PHY-918 Introduction to Quantum Optics

Credit Hours: 3-0

Prerequisite: Quantum Mechanics

Course Objectives: The main objective of this course is to introduce basic concepts of the quantum optics, and their applications to quantum technologies, such as quantum information processing and quantum metrology.

Core Contents: The course mainly covers core topics regarding quantization of electromagnetic fields, introduction of the field operators, relevant quantum states of light, and their quantum fluctuations, and atom-field interaction, both, in semi-classical and purely quantum-mechanical regimes. Then it includes the nonclassical light and its applications to quantum technologies, such as, quantum information processing and quantum technologies.

Detailed Course Contents:

The detailed contents are given the table below along with week-wise breakdown.

Textbooks:

1. Christopher Gerry and Peter Knight, Introductory Quantum Optics, Cambridge University Press (2005). (referred as GK)
2. Girish S. Agarwal, Quantum Optics, Cambridge University Press (2012). (referred GSA)

Reference Books:

1. M. O. Scully and M. S. Zubairy, Quantum Optics; Cambridge University Press, 1997.
2. W. P. Schleich, Quantum optics in phase space, Wiley-VCH Verlag 2001.
3. L. Mandel and E. Wolf, Optical Coherence and Quantum Optics, Cambridge University Press, New York, 1995.

Weekly Breakdown

Week	***Section***	***Topics***
1	Handouts, GK 2.1	Introduction, Energy and Hamiltonian of classical electromagnetic field, Quantization of electromagnetic field
2	GK 2.2, 2.3,2.4, 2.6	Quantum fluctuations of a single-mode field, Quadrature operators, Multimode fields, Vacuum fluctuations and the zero-point energy
3	GK 3.1, 3.2, 3.3,3.4	Coherent states as: Eigenstates of the annihilation operator, minimum uncertainty states, Displaced vacuum states, Wave packets and time evolution, Generation of coherent states
4	GK 3.5, 3.6	Properties of coherent states, non-orthogonality, over-completeness, Phase-space pictures of coherent states
5	GK 3.7, 3.8	Density operators and phase-space probability distributions, Glauber-Sudarshan P function, Q function, Characteristic functions, Wigner Function
6	Handouts, GK 4.1, 4.2	Atom–field interactions, Gauge transformations, dipole approximation, Interaction of an atom with a classical field,
7	GK 4.3, 3.4	Interaction of an atom with a quantized field, The Rabi model
8	GK 4.5, 4.7	Fully quantum-mechanical model; the Jaynes–Cummings model, Density-operator approach: application to thermal states
9	GK 4.8, 4.9	The Jaynes–Cummings model with large detuning: a dispersive interaction
10	GSA 5.1, 5.2, 5.3	Quantum mechanics of beam splitters, Beam splitter transformation equivalent to evolution under a Hamiltonian, Transformation of states by the beam splitter
11	GSA 5.4, 5.5,5.6,5.7	Transformation of photon number states by a beam splitter, Single photons at beam splitters, Pairs of photons at beam splitters, Generalization of the Hong–Ou–Mandel interference to N photons from both ports of the beam splitter
12	GSA 5.11, 5.12,5.15	Transformation of quantized light fields by phase shifters, The Mach–Zehnder interferometer, Two-photon Mach–Zehnder interferometer

13	GSA 2.1, 2.2	Nonclassical light, quantification of nonclassicality, Mandel Q-parameter, Phase-dependent measure of nonclassicality-squeezing parameter S, squeezed states, squeezed vacuum states, squeezed coherent states, Entangled coherent states,
14	GSA Ch.3	Gaussian and Non-Gaussian States
15	Handouts	Applications of nonclassical light to quantum metrology, quantum phase-estimation, Standard quantum limit in phase-estimation, beating the standard quantum limit