show them all to be both dog-eared and treasured. But probably the strongest indication of use has come from personal feedback to the authors, all of it anecdotal and all of it very positive. Typical are "It's always within reach," "I never let it out of the office," and "It's always researched whenever we start something new."

The extent of the compilation and evaluation of data is truly comprehensive. Even today, newly measured data fit within the ranges and predictions of the authors. The explanatory text is, of course, still valid and just as relevant as when the book was published. For anyone attempting to design, build, or interpret an experiment at low temperatures, even 17 years later or 17 years hence, the book is, and will be, an extraordinarily useful reference.

Richard Reed received his Ph.D. in physical metallurgy in 1966. At NBS, he served as Chief of the Fracture and Deformation Division through 1986. Officially retired now, he still consults on the low-temperature properties of materials. Reed and Clark are credited with founding the International Cryogenic Materials Conference, and each has served as editor of many conference proceedings and journals.

Alan Clark received his Ph.D. in physics in 1964. With a specialty in low-temperature physics and superconductivity, he has served as Group Leader of both the Superconductor and Magnetic Measurements group (NBS-Boulder) and the Fundamental Electrical Measurements group (NIST-Gaithersburg). He also has served as a Liaison Scientist for the Office of Naval Research, London. He is now Deputy Chief of the Optoelectronics Division (NIST-Boulder).

Of the thirteen authors, six are still employed at NIST, three in EEEL (Al Clark, Jack Ekin, and Ron Goldfarb) and three in MSEL (Fred Fickett, Hassel Ledbetter, and Dave Read). Five are retired from NIST (Jerry Hust, Bud Kasen, Harry McHenry, Dick Reed, and Larry Sparks); several of these now have small consulting businesses. One (John Moulder) is deceased.

Prepared by Fred Fickett.

Bibliography

[1] Richard P. Reed and Alan F. Clark (eds.), *Materials at Low Temperatures,* American Society for Metals, Metals Park, OH (1983).