# THEORY OF METALS FROM THE RUSSIAN SCHOOL

## Fundamentals of the Theory of Metals

**A. A. Abrikosov**
*North-Holland, New York, 1988. 630 pp. $118.50 hc*
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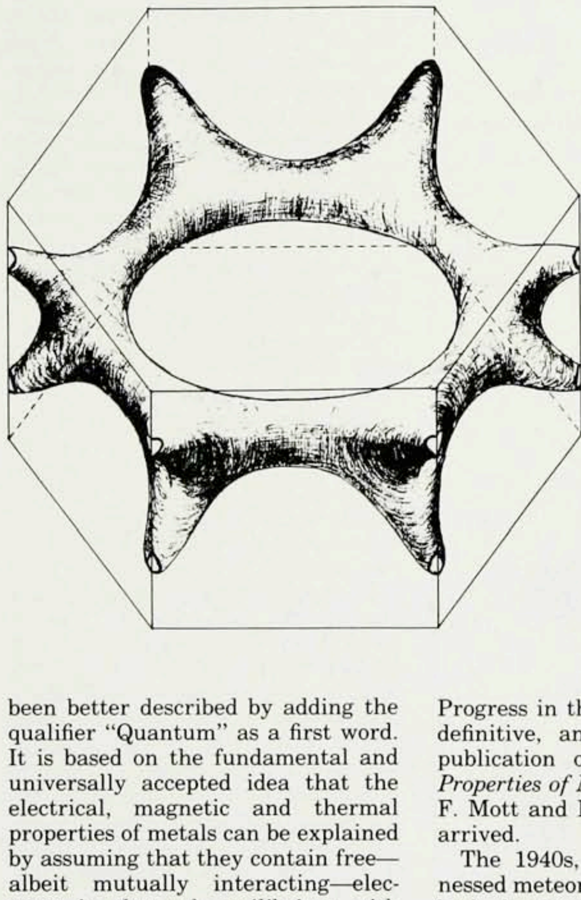
*Reviewed by L. M. Falicov*

Among the large number of useful materials that humankind has identified, many have been the subject of study, fascination, creation and even war. Metals undoubtedly occupy a very special place among them. An alloy (bronze) and a simple element (iron) have given their names to two early historic ages. Gold and silver have traditionally been the symbols of wealth, power and lasting value. The 19th-century industrial revolution was based fundamentally on the manufacture and processing of metals, especially steel. The price and availability of common, less common and rare metals are the subjects of daily scrutiny by economists and policy makers.

Metallurgy, the study of the properties of metals and their attendant technological applications, is the oldest of the materials sciences, probably over 5000 years old. However, only in the 20th century, after the discovery of the electron and the subsequent advent of quantum mechanics, could an understanding of the microscopic properties of metals be achieved. These microscopic aspects constitute the theory of metals referred to in the title of the English-language edition of A. A. Abrikosov's book, *Fundamentals of the Theory of Metals*; it could have been better described by adding the qualifier "Quantum" as a first word. It is based on the fundamental and universally accepted idea that the electrical, magnetic and thermal properties of metals can be explained by assuming that they contain free—albeit mutually interacting—electrons in thermal equilibrium with ions in a crystal. Although such a theory had its origins before quantum mechanics—with the pioneering work of Paul Drude (1900), Hendrik A. Lorentz (1904) and Arnold Sommerfeld (1928)—its real birth was in 1925 with the formulation of the Pauli exclusion principle and in 1928 with Felix Bloch's formulation of his now famous theorem. The former produced the correct (Fermi–Dirac) statistics to treat the electrons, whereas the latter assigned well-defined quantum numbers to the wave functions of electrons in a periodic potential. These two milestones opened the path for rapid advances in the formal development of the theory.



**The Fermi surface** of magnesium, a hexagonal-close-packed metal, as calculated from first principles. The Fermi surface can be measured by a variety of techniques, in particular by use of the de Haas–van Alphen effect. (Courtesy of L. M. Falicov.)

Progress in the 1930s was rapid and definitive, and by 1936, with the publication of *The Theory of the Properties of Metals and Alloys* by N. F. Mott and H. Jones, maturity had arrived.

The 1940s, 1950s and 1960s witnessed meteoric advances in the field, both theoretically and experimentally, based on several causes including: better sample preparation and characterization techniques; availability of very low temperatures; higher and more uniform and stable magnetic fields; microwaves; better detectors of all kinds; superconducting technology; better sources of x-ray, ultraviolet, visible and infrared radiation; neutron sources; larger and more accurate computers. Those decades also saw the birth of some of the most successful theoretical ideas: the Landau theory of Fermi liquids (1941), the Bardeen–Cooper–Schrieffer microscopic theory of superconductivity (1957) and the Anderson theory of localization (1958). These ideas per-

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meate the field and constitute its modern, secondary foundation.

Abrikosov, one of Lev D. Landau's youngest students, is a very distinguished scientist who has made many important contributions to both the theory of normal metals and semimetals and the theory of superconductivity—in particular the theory of type-II superconductors. He is also the coauthor, with L. P. Gor'kov and I. E. Dzyaloshinskii, of the highly acclaimed *Methods of Quantum Field Theory in Statistical Physics* (1962) and the sole author of *An Introduction to the Theory of Normal Metals* (1972). Part I of the book under review here should be considered, according to the preface, a "thoroughly revised version" of the 1972 book.

Abrikosov's aim is extremely ambitious: to cover in a single-volume textbook all aspects of the quantum theory of metals in both the normal and superconducting states. A cursory inspection of the available titles and number of pages published in the last three years in the subfield of superconductivity is sufficient to indicate that that aim is not easy to achieve. In the hands of a lesser scientist or a less skillful writer, the results could be either incomprehensible or indigestible; it is an indication of Abrikosov's stature on both accounts that this book succeeds admirably, although at times the going is not smooth.

The book is divided into two parts of roughly the same length. Part I, devoted to normal metals, is the revised version of the earlier 1972 book and is enlarged to include a considerable number of more recent issues. Part II is, for all practical purposes, a welcome new text on the established (pre-1987) science of superconductivity that thoroughly covers all aspects of the phenomenological, macroscopic and microscopic theories.

Part I is devoted to all the quantum-mechanical, many-body aspects of metallic electron states, electrical and thermal conductivity, thermoelectric and thermomagnetic phenomena, behavior of electrons in a magnetic field, absorption of sound in metals, geometric and size effects and methods of calculating electronic spectra. It does not include collective magnetic effects or density waves, but it covers the scattering of ordinary electrons by localized moments (the Kondo effect). Even though Abrikosov examines the field thoroughly, with proper coverage of developments regardless of where they took place, his viewpoint is essentially that of the "Landau school," with emphasis on contributions made by Soviet scientists. As a consequence, the book is very strong in those areas where the Landau school excelled: Fermi liquid effects, oscillatory magnetic effects, transport phenomena (especially galvanomagnetic effects) and quantum effects in metallic conductivity.

The treatment is not as strong when real Fermi surfaces, real lattice effects, symmetry properties or three-dimensional bodies other than spheres, ellipsoids, corrugated cylinders or intersecting tubes are needed. Among the many beautiful effects described throughout the book, I found very few references to metals as they exist in nature, with the exception of a few figures and a rather skimpy and unsatisfactory chapter on the "Methods for Calculating Electronic Spectra of Metals."

On the other hand, the analytic treatment of the various effects is masterful. Throughout the book there is a good blend of rigorous derivations and order-of-magnitude arguments. The algebraic complexity is neither hidden nor spoon-fed in boring detail. And the insertion of qualitative arguments at crucial points in the text makes reading it worthwhile for the less theoretically inclined individual.

Part II of this book provides the long-delayed and eagerly awaited text on superconductivity from a distinguished member of the Russian school. Its eight chapters cover all aspects of superconductivity: general properties and macroscopic aspects; the phenomenological (Ginzburg–Landau) and microscopic (Bardeen–Cooper–Schrieffer) theories; type-II superconductivity; kinetics; interface, tunneling and Josephson effects; the relationship between superconductivity and magnetism. There is a brief (and already outdated) ten-page section on high-temperature superconductivity that, even if the book had to be *au courant*, could have been omitted.

As in Part I, the text's strengths are its coherent derivation of the various aspects of the theory and its appealing mixture of rigorous presentations and qualitative, order-of-magnitude arguments. The physics becomes transparent and is not heavily dependent on the rigor of the mathematics. As before, little connection is made to real systems.

Despite its strong character and its excellent features, the book is unfortunately not technically well produced. Given its price and the quality of the original material, the translation and proofreading are inferior and, in many cases, infuriating. For

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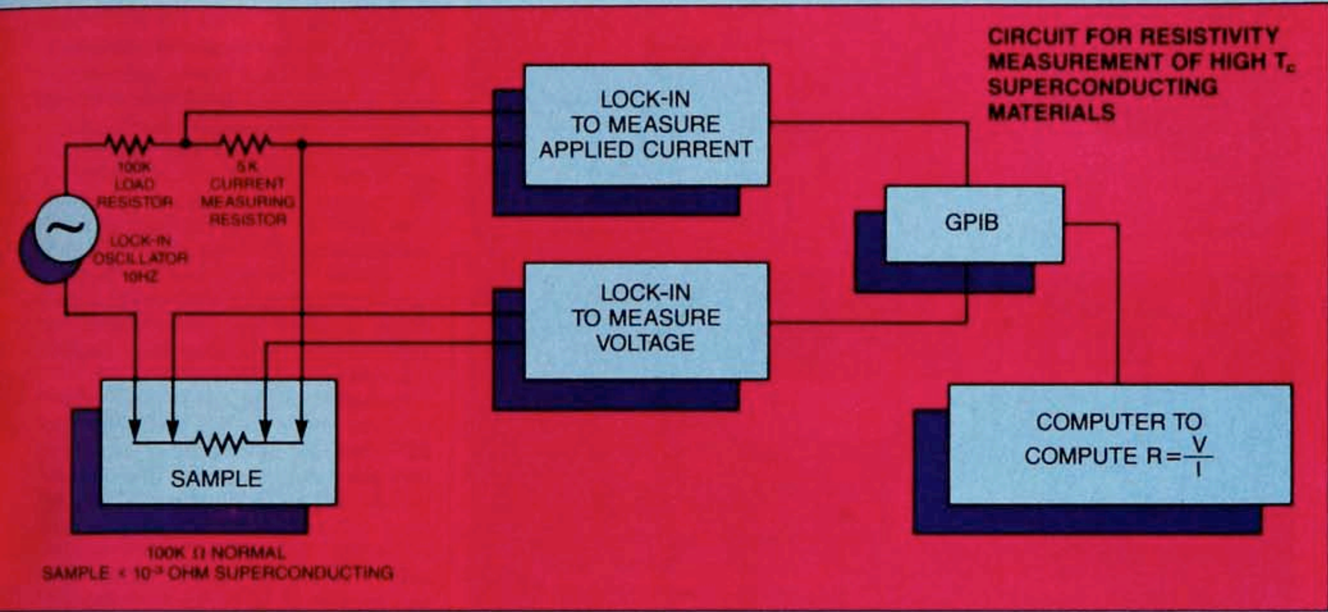


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example, the index contains many errors, spelling is inconsistent, typographical errors are common, nomenclature is sometimes nonstandard, some formulas are incorrectly defined and errors in the translation result in confusing, even amusing, nonsense.

These are not minor annoyances. They should be corrected, and soon. I hope that a technically revised edition—a good translation and an error-free printing—will be published soon so that the scientific community may enjoy this excellent textbook, which covers an extensive and mature field in such a conceptually clear and appealing fashion.

## The Experimental Foundations of Particle Physics

**Robert N. Cahn and Gerson Goldhaber**
*Cambridge U. P., New York, 1989. 429 pp. $49.50 hc*
*ISBN 0-521-33255-9*

Physics is undeniably an experimental science. Still, that side of its history is all too often neglected. This is particularly true for particle physics, where progress in theory is accepted as the rationale for the whole research effort. In any event, theory provides a tidy framework on which to hang a story.

In this volume, Robert N. Cahn and Gerson Goldhaber try to set the record straight in a collection of some sixty or so experimental papers, spanning the half-century from the discovery of the neutron to that of the $W^{\pm}$. The papers are grouped in 12 chapters, each of which includes a brief explanatory text written by Cahn and Goldhaber. The organization follows experimental topics, such as the pion–muon problem and jet structure in high-energy annihilations, rather than theoretical issues.

Exercises are provided in an effort to make this a textbook suitable for advanced undergraduate or introductory graduate courses. Unfortunately, the explanatory material is too brief to serve as an adequate stand-alone text for a true novice in the field. The authors freely admit this and suggest D. H. Perkins's *Introduction to High Energy Physics* (Addison–Wesley, Menlo Park, Calif., 1987) as a companion text.

What material there is, however, is mostly well written. The treatment of the subtle and elegant experiment that established the helicity of the neutrino, the work of Maurice Goldhaber (brother of one of the authors), Lee Grodzins and A. W. Sunyar, is an exemplar of clear but economical prose. The paper itself offers the student a laudable lesson in what can sometimes be done with a minimum of equipment and a maximum of imagination.

But there is little room in this sparse rendition to portray the full historical context of every experiment. Younger readers can scarcely imagine the difficulties overcome by Marcello Conversi, Ettore Pancini and Oreste Piccioni to demonstrate that the muon could not be Yukawa's strongly interacting "mesotron," while World War II raged about them.

From a pedagogical standpoint, it is obviously easier to teach particle physics from the secure anchor of contemporary theory. But an experimental chronicle built on the original papers may help to build perspective, not only for fledgling experimenters but for would-be theorists as well. It can be useful to learn that great discoveries often meant something quite different in their own time than they do today.

It is easy to criticize any anthology for its selections, a temptation that I