THEORETICAL QUANTUM OPTICS (WS 13/14)

1. Quantization of the electromagnetic field

- Quantization of the electromagnetic field
- Fock states
- Coherent states.
    - Definition
    - Displacement operator
    - Relation between Fock and coherent states. Poissonian distribution
- Squeezed states
    - Quadratures
    - Minimal uncertainty states. Squeezed states
    - Squeezing operator. Squeezing
    - Photon number distribution
    - Squeezing and the variance of the electromagnetic field

2. Atom-light interaction

- Quantization of the electron wave field
- Dipole approximation
- Two-level approximation
- Rotating-wave approximation
- Pseudo-spin. Jaynes-Cummings Hamiltonian
- Rabi oscillations. Dressed states
- Collapse and revival of the oscillations
- Quasi-classical limit

3. Coherence properties of the electromagnetic field

- Photon detection
- Correlation functions
- Young's double-slit experiment
- First-order coherence
- Single-photon interference
- Photon-correlation measurements. Hanbury-Brown and Twiss experiment
- Second-order coherence
- Classical fluctuating fields
- Photon bunching
- Quantum mechanical fields. Antibunching
- Second-order correlations in squeezed states

4. Representations of the electromagnetic field

- Fock representation
    - Chaotic states
- P-representation
    - Examples
    - Averages of normally-ordered products
    - Second-order correlations
- Characteristic functions

- Wigner representation
    - Coherent states
    - Squeezed states
- Q-representation

5. Parametric amplifiers

- Hamiltonian
- Squeezing
- Second-order correlation function
- Wigner function

6. Stochastic methods

- Master equation
    - Derivation. Born and Markov approximations
- The damped harmonic oscillator
    - Master equation
    - Physical interpretation
    - Calculation of averages
- The quantum regression theorem
    - Derivation
    - Application to the damped harmonic oscillator

7. Spontaneous emission in a two-level atom

- Master equation
- Physical interpretation
- Einstein's A coefficient
- Time evolution of averages
- Lorentzian spectrum

8. Resonance fluorescence

- Master equation
- Optical Bloch equations
- Bloch vector and Bloch sphere
- Stationary state
- Fluorescence spectrum
    - Relation between atomic operators and electromagnetic operators
    - First order correlation function. Coherent and incoherent contributions
    - Mollow's triplet
    - Dressed-state formalism
- Second-order coherence of the fluorescence. Antibunching

9. Fokker-Planck equation

- Fokker-Planck equation for the damped harmonic oscillator in the P-representation
- General ideas concerning the Fokker-Planck equation
- Green's function for the Fokker-Planck equation of the damped harmonic oscillator in the P-representation

- Fokker-Planck equation for the characteristic functions
- Fokker-Planck equation for the Q and Wigner representation
- Evolution of the Q-representation for an initial squeezed state of a damped harmonic oscillator

<u>10. Mechanical effects of light on atoms</u>

- Spatially-dependent Bloch equations
- Force exerted by the laser on the atom
- Radiation pressure
- Dipolar force
- Understanding the dipole force in the dressed state picture

<u>11. Laser cooling</u>

- The idea of temperature
- Doppler cooling.
    - Intuitive idea
    - Friction coefficient. Optical molasses
    - Limits of Doppler cooling. Doppler temperature
- Sisyphus cooling
    - The idea
    - Limits of Sisyphus cooling
- Using dark states to cool atoms:VSCPT
- Photon reabsorption.
- Getting degeneracy with laser cooling at last. Invisibility cap experiments.

<u>11. Some ideas on ultracold gases</u>

- Trapping neutral atoms: dipole traps, MOT, magnetic traps
- Evaporative cooling
- Matter waves. Atom Optics: Atom interferometers
- Quantum degeneracy
- Bose-Einstein condensation
    - Ideal condensate. The idea
    - The role of interactions. Resonances.
    - The Gross-Pitaevskii equation
    - Nonlinear atom optics: solitons, collapse
- Optical lattices
    - Bands and gaps. Tight-binding: Wannier functions
    - Lattice models: example: Bose-Hubbard model
    - Spin models: example: XY model from hard-core lattice bosons