

Advanced Quantum Mechanics

2021/22

Lecture topics

Lecture	Topic
04/10/21	Introduction to the course. Circuit model for classical computation: input bits, output bits, gates. Examples of logical gates; universal set of gates. Reversible vs irreversible gates.
06/10/21	Probabilistic computational model and vector formulation. Examples.
07/10/21	Quantum physics for a new model of computation. Review of linear algebra: vectors, basis vectors, computational basis. Inner product, norm. Dual vectors. Dirac formalism and corresponding matrix formalism.
11/10/21	Linear operators: Hermitian and unitary operators. Spectral decomposition of Hermitian operators: eigen-states and eigen-values. Spectral resolution of the identity. Pauli matrices: eigen-values, eigen-states, eigen-projectors and exponentiation of the matrices. Examples.
13/10/21	Tensor product of two Hilbert spaces: vectors and operators; main properties. Examples. Separable states and entangled states. Schmidt decomposition. The postulates of quantum mechanics. States, Schrödinger evolution, observables as Hermitian operators, the Born rule and the collapse of the wave function after the measurement.
14/10/21	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. The CCNOT and Fredkin gates as examples of three-qubit gates.
15/10/21	QM+SR: Newtonian mechanics and the Galileo principle of relativity. Galilei transformations. Maxwell's electrodynamics and the lack of Galilei invariance
18/10/21	Lemma: Every unitary matrix can be decomposed at product of two-level unitary matrices. Examples. Proof with examples (for 2 and 3 qubit gates) that a generic two-level unitary matrix can be decomposed as a product of CNOT and C-U operations, and their variants.
21/10/21	Proof that a $U(2)$ matrix can be decomposed as a product of CNOT and single qubit gates. The general structure of quantum algorithms.
22/10/21	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. Derivation of the Lorentz transformations from homogeneity and isotropy of spacetime.
25/10/21	The Deutsch algorithm. The Deutsch-Jozsa algorithm. The Bernstein-Vaziarani algorithm.
27/10/21	Presentation of the IBM Q platform and examples.
28/10/21	Exercise about the Deutsch-Jozsa algorithm. Grover's algorithm.
29/10/21	QM+SR: Derivation of the Lorentz transformations from homogeneity and isotropy of spacetime (continuation). Length contraction, time dilation, relativity of simultaneity. The ladder-barn paradox.
04/11/21	The Quantum Integral Transform and the Quantum Fourier Transform (QFT). Circuit implementation of the QFT; number of resources and exponential speedup.
05/11/21	QM+SR: The ladder-barn paradox (continuation). The twins' paradox revisited. Transformation of velocities in special relativity.
08/11/21	Walsh-Hadamard transform e selective phase rotation transform. Shor's factorization algorithm and period finding.
10/11/21	Exercises on the IBM Q platform.
11/11/21	Shor's algorithm (continuation). The density matrix - introduction
12/11/21	QM+SR: Uniformly accelerated motion and Rindler observer. Relativistic momentum and energy.
15/11/21	The statistical operator and its properties. Pure stare and statistical mixtures and their characterization. The Bloch sphere.
17/11/21	Exercises on the IBM Q platform.
18/11/21	The reduced density matrix: definition and properties. Introduction to decoherence.
19/11/21	Relativistic force. Newton's laws in Special Relativity. 4-vectors and the Minkowski space-time
22/11/21	Strongly continuous semigroups and quantum dynamical semigroups (QDS). Kraus decomposition.

24/11/21	Kraus decomposition: examples - bit-flip, phase-flip, bit-phase-flip, amplitude damping, and generalized amplitude damping channels. Complete positivity
25/11/21	Derivation of Lindblad's equation. Comments and examples.
26/11/21	QM+SR: Exercises on momentum and energy conservation.
29/11/21	Lindblad's dynamics: Relaxation to zero and to finite temperature. Microscopic derivation of collisional decoherence.
01/12/21	Exercises on the IBM Q platform.
02/12/21	Microscopic derivation of collisional decoherence (continuation)
03/12/21	QM+SR: Electricity + Relativity implies Magnetism. Relativistic formulation of electrodynamics. Exercises.
06/12/21	QM+SR: Completeness and Incompleteness in Quantum Mechanics. The EPR paradox. The telepathy game of Alice and Bob. Quantum non-locality: Bell's theorem
13/12/21	QM+SR: Bell's theorem (continuation). No faster-than-light-signalling theorem. Quantum teleportation.
15/12/21	QM+SR: The FLASH cloning machine and the no-cloning theorem. QKD and the BB84 protocol.
22/12/21	Discussion of the project on quantum computation and concluding remarks.