

Special Issue

Quantum Information Theory

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INTRODUCTION

Quantum information theory is a rapidly growing field, which lies at the intersection of quantum mechanics, information technology, and computer science. Its roots extend back to the early days of quantum mechanics, when the mathematical structure of states and operators was introduced in order to provide a consistent computational framework for quantum theory. The original purpose of quantum mechanics was to understand and make predictions about the behavior of microscopic physical systems, and, in this regard, the theory has been extremely successful. However, one significant feature of quantum theory is that it puts limits on the experimenter's ability to predict the outcome of measurements, and even imposes constraints on the kinds of measurements which can be performed on a system. This seems quite strange from the perspective of classical physics, and this and other aspects of quantum theory were long viewed as obstacles to be surmounted in the course of explaining observed phenomena.

The modern development of quantum information theory has been driven by the observation that the nonclassical weirdness of quantum systems provides resources which can be exploited. By adopting this viewpoint, scientists have developed remarkable new ways of processing information, with notable examples being Shor's factoring algorithm, Grover's search algorithm, and methods for quantum cryptography. These theoretical results spurred attempts to develop a working quantum computer and to implement quantum key distribution. The last decade has seen a general effort to find new ways to exploit the exotic properties of quantum systems, accompanied by parallel programs to build working implementations of these ideas. A concomitant effort to understand the mathematical structures associated with these developments has brought together ideas from a variety of fields and has provided impetus for research in new directions. For example, the study of noise and decoherence requires a better understanding of open quantum systems, and this builds on ideas first introduced in the study of nonequilibrium statistical mechanics; while the classification and quantification of entanglement is a relatively new subject, which is encouraging research into the geometry of tensor products of Hilbert spaces.

This special issue on **Quantum Information Theory** is intended to provide a broad perspective on recent results in several major areas of interest, as well as an overview of the current state of knowledge. The contributions are arranged into sections corresponding to several broad themes. The first section, titled "Entanglement," begins with a survey of entanglement measures, followed by six papers on different aspects of this important nonclassical property. The second, and longest, section, "Noise, Entropy, and Channel Capacity," is primarily concerned with the information carrying capacity of quantum channels. The first three papers are directly concerned with the capacity when quantum states are used to transmit classical information; the next three consider some closely related mathematical questions; and the remainder study issues which arise in the transmission of quantum information. The third section, "Quantum Computing Architectures," explores several different questions relevant to the design and performance of quantum computers; while the fourth, "Quantum Cryptography," contains two papers on secrecy protocols. The issue concludes with a section, "Knowledge of Quantum States," containing two papers, which examine fundamental issues associated with the information content of quantum states.

The field of Quantum Information Theory is evolving rapidly, and the selection of papers in this issue is neither representative nor comprehensive with respect to the broad range of topics being actively studied within the field. In keeping with the nature of the Journal, the papers consider issues in which analysis of the associated mathematical structures is particularly important. Most of the papers contain new results and many include proofs of new theorems. However, a few of the papers are primarily expository, and some contain speculative new ideas and open questions. In all cases, we hope they will enhance our physical insight and illuminate some of the directions for future research.

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