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Tôru Moriya

Spin Fluctuations in Itinerant Electron Magnetism

With 98 Figures

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Preface

Ferromagnetism of metallic systems, especially those including transition metals, has been a controversial subject of modern science for a long time. This controversy stems from the apparent dual character of the *d*-electrons responsible for magnetism in transition metals, i.e., they are itinerant electrons described by band theory in their ground state, while at finite temperatures they show various properties that have long been attributed to a system consisting of local magnetic moments. The most familiar example of these properties is the Curie-Weiss law of magnetic susceptibility obeyed by almost all ferromagnets above their Curie temperatures.

At first the problem seemed to be centered around whether the *d*-electrons themselves are localized or itinerant. This question was settled in the 1950s and early 1960s by various experimental investigations, in particular by observations of d-electron Fermi surfaces in ferromagnetic transition metals. These observations are generally consistent with the results of band calculations.

Theoretical investigations since then have concentrated on explaining this dual character of *d*-electron systems, taking account of the effects of electron-electron correlations in the itinerant electron model. The problem in physical terms is to study the spin density fluctuations, which are neglected in the mean-field or one-electron theory, and their influence on the physical properties.

There have been two main streams in the research in this direction. One has been to study the local moments in metals or the possibility for the itinerant electrons to exhibit spin density fluctuations that are described at least approximately as a set of local magnetic moments. This approach attained remarkable success in the 1960s from a qualitative point of view and has been extended further since then.

The other stream of research has been to improve the mean-field theory by taking into account the spatially extended spin density fluctuations in contrast with the local moment picture. This line of approach, represented by the random-phase approximation, was, however, not successful until the early 1970s when a self-consistent theory of coupled modes of extended spin fluctuations was advanced and the difficulties of the random-phase approximation were removed. This improved theory was remarkably successful when applied to weakly ferromagnetic metals where the long-wavelength components of spin fluctuations are the predominant thermal excitations.

For example, this theory postulates a new mechanism, without local magnetic moment, for the Curie-Weiss susceptibility. The theoretical and experimental investigations in this decade have well established the picture and theory of extended spin fluctuations in weakly ferro- and antiferromagnetic metals; there is now a new class of magnets at the opposite extreme to the quite familiar local moment systems.

This success has given a breakthrough to the theory of itinerant electron magnetism, since it is quite natural to expect that the properties of many metallic magnets are distributed between these mutually opposite extremes. Thus the latest investigations are focused on the intermediate regime between the extremes, to which most metallic magnets including Fe, Co, and Ni are considered to belong. The concept of spin fluctuations is now generalized to include both the local and extended moment limits and a theory of interpolation between them is expected to lead to a unified description of magnetism.

This monograph is intended to review the above-mentioned developments in the field of itinerant electron magnetism. The important steps in the theoretical developments in this area are treated, emphasizing recent theories including the latest attempts at a unified theory. We try to clarify as far as possible to what extent the subject is understood at present and what still has to be examined and clarified in future.

Since the emphasis is on the finite-temperature properties of magnets, important topics relating to the underlying electronic structures were largely omitted: the band-structure calculation, many-body effects in the ground state, and the experimental and theoretical investigations of photoemission which have marked significant progress in recent years. This specialization of topics seems reasonable in view of the size of the volume and of the author's knowledge. Also it is justifiable to discuss important concepts, giving a general picture of magnetism, without going into too fine details of the underlying electronic structure, as has actually been seen in the past theoretical developments.

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Tokyo, January 1985 *T. Moriya*

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