QUANTUM OPTICS AND INFORMATION

[Mikel Palmero & Mikel Sanz]

Fundamentals

Introduction (Chap. 1 of Gerry-Knight, 4 h). Scope and aim of the course: Quantum Optics as a generic vehicle for quantum information and technologies. History.

Field quantization (Chap. 2 of Gerry-Knight, 8 h). Quantization of a single-mode field. Quantum fluctuations of a single-mode field. Quadrature operators for a single-mode field. Multimode fields. Thermal fields. Vacuum fluctuations and the zero-point energy. The quantum phase.

Coherent states (Chapter 3 of Gerry-Knight, 8 h). Eigenstates of the annihilation operator and minimum uncertainty states. Displaced vacuum states. Wave packets and time evolution. Generation of coherent states. More on the properties of coherent states. Phase-space pictures of coherent states. Density operators and phase-space probability distributions. Characteristic functions.

Gaussian quantum states and simplectic notation (Serafini, 2 h). Introduction : continuous vs. discrete variables. Definition of continuous-variable quantum state; phase space; Wigner function and quantumness**;** Gaussian quantum states: Wigner and Characteristic Functions**;** Bi-linear Hamiltonians**;** Williamson Theorem**;** Single- and Two-Mode Quantum States**;** Negativity and Purity**;** Gaussian Measurements.

Light-Matter interaction (Chapter 4 of Gerry-Knight, 3 h). Atom–field interactions. Interaction of an atom with a classical field. Interaction of an atom with a quantized field. The quantum Rabi model; the Jaynes–Cummings model. The Jaynes–Cummings model with large detuning: a dispersive interaction.

Applications

Quantum metrology (Kok-Lovett, 5 h)
From Classical to Quantum Fisher Information: the Continuous-Variable Case; Quantum Fisher Information for Gaussian States; Quantum parameter estimation and hypothesis testing; Entanglement-Assisted Parameter Estimation; Hypothesis Testing; Example: Quantum Illumination; Heisenberg-Limit Interferometry

Quantum computation (Kok-Lovett, 6 h)
Fundamentals of quantum computation: From Boolean functions to Unitaries: Reversible Computation; The Circuit Model: Qubits & Basic Operations; Classical Theorems on Quantum Computation; Measurements: Single-Shot vs. Mean-Values. Quantum Computation in Quantum Optics: the single-photon case; Limitations of Quantum Optics for Quantum Computing: N-port Interferometers; Qubit Codification and Basic

Operations: Knill-Lafflame-Milburn Protocol; Post-Selection and Probabilistic Gates. Quantum Computation in Quantum Optics: continuous variables; Quantum States: Squeezed States; Single-Mode Gates; Entanglement: Two-Mode Operations; The Gottesman-Knill Theorem for Continuous Variables

Quantum communications (Kok-Lovett, 4 h)
Remote state preparation and quantum teleportation; Quantum Teleportation: From Qubits to Continuous-Variables; Improvements: Entanglement Swapping and Distillation; Remote State Preparation: From Qubits to Continuous-Variables. Quantum Cryptography: Quantum Key Distribution with Continuous Variables

Bibliography

Introductory Quantum Optics by Gerry and Knight (Cambridge), Chapters 1, 2, 3, 4, 8, and 10.

Quantum Continuous Variables by Alessio Serafini (Taylor and Francis)

Introduction to Optical Quantum Information Processing by Pieter Kok and Brendan W. Lovett (Cambridge)

Additional material is provided via Egela (other books, articles, news, and auxiliary notes for specific topics).

Assessment

The assesment will be a continuous evaluation of homework, where students will have to hand mathematical exercises and short essays.