Basics of quantum optics

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Goals and objectives

The goal of the lecture course is to present the quantitative description of basic experiments in quantum optics.
The main objectives are the following:
- description of various quantum states of light;
- description of quantum state transformation in linear and nonlinear optical processes;
- description of quantum noise in light detection.

Syllabus

Lecture 1. Introduction.
Quantum optics as a part of quantum physics. Avoiding ultraviolet catastrophe. Quantum state as a new concept of knowledge. Main rules and recipes of quantum physics. Schrodinger's and Heisenberg's way.

Lecture 2. Second quantization.
Second quantization: from photon wave-function to states of e-m field. Light field as a quantum oscillator. Creation and annihilation operators. Fock-states as a basis in the space of light states.

Lecture 3. Coherent states of light.
Insufficiency of N-photon states in laser physics. Definition and properties of coherent states of light. Shift operators. Quasiprobability functions.

Lecture 4. Squeezed states of light.
Definition and properties of squeezed states of light; shift operators. Quantum-state tomography by homodyne measurements.

Lecture 5. Thermal light.
Method of density matrix in optics. Properties of thermal states of light. Imitation of thermal light by pure state.

Lecture 6. Schrodinger-cat states of light.
Definition and properties; appearance of quantum interference. 'Schrodinger-cat state' versus the state of 'Schrodinger cat'. Entanglement in quantum physics.

Lecture 7. Beam-splitter.
Splitting of light beam as a primary problem in quantum optics. Solution by Schrodinger's and Heisenberg's modus operandi. Relation to light attenuation.

Lecture 8. Photoelectron statistics.

Quantum efficiency of photodiode. Transformation of photon distribution into electron distribution. Moment generated functions. Projection operator.

Lecture 9. Amplification of light.

Heisenberg picture of light amplification. Quantum noise limit in amplification. Phase insensitive and phase sensitive amplification. Quasiprobability functions of output light.

Lecture 10. Notes.

Quantum state formation in nonlinear optical processes.
QND measurements.

Seminar 1. Photodiode

Photodiode as a key element of quantum measurements. Photodiode characteristics. Noise in photodetection: noise of dark current, thermal noise, light noise. Standard quantum level of light noise.

Seminar 2. Methods of photodetection.

Direct photodetection: feeble light detection, detection of light modulation. Heterodyning of light: limit of sensitivity.

Seminar 3. Homodyning of light.

Detection of amplitude and phase modulation. Measurements of light quadratures. Quantum tomography.

Seminar 4. Photon pairs.

Spontaneous parametric down-conversion as a unique source of photon pairs. Entanglement and paradox EPR.

Seminar 5. Single-photon source.

Brown-Twiss interferometry. Anticorrelation of photon ‘clicks’.

Literature

1. M.O.Scally, M.S.Zubairy. Quantum optics. Cambridge University Press, 1997.

2. M.Fox. Quantum Optics. An Introduction. Oxford University Press, 2006.

3. L.Mandel and E.Wolf. Optical coherence and quantum optics. Cambridge University Press, 1995.