MATH 4252
Quantum Information and Computing

Quantum information and computing are topics of fundamental scientific interest, lying at the intersection of modern mathematics and physics with close ties to computer science. Their main purpose is to achieve drastic improvements (speedup) in methods and algorithms for solving complex problems, relative to existing, `classical’ methods. To do so, one takes advantage of previously not exploited quantum properties, such as coherence and entanglement.

The fundamental building block is the qubit (quantum bit), which replaces the notion of the usual bit in classical information theory. Qubits exist as real objects in laboratories. They are manipulated, and evolve, according to the rules of quantum theory (the Schrödinger equation). Mathematically a qubit is quite simple, its state is given by a vector with two (complex) components. Nevertheless, a qubit encodes much more information than a classical bit, because it may be in a state which is a `superposition’ of the basic states 0/1. A quantum register is a system of several, say N, qubits. Its state is given by the (tensor) product of N vectors with two components. The qubits in a register can be `entangled’, or quantum correlated, allowing for very efficient simultaneous, nonlocal manipulation which are spread over the whole register.

The course is a basic introduction to this rapidly evolving field of science. The beginning of the course is dedicated to the basic formulation of quantum theory, tailored to the needs of quantum information and computing. No prior knowledge of quantum mechanics is necessary. We will learn the postulates of quantum theory, which say exactly what a state of a qubit (register) is, how a state evolves in the course of time and what it means to make measurements of a quantum register (readout). The mathematical formulation is built on basic linear algebra (vectors, matrices, eigenvalues). The postulates of quantum theory are essentially a dictionary telling us how to interpret facts and equations of linear algebra as physical properties of qubits. We will then discuss the notions of density matrix, entanglement, quantum gates, superdense coding, quantum teleportation, quantum algorithms, open systems, decoherence.

Texts. There are many excellent introductory books on the topic. A standard reference is: M.A. Nielsen & I.L. Chuang: *Quantum Computation and Quantum Information* (2nd ed.), Cambridge University Press.

Marks. The exact formula may vary, but is close to: assignments 30%, midterm test 20%, final exam 50%.

Calendar description: **4252 Quantum Information and Computing** (same as Physics 4852) covers postulates of quantum mechanics, matrix theory, density matrices, qubits, qubit registers, entanglement, quantum gates, superdense coding, quantum teleportation, quantum algorithms, open systems, decoherence, physical realization of quantum computers.
CR: Physics 4852
PR: MATH 2051 or Physics 3820