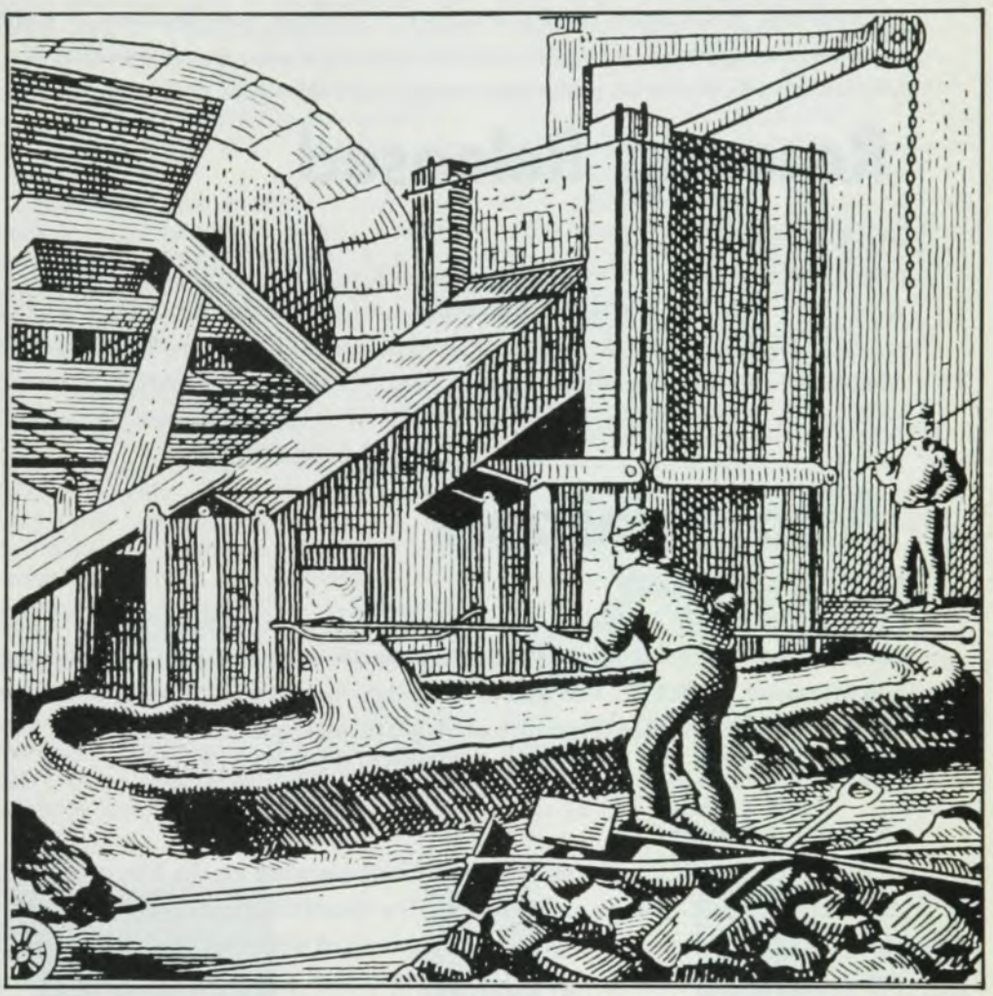
Liquid metals for metallurgists and experimental physicists

Introduction to the Theory of Liquid Metals

T. E. Faber
587 pp. Cambridge U.P., New York, 1972. $37.50

Reviewed by Robert S. Allgaier



This process of forming copper pigs took place in nineteenth-century Lancashire.

The 1972 edition of *Scientific and Technical Books in Print* (R. R. Bowker, Ann Arbor) contains only nine items under the subject heading, "Liquid Metals." Four of the books listed deal with single aspects of the topic (corrosion, magnetohydrodynamics, thermodynamics and pressure effects). Included in the five books that cover the subject more generally are a conference proceedings and a compendium of short articles by different authors. One of the remaining three is A. I. Gubanov's *Quantum Electronic Theory of Amorphous Conductors* (Consultants Bureau, New York, 1965). It contains chapters on the Ziman and Edwards treatments of liquid metals, but the core of the book is Gubanov's own deformed-lattice calculation, which is developed, for the most part, from a semiconductor-like point of view. The second book is N. H. March's *Liquid Metals* (Pergamon, Oxford, 1968), a slim volume that provides only a bird's-eye view of the subject. The remaining item in the liquid-metals listing is T. E. Faber's book, and it is therefore the only comprehensive and detailed book available on the topic written by a single author. Thus the potential for this book to have a major impact on the field of liquid metals is clearly present. The likelihood of this occurring is enhanced because the author has been at Cambridge University for more than twenty years (a very good place to be if one is writing a book on an important aspect of the disordered state of matter), and has contributed significantly to the field since he entered it in the early 1960's via his collaborative efforts with J. M. Ziman.

Faber states in the preface to his book that he was determined before writing to understand thoroughly all the important theoretical arguments (including the more difficult and obscure ones, which are often glossed over). He also reveals that the book was written for the experimental physicist and metallurgist and that, therefore, he would go back to first principles frequently, explain the nature of specialized phenomena, and try to illuminate the physics of the subject more clearly by providing sufficient mathematical detail of a nonsophisticated nature (no Green's functions or other many-body techniques are included).

These are challenging goals for so complex a subject, and perhaps it explains why he worked on the task for more than ten years. In any event, the result is very impressive. I don't recall any other book in which such a great mass of material has been as well organized and as carefully and thoughtfully presented and commented upon. The book contains nearly 600 pages, including 769 references and a very useful summary of the symbols used. It should be pointed out that despite the long preparation time, about half of the references date from 1967 or later (some of the earlier references, Faber comments, are best forgotten).

The easy way to have "organized" a book about this complicated subject would have been to string out a large number of relatively short chapters on its myriad aspects. Instead, Faber has done a remarkably successful job of arranging 124 sections into just six long but highly coherent chapters. Each chapter reads as a more or less continuous narrative, and each begins with a very carefully written prologue that

outlines the route to be taken and the major conclusions to be reached. From start to finish there is a remarkably well maintained sense of momentum that makes the book quite stimulating—even exciting to read. To convey this sense of evolution and development to the reader, I will adopt the not-usually-recommended procedure of describing the contents of the book in the order in which they appear.

Faber begins with a discussion of potentials and pseudopotentials and summarizes almost immediately the evidence that justifies the use, throughout the book, of second-order perturbation theory based on the plane waves of the free-electron model. A basic review of exchange, correlation and screening in the free-electron model leads into treatments of electron scattering by a single point charge that use partial waves and the Born approximation, and then into the use of screened pseudopotentials. This is generalized to an assembly of point charges by the incorporation of the structure factor; then the effective mass, energy gaps, pseudogaps, and compressibilities, as influenced by the ion–ion interaction, are examined.

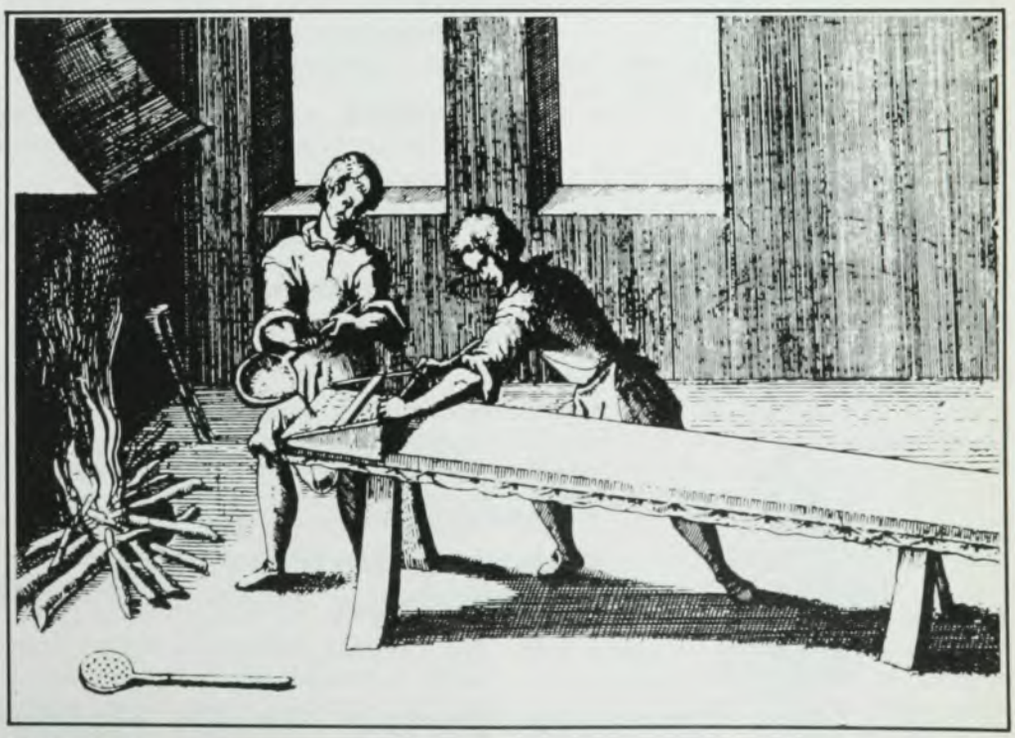
Next comes a discussion of that subtle and fascinating basic property of a noncrystalline medium, its structure. The entropy, specific heat and surface entropy are discussed for a static model, while dynamic models are introduced in order to analyze phase changes, the equation of state and Lindemann's rule. Thinking in terms of models is then replaced by the language of distribution functions (pair distribution, interference function, pair potential, Debye–Waller factor). Faber carefully examines experimental methods for measurement of the interference function, reviews experimental data, and evaluates the attempts to solve the central problem of liquid state theory—the relation between pair distribution and pair potential.

The macroscopic characteristics associated with molecular motion in liquids—diffusion, viscosity, and the friction coefficient—are dealt with in chapter 3. The importance of the autocorrelation function of molecular motion emerges, as do the distinctions between coherent and incoherent, elastic and inelastic scattering. A discussion of time-dependent pair-distribution functions and phonon scattering and lifetime makes it appropriate to insert a section on the relaxation times for conduction electrons, an essential characteristic that will be needed in the later chapters on transport.

We then return to a consideration of the electrons in liquid metals and examine the nature and distribution of electronic states. After surveying the published literature on one- and three-dimensional disordered systems, Faber considers "hot" and "dislocated" solids in one dimension, paying particular attention to the conditions for the appearance of energy gaps and the localization of the electronic states, and examining in detail the capabilities and limitations of the perturbation-theory approach to one-dimensional disordered systems. The perturbation approach is then extended to three dimensions, and a number of more sophisticated calculations are considered in the course of examining the conditions that will lead to localization and band gaps in three dimensions. Some second thoughts on screening, and sections on positron annihilation, Compton scattering, magnetic susceptibility, and the Knight shift complete this chapter.

The final two chapters deal with transport processes in liquid metallic elements and alloys, and all that has preceded them may be regarded as a very detailed preparation for this grand finale. Chapter 5 begins with a resumé of the elegant, nearly-free-electron (NFE) theory, due mostly to Ziman, and details the very satisfying semiquantitative agreement it provides with a variety of experimental transport data (electrical and thermal conductivities, thermoelectric power, and compressibility). Nevertheless, a very careful examination of the approximations, assumptions and limitations of the theory is carried out. Faber then examines some experimental results at high temperatures and low densities, thereby launching a discussion of the alternative approaches that are needed when it is no longer possible to regard the liquid as metallic. One alternative is to calculate the conductivity with Greenwood's formula, which uses the more accurate eigenfunctions already discussed in chapter 4, rather than the plane waves of the NFE theory. Some important factors that may influence the results are then taken up: short mean free paths (blurred Fermi surfaces), an effective mass different from the free electron value, and the distinction between the electronic relaxation time and lifetime. The subject then shifts to optical properties, beginning with a derivation of the Drude equations that includes a rather extended investigation of several approximations involved in the derivation. This requires an examination (which Faber admits may be rather wearisome to the nonspecialist) of the anomalous skin effect, dynamic screening and other many-body effects, interband absorption and ion core polarizability. Sections on photoemission, work function, and plasma oscillations follow and the chapter concludes with a discussion of the Hall effect and magnetoresistance. The only type of experimental Hall data we understand well is that corresponding to the free-electron value $1/ne$, and it has not yet been established that a true magnetoresistance effect has ever been measured in a liquid metal.

Over 200 different alloys of liquid metals have already been studied experimentally, notes Faber in his final chapter. To try to keep things in focus, he reiterates the set of basic assumptions and procedures, which were applied to the elemental metallic liquids in the earlier chapters and must



Cast sheets of lead or tin were formed in the early seventeenth century by pouring the molten metal on an inclined sand-bed. This engraving dates from 1624.

The first volume is completed.

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now be extended to alloys. The extension is decidedly nontrivial. On one hand he shows how an idealized picture may be developed from Ziman's NFE theory of how an alloy *ought* to behave. On middle ground are some problems that have been "resolved" only by recourse to rather crude models, such as those that attack the problems of the equilibrium volume, and the energy and entropy of mixing. And at the other extreme, which is approached when there is a large difference in the valence or the electronegativity of the alloy constituents, almost everything may go wrong: Linear screening and perturbation theory may break down, and some electronic states may become localized; the NFE model may have to be completely abandoned in favor of a tight-binding model that incorporates the notion of chemical bonds, or even of compound formation, in the melt.

The second part of the chapter considers in a systematic fashion a variety of experimental data: diffraction experiments; thermodynamic and surface properties; diffusion, viscosity and electromigration; magnetic susceptibility, nuclear magnetic resonance, and Hall effect; and resistivity, thermoelectric and optical properties. This part of chapter 6 is especially admirable and fascinating: first, the degree to which each type of result may be explained by the NFE rigid-sphere model or some extension thereof is considered, and then the remaining anomalies, wherever they appear, are discussed in relation to "compound formation."

It is as though Faber, having steered an admirable course through the well charted NFE and a few other theoretical seas (and having added significantly to the reliability and clarity of those charts), now finds himself irresistibly drawn toward the murkier regions of less randomly arranged liquids. He does discuss as examples the Tl–Te and Mg–Bi liquid systems, and observes that the anomalies are so severe in these cases that they must be regarded as liquid semiconductors. And with the comment that he is now poaching on territory already covered by N. F. Mott and E. A. Davis [*Electronic Processes in Non-crystalline Materials*, (Clarendon, Oxford, 1971)], Faber ends his journey.

Inevitably, there were a few shortcomings in this first edition: some typographical errors, unclear sentences, unreferenced citations (e.g., Percus–Yevick dense-fluid theory) and obscure references (the ones by B. W. Mott).

But as it stands, this book deserves to be in many libraries. I believe it will have a major impact on the field of liquid metals, leading to substantial clarification and stimulating further interest in the subject. Faber has worked long and hard on the book and deserves much praise for the high-quality product that has emerged. This volume should remain a valuable and thought-provoking contribution to the field of liquid metals for at least as long as, and probably much longer than, it took the author to write it.

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Fiber Optics

M. P. Lisitsa, L. I. Berezhinskii, M. Y. Valakh
272 pp. Israel Program for Scientific Translation, New York, 1972

This book is intended to cover the state-of-the-art in the field of fiber optics as of the year 1968 and is an English translation of the original Russian publication entitled *Volokonnaya Optika*. In the preface the authors state that "... Despite these growing uses of fiber optics, no book has been published so far in the world literature ..." and they go on to state "Being the first monograph in the world literature on the subject ..." The authors seem to have missed a 1967 book with the same title that I wrote, which has subsequently been translated into Russian.

Approximately 20% of the book is devoted to general and elementary theory of optics: laws of photometry, image formation, basic electromagnetic theory, reflection and refraction at dielectric interfaces and optical thin-film theory.

The second chapter deals with the geometrical optical theory of ray propagation in large diameter (compared to the wavelength of light) cylindrical and conical fibers. The light-transmission efficiency and angular-flux distribution is calculated using meridional and skew rays.

The next chapter describes the theory and experiments on mode propagation through optical waveguides. Solutions of the dielectric waveguide equations are developed for near cut-off and far from cut-off conditions, and the field configuration in the waveguide is calculated for various lower-order modes. The discussion of mode launching, mode identification, waveguide mode coupling and evanescent wave propogation is sketchy.

The next two chapters deal with factors affecting image quality through fiber optics (including methods for its assessment) and simple techniques of optical fiber fabrication and quality control.

Chapters 6–8 are devoted to an extensive discussion of various applications of fiber optics in optical, electron-optical and other systems. Particular emphasis is given to fiber-optics configurations for use as field flatteners, photorefractometer, couplers for multistage image intensifiers and medical (endoscopic) applications with or without the use of lasers. The discussion of some designs for scanning and control systems incorporating fiber optics is particularly lucid and imaginative. Other applications in high-speed photography, scintillation chambers and contactless potentiometers are included.

This book is one of a number of translations from Russian literature undertaken by Israel Programs for Scientific Translations. The quality of translation, typesetting, illustrations and binding is excellent. Unfortunately, however, in a fast-moving field such as fiber optics, the material can become out of date in a few years' time, and this book is the first to fall victim of obsolescence. In the year 1968 this book would have served its purpose, but the field has advanced and expanded a great deal during this period. However, this book is of considerable value as an introductory treatise on the subject.

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Thermodynamics

Frank C. Andrews
288 pp. Wiley, New York, 1971. $9.95

This book by Frank C. Andrews is intended to serve as a first treatment of thermodynamics following courses in introductory physics, chemistry and calculus. It is sufficiently brief that it can be covered in one semester, or even in one quarter.

Part I is a 100-page survey of the principles of thermodynamics, covering briefly such topics as systems, work, heat, the First and Second Laws of Thermodynamics, thermal equilibrium, entropy, thermodynamic potentials and temperature. This part contains fewer than 50 problems, in line with the author's expressed intent of deviating from the usual pedagogy of thermodynamics. Instead of using a number of problems to illustrate each basic principle or definition as it is presented, the plan of Andrews is to streamline the study of thermodynam-