PHY-929, Quantum Computation

Credit Hours: 3-0
Prerequisite: None

Objectives and Goals: It is graduate course, which aims at students having basic knowledge on classical computing and quantum mechanics. The course introduces basic structure and procedures of quantum computation. It explains quantum speed up in computation and then its applications in Shor's factoring algorithm, Grover's search algorithm and quantum error correction. A section of the course is also dedicated to application of quantum gates in quantum information processing.

Core Contents: Quantum bits, quantum gates, quantum algorithms, quantum error correction, application to quantum information

Detailed Course Contents: Motivation. Quantum bits. Introduction to quantum mechanics, Density matrix, Schmidt decomposition, tensor products, quantum entanglement, Quantum measurement, Projective measurement, POVM, Introduction to computer science, how to quantify computational resources, Computational complexity, Decision problems and the complexity classes P and NP, A plethora of complexity classes, Energy and computation, Quantum gates: Quantum algorithms, Single qubit operations, Controlled operations Measurement, Universal quantum gates Quantum Gates: Simulation of quantum circuits, Quantum algorithms, Deutsch, Josza, Quantum Fourier Transform, factoring, order-finding, Application of Quantum Fourier Transform: Period finding, discrete logarithms, The hidden subgroup problem, Quantum Phase estimation, Bernstein Vazirani algorithm, Quantum Search algorithm: Grover's algorithm, Solving Linear equations HHL Algorithm, Quantum error correction: The three-qubit bit flip code, Three-qubit phase flip code, The Shor code, CSS codes, Stabilizer codes, Application to Quantum Information, QKD, Quantum Dense coding, quantum teleportation, Physical realization of quantum computers: overview of all and three in detail

Course Outcomes: At the end of the course, students will be able to

- understand basic principles of quantum computation
- understand most known quantum algorithms and their significance
- understand quantum error correction codes
- apply quantum gates to achieve quantum information processing

Textbook: Nielsen and Chuang, Quantum Information and Computation, Cambridge University Press, 2011.

Reference Books:

1. N. David Mermin, Quantum Computer Scienc: An Introduction, Cambridge University Press 2007.
2. G. Benenti, G. Casati and G. Strini, Principles of Quantum Computation and Information, Vol I&II, World Scientific 2007. (referred as BCS)
3. John Preskill, Lecture notes on Quantum Information and Computation http://www.theory.caltech.edu/~preskill/ph219/index.html#lecture

Weekly Breakdown		
Week	***Section***	***Topics***
1	Chapter 1 2.1-2.2	Motivation. Quantum bits. Introduction to quantum mechanics
2	Chapter 2.4-2.6	Density matrix, Schmidt decomposition, tensor products, quantum entanglement
3	2.2, 2.3	Quantum measurement, Projective measurement, POVM
4	Chap. 3	Introduction to computer science, how to quantify computational resources Computational complexity, Decision problems and the complexity classes P and NP, A plethora of complexity classes, Energy and computation
5	Chapter 4	Quantum gates: Quantum algorithms, Single qubit operations, Controlled operations Measurement, Universal quantum gates
6	4.6-4.7	Quantum Gates: Simulation of quantum circuits
7	Chapter 4 Handouts	Quantum algorithms, Deutsch, Josza
8	Chapter 5.1-5.3	Quantum Fourier Transform, factoring, order-finding
9	Chapter 5.4	Application of Quantum Fourier Transform: Period finding, discrete logarithms, The hidden subgroup problem,
10	Handout	Quantum Phase estimation, Bernstein Vazirani algorithm,
11	Chapter 6 6.1,6.2, 6.3	Quantum Search algorithm: Grover's algorithm,
12	Handout	Solving Linear equations HHL Algorithm
13	Chapter 10.1-10.5	Quantum error correction: The three-qubit bit flip code, Three-qubit phase flip code, The Shor code, CSS codes, Stabilizer codes
14	Chapter 4 (BCS)	Application to Quantum Information, QKD, Quantum Dense coding, quantum teleportation
15	Chapter 7 Handouts	Physical realization of quantum computers: overview of all and three in detail