MIT Physics graduate oral exam in Quantum Information

Format
The exam begins with a short (20-minute) blackboard presentation by the student on a question given about two weeks in advance. This presentation is meant as a conversation starter and the student should expect many questions during it. Building first on the topic in the presentation and then moving onto other topics, the committee will continue with questions on both technical details and high-level concepts Notes and outside references are not allowed.

Topics
The student should be able to comfortably discuss the material in 8.370, 8.371 and the textbook by Nielsen and Chuang.

A rough list of possible exam topics is below. Topics that go beyond N&C are have a (*).

Basics
Quantum states and density matrices
Tensor product, entanglement, Schmidt decomposition, partial trace, purifications
Dynamics (gates, Schrodinger equation, TPCP maps) and measurement.
SU(2). Calculations with single-qubit density matrices and gates.

Computation
Universal gate sets. Solovay-Kitaev.
Clifford gates and Gottesman-Knill.
Quantum circuits and circuit identities.
Measurement-based quantum computing (*)

Algorithms
Grover: How it works, the lower bound, applications to related problems like minimum-finding and counting, how to use it in a larger algorithm.
Quantum Fourier transform.
Phase estimation
Factoring, period finding and the hidden subgroup problem.
Hamiltonian simulation (*)
Adiabatic optimization and state preparation (*)
Variational quantum algorithms (*)

Experimental implementations
Basic descriptions of the state space and Hamiltonians for ion traps, neutral atoms (), and superconducting qubits (*).
Fermions and bosons

Noise

Example of quantum noise processes
Trace distance, fidelity and diamond norm.

Quantum error correction
Classical error correction. Linear codes.
Specific codes: 5-qubit code, 7-qubit Steane code, 9-qubit Shor code, toric/surface code (*)
Stabilizer and CSS codes
Subsystem codes such as Bacon-Shor (*)
Knill-Laflamme conditions
How encoding, decoding and error correction work in QECC.
FTQC considerations: transversal gates, error propagation, basic ideas of FTQC via code concatenation, magic states (*).

Information theory
Entropy and related measures (mutual information, relative entropy, conditional entropy, conditional mutual information).
Compression, HSW theorem (the statement is enough, you don't need the proof), entanglement concentration and dilution.
Mixed-state entanglement. PPT condition (*).

Nonlocality and cryptography
CHSH game
Quantum key distribution
No-go for quantum bit commitment (*)

Quantum complexity theory
QMA-completeness of the local Hamiltonian problem (*)
Quantum supremacy via random sampling (*)

Sample questions

Given a bipartite density matrix, what does it mean for it to be entangled? How can one test this, either mathematically or physically?

Explain a simple QECC and describe how it corrects errors.

Guidelines last revised Sep 2026.