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Single Electron Tunneling

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Financial support for this project has led to advances in the science of single-electron phenomena. Our group reported the first observation of the so-called "Coulomb Staircase," which was produced by tunneling into ultra-small metal particles. This work showed well-defined tunneling voltage steps of width e/C and height e/RC, demonstrating tunneling quantized on the single-electron level. This work was published in a now well-cited Physical Review Letter. Single-electron physics is now a major sub-field of condensed-matter physics, and fundamental work in the area continues to be conducted by tunneling in ultra-small metal particles. In addition, there are now single-electron transistors that add a controlling gate to modulate the charge on ultra-small photolithographically defined capacitive elements. Single-electron transistors are now at the heart of at least one experimental quantum-computer element, and single-electron transistor pumps may soon be used to define fundamental quantities such as the farad (capacitance) and the ampere (current). Novel computer technology based on single-electron quantum dots is also being developed.

DISCLAIMER

In related work, our group played the leading role in the explanation of experimental results observed during the initial phases of tunneling experiments with the high-temperature superconductors. When so-called "multiple-gap" tunneling was reported, the phenomenon was correctly identified by our group as single-electron tunneling in small grains in the material.

The main focus throughout this project has been to explore single electron phenomena both in traditional tunneling formats of the type metal/insulator/particles/insulator/metal and using scanning tunneling microscopy to probe few-particle systems. This has been done under varying conditions of temperature, applied magnetic field, and with different materials systems. These have included metals, semi-metals, and superconductors. Amongst a number of results, we have verified that clusters of down to one, two, and three metal atoms can be identified with single-electron techniques. We have also extended the regime of single-electron phenomenology through the observation of single-electron effects in metal droplets in the high-conductance regime.

The grant has supported fully or in part:

1. Eleven graduate students
2. One post-doctoral associate
3. Eight undergraduate assistants

Refereed Publications supported fully or in part by this Grant:

"Transport Properties of Anisotropic Systems," S.T. Ruggiero, J.B. Barner, and S.M. Schwarzbek in Metallic Multilayers & Epitaxy, ed. M. Hong, W. Wolf and D.C. Gubser (The Metallurgical Society, Warrendale, PA, 1988), p.135.

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Talks supported fully or in part by this Grant

"Single-Electron Charging Effects," University of Michigan, Ann Arbor, MI, January 1988.

"Single-Electron Charging Effects," Michigan State University, E. Lansing, MI, February 1, 1988.

"Single-Electron Charging Effects," Illinois Institute of Technology, Chicago, IL, May 4, 1988.

"Single-Electron Charging Effects," Purdue University, West Lafayette, IN, September 23, 1988.

"Electron tunneling in ultra-small capacitance particles and high-temperature superconductors," Superconductor Technologies, Inc., Santa Barbara, CA, October 13, 1988.

"Electron tunneling in ultra-small capacitance particles," Indiana University, Bloomington, IN, October 21, 1988.

"Single-Electron Charging Effects," invited talk, March Meeting of the American Physical Society, 1989.

"Mixing in TlBaCaCuO Films," Materials and Mechanisms of Superconductivity, Kanazawa, Japan, July 24, 1991.

"Charging Effects in Single Particle Systems," Nordita Workshop on Nanometer Structures and Mesoscopic Physics, Trondheim, Norway, June 21, 1992.

"Far-Infrared Superconducting Devices Collaboration," National Institute of Standards and Technology, Boulder, CO, August 5, 1994.

"High-Field Effects in Single-Electron Systems," 100 Tesla Workshop, Los Alamos, NM, January 19, 1995.

"Photoresponse of YBCO Narrow-Line Systems," Jet Propulsion Laboratory, Pasadena, CA, October 22, 1997.

"Electron Tunneling in Ultra-small Clusters," Colloquium, Central Michigan University, Mount Pleasant, MI, April 9, 1998.

"Single Electron Tunneling in the High Conductance Regime," invited talk at the National Institute of Standards and Technology, Boulder, Colorado, November 16, 2000.

"Single-electron tunneling in metal nanoclusters," Seminar, University of Colorado, Boulder, CO, May 10, 2002.

"Spin Tunneling in Co/GaAs," Seminar, National Institute of Standards and Technology, Boulder, CO, July 29, 2002.

"Dilute Al-Mn Alloys for Superconductor Device Applications," Jet Propulsion Laboratory, Pasadena, CA, July 29, 2003.

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