Advanced Quantum Mechanics
2021/22
Lecture topics

Lecture	Topic
04/10/22	Introduction to the course. History of Quantum Computing. Platforms for quantum computing.
07/10/22	Circuit model for classical computation: input bits, output bits, gates. Examples of logical gates; universal set of gates. Reversible vs irreversible computation. Probabilistic classical computational model and vector formulation.
10/10/22	QM+SR: Newtonian mechanics and the Galileo principle of relativity. Galilei transformations. Maxwell's electrodynamics and the lack of Galilei invariance.
11/10/22	Probabilistic classical computational model and vector formulation - continuation.
13/10/22	Introduction to quantum computing: the beam splitter. Brief review of linear algebra.
14/10/22	Review of linear algebra - continuation. The rules of Quantum Mechanics.
17/10/22	QM+SR: The experiments of Fizeau and of Michelson-Morley. Lorentz theory to explain the null results of experiments, and its consequences. Relativity according to Einstein.
20/10/22	Elements of quantum computation: register, gates and measurements. Single qubit gates; the CNOT gate and the Hadamard gate. Exercises and examples of a decomposition of a two-qubit matrix into single qubit gates and CNOT.
21/10/22	The CCNOT and Fredkin gates as examples of three-qubit gates. Lemma: Every unitary matrix can be decomposed at product of two-level unitary matrices. Examples.
24/10/22	QM+SR: Derivation of the Lorentz transformations from homogeneity and isotropy of spacetime. Length contraction, time dilation.
25/10/22	Proof with examples that a generic two-level unitary matrix can be decomposed as a product of CNOT and C-U operations, and their variants. Proof that a U(2) matrix can be decomposed as a product of CNOT and single qubit gates.
27/10/22	Presentation of the IBM Q platform and examples.
28/10/22	The general structure of quantum algorithms. The Deutsch algorithm. The Deutsch-Jozsa algorithm.
31/10/22	QM+SR: relativity of simultaneity. The ladder-barn paradox. The twins' paradox revisited.
07/11/22	QM+SR: The twins' paradox revisited (continuation). Exercises. Transformation of velocities and accelerations in Special Relativity.
08/11/22	The Bernstein-Vazirani algorithm. Exercise about the Deutsch-Jozsa algorithm. Grover's algorithm.
10/11/22	Grover's algorithm (continuation). Exercises.
11/11/22	The Quantum Integral Transform and the Quantum Fourier Transform (QFT). Walsh-Hadamard transform e selective phase rotation transform. Shor's factorization algorithm and period finding (quick introduction).
14/11/22	QM+SR: Uniformly accelerated motion and Rindler observer. Relativistic momentum and energy.
15/11/22	The density matrix: meaning of the diagonal and off-diagonal elements and examples.
17/11/22	Quantum lab on the IBM Q platform.
18/11/22	The statistical operator and its properties. Pure stare and statistical mixtures and their characterization. The Bloch sphere. Quantum Mechanics in the language of the density matrix: the von Neumann equation; selective and non-selective measurements.
21/11/22	QM+SR: Relativistic force. Newton's laws in Special Relativity. Exercises
22/11/22	The reduced density matrix: definition and properties. Introduction to decoherence.
24/11/22	Strongly continuous semigroups and quantum dynamical semigroups (QDS). Kraus decomposition.
25/11/22	Kraus decomposition (continuation). Complete positivity. Examples - bit-flip, phase-flip, bit-phase-flip, amplitude damping, and generalized amplitude damping channels.
28/11/22	QM+SR: 4-vectors and the Minkowski space-time. Electricity + Relativity implies Magnetism. Relativistic formulation of electrodynamics.
29/11/22	Quantum lab on the IBM Q platform.

01/12/22	Derivation of Lindblad's equation. Comments and examples.
02/12/22	Lindblad's dynamics: Relaxation to zero and to finite temperature.
05/12/22	QM+SR: Completeness and Incompleteness in Quantum Mechanics. The EPR paradox. The telepathy game of Alice and Bob.
06/12/22	Quantum lab on the IBM Q platform.
07/12/22	QM+SR: Quantum non-locality: Bell's theorem
12/12/22	QM+SR: No faster-than-light-signaling theorem. Quantum teleportation.
13/12/22	Discussion of the project on quantum computation and concluding remarks
14/12/22	QM+SR: The FLASH cloning machine and the no-cloning theorem. QKD and the BB84 protocol.