Quantum Optical Technologies

Syllabus autumn 2014

1. **Introduction (4 hours)**
    - 1.1 Goals: why this course
    - 1.2 Learning Quantum ideas
    - 1. 3 Quantum Theory: The language of physics
    - 1.4 Overview (review) of algebra of matrix
2. **Basic principles of Quantum Theory revisited (8 hours)**
    - 2.1 The quantum description of a system: states and operators
    - 2.2 Quantum optics: Photons, electrons, atoms
    - 2.3 Different types of states: Coherent, thermal, one and two-photon states
    - 2.4 Information and interference, distinguishability and orthogonality
    - 2.5 Cloning in quantum theory: the No-cloning theorem
    - 2.6 Quantum Cryptography I: the Bennett-Brassard (BB84) protocol
3. **Entanglement and some applications: Teleportation and Quantum Cryptography (12 hours)**
    - 3.1 Entangled states: Quantum correlations and its measurement
    - 3.2 Entanglement in polarization as example. Entanglement in other scenarios
    - 3.3 Experimental implementations: entanglement in-the-lab and out-of-the-lab
    - 3.4 Teleportation
    - 3.5 Quantum Cryptography II: the Ekert-91 Quantum key Distribution (QKD) protocol
4. **Fundamental test of how Nature works (8 hours)**
    - 4.1 Bell's inequalities and its meaning
    - 4.2 Experimental implementations of the Bell's inequalities
    - 4.3 Greenberger-Horne-Zeilinger (GHZ) states
5. **Decoherence: implications for the implementation of quantum technologies (6 hours)**
    - 5.1 Decoherence: the appearance of the classical world. Examples
    - 5.2 Schrodinger-cat states
    - 5.3 Implications for the implementation of Quantum Technologies
    - 5.4 Experiments
6. **Quantum Computing (24 hours)**
    - 6.1 Introduction. What classical/quantum computers can and cannot do. P and NP problems.
    - 6.2 Quantum Circuits Basic Elements.
        - 6.2.1 Operators and quantum gates. Universal Basis. Pauli's matrices. Bloch sphere and Rotational matrices. 2-qubit gates and 3-qubit gates.
        - 6.2.2 Quantum measurements. Measurement operators. Basis-state, projection and POVM measurements.
        - 6.2.3 Quantum Circuits. Notation and Basic Examples: superdense coding, teleportation, teleportation of a CNOT.
    - 6.3 Quantum algorithms
        - 6.3.1 Quantum parallelism. An academic example: the Deutsch's algorithm
        - 6.3.2 Shor's algorithm: breaking RSA.
        - 6.3.3 Grover's algorithm: faster searching database
    - 6.4 Quantum Processors
        - 6.4.1 What is a quantum computer? DiVincenzo criteria. Is D-Wave really the first QC?
        - 6.4.2 Optical Quantum Computer
        - 6.4.3 Ion-trap Quantum Computer
        - 6.4.4 Nuclear Magnetic Resonance Quantum Computer.

BIBLIOGRAPHY

Basic

Textbooks in quantum information

1) Michael A. Nielsen and Isaac L. Chuang, *Quantum Computation and Quantum Information*, Cambridge University Press 2000.
2) Emmanuel Desurvire, *Classical and Quantum Information: an Introduction for the Telecom Scientist*, Cambridge University Press 2009.
3) N. David Mermin, *Quantum Computer Science: an Introduction*, Cambridge University Press 2007.

Textbooks in quantum theory

4) Leonard Susskind, *Quantum mechanics: the theoretical minimum*, Penguin books 2014
5) Christopher Gerry and Peter Knight, *Introductory Quantum Optics*, Cambridge University Press 2004.
6) Claude Cohen-Tannoudji, Bernard Diu and Franck Laloe, *Quantum Mechanics Vols. I and II*, John Wiley and Sons 1977.
7) Richard P. Feynman, *Feynman Lectures on Physics vol. III*, Addison Wesley 1965.
8) Asher Peres, *Quantum Theory: Concepts and Methods*, Kluwer Academic Publishers 1998.

Complementary

Books addressing specific topics of the course in an excellent manner

9) *Christopher C. Gerry and Kimberley M. Bruno, The Quantum Divide: Why Schrodinger Cat is Either Dead or Alive, Oxford University Press 2013.*
10) *Brian Cox and Jeff Forshaw, The Quantum Universe: Everything that Can Happen Does Happen, Penguin Books 2011.*
11) Valerio Scarani, Chua Lynn and Liu Shi Yang, *Six Quantum Pieces*, World Scientific 2010.
12) Valerio Scarani, *Quantum Physics: a first encounter. Interference, entanglement and reality*.
13) Scott Aaronson*, Quantum Computing Since Democritus, Cambridge University Press 2013.*

EVALUATION

Two exams during the course (weights: 35% + 35%)
First exam (E1): During the exam week from 29nd October to 5th November
Second exam (E2): Last day of the course Wednesday the 17th December
One final exam (EF), which is optional (January 2015)

One assigned project (P): written report and public presentation
Presentation during January 2015, one day of exams.
(Weight: 30%)

Mark=MAX (0.35*E1+0.35*E2, 0.7*EF)+0.3*P