PHY- 923 Quantum Information and Computation

Credit Hours: 3-0
Prerequisite: None

Objectives and Goals: It is graduate course, which aims at students having basic knowledge on quantum mechanics. The course introduces basic structure and procedures of quantum information and its applications. A section of the course is also dedicated to quantum computation and quantum error correction.

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

Detailed Course Contents: Motivation; Qubits, orthogonal states; Non orthogonal states; Stern Gerlach experiment, Qubit, Operators, Bloch Sphere; density operator for single qubit, Measurement of a density matrix of qubit, generalized measurements, POVM, Quantum Key distribution (using single qubits), System of qubits, Density matrix, faster than light communication, Quantum entanglement, Bell states, non separability of EPR pairs, Bell inequalities, maximal violation of Bell inequalities, Uses of entanglement: quantum key distribution (quantum no-cloning), quantum dense coding, quantum state discrimination, quantum teleportation, The Shannon entropy, classical data compression, Von Neumann entropy, quantum data compression, Accessible information, Quantifying entanglement: entanglement concentration and von Neumann entropy, the Peres separability criteria, Introduction to computer science, Turing machines, classical gates, complexity classes, Quantum computation: quantum circuits, quantum gates, simulations, Deutsch algorithm, Quantum search algorithm: the Grover's algorithm, Quantum Fourier transform, phase estimation and application to order finding and factoring, Quantum computation of dynamical systems, physical realization of quantum computers, Decoherence model for a single qubit, the bit-flip channel, the phase-flip channel, the bit-phase-flip channel, the depolarizing channel, amplitude damping, phase damping, de-entanglement

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

- understand basic principles of quantum information
- understand most known applications using entanglement
- understand quantum information theory
- apply quantum gates to achieve quantum information processing

Textbooks:

1. N. David Mermin, Quantum Computer Science: An Introduction, Cambridge University Press 2007. (referred as DM)
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

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

Weekly Breakdown		
Week	***Section***	***Topics***
1	JP Ch. 1, 2.2 BCS 2.1	Motivation; Qubits, orthogonal states; Non orthogonal states; Stern Gerlach experiment, Qubit,
2	JP 2.3, 2.4 BCS 5.1 Plenio 2.4	Operators, Bloch Sphere; density operator for single qubit
3	BH Ch. 5	Measurement of a density matrix of qubit, generalized measurements, POVM
4	Handout	Quantum Key distribution (using single qubits)
5	Plenio	System of qubits, Density matrix, faster than light communication?
6	JP 4.1	Quantum entanglement, Bell states, no separability of EPR pairs, Bell inequalities, maximal violation of Bell inequalities
7	JP 4.2	Uses of entanglement: quantum key distribution (quantum no-cloning), quantum dense coding, quantum state discrimination, quantum teleportation
8	BCS 5.7, 5.8	The Shannon entropy, classical data compression, Von Neumann entropy, quantum data compression, Accessible information
9	JP 5.5 BCS 5.12	Quantifying entanglement: entanglement concentration and von Neumann entropy, the Peres separability criteria
10	BCS Ch. 1	Introduction to computer science, Turing machines, classical gates, complexity classes
11	BCS Ch. 3 DM Ch. 4	Quantum computation: quantum circuits, quantum gates, simulations, Deutsch algorithm
12	BCS Ch. 3 DM Ch. 2	Quantum search algorithm: the Grover's algorithm
13	BCS Ch. 3 DM Ch. 3	Quantum Fourier transform, phase estimation and application to order finding and factoring
14	BCS Ch. 3	Quantum computation of dynamical systems, physical realization of quantum computers
15	BCS 6.1 DM Ch. 5	Decoherence model for a single qubit, the bit-flip channel, the phase-flip channel, the bit-phase-flip channel, the depolarizing channel, amplitude damping, phase damping, de-entanglement