

QUANTUM TRANSPORT MEASUREMENTS: AN OVERVIEW

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Abstract

This paper offers a comprehensive overview of quantum transport measurements, a crucial aspect of quantum mechanics research with implications for various fields, including condensed matter physics and quantum computing. Quantum transport measurements involve probing the behavior of electrons and other charge carriers in nanostructured materials and devices, offering insights into their quantum mechanical properties and behaviors. The abstract discusses key measurement techniques, such as conductance measurements, magneto-transport measurements, and scanning probe microscopy, highlighting their significance in elucidating quantum phenomena at the nanoscale. Furthermore, the abstract explores emerging trends and advancements in quantum transport measurement techniques, including advancements in nanofabrication, single-electron transistors, and quantum dot devices. Overall, the abstract underscores the importance of quantum transport measurements in advancing our understanding of fundamental quantum phenomena and driving technological innovations in various fields.

Keywords: Quantum Transport Measurements, Computing, Techniques, Electron.

Introduction

Quantum transport measurements investigate the behaviour of electrons and their mobility in nanoscale systems. These measurements provide insights that are essential for both fundamental physics and modern technologies. The Quantum Hall Effect (QHE) and single-electron transistors are two examples of techniques that are considered to be fundamental instruments in this research field. The quantum Hall effect (QHE) displays the quantization of conductance in a two-dimensional electron system that is the subject of a strong magnetic field. This reveals the delicate relationship that exists between topology and the behaviour of electrons. In addition to this, it offers a precise method for determining fundamental constants and for researching exotic quantum states. Single-electron transistors make it possible to observe and manipulate the transit of individual electrons, which is critical for comprehending the quantum effects that occur in nanoscale electronics.

These observations not only provide a more in-depth comprehension of the behaviour of electrons in restricted systems, but they also hold a great deal of promise for the development of innovative technologies in the future, particularly in the fields of quantum computing and nanoelectronics. By harnessing and exploiting the quantum events that are discovered through these transport measurements, it may be possible to design electronic devices that are more efficient and robust. This would pave the way for the next generation of computing and information processing systems that

have capabilities that are unmatched. When it comes to researching the behaviour of electrons and other charge carriers in materials at the quantum level, quantum transport measurements are an essential component of the research process. These experiments entail analysing the movement of these particles through a variety of structures or devices, which provides insights into the quantum features that are specific to these particles.

Literature Review

Liu (2016) [1] In highly correlated quantum materials, there are pervasive electronic, magnetic, & structural phase inhomogeneities. The phase inhomogeneities' typical length scales might vary from atomic to mesoscopic, contingent upon their microscopic origins and other characteristics specific to the sample. Therefore, the development of experimental methods that can offer enough spatial resolution is crucial to the understanding of linked events. For some of the most revealing methods used for condensed matter physics, such as optical and infrared spectroscopy, this criteria is challenging to meet. However, recent advancements in near-field photography and optics have made it possible to characterise the electromagnetic response in great detail with a spatial resolution of less than 10 nm. Thus, well-established optical procedures for the characterization of electronic operations and lattice dynamics in several kinds of coupled quantum systems may now be exploited at the nanoscale. A succinct overview of the most recent near-field the methods used to prototypical

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related quantum substances are provided in this article. Additionally, we go over complementary spectroscopic and microscopic techniques that shed light on significant mesoscopic dynamics of quantum materials across different energy scales.

Granata (2016) [2] One intriguing and promising area of nanoscience study is magnetic sensing at the nanoscale level. Magnetic imaging is, in fact, an extremely useful technique for examining chemical, biological, and physical processes. One of the most exciting areas of both basic and applied research in the next years is the study of small spin clusters, such as magnetic molecules including nanoparticles, single electrons, and cold atom clouds. In instance, the study of magnetic nanoparticles is essential to contemporary material science and its related technological applications, such as ferrofluids, magnetic refrigeration, and biomedical uses such as drug delivery, cancer treatment for hyperthermia, as well as magnetic resonance imaging contrast agents. Actually, the detection of elementary magnetic moment or spin is one of the most ambitious objectives of the high sensitivity magnetometry. Within this context, numerous efforts have been made to bring detecting capabilities down to the individual spin level by developing a high sensitivity magnetic nanosensor. Superconducting Quantum Interference Devices (SQUIDS) are a type of magnetic sensor that are used in many different applications due to its extremely high sensitivity. A superconducting ring, or sensitive area, is the basic building block of a SQUID and is divided into two Josephson junctions.

Quantum Transport Measurements

In most cases, these measurements entail introducing an electric or magnetic field to a material or device and monitoring how charge carriers react to the field. Here are some important methods:

1. Hall Effect Measurements

- The mobility, density, and polarity of charge carriers in a material can be determined through the use of Hall Effect measurements. These measurements include measuring the voltage that is produced when a magnetic field is applied in a direction that is perpendicular to the flow of current.
- The Quantum Hall Effect (QHE) is a technique that investigates the behaviour of electrons in two-dimensional materials when they are exposed to intense magnetic fields. This technique demonstrates quantized conductance and unveiled fundamental constants.

2. Quantum Interference Effects

The observation of interference patterns in the conductance of nanostructures (such as quantum dots or rings) as a result of the wave nature of electrons is referred to as quantum interference effects.

3. Scanning Probe Microscopy

Techniques such as scanning tunnelling microscopy (STM) and atomic force microscopy (AFM) provide insights into the quantum behaviour of electrons at the atomic scale. Scanning probe microscopy is one of these techniques.

4. Transport through Nanostructures

- Studying electron transport in nanostructures such as quantum wells, wires, or dots in order to gain an understanding of the electronic properties and behaviours of these nanostructures is referred to as "transport through nanostructures."
- These transistors make it possible to investigate the movement of individual electrons, which is essential for comprehending the quantum phenomena that occur in nanoscale devices.

Several disciplines, including as condensed matter physics, materials science, and quantum computing, rely heavily on these data for their scientific understanding. In addition to assisting in the comprehension and design of new materials with individualised electrical properties, they also contribute to the investigation of the possibilities for future quantum technologies.

Conclusion

Understanding and harnessing quantum mechanical effects that become prominent at the nanoscale, such as quantum confinement, tunneling, and quantum dots' discrete energy levels. The term "quantum effects" refers to a wide variety of phenomena that manifest themselves at the atomic and subatomic levels, posing a fundamental challenge to the field of classical physics. When viewed at this scale, particles display behaviours that are incomprehensible to conventional wisdom. Schrodinger's cat thought experiment is an example of how quantum superposition enables particles to exist in numerous states simultaneously until they are noticed. Instantaneous correlations between entangled particles are demonstrated by the phenomenon of entanglement, which occurs when particles become interconnected regardless of their distance from one another. The quantization of energy indicates that particles do not have a continuous spectrum of energy but rather discrete energy levels. In accordance with the principles of classical physics, quantum tunnelling is an additional effect that enables particles to travel

through energy barriers that appear to be insurmountable. These effects are the foundation of contemporary quantum mechanics, which has revolutionised both science and technology. In order to do computations at an exponentially quicker rate, quantum computing makes use of superposition and entanglement. This technology holds the promise of revolutionary improvements in the fields of data processing and cryptography. In order to achieve precisely controllable electrical and optical properties, quantum dots make use of quantization. This enables quantum dots to facilitate advancements in displays and medical imaging. The ability to comprehend and control these effects is essential for developing technologies, which have the potential to revolutionise a wide range of fields, including but not limited to computing and communications, materials science, and other areas.

Conflict of Interest

There is no conflict of interest in this manuscript by the authors.

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