

PHY 631 Quantum Information Physical Systems and Materials Spring 2026 (1-3 credits)

Instructor: Prof. Qiang Li
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Meeting Time and Place: Wednesday 3:30 – 6:20 pm, Physics B131
Office Hour: Wednesday 6:20 - 7:20pm, Physics B143
Grades: Homework 50%, Participation 20%, Final presentation 30%
Required Textbooks: None. The instructor's lecture notes provided when available
Recommended: Quantum Computation and Quantum Information, M. Nielsen and I. Chuang (Cambridge University Press) and Review articles

Course Description:

This course will cover various physical systems and materials currently used for quantum information processing. It is divided into a few modules, including quantum computers based on superconducting qubits, solid-state spins, photons, trapped ions, and topologically protected states, and also including quantum communications and networks. The course aims to bridge the gap between the physical principles and the state-of-the-art and future quantum information technologies.

This course has an emphasis on how to build and perform various quantum information experiments, as well as how to characterize materials used in quantum information systems. Experts in the field of quantum information science and technology may be invited for guest lectures on some topics. Programming on publicly available quantum computers is demonstrated in real time and visits to quantum information laboratories are planned. Lab skills (at undergraduate senior lab level) and general knowledge of quantum information science can be helpful, but not required.

Topics/Syllabus:

- 1) Introduction to quantum information science and technology (QIST), current status and challenges for quantum computing and communication hardware
- 2) Quantum computing basics: qubits, quantum process tomography, quantum memory, quantum gates, error-corrections
- 3) Superconducting materials and properties relevant to QIST, Josephson junction, microwave cavities, measurements of coherence time and loss tangents

- 4) Superconducting circuits and qubit processor, Rabi oscillations, low temperature experimental methods, dilution refrigerators
- 5) Programing on quantum computer
- 6) Semiconductor quantum dot qubits and characterizations
- 7) Tools and experiments to characterize noise and defects in quantum materials
- 8) Photoluminescence and color centers in diamond
- 9) Cooling and trapping of atoms, trapped ion processors
- 10) Topologically protected systems and qubit, Majorana fermions, integer and fractional quantum Hall effect, chiral qubits and transductions
- 11) Topological superconductivity, semiconductor/semimetal-superconductor hybrid systems, experimental probes to topological states
- 12) Spins in quantum materials and characterizations, spin-orbit coupling, spin chain, quantum spin liquid, quantum magnets
- 13) Light matter interaction, nonlinear electro-optic effect, second harmonic and sum frequency generation
- 14) Single-photon source and photonic qubit experiments
- 15) Cavity quantum electrodynamics experiments
- 16) Quantum network and distributed quantum computing, quantum transduction, acoustic-optical modulators
- 17) Quantum communications, cryptography, teleportation, repeaters
- 18) Quantum applications in sensing, imaging, metrology, and simulations

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integrity, including categories of academic dishonesty please refer to the academic judiciary website at http://www.stonybrook.edu/commcms/academic_integrity/index.html.

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