An exactly solvable model for a strongly spin-orbit-coupled nanowire quantum dot

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In the presence of spin-orbit coupling, quantum models for semiconductor materials are generally not exactly solvable. As a result, understanding of the strong spin-orbit coupling effects in these systems remains incomplete. Here we develop a method to exactly solve the one-dimensional hard-wall quantum dot problem in the presence of strong spin-orbit coupling and magnetic field, which allows us to obtain exact eigenenergies and eigenstates of a single electron. With the help of the exact solution, we demonstrate unique effects from the strong spin-orbit coupling in a semiconductor quantum dot, in particular the anisotropy of the electron g-factor and its tunability.

Calculating long-range two-photon visibility for quantum communication with up to six entanglement swapping stations

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We develop a Monte-Carlo sampling approach to redress the enormous computational time required to calculate two-photon visibility for multiple-entanglement-swapping-based long-distance quantum communication. We employ our theory to study both the realistic setting involving dark counts, multi-photon events and loss, and we also study the semi-idealistic case of perfect synchronized single-photon sources; this semi-idealistic case is used to verify our sampling method. Our new sampling method enables successful, reliable calculation of visibility for up to six consecutive entanglement-swapping stations. Although six entanglement-swapping stations leads to low rates in the real-world setting, our sampling method for solving long-distance quantum communication rates and visibility serves as a valuable tool for modeling future viable quantum communication strategies incorporating promising technology such as optical quantum memory.

Cavity QED with ferromagnetic magnons in a small YIG sphere

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Hybridizing collective spin excitations in ferromagnetic crystals and a cavity with high cooperativity provides a new research subject in the field of cavity quantum electrodynamics and can also have potential applications to quantum information. In contrast to spin ensembles based on dilute paramagnetic impurities, these spins are strongly exchange-coupled and have a much higher density. Here we report a direct observation of the strong coupling between magnons and microwave photons at both cryogenic and room temperatures by using the same small yttrium-iron-garnet (YIG) ferromagnetic sphere in a 3D copper cavity. We observed strong couplings of the same cavity mode to both ferromagnetic-resonance (FMR, uniform precession) mode and a magnetostatic (MS, non-uniform precession) mode in the quantum limit at 22 mK. Then, at room temperature, we observed a strong coupling of the cavity mode to the FMR mode with slightly increased damping rate. This reveals the robustness of the FMR mode against temperature. However, the coupling to MS mode disappears at room temperature and numerically simulations show that this is due to a drastic increase of the damping rate of the MS mode. Our work unveils quantum-coherence properties of the magnons at both cryogenic and room temperatures.

First-Principles Hyperfine Tensors in Si and GaAs

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Due to the anisotropic nature of the hyperfine coupling for hole spins in semiconductor quantum dots, these systems may show significantly longer coherence times than electron spins given the correct quantum-dot geometry and magnetic field orientation. This advantage of hole spins relies on the hyperfine tensor taking-on an Ising-like form. This form of the hyperfine coupling has been recently called into question with experiments [1] that have been interpreted to indicate a strong hybridization of p-like and d-like components in the valence band of III-V semiconductors. Using a generalization of the group-theoretic analysis in [1], we show that the Ising-like nature of the hyperfine tensor can be restored, for a particular choice of coupling constants. We also propose a way in which to test for the d-like components using optical selection rules. We use density functional theory (D.F.T.) to estimate hyperfine couplings in the conduction band of Si and get good agreement with experimental values. We also calculate the couplings for the conduction band of GaAs and get a values that are different from the estimated values [2] that are generally accepted. Finally, we calculate the hyperfine couplings in the valence band of GaAs. In contrast to other works, we include off-diagonal elements of the spin-density operator.

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Holonomic quantum computation in ultrastrongly coupled circuit QED

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We present an experimentally feasible scheme to implement holonomic quantum computation in ultrastrong coupling regime of light-matter interaction. The large anharmonicity and the selection rules of the quantum Rabi model allow us to build an effective three-level _ structure for quantum computation. Single qubit quantum gates are realized by a two-tone driving method on the physical qubit and two qubit quantum gate is achieved with time-dependent coupling between the field quadratures of the two resonators. Moreover, we propose a circuit quantum electrodynamics configuration for physical implementation — two gradiometric tunable-gap flux qubits are coupled galvanically to two transmission line resonators which are then connected by a superconducting quantum interference device. Our work paves the way for scalable holonomic quantum computation in ultrastrongly and deep strong coupled systems.

Improved power output of quantum-mechanical Carnot engine via shortcuts to adiabaticity

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We present the optimal power output of quantum-mechanical Carnot engine proposed by Bender, Brody and Meister[1], in which the two states are considered in the box expansion/compression. As compared to the linear-in-time trajectory, the quasi-adiabatic approach provides the fastest adiabatic box expansion/compression, which gives maximal power output for a given efficiency. Moreover, the shortcuts to adiabaticity have been applied to optimize the power output for a given supplementary potential based on counter-diabatic driving. We also find that the extra work caused by the auxiliary potential is due to non-adiabatic force essentially. The main objective of this workshop is to provide a comprehensive review of the current status and future directions of research on quantum optics and quantum information. The setup of the workshop should allow free interactions among experts from different fields, and exchanges between experimentalists and theorists.

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Optomechanical effects in rotating frame

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Opto-mechanically induced transparency is studied in a rotating frame. It is found that rotation rates in the order of 10-3 Hz can signicantly modify the OMT window. An analytic parameter, in terms of frequency shift, is derived to recover the OMT transparency window in a rotating frame.

Quantum Fisher information as a signature of the superradiant quantum phase transition

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The single-mode Dicke model is well known to undergo a quantum phase transition from the so-called normal phase to the superradiant phase (hereinafter called the 'superradiant quantum phase transition'). Normally, quantum phase transitions can be identified by the critical behavior of quantities such as entanglement, quantum fluctuations, and fidelity. In this talk, we present out recent work about the quantum Fisher information (QFI) [1] and its behavior of both the field mode and the atoms in the ground state of the Dicke Hamiltonian [2]. For a finite but large number of atoms, we show that near the critical atom-field coupling, the QFI of the atomic and the field subsystems can surpass their classical limits, due to the appearance of nonclassical quadrature squeezing [3]. As the coupling increases far beyond the critical point, each subsystem becomes a highly mixed state, which degrades the QFI and hence the ultimate phase sensitivity. In the thermodynamic limit, we present the analytical results of the QFI and their relationship with the reduced variances of the field mode and the atoms. For each subsystem, we find that there is a singularity in the derivative of the QFI at the critical point, a clear signature of the quantum criticality in the Dicke model.

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Shortcuts to adiabatic state control in three-level systems with SU(2) symmetry

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Shortcuts to adiabaticity have been proposed to speed up the adiabatic passage in quantum systems. Among the techniques, the counter-diabatic driving provides the supplemental interaction to achieve the adiabatic-like state transfer but within a finite short time. However, it is found in some experiments that the phase mismatching between laser and magnetic fields results in the inefficiency. In this paper, we address counter-diabatic driving for state transfer in three-level systems in the large detuning case. By using adiabatic elimination, we derive the counter-diabatic interaction for the effective two-level system, and apply the unitary transformation to cancel it. This allows to modify the pulses for achieving shortcuts to adiabatic population transfer in three-level systems without applying the additional coupling.

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Simulation of Zitterbewegung by modelling the Dirac equation in Metamaterials

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Fundamental properties of physics can be studied in relativistic quantum field theory, but the experimental implementation and numerical modelling of these processes demand extended efforts. In our theoretical study, we demonstrate that relativistic quantum dynamics can be emulated by electrodynamics in a tailored metamaterial structure. [1] To do this, we identify a plane-wave expansion of the electromagnetic field with the plane-wave spinor expansion of the effective Dirac equation. [2] We develop a theory description for the association of electrodynamics and relativistic quantum dynamics and explain, how the electromagnetic field can be related to the wave function. We also discuss how the electromagnetic excitation can be injected at the metamaterial boundaries and based on that we show the Zitterbewegung in a numeric simulation, which is a genuine relativistic effect of relativistic quantum wave equations. Our theory is verified by a comparison with an analytic solution of the exact Dirac equation.

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The surface plasmon resonance of composite nanostructure consisting of a metal core and a coherent atomic medium shell

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The optical properties of a nanoparticle with a core-shell structure, consisting of a silver core and a multilevel-atoms shell, are investigated in the framework of quasi-static and Maxwell-Garnett approximation. In particular, we studied the local field enhancement and the optical extinction and scattering of the composite nanoparticle. It was shown that the extra-narrow and multi-peaks structure scattering and extinction spectra can be obtained. The coherent driving allows us to control the surface plasmon resonance modes including frequency shifting and intensities by manipulating the coherent medium. It provides the potential applications of plasmonic nano-structures for high-sensitive frequency detection.