QUANTUM TECHNOLOGIES

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Introduction to quantum technologies: quantum computation, quantum simulation, quantum communication, and quantum metrology.

Introduction to quantum platforms: cavity quantum electrodynamics, trapped ions, optical lattices, and superconducting circuits.

Cavity quantum electrodynamics: Jaynes-Cummings model, three-level atoms and adiabatic elimination, atom-photon selective interactions, quantum Rabi model, microwave cavities, optical cavities, and measurement techniques.

Trapped ions: basics on ion trapping and motional cooling, Lamb-Dicke regime, carrier excitation, red-sideband excitation, blue-sideband interaction, state reconstruction and measurement techniques.

Introduction to quantum computation and quantum simulations with ion traps: one-qubit and two-qubit gates for quantum computing, quantum simulation of the Dirac equation and quantum Rabi models, scalability issues.

Superconducting quantum technologies: Superconducting technologies are among the most promising options to achieve large-scale controllable quantum devices. This part of the course covers Coulomb-blockade physics and the Josephson effect, which are the essential ingredients for the design of superconducting nanocircuits. Further topics are a general discussion of superconducting qubits as well as an outline of circuit quantum electrodynamics. This part will be self-contained and should be accessible with standard knowledge of non-relativistic quantum mechanics and classical electrodynamics.

Single-electron effects: discreteness of electric charge, the single-electron box, Coulomb blockade, single-electron transistors, Lagrange formalism.

Josephson effect: brief introduction to superconductivity and the London two-fluid model, derivation of Josephson effects a la Feynman, Hamiltonian of Josephson junction, commutation relations for charge and phase.

Superconducting artificial atoms: Hamiltonian, characteristic energies, spectrum.

Superconducting qubits: derivation and discussion of two-level charge-qubit Hamiltonian, manipulation by external AC fields, other qubit types: transmon, flux qubit.

Harmonic oscillator circuits: design of circuits, equations of motion, Hamiltonian formalism and quantization, typical regimes for superconducting circuits.

Transmission line resonators: wave equation for voltage and current, quantization.

Circuit QED: combination of superconducting qubits + transmission line resonators, derivation of circuit QED Hamiltonian.