Completeness of quantum theory implies that wave functions are physical properties

Roger Colbeck1 and Renato Renner

arXiv:1111.6597

Given the wave function associated with a physical system, quantum theory allows us to compute predictions for the outcomes of any measurement. Since, within quantum theory, a wave function corresponds to an extremal state and is therefore maximally informative, one possible view is that it can be considered an (objective) physical property of the system. However, an alternative view, often motivated by the probabilistic nature of quantum predictions, is that the wave function represents incomplete (subjective) knowledge about some underlying physical properties. Recently, Pusey et al. [arXiv:1111.3328, 2011] showed that the latter, subjective interpretation would contradict certain physically plausible assumptions, in particular that it is possible to prepare multiple systems such that their (possibly hidden) physical properties are uncorrelated. Here we present a novel argument, showing that a subjective interpretation of the wave function can be ruled out as a consequence of the completeness of quantum theory. This allows us to establish that wave functions are physical properties, using only minimal assumptions. Specifically, the (necessary) assumptions are that quantum theory correctly predicts the statistics of measurement outcomes and that measurement settings can (in principle) be chosen freely.

Compressed Quantum Simulation of the Ising Model

B. Kraus

Phys. Rev. Lett. 107, 250503 (2011), doi:10.1103/PhysRevLett.107.250503

Jozsa et al. [Proc. R. Soc. A 466 809 (2009)] have shown that a match gate circuit running on n qubits can be compressed to a universal quantum computation on $\log(n) + 3$*qubits. Here, we show how this compression can be employed to simulate the Ising interaction of a 1D chain consisting of n qubits using a universal quantum computer running on* $\log(n)$ *qubits. We demonstrate how the adiabatic evolution can be realized on this exponentially smaller system and how the magnetization, which displays a quantum phase transition, can be measured. This shows that the quantum phase transition of very large systems can be observed experimentally with current technology.*

Microwave amplification with nanomechanical resonators

F. Massel, T. T. Heikkila1, J.-M. Pirkkalainen1, S. U. Cho1, H. Saloniemi, P. J. Hakonen1, and M. A. Sillanpaa

Nature 480, 351-354 (2011), doi:10.1038/nature10628

The sensitive measurement of electrical signals is at the heart of modern technology. According to the principles of quantum mechanics, any detector or amplifier necessarily adds a certain amount of noise to the signal, equal to at least the noise added by quantum fluctuations. This quantum limit of added noise has nearly been reached in superconducting devices that take advantage of nonlinearities in Josephson junctions. Here we introduce the concept of the amplification of microwave signals using mechanical oscillation, which seems likely to enable quantum-limited operation. We drive a nanomechanical resonator with a radiation pressure force, and provide an experimental demonstration and an analytical description of how a signal input to a microwave cavity induces coherent stimulated emission and, consequently, signal amplification. This generic scheme, which is based on two linear oscillators, has the advantage of being conceptually and practically simpler than the Josephson junction devices. In our device, we achieve signal amplification of 25 decibels with the addition of 20 quanta of noise, which is consistent with the expected amount of added noise. The generality of the model allows for realization in other physical systems as well, and we anticipate that near-quantum-limited mechanical microwave amplification will soon be feasible in various applications involving integrated electrical circuits.

Entanglement can Completely Defeat Quantum Noise

Jianxin Chen,Toby S. Cubitt, Aram W. Harrow, and Graeme Smith

Phys. Rev. Lett. 107, 250504 (2011), doi:10.1103/PhysRevLett.107.250504

We describe two quantum channels that individually cannot send any classical information without some chance of decoding error. But together a single use of each channel can send quantum information perfectly reliably. This proves that the zero-error classical capacity exhibits superactivation, the extreme form of the superadditivity phenomenon in which entangled inputs allow communication over zero-capacity channels. But our result is stronger still, as it even allows zero-error quantum communication when the two channels are combined. Thus our result shows a new remarkable way in which entanglement across two systems can be used to resist noise, in this case perfectly. We also show a new form of superactivation by entanglement shared between sender and receiver.

Demonstration of a Controlled-Phase Gate for Continuous-Variable One-Way Quantum Computation

Ryuji Ukai, Shota Yokoyama, Jun-ichi Yoshikawa, Peter van Loock, and Akira Furusawa

Phys. Rev. Lett. 107, 250501 (2011), doi:10.1103/PhysRevLett.107.250501

We experimentally demonstrate a controlled-phase gate for continuous variables using a cluster-state resource of four optical modes. The two independent input states of the gate are coupled with the cluster in a teleportation-based fashion. As a result, one of the entanglement links present in the initial cluster state appears in the two unmeasured output modes as the corresponding entangling gate acting on the input states. The genuine quantum character of this gate becomes manifest and is verified through the presence of entanglement at the output for a product two-mode coherent input state. By combining our gate with the recently reported module for single-mode Gaussian operations [R. Ukai et al. Phys. Rev. Lett. 106 240504 (2011)], it is possible to implement any multimode Gaussian operation as a fully measurement-based one-way quantum computation.

Nonequilibrium Transport through a Spinful Quantum Dot with Superconducting Leads

B. M. Andersen, K. Flensberg, V. Koerting, and J. Paaske

Phys. Rev. Lett. 107, 256802 (2011), doi:10.1103/PhysRevLett.107.256802

We study the nonlinear cotunneling current through a spinful quantum dot contacted by two superconducting leads. Applying a general nonequilibrium Green function formalism to an effective Kondo model, we study the rich variation in the IV characteristics with varying asymmetry in the tunnel coupling to source and drain electrodes. The current is found to be carried, respectively, by multiple Andreev reflections in the symmetric limit, and by spin-induced Yu-Shiba-Rusinov bound states in the strongly asymmetric limit. The interplay between these two mechanisms leads to qualitatively different IV characteristics in the crossover regime of intermediate symmetry, consistent with recent experimental observations of negative differential conductance and repositioned conductance peaks in subgap cotunneling spectroscopy.

Optimized control of multistate quantum systems by composite pulse sequences

G. T. Genov, B. T. Torosov, and N. V. Vitanov

Phys. Rev. A 84, 063413 (2011), doi:10.1103/PhysRevA.84.063413

We introduce a technique for derivation of high-fidelity composite pulse sequences for two types of multistate quantum systems: systems with the SU(2) and Morris-Shore dynamic symmetries. For the former type, we use the Majorana decomposition to reduce the dynamics to an effective two-state system, which allows us to find the propagator analytically and use the pool of available composite pulses for two-state systems. For the latter type of multistate systems, we use the Morris-Shore decomposition, which reduces the multistate dynamics to a set of two-state systems. We present examples which demonstrate that the multistate composite sequences open a variety of possibilities for coherent control of quantum systems with multiple states.

Nonperturbative Gadget for Topological Quantum Codes

Samuel A. Ocko and Beni Yoshida

Phys. Rev. Lett. 107, 250502 (2011), doi:10.1103/PhysRevLett.107.250502

Many-body entangled systems, in particular topologically ordered spin systems proposed as resources for quantum information processing tasks, often involve highly nonlocal interaction terms. While one may approximate such systems through two-body interactions perturbatively, these approaches have a number of drawbacks in practice. In this Letter, we propose a scheme to simulate many-body spin Hamiltonians with two-body Hamiltonians nonperturbatively. Unlike previous approaches, our Hamiltonians are not only exactly solvable with exact ground state degeneracy, but also support completely localized quasiparticle excitations, which are ideal for quantum information processing tasks. Our construction is limited to simulating the toric code and quantum double models, but generalizations to other nonlocal spin Hamiltonians may be possible.

Two-Dimensional Topological Insulator State and Topological Phase Transition in Bilayer Graphene

Zhenhua Qiao, Wang-Kong Tse, Hua Jiang, Yugui Yao, and Qian Niu

Phys. Rev. Lett. 107, 256801 (2011), doi:10.1103/PhysRevLett.107.256801

We show that gated bilayer graphene hosts a strong topological insulator (TI) phase in the presence of Rashba spin-orbit (SO) coupling. We find that gated bilayer graphene under preserved time-reversal symmetry is a quantum valley Hall insulator for small Rashba SO coupling R, and transitions to a strong TI when R¿U2+t2, where U and t are, respectively, the interlayer potential and tunneling energy. Different from a conventional quantum spin Hall state, the edge modes of our strong TI phase exhibit both spin and valley filtering, and thus share the properties of both quantum spin Hall and quantum valley Hall insulators. The strong TI phase remains robust in the presence of weak graphene intrinsic SO coupling.