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Volume 7 (1986)

Edited by

I. M. KHALATNIKOV

Soviet Scientific Reviews, Section A

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Volume 7

SOVIET SCIENTIFIC REVIEWS

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PREFACE TO THE SERIES

Soviet Scientific Reviews presently publishes annual volumes in Physics, Chemistry, Physicochemical Biology, Mathematical Physics, and Astrophysics and Space Physics. Additional volumes in preparation include Physiology and General Biology, Physicochemical Medicine, Atmosphere, Ocean and Climate, and Earth Sciences.

The series is intended to make accounts of recent scientific advances in the USSR more readily and rapidly accessible to the scientist who does not read Russian. Important developments in Soviet science may not receive as much attention as they deserve from the international community because of difficulties with language and distribution. This series, by making available accounts of Russian research in English, will ensure a wider circulation. The articles in these volumes are reviews of recent developments and are written by Soviet experts, most of them in Russian, and translated from the Russian by the publisher.

We are indebted to the volume editors and individual authors for their cooperation in writing and assembling these contributions and getting them to press, usually under considerable time pressure.

The continued success of this series is of course dependent on its continuing to meet the needs and requirements of readers. The distinguished editorial committee of both Soviet and international scholars has been successful in commissioning the best Soviet contributors for these series and will continue to seek out and publish the best of Soviet science.

In making these volumes available, the publisher hopes to contribute to the further development of international cooperation between scholars and to a greater understanding among scientists.

THE EDITORS

FOREWORD

Volume 7 is comprised of articles on localization in disordered systems, the theory of liquid crystals, the problems of the interaction of laser irradiation with matter, etc.

The survey by M. V. Sadovskiĭ "Theory of Electron Localization in Disordered Systems" covers a number of problems of the modern theory of electron localization. The author formulates the general principles, making it possible to find the criterion of localization and the associated instability effects. He also studies the influence of localization on physical properties of disordered systems.

In their article "New Aspects of the Dynamics of Liquid Crystals" V G. Kamenskiĭ, E. I. Kats, and V. V. Lebedev discuss the influence of fluctuation effects on the dynamics of liquid crystals. It is shown that the nonlinear effects of the interaction of fluctuations in liquid crystals also plays an essential role in the absorption of sound and affects the hydrodynamics of such systems.

In the paper by V. V. Ustinov "Conduction Electron Surface Spin-Flip Scattering and Resonance Phenomena in Metals" the author has developed a consistent approach to the study of the role of surfacial scattering with spin flip in the kinetics of spin magnetization of conduction electrons in metals.

As a whole, Volume 7 contains theoretical reviews that are well illustrated by available experimental data; however, in subsequent volumes we are planning to increase the number of applied papers.

I. M. KHALATNIKOV

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THEORY OF ELECTRON LOCALIZATION IN DISORDERED SYSTEMS

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Abstract

In this review article many aspects of the modern theory of electron localization in disordered systems are discussed and the general criterion for localization is formulated. This criterion is given as a requirement that a two-particle Green's function have a pole in terms of the frequency with a factorizable residue (in a momentum representation). A search for such a solution can be based on the use of a homogeneous Bethe-Salpeter equation, from which the point where the metallic phase is unstable (the mobility edge) can be determined but which does not describe the region of localized states. The self-consistent theory of localization of Vollhardt and Wölfle is extended to the space with a dimension $d > 2$ and the behavior of the principal physical quantities near the mobility edge is calculated. The mobility edge is situated in the "strong-coupling" region (which diverges in the limit $d \to 2$). This region is the exact analog of the "Ginzburg critical region" in the theory of critical phenomena, in which the perturbation theory breaks down. The analytic properties of the effective field theory, for an electron in a random field, are studied in the complex plane of the coupling constant. The role of finite-action nonlinear solutions (instantons) of the classical field equations in the formation of the "tail" in the density of states is demonstrated. A method of calculating the coefficient of the exponential function of the density of states is proposed. This method is based on the use of the dispersion relation over the coupling constant and on the correspondence with the standard theory of critical phenomena. It is demonstrated that a singular (pole) contribution, in terms of the frequency, to a two-particle Green's function with a factorizable residue, which corresponds to the proposed general criterion for localization, can be determined explicitly within the framework of the instanton approach. A unified approach for the search of instabilities in the system, giving rise to the localization, is formulated. This approach is based on the use of the effective-action formalism for composite fields. The Hartree-Fock corrections, resulting from the interaction between the electrons, to the density of states and thermodynamic quantities near the mobility edge are examined. The localization corrections, which are linked directly to the probability for return of an electron, are found. It is shown that these corrections correspond to the formation of a band of singly occupied states below the Fermi level. A cusp in the state density at the Fermi level, which occurs in a "dirty" metal, is shown, within the framework of the self-consistent theory of localization, to smooth out in the insulator region. The correction to the density of states at the Fermi

level, however, diverges logarithmically in the entire region of localized states. The localization contribution to the polarization operator corresponding to a nonergodic behavior of the system, which accounts for the difference between the isothermal static response and the adiabatic static response, is analyzed. The isothermal static dielectric constant conserves the "metallic" behavior corresponding to the finite screening range even in the insulator phase: The "Fermi glass" screens the external static electric field.

Contents

1. Introduction

The concept of electron localization in disordered systems is central to the understanding of the modern theory of disordered systems. It is the foundation of the basic understanding of the energy spectrum and of the kinetic and other electronic properties of these systems [1, 2]. Formulated for the first time in a fundamental paper by Anderson [3], the concept of electron localization was developed qualitatively by Mott, who used it to formulate the foundations of electronic theory of disordered systems [1, 2].

The localization phenomenon has recently been discussed in many review articles and monographs [4–10] and its principal propositions are now well known. In spite of its importance, the problem of localization is, nonetheless, far from being solved satisfactorily. At issue here is principally our conceptual understanding of the behavior of electronic states near the so-called mobility edge and of the related question of the physical properties of the system, in which the Fermi level of electrons is situated near the mobility edge. The effect of electron–electron interaction, i.e., the relationship between the Mott and Anderson mechanisms for a metal-insulator transition in disordered systems is yet to be studied extensively. The difficulty in understanding this relationship stems from the extreme mathematical complexity of this problem and from the fact that there is no direct experimental evidence for electron localization [1, 2]. In particular, it is very difficult to distinguish between disorder and electron–electron interaction in a real metal-insulator transition.

Let us summarize the principal propositions of the localization theory which is customarily based on the Anderson model [3]. In this model the electron which propagates in the regular lattice in a d-dimensional space is analyzed. Each lattice site has a random level E_j (j is the number of the lattice site in the lattice). It is assumed that there is a certain probability amplitude for the transition V_{ij} from the jth lattice site to the ith lattice site. This amplitude is usually assumed [3] to be nonvanishing and equal to a certain constant V for the transitions between the nearest neighbors. The energy levels E_j are assumed to be distributed independently at different sites and the energy distribution at a given site is usually assumed to be uniform

over a certain energy interval of width W. The qualitative results do not seem to depend too strongly on these assumptions. Another useful model for analyzing the localization is the model of free electrons in a field of point scatterers randomly distributed in a space with density ρ. Each of these point scatterers has the same scattering amplitude which we will denote by V [11].

If there is no disorder in the system ($W = 0$ in the Anderson model or $\rho = 0$ in the free-electron model), then the problem of the electronic spectrum can be solved in a straightforward manner. In the Anderson model the electronic states form a band of width $2ZV$, where Z is the number of nearest neighbors. An infinitely wide band of free electrons is formed in a similar manner. The introduction of disorder accounts for some important changes, giving rise to a strong dependence on the dimensionality of the space d. At $d = 1$ a disorder, however small, completely changes the nature of the electronic states, localizing all of them. In other words, the wave functions of these states begin to fall off exponentially in the coordinate space, while the static electrical conductivity of the system goes down to zero at $T = 0$ [12–15]. The two-dimensional ($d = 2$) systems are the limiting case ("lower critical dimensionality"). In these systems the electronic states presumably also become completely localized as a result of appearance of the slightest disorder. For $d > 2$ all the electronic states in the band become completely localized if the ratio W/V in the Anderson model is sufficiently large—larger than a certain critical ratio $(W/V)_c$, i.e., if the disorder is appreciable. If $W/V < (W/V)_c$, the electronic states become localized at the band edges but remain delocalized at the band center (Fig. 1a). This situation gives rise to critical values of the energy $\pm E_c$, which separates the regions of the localized states from those of the extended states, customarily called mobility edges. In a model of nearly free electrons a qualitative picture of the electronic states for $d > 2$ is also well known (Fig. 1b). If the Fermi level E_F is in the region of fairly high energies, the electronic states near it are just the plane waves that are slightly distorted by scattering. The importance of this scattering increases with decreasing Fermi energy toward the edge of the original band. A density of states "tail," which stems from the electron localization due to random-potential fluctuations of the scatterers [8], appears at