Theoretical Quantum Optics and Quantum Information
Heinrich-Heine-Universität Düsseldorf, SS 2021
Prof. Dr. Dagmar Bruß

Time and location: Mondays 12:30 - 14:30 (online via webex),
Wednesdays 08:30 - 10:30 (online via webex)
Beginning of lecture: *Monday, 12.04.21*
Problem class: (Giacomo Carrara, Sarnava Datta)
alternating with lecture (ratio 1:3), planned dates for problem classes:
21.4., 5.5., 19.5., 7.6., 21.6., 5.7., 19.7.

Content

0. *Introduction and reminder of important concepts in quantum mechanics*

I. *Quantisation of the electromagnetic field*

   1) Canonical Quantisation
   2) Number operator
   3) Quadrature operators
   4) Continuous limit

II. *Quantum states of the electromagnetic field*

   1) Fock states
   2) Coherent states
   3) Squeezed states
   4) Thermal states
   5) Phase space representations of the electromagnetic field (P-, Q-, Wigner function)

III. *Interaction between atom and field*

   1) Quantised Hamilton operator with interaction
   2) Approximations
   3) Jaynes Cummings model
   4) Spontaneous emission

IV. *Non-linear quantum optics and quantum correlations*

   1) Parametric downconversion
   2) Correlations
   3) 2-mode squeezing and quantum correlations

V. *Classical information versus quantum information*

   1) What is information?
   2) Qubits
   3) Composite quantum states: entanglement
   4) Time evolution, decoherence
   5) Measurements: projective measurements, POVM's
   6) Entanglement as a resource

VI. *Towards quantum computing: from quantum gates to simple quantum networks*

1) Classical gates, universality
2) Quantum gates, universality
3) Simple quantum networks: quantum adder, Bell measurement, Deutsch-Jozsa algorithm
4) Requirements for a quantum computer

VII. *Quantum cryptography*

1) Classical Cryptography
2) No-Cloning theorem
3) BB84 protocol
4) Entanglement based quantum cryptography
5) Eavesdropping strategies

VIII. *Entanglement theory*

1) Separability and entanglement
2) Distillability
3) Quantification of entanglement

IX. *Quantum information with continuous variables (CV)*

1) Two-mode squeezing and entanglement
2) Quantum teleportation with CV

Literature:

Quantum optics:

- U. Leonhardt, *Measuring the Quantum State of Light*, Cambridge University Press, 1997.
- L. Mandel and E. Wolf, *Optical Coherence and Quantum Optics*, Cambridge University Press, 1995.
- W. Vogel, D.-G. Welsch, and S. Wallentowitz, *Quantum Optics, An Introduction*, Wiley-VCH, 2001.
- D.F. Walls and G.J. Milburn, *Quantum Optics*, Springer-Verlag, Berlin, Heidelberg, 1994.

Quantum information:

- G. Alber et al (Editors), *Quantum information*, Springer Heidelberg (2001).
- G. Benenti, G. Casati, and G. Strini, *Principles of Quantum Computation and Information - Vol.1 + Vol. 2*, World Scientific Publishing Company (2004).
- D. Bouwmeester, A. Ekert, and A. Zeilinger, *The Physics of Quantum Information: Quantum Cryptography, Quantum Teleportation, Quantum Computation*, Springer-Verlag (2000).
- D. Bruß and G. Leuchs, *Quantum Information: From Foundations to Quantum Technology Applications*, Wiley-VCH (2019).
- M. Nielsen and I. Chuang, *Quantum Computation and Quantum Information*, Cambridge University Press (2000).
- A. Peres, *Quantum Theory: Concepts and Methods*, Kluwer Academic Publishers, Dordrecht (1998).