40 years of the exchange integral

EXCHANGE INTERACTIONS AMONG ITINERANT ELECTRONS. By Conyers Herring. (Vol. 4 of Magnetism, A Treatise on Modern Theory and Materials. George T. Rado, Harry Suhl eds.) 407 pp. Academic Press, New York, 1966. $14.50

by J. H. Van Vleck

This book differs from other volumes of the Rado-Suhl series in that it is written entirely by one author. It is not to be confused with the chapter on "Direct Exchange Between Well Separated Atoms," which Herring also wrote as part of volume 2b, now in process of publication. When referring to the various chapters of the book now under review, the author always speaks of them as "sections," and the volume in toto as a "chapter," perhaps an indication of what he originally planned, but certainly a gross underappraisal of his magnum opus of over 400 pages. At Harvard, where we were fortunate enough to have a copy or two in preprint form, the solid-state physicists usually called it *the* telephone book, because of its origin at Murray Hill, its bulky size in mimeographed form, accuracy, attention to detail and usefulness. However, it has one quality that a telephone book lacks, namely the quality of being critical in the best sense of the word—the type of review of the literature for which Goudsmit made such an eloquent plea in PHYSICS TODAY (September 1966). There are references to almost 500 different journal articles or books, and the author has spent an immense amount of effort in assessing their correctness and relevance—in contrast to most volumes of encyclopedic coverage that tend to follow the rather noncommital "Jones says this, Smith says that ... etc." style. About the only point on which the author avoids taking a stand is whether Hund's-rule coupling, that is, the intraätomic exchange integral, must *always* be invoked in order to make transition metals ferromagnetic.

When Werner Heisenberg first published his paper on ferromagnetism in 1927, physicists thought for a while that all the mystery had been taken out of the subject. It was, of course, true that the exchange effects of quantum mechanics provided the necessary coupling between elementary magnets so sadly lacking in classical theory. However, as time progressed, it became increasingly clear that the mechanism was a much more involved one than the direct exchange originally contemplated, just because the interatomic exchange integral is not large enough, and perhaps not even of the right sign. In fact "forty years of the exchange integral" might have been an appropriate subtitle for the book. The two metals that come first to mind when one mentions the word "ferromagnetism," namely iron and nickel (or related alloys), are the materials whose magnetic mechanism is the least perfectly understood—in marked contrast to the nonconducting ferrites or the rare earths. Many physicists have proposed different models for explaining the essential features, and Herring himself in one of his talks has likened them to a party where each person has a different favorite recipe for a cocktail mix, but I prefer a comparison to a group of evangelists each with his own road to salvation because of the zeal and conviction displayed by the various proponents.

During the past forty years it has become increasingly clear that metals of the iron group present the baffling intermediate case where it is at best a very mediocre approximation to consider the 3d electrons to be completely bound, as in the original localized Heisenberg model, or to be completely free as in the Stoner version of the molecular field theory. This intermediate, no man's land of magnetism, where one must encounter itineracy with correlation, is one that most textbook writers on magnetism shun by postulating unrealistic models that facilitate calculation. Herring is to be congratulated on his courage in trying to face things as they really are—he does not promote unrealistic models—in fact one "section" is candidly called "properties of special correlated models unlike real metals." The proper handling of correlation is always the main nightmare of many-body theory, and this is particularly true for magnetism, where the balance between magnetic order and disorder can be tipped one way or the other depending on the amount of correlation.

The first quarter of the volume treats the magnetic behavior of free electrons devoid of all forces except their Coulomb repulsions—in other words the Fermi gas. Proper analysis of this subject is far more difficult than it appeared to be at the time of Felix Bloch's first paper on this subject in 1929. The central half of the volume is concerned with the central problem of the origin of ferromagnetism in the transition metals. As we have already intimated, this is a slippery and elusive subject, so complex that there are elements of truth and falsehood in any simple and readily understandable model. The actual situation seems to be that in nickel, for instance, there is in the main an exchange between d^{10}, $d^{9}s$, and $d^{8}s^{2}$ sites, with s electrons rushing in when there are deficits in the d shell so as to keep the unit cell neutral. Herring

Reviewed in this Issue

rightfully demonstrates that my 1953 paper overestimated the promotional energy from $3d^{10}$ to $3d^94s$ or $3d^84s^2$ in the metallic state and that ambulatory or fluctuation effects are correspondingly increased. Some may claim that this is a victory for the band model, but the situation is vastly different from that of d electrons roving in an uncorrelated 4s distribution. Possibly a little more might have been said about states of minimum polarity as a starting point for a perturbation calculation—this happens to be one of my favorite modes of approach, but unfortunately it gives at best only qualitative information. The final quarter of the book is devoted about equally to "states of metals with oscillatory polarization" and to "Bloch wall stiffness and ferromagnons." Here, and also in the early part of the book, considerable attention is given to spin-density waves, whose existence he concedes in chromium but which he believes in general occur less frequently than claimed by Overhauser.

Even in a book of 400 pages, Herring has found it impossible, because of his thoroughness, to treat all varieties of ferromagnetism—for example, the nonconducting ferrites, or the rare earths. In other words, the primary emphasis of the book is not on superexchange or indirect exchange. Localized moments generated by potentially ferromagnetic impurities are also not discussed and comparatively little attention is given to s-d interactions. Otherwise a volume of nearly double the size would have been needed. Purely computational techniques for specific idealized models, for example, series expansions for the Heisenberg model, are not examined since this subject is in the province of volume 2. Instead the primary question that Herring is striving to answer is: "What's going on in metals like iron or nickel?"

Herring's volume is a scholar's one and not a textbook. It is not easy reading. The book will be of particular value to two classes of readers. One of these is the experimentalist or nonspecialist who wants a rapid expert assessment of the status of the literature without going to the effort of thorough study, and for his benefit Herring starts each chapter with a summary appraisal of its contents. The other is the specialist in the theory of magnetic metals, who probably already understands such techniques as Green's functions, Feynman diagrams, etc., with which some familiarity is assumed. For brevity steps in the proof are often omitted, and painstaking readers may want to refer back to the original papers for details.

It is to be stressed in conclusion that Herring's book contains not only careful evaluation of the work of others, but also many original contributions by the author that could have been published as research articles in journals rather than incorporated for the first time in the present volume. If all writers had Herring's reservation against rushing into print, the problem of the continual burgeoning of scientific libraries would not be so devastating.

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Bringing man back into science

SCIENCE AS A CULTURAL FORCE. Harry Woolf, ed. 110 pp. Johns Hopkins Press, Baltimore, 1964. $3.95

by G. C. Amstutz

The growing positive and negative roles of science in society have led Harry Woolf, a well known historian of science at Johns Hopkins, to organize a sort of symposium on "science as a cultural force." What we experience today are the effects of a composite force whose three separate components are the public or political one, the philosophical or psychological one, and a third one related to the inner growth and development of science. Accordingly, the book may be subdivided into three reasonably distinct parts.

The first two essays are authoritative discussions of the first component. The respective authors and titles are: J. R. Killian Jr, "Toward a Research-Reliant Society: Some Observations on Government and Science" (25 pages), and Jerome B. Wiesner, "Technology and Society" (20 pages). One aspect of the second component is aptly covered by Michael Polanyi in his outline "Science and Man in the Universe" (22 pages), and Gerald Holton touches upon the most critical guides of the third component in his essay on "Presupposition in the Construction of Theories" (31 pages). In his introduction, Woolf offers a clear glance at the spectrum of problems discussed by the authors and points to the above scope of the symposium lecturers. Short biographical notes precede the text.

The lectures of Killian and Wiesner outline in an impressive way the tremendous involvement (especially by national governments) between public life and science. The factual contents of these two lectures have been published in many other places and need no repetition. Three specific and outstanding items, however, are of interest to the scientist.

In Killian's lecture there is first the warm and profound understanding of the human nature of the scientist and of scientific discovery. He shows that we are on the way to become a "research-reliant" society. Because of the great speed with which we are ad-

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