Topological Kondo Effect with Majorana Fermions

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The Kondo effect is a striking consequence of the coupling of itinerant electrons to a quantum spin with degenerate energy levels. While degeneracies are commonly thought to arise from symmetries or fine-tuning of parameters, the recent emergence of Majorana fermions has brought to the fore an entirely different possibility: a topological degeneracy that arises from the nonlocal character of Majorana fermions. Here we show that nonlocal quantum spins formed from these degrees of freedom give rise to a novel topological Kondo effect. This leads to a robust non-Fermi liquid behavior, known to be difficult to achieve in the conventional Kondo context. Focusing on mesoscopic superconductor devices, we predict several unique transport signatures of this Kondo effect, which would demonstrate the nonlocal quantum dynamics of Majorana fermions and validate their potential for topological quantum computation.

A valley-spin qubit in a carbon nanotube

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arXiv:1210.3085

Although electron spins in III-V semiconductor quantum dots have shown great promise as qubits, a major challenge is the unavoidable hyperfine decoherence in these materials. In group IV semiconductors, the dominant nuclear species are spinless, allowing for qubit coherence times that have been extended up to seconds in diamond and silicon. Carbon nanotubes are a particularly attractive host material, because the spin-orbit interaction with the valley degree of freedom allows for electrical manipulation of the qubit. In this work, we realise such a qubit in a nanotube double quantum dot. The qubit is encoded in two valley-spin states, with coherent manipulation via electrically driven spin resonance (EDSR) mediated by a bend in the nanotube. Readout is performed by measuring the current in Pauli blockade. Arbitrary qubit rotations are demonstrated, and the coherence time is measured via Hahn echo. Although the measured decoherence time is only 65 ns in our current device, this work offers the possibility of creating a qubit for which hyperfine interaction can be virtually eliminated.

Nonperturbative Master Equation Solution of Central Spin Dephasing Dynamics

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We solve the long-standing central spin problem for a general set of inhomogeneous bath couplings and a large class of initial bath states. We compute the time evolution of the coherence of a central spin coupled to a spin bath by resumming all orders of the time-convolutionless master equation, thus avoiding the need to assume weak coupling to the bath. The fully quantum, non-Markovian solution is obtained in the large-bath limit and is valid up to a time scale set by the largest coupling constant. Our result captures the full decoherence of an electron spin qubit coupled to a nuclear spin bath in a GaAs quantum dot for experimentally relevant parameters. In addition, our solution is quite compact and can readily be used to make quantitative predictions for the decoherence process and to guide the design of nuclear state preparation protocols.

Stabilizing Rabi oscillations in a superconducting qubit using quantum feedback

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The act of measurement bridges the quantum and classical worlds by projecting a superposition of possible states into a single (probabilistic) outcome. The timescale of this 'instantaneous' process can be stretched using weak measurements, such that it takes the form of a gradual random walk towards a final state. Remarkably, the interim measurement record is sufficient to continuously track and steer the quantum state using feedback. Here we implement quantum feedback control in a solid-state system, namely a superconducting quantum bit (qubit) coupled to a microwave cavity. A weak measurement of the qubit is implemented by probing the cavity with microwave photons, maintaining its average occupation at less than one photon. These photons are then directed to a high-bandwidth, quantum-noise-limited amplifier, which allows real-time monitoring of the state of the cavity (and, hence, that of the qubit) with high fidelity. We demonstrate quantum feedback control by inhibiting the decay of Rabi oscillations, allowing them to persist indefinitely. Such an ability permits the active suppression of decoherence and enables a method of quantum error correction based on weak continuous measurements. Other applications include quantum state stabilization, entanglement generation using measurement, state purification and adaptive measurements.

Quantum memories and error correction

James R. Wootton

arXiv:1210.3207 (Review article for Journal of Modern Optics)

Controlling the Dynamics of Many-Electron Systems from First Principles: A Combination of Optimal Control and Time-Dependent Density-Functional Theory
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Phys. Rev. Lett. **109**, 153603 (2012)
Quantum optimal control theory (QOCT) provides the necessary tools to theoretically design driving fields capable of controlling a quantum system towards a given state or along a prescribed path in Hilbert space. This theory must be complemented with a suitable model for describing the dynamics of the quantum system. Here, we are concerned with many electron systems (atoms, molecules, quantum dots, etc.) irradiated with laser pulses. The full solution of the many-electron Schrödinger equation is not feasible in general, and therefore, if we aim for an ab initio description, a suitable choice is the time-dependent density-functional theory (TDDFT). In this Letter, we establish the equations that combine TDDFT with QOCT and demonstrate their numerical feasibility.

Quantum-circuit design for efficient simulations of many-body quantum dynamics
Sadegh Raeisi, Nathan Wiebe, and Barry C Sanders
New Journal of Physics **14**, 103017 (2012)
We construct an efficient autonomous quantum-circuit design algorithm for creating efficient quantum circuits to simulate Hamiltonian many-body quantum dynamics for arbitrary input states. The resultant quantum circuits have optimal space complexity and employ a sequence of gates that is close to optimal with respect to time complexity. We also devise an algorithm that exploits commutativity to optimize the circuits for parallel execution. As examples, we show how our autonomous algorithm constructs circuits for simulating the dynamics of Kitaev's honeycomb model and the Bardeen–Cooper–Schrieffer model of superconductivity. Furthermore, we provide numerical evidence that the rigorously proven upper bounds for the simulation error here and in previous work may sometimes overestimate the error by orders of magnitude compared to the best achievable performance for some physics-inspired simulations.

Revisiting foundations for the fault-tolerant quantum computation
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arXiv:1210.1782
The hopes for scalable quantum computing rely on the "threshold theorem": once the error per qubit per gate is below a certain value, the methods of quantum error correction allow indefinitely long quantum computations. The proof is based on a number of assumptions, which are supposed to be satisfied exactly, like axioms, e.g. zero undesired interactions between qubits, etc. However in the physical world no continuous quantity can be exactly zero, it can only be more or less small. Thus the "error per qubit per gate" threshold must be complemented by the required precision with which each assumption should be fulfilled. This issue was never addressed. In the absence of this crucial information, the prospects of scalable quantum computing remain uncertain.

Rashba spin-orbit interaction in graphene armchair nanoribbons
Lucia Lenz, Daniel Urban, Dario Bercioux
arXiv:1210.2865
We study graphene nanoribbons (GNRs) with armchair edges in the presence of Rashba spin-orbit interaction (RSOI). We impose the boundary conditions on the tight binding Hamiltonians for bulk graphene with RSOI by means of a sine transform and use the results to derive different approximations and to investigate their ranges of validity. Finally, we derive an approximation for the lowest two energy bands, which is valid for experimentally available sizes of RSOI. In addition we study the spin polarization in GNRs resulting from the RSOI.

Strain Tuning of Individual Atomic Tunneling Systems Detected by a Superconducting Qubit
Grigorij J. Grabovskij, Torben Peichl, Jürgen Lisenfeld, Georg Weiss, and Alexey V. Ustinov
Science **338**, 232 (2012)
In structurally disordered solids, some atoms or small groups of atoms are able to quantum mechanically tunnel between two nearly equivalent sites. These atomic tunneling systems have been identified as the cause of various low-temperature anomalies of bulk glasses and as a source of decoherence of superconducting qubits where they are sparsely present in the disordered oxide barrier of Josephson junctions. We demonstrated experimentally that minute deformation of the oxide barrier changes the energies of the atomic tunneling systems, and we measured these changes by microwave spectroscopy of the superconducting qubit through coherent interactions between these two quantum systems. By measuring the dependence of the energy splitting of atomic tunneling states on external strain, we verify a central hypothesis of the two-level tunneling model for disordered solids.