About This Volume and Quantum Research at Los Alamos

In line with six decades of Laboratory tradition, the breadth of Los Alamos research in quantum science spans the gamut from fundamental questions in quantum theory and measurement to practical applications of quantum information science. The Los Alamos program started in the early 1980s with Wojciech Zurek and his postdoctoral fellows conducting a lively investigation into the emergence of classical reality from the quantum world. Zurek developed the theory of decoherence, which recognizes the role of the coupling between real quantum systems and the environment in the rapid loss of the coherence that endows quantum states with their special properties. In this volume, he surveys the progress in understanding decoherence since his now classic article published in *Physics Today*. In related pieces, Salman Habib and Tanmoy Bhattacharya apply the model of continuous measurement to describe the quantum-to-classical transition and to explore the possibility of controlling quantum systems through continuous quantum feedback. In 1994, as part of the general expansion of interest in quantum computing, Raymond Laflamme and Manny Knill joined Zurek in ground-breaking studies of quantum error correction, which can prevent quantum computers from falling prey to decoherence, and later adapted nuclear magnetic resonance (NMR) technology with molecules to test theoretical ideas in quantum computing.

In the early 1990s, in a parallel development at Los Alamos, Richard Hughes started to implement the quantum cryptographic protocols of Charles Bennett and Gilles Brassard. Hughes, Beth Nordholt, Paul Kwiat, Daniel James, and other colleagues and postdoctoral fellows gradually expanded their studies of quantum cryptography to include quantum state entanglement of photon pairs and ion-trap quantum computing, in which the qubits are single ions trapped in a linear array inside an electromagnetic trap. In the late 1990s, Chris Hammel started a collaboration with Bruce Kane, Bob Clark, and the quantum technology center in Sydney, Australia, to develop a solid-state quantum computer.

This volume is dedicated to conveying the intellectual excitement of this new field. It opens with an elegant hands-on primer in which Knill and his colleagues define the basic unit of quantum information and introduce all the elements needed to process quantum information. The presentation culminates with a description of a simple quantum network for solving a real problem and a step-by-step solution that shows how the quantum operations produce the answer. The primer ends with a brief but realistic assessment of the advantages of quantum information, particularly for computation. It is a good place to gain a perspective on the future.

Communication, the other major task of information processing, has been profoundly altered by the ideas of quantum information science. Quantum teleportation, quantum cryptography, and other efficient communication schemes exploit the simplest qubit, a linearly polarized photon, to achieve their goals. Often, the use of maximally entangled pairs, or Bell states, has a definite advantage in these contexts. In their article on entanglement, Kwiat and James succeed in explaining and demystifying those schemes. Hughes and Nordholt have developed a working quantum cryptographic system in fiber optics and free space. In their article, they explain both the protocols developed by Bennett and Brassard and their experimental systems in very simple language, accessible to a wide audience.

Most efforts to build a scalable quantum computer struggle with how to construct single qubits and examine their properties. Only ion traps, cavity quantum electrodynamics, and liquid NMR have been used successfully for manipulation of more than one qubit. Laflamme, Knill, and colleagues explain their methods for adapting liquid NMR to a quantum information-processing system. Although the quantum states describing this form of information processing are provably not entangled at any time and the system cannot be scaled up much beyond ten qubits, research at Los Alamos has demonstrated the establishment of well-defined initial states, the system's controlled evolution in the presence of real-world noisy environments, and the ability to read out significant results of a computation from a single qubit.

To date, however, quantum information science has far more results from theory than experiment. In his article, Eddy Timmermans explains how dilute Bose-Einstein condensates, many-body quantum states created in atom traps, have become new "laboratories" for studying fundamental quantum phenomena. Dave Vieira and colleagues at Los Alamos are developing an experimental capability in this area.

The diverse quantum efforts at Los Alamos are now supported and fostered by the Quantum Information Research Institute. Contact the steering committee at qsc@lanl.gov for further information. ■