

Fifty years of Anderson localization

Ad Lagendijk, Bart van Tiggelen, and Diederik S. Wiersma

What began as a prediction about electron diffusion has spawned a rich variety of theories and experiments on the nature of the metal-insulator transition and the behavior of waves—from electromagnetic to seismic—in complex materials.

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Very few believed [localization] at the time, and even fewer saw its importance; among those who failed to fully understand it at first was certainly its author. It has yet to receive adequate mathematical treatment, and one has to resort to the indulgence of numerical simulations to settle even the simplest questions about it.

— Philip W. Anderson, Nobel lecture,
8 December 1977

The study of the conductance of electrons belongs to the very heart of condensed-matter physics. The classical Drude theory of electronic conductivity was built on the idea of free electrons scattered by positive ions in metal lattice sites. A key concept in that description was the mean free path, the average length an electron travels before it collides with an ion. According to classical theory, the electronic conductivity should be directly proportional to the mean free path, which experiment had established as large in metals—around 100 nm, some two orders of magnitude larger than the lattice constant.

Physicists had to wait for the discovery of quantum mechanics to understand why electrons apparently do not scatter from ions that occupy regular lattice sites: The wave character of an electron causes the electron to diffract from an ideal crystal. Resistance appears only when electrons scatter from imperfections in the crystal. With that quantum mechanical revision, the Drude model can still be used, but in the new picture an electron is envisaged as zigzagging between impurities. The more the impurities, the smaller the mean free path and the lower the conductivity.

Will any increase in the degree of lattice disorder lead to just a decrease in the mean free path and thus to a lower conductivity, or might something unusual happen along the way? That question was raised a half century ago by Philip Anderson, pictured in figure 1. Beyond a critical amount of impurity scattering, he discovered, the diffusive, zigzag motion of the electron is not just reduced, it can come to a complete halt.¹ The electron becomes trapped and the conductivity vanishes.

To appreciate how that's possible, at least intuitively, one can start with elementary wave mechanics. Suppose an electron propagates in a disordered medium from point A to

point B. One has to sum the amplitudes of all possible paths and square the complex-valued end result to obtain the total probability that the electron arrives at B. That probability consists of a sum of squares—the classical, incoherent contribution—plus many cross-product, interference terms. One could argue that in disordered media, the phases of the interference terms are so random that their sum vanishes on average. That assumption would bring us back to the diffusion model of metallic conductance.

But that neglect of interferences is not always justified. Imagine a wave that travels from point A along a random path to point B and then goes back to A. In figure 2, two possible paths are depicted: a randomly chosen path and the same path traversed in the opposite sense. The two paths interfere constructively and should be treated coherently—that is, summed before being squared. The probability of the electron's returning to A is then twice as large as it would have been if probabilities were added by first squaring and then summing. The enhanced backscattering, known as weak localization, lowers the conductance between A and B by increasing the electron's likelihood of returning to its starting point. But can it eventually localize the electron around A?

Metal-insulator transition

Anderson had been confronted with experiments performed by George Fisher's group at Bell Labs—experiments that showed anomalously long relaxation times of electron spins in doped semiconductors. The concept of localized electrons could explain the observation but would break with the conventional diffusion picture. To explain the effect, Anderson used a tight-binding model of an electron in a disordered lattice; at each lattice site an electron feels a random potential and is allowed to tunnel between nearest neighbor sites with a constant rate (see figure 3).

Electrons are waves, of course. But rather than thinking of conduction electrons as extended plane waves with short lifetimes and small mean free paths, one should instead view them as standing waves that are confined in space and thus have long lifetimes. Moreover, not just one or two electrons are localized by a random well in the landscape of the random potential energy; nearly all conduction electrons be-

50 Years Of Anderson Localization 50 Years Of Anderson Localization

Franz Wegner



50 Years Of Anderson Localization 50 Years Of Anderson Localization:

50 Years of Anderson Localization Elihu Abrahams, 2010 This unique volume celebrates the five decades of the impact of Anderson localization on modern physics In addition to the historical perspective on its origin it provides a comprehensive description of the experimental and theoretical aspects of Anderson localization

50 Years Of Anderson Localization Elihu Abrahams, 2010-06-25 In his groundbreaking paper Absence of diffusion in certain random lattices 1958 Philip W Anderson originated described and developed the physical principles underlying the phenomenon of the localization of quantum objects due to disorder Anderson s 1977 Nobel Prize citation featured that paper which was fundamental for many subsequent developments in condensed matter physics and technical applications After more than a half century the subject continues to be of fundamental importance In particular in the last 25 years the phenomenon of localization has proved to be crucial for the understanding of the quantum Hall effect mesoscopic fluctuations in small conductors some aspects of quantum chaotic behavior and the localization and collective modes of electromagnetic and matter waves This unique and invaluable volume celebrates the five decades of the impact of Anderson localization on modern physics In addition to the historical perspective on its origin the volume provides a comprehensive description of the experimental and theoretical aspects of Anderson localization together with its application in various areas which include disordered metals and the metal insulator transition mesoscopic physics classical systems and light strongly correlated systems and mathematical models The volume is edited by E Abrahams who has been a contributor in the field of localization A distinguished group of experts each of whom has left his mark on the developments of this fascinating theory contribute their personal insights in this volume They are A Amir Weizmann Institute of Science P W Anderson Princeton University G Bergmann University of Southern California M B ttiker University of Geneva K Byczuk University of Warsaw University of Augsburg J Cardy University of Oxford S Chakravarty University of California Los Angeles V Dobrosavljevi Florida State University R C Dynes University of California San Diego K B Efetov Ruhr University Bochum F Evers Karlsruhe Institute of Technology A M Finkel stein Weizmann Institute of Science Texas A M University A Genack Queens College CUNY N Giordano Purdue University I V Gornyi Karlsruhe Institute of Technology W Hofstetter Goethe University Frankfurt Y Imry Weizmann Institute of Science B Kramer Jacobs University Bremen S V Kravchenko Northeastern University A MacKinnon Imperial College London A D Mirlin Karlsruhe Institute of Technology M Moskalets NTU Kharkiv Polytechnic Institute T Ohtsuki Sophia University P M Ostrovsky Karlsruhe Institute of Technology A M M Praisken University of Amsterdam T V Ramakrishnan Indian Institute of Science M P Sarachik City College CUNY K Slevin Osaka University T Spencer Institute for Advanced Study Princeton D J Thouless University of Washington D Vollhardt University of Augsburg J Wang Queens College CUNY F J Wegner Ruprecht Karls University and P W Ifle Karlsruhe Institute of Technology

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50 Years Of The Renormalization Group: Dedicated To The Memory Of Michael E Fisher Amnon Aharony, Ora

Entin-wohlman, David A Huse, Leo Radzihovsky, 2024-07-26 The contributions in the book are devoted to the memory of Michael E Fisher and hence include many personal memories from people whose work was influenced by him Also the book is a collection of articles from leaders in the field of phase transitions and critical phenomena to celebrate 50 years of the renormalization group and the 1972 paper by Wilson and Fisher Many of the articles review in tutorial form the progress in the fields of phase transitions and the renormalization group Conductor Insulator Quantum Phase Transitions Vladimir Dobrosavljevic, Nandini Trivedi, James M. Valles (Jr), 2012-06 When many particles come together how do they organize themselves And what destroys this organization Combining experiments and theory this book describes intriguing quantum phases metals superconductors and insulators and transitions between them It captures the excitement and the controversies on topics at the forefront of research Supermathematics and its Applications in Statistical Physics Franz Wegner, 2016-03-25 This text presents the mathematical concepts of Grassmann variables and the method of supersymmetry to a broad audience of physicists interested in applying these tools to disordered and critical systems as well as related topics in statistical physics Based on many courses and seminars held by the author one of the pioneers in this field the reader is given a systematic and tutorial introduction to the subject matter The algebra and analysis of Grassmann variables is presented in part I The mathematics of these variables is applied to a random matrix model path integrals for fermions dimer models and the Ising model in two dimensions Supermathematics the use of commuting and anticommuting variables on an equal footing is the subject of part II The properties of supervectors and supermatrices which contain both commuting and Grassmann components are treated in great detail including the derivation of integral theorems In part III supersymmetric physical models are considered While supersymmetry was first introduced in elementary particle physics as exact symmetry between bosons and fermions the formal introduction of anticommuting spacetime components can be extended to problems of statistical physics and since it connects states with equal energies has also found its way into quantum mechanics Several models are considered in the applications after which the representation of the random matrix model by the nonlinear sigma model the determination of the density of states and the level correlation are derived Eventually the mobility edge behavior is discussed and a short account of the ten symmetry classes of disorder two dimensional disordered models and superbosonization is given **New Trends in Statistical Physics of Complex Systems** Antonio M. Scarfone, 2019-01-28 This book is a printed edition of the Special Issue New Trends in Statistical Physics of Complex Systems that was published in Entropy **Lessons From Nanoelectronics: A New Perspective On Transport (Second Edition) - Part A: Basic Concepts** Supriyo Datta, 2017-03-20 Everyone is familiar with the amazing performance of a modern smartphone powered by a billion plus nanotransistors each having an active region that is barely a few hundred atoms long The same amazing technology has also led to a deeper understanding of the nature of current flow and heat dissipation on an atomic scale which is of broad relevance to the general problems of non equilibrium statistical mechanics that pervade many different fields This

book is based on a set of two online courses originally offered in 2012 on nanoHUB U and more recently in 2015 on edX In preparing the second edition the author decided to split it into parts A and B titled Basic Concepts and Quantum Transport respectively along the lines of the two courses A list of available video lectures corresponding to different sections of this volume is provided upfront To make these lectures accessible to anyone in any branch of science or engineering the author assume very little background beyond linear algebra and differential equations However the author will be discussing advanced concepts that should be of interest even to specialists who are encouraged to look at his earlier books for additional technical details

Disorder-Free Localization Adam Smith, 2019-07-01 This thesis is a contribution at the intersection of a number of active fields in theoretical and experimental condensed matter particularly those concerned with disordered systems integrable models lattice gauge theories and non equilibrium quantum dynamics It contributes an important new facet to our understanding of relaxation in isolated quantum systems by conclusively demonstrating localization without disorder for the first time answering a long standing question in this field This is achieved by introducing a family of models intimately related to paradigmatic condensed matter models and studying their non equilibrium dynamics through a combination of exact analytical mappings and an array of numerical techniques This thesis also makes contributions relevant to the theory of quantum chaotic behaviour by calculating novel and often intractable entanglement measures and out of time ordered correlators A concrete and feasible proposal is also made for the experimental realization and dynamical study of the family of models based on currently available technologies

Localisation 2011 Stefan Kettemann, 2012 The proceedings of Localisation 2011 a satellite conference of the 26th International Conference on Low Temperature Physics LT26 comprise both invited and contributed papers that discuss the latest progress on localisation phenomena The main topics include quantum transport in disordered systems Anderson localisation effects of interactions on localisation Anderson OCoMott transition mesoscopics the superconductor OCoinsulator transition quantum Hall effects fractional and integer topological insulators graphene dynamical localisation heavy fermions Kondo effect Kondo lattice effects of disorder and many body localisation spin glass Coulomb glass The volume is also dedicated to Professor Bernard Coqblin former CNRS Directeur de Recherche and a Honorary Chairman of the AMS APCTP Conference Localisation 2011 whose contribution to condensed matter theory will always be remembered

Localisation 2011 - Proceedings Of The Satellite Conference Of Lt 26 Stefan Kettemann, 2012-10-30 The proceedings of Localisation 2011 a satellite conference of the 26th International Conference on Low Temperature Physics LT26 comprise both invited and contributed papers that discuss the latest progress on localisation phenomena The main topics include quantum transport in disordered systems Anderson localisation effects of interactions on localisation Anderson Mott transition mesoscopics the superconductor insulator transition quantum Hall effects fractional and integer topological insulators graphene dynamical localisation heavy fermions Kondo effect Kondo lattice effects of disorder and many body localisation spin glass Coulomb glass The volume is

also dedicated to Professor Bernard Coqblin former CNRS Directeur de Recherche and a Honorary Chairman of the AMS APCTP Conference Localisation 2011 whose contribution to condensed matter theory will always be remembered **Bcs: 50 Years** Leon N Cooper, Dmitri Feldman, 2010-11-10 Named a Top Five Book of 2011 by Physics Today USA the editors deserve praise for the selection of topics and for enlisting a distinguished set of authors BCS 50 Years is a successful attempt to capture the history of the development of superconductivity theory and its continuing impact Any person curious about superconductivity will find something in this book to enjoy Physics Today The BCS theory of superconductivity developed in 1957 by Bardeen Cooper and Schrieffer has been remarkably successful in explaining the properties of superconductors In addition concepts from BCS have been incorporated into diverse fields of physics from nuclear physics and dense quark matter to the current standard model Practical applications include SQUIDS magnetic resonance imaging superconducting electronics and the transmission of electricity This invaluable book is a compilation of both a historical account and a discussion of the current state of theory and experiment With contributions from many prominent scientists it aims to introduce students and researchers to the origins the impact and the current state of the BCS theory **Integrated Devices for Quantum Information with Polarization Encoded Qubits** Linda Sansoni, 2014-06-03 Quantum information science has found great experimental success by exploiting single photons To date however the majority of quantum optical experiments use large scale bulk optical elements bolted down to an optical bench an approach that ultimately limits the complexity and stability of the quantum circuits required for quantum science and technology The realization of complex optical schemes involving large numbers of elements requires the introduction of waveguide technology to achieve the desired scalability stability and miniaturization of the device This thesis reports on surprising findings in the field of integrated devices for quantum information Here the polarization of the photon is shown to offer a suitable degree of freedom for encoding quantum information in integrated systems The most important results concern the quantum interference of polarization entangled photons in an on chip directional coupler the realization of a Controlled NOT CNOT gate operating with polarization qubits the realization of a quantum walk of bosons and fermions in an ordered optical lattice and the quantum simulation of Anderson localization of bosons and fermions simulated by polarization entangled photons in a disordered quantum walk The findings presented in this thesis represent an important step towards the integration of a complete quantum photonic experiment in a chip **Ultracold Gases and Quantum Information** Christian Miniatura, Leong-Chuan Kwek, Martial Ducloy, Benoît Grémaud, Berthold-Georg Englert, Leticia Cugliandolo, Artur Ekert, Kok Khoo Phua, 2011-05-05 In recent years there has been much synergy between the exciting areas of quantum information science and ultracold atoms This volume as part of the proceedings for the XCI session of Les Houches School of Physics held for the first time outside Europe in Singapore brings together experts in both fields The theme of the school focused on two principal topics quantum information science and ultracold atomic physics The topics range from Bose Einstein Condensates

to Degenerate Fermi Gases to fundamental concepts in Quantum Information Sciences including some special topics on Quantum Hall Effects Quantum Phase Transition Interactions in Quantum Fluids Disorder and Interference Phenomena Trapped Ions and Atoms and Quantum Optical Devices **Forum Bildverarbeitung 2024** Längle, Thomas, Heizmann, Michael, 2024-11-21 Bildverarbeitung verknüpft das Fachgebiet der Sensorik von Kameras bildgebender Sensorik mit der Verarbeitung der Sensordaten den Bildern Daraus resultiert der besondere Reiz dieser Disziplin Der vorliegende Tagungsband des Forums Bildverarbeitung das am 21 und 22.11.2024 in Karlsruhe als Veranstaltung des Karlsruher Instituts für Technologie und des Fraunhofer Instituts für Optronik Systemtechnik und Bildauswertung stattfand enthält die Aufsätze der eingegangenen Beiträge Image processing combines the disciplines of cameras image based sensors with the processing of the sensor data the images From this follows the particular attraction of this field The conference proceedings at hand of the Image Processing Forum which took place on 21.22.11.2024 in Karlsruhe as a common event of the Karlsruhe Institute of Technology and the Fraunhofer Institute of Optronics System Technologies and Image Exploitation contain the articles of the contributions Scattering Matrix Approach to Non-stationary Quantum Transport Michael V. Moskalets, 2012 The aim of this book is to introduce the basic elements of the scattering matrix approach to transport phenomena in dynamical quantum systems of non interacting electrons This approach admits a physically clear and transparent description of transport processes in dynamical mesoscopic systems promising basic elements of solid state devices for quantum information processing One of the key effects the quantum pump effect is considered in detail In addition the theory for a recently implemented new dynamical source OCo injecting electrons with time delay much larger than the electron coherence time OCo is offered This theory provides a simple description of quantum circuits with such a single particle source and shows in an unambiguous way that the tunability inherent to the dynamical systems leads to a number of unexpected but fundamental effects **The Theory of the Quantum World** David Gross, Marc Henneaux, Alexander Sevrin, 2013 Ever since 1911 the Solvay Conferences have shaped modern physics The 25th edition held in October 2011 in Brussels and chaired by David Gross continued this tradition and celebrated the first centennial of this illustrious series of conferences The development and applications of quantum mechanics have always been the main threads in the history of the Solvay Conferences hence the 25th Solvay conference gathered many of the leading figures working on a wide variety of profound problems in physics where quantum mechanical effects play a central role The conference addressed some of the most pressing open questions in the field of physics The proceedings contain the OC rapporteur talksOCO which give a broad overview with unique insights by distinguished and renowned scientists These lectures cover the seven sessions OC History and ReflectionsOCO OC Foundations of Quantum Mechanics and Quantum ComputationOCO OC Control of Quantum SystemsOCO OC Quantum Condensed MatterOCO OC Particles and FieldsOCO OC Quantum Gravity and String TheoryOCO and it ended with a general discussion attempting to arrive at a synthesis In the Solvay tradition the proceedings also include the prepared comments to

the rapporteur talks The discussions among the participants OCo some of which quite lively and involving dramatically divergent points of view OCo have been carefully edited and are reproduced in full **Theory Of The Quantum World, The - Proceedings Of The 25th Solvay Conference On Physics** David J Gross,Alexander Sevrin,Marc Henneaux,2013-03-25 Ever since 1911 the Solvay Conferences have shaped modern physics The 25th edition held in October 2011 in Brussels and chaired by David Gross continued this tradition and celebrated the first centennial of this illustrious series of conferences The development and applications of quantum mechanics have always been the main threads in the history of the Solvay Conferences hence the 25th Solvay conference gathered many of the leading figures working on a wide variety of profound problems in physics where quantum mechanical effects play a central role The conference addressed some of the most pressing open questions in the field of physics The proceedings contain the rapporteur talks which give a broad overview with unique insights by distinguished and renowned scientists These lectures cover the seven sessions History and Reflections Foundations of Quantum Mechanics and Quantum Computation Control of Quantum Systems Quantum Condensed Matter Particles and Fields Quantum Gravity and String Theory and it ended with a general discussion attempting to arrive at a synthesis In the Solvay tradition the proceedings also include the prepared comments to the rapporteur talks The discussions among the participants some of which quite lively and involving dramatically divergent points of view have been carefully edited and are reproduced in full **Bogoliubov-de Gennes Method and Its Applications** Jian-Xin Zhu,2016-06-21 The purpose of this book is to provide an elementary yet systematic description of the Bogoliubov de Gennes BdG equations their unique symmetry properties and their relation to Green s function theory Specifically it introduces readers to the supercell technique for the solutions of the BdG equations as well as other related techniques for more rapidly solving the equations in practical applications The BdG equations are derived from a microscopic model Hamiltonian with an effective pairing interaction and fully capture the local electronic structure through self consistent solutions via exact diagonalization This approach has been successfully generalized to study many aspects of conventional and unconventional superconductors with inhomogeneities including defects disorder or the presence of a magnetic field and becomes an even more attractive choice when the first principles information of a typical superconductor is incorporated via the construction of a low energy tight binding model Further the lattice BdG approach is essential when theoretical results for local electronic states around such defects are compared with the scanning tunneling microscopy measurements Altogether these lectures provide a timely primer for graduate students and non specialist researchers while also offering a useful reference guide for experts in the field *Charge Transport in Disordered Molecular Systems* Aleksey Kocherzhenko,2011

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