ITMO UNIVERSITY
Saint Petersburg, Russia

Department of Laser Physics & Optoelectronics

Foundations of Quantum information *(18 hours, in English)*

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Course Short Description

Nowadays Quantum Information is one of the liveliest field of research in modern quantum physics that closely connected with current technological achievements. The aim of this course is to give fundamental and practical knowledge for graduate students which assumed to have suffered through a course in quantum mechanics, statistical physics, quantum optics and specialize in quantum technologies, photonics and material science where implementation of quantum technologies are important. Within the course special attention is devoted to practical skills in solution and understanding of keystone problems in this area. Topics covered are: quantum approach to information science, the issue of quantum entanglement as quantum information processing resource, mostly important quantum algorithms demonstrating quantum supremacy and their physical realization, quantum computers and relevant technologies to be used, some versatile applications to quantum information processing in neighbor areas of research.

Course Content

1. Quantum information with discrete variables

1. Introduction. Prerequisites of quantum information. Classical and Quantum information processing. Complexity of algorithms. Classical (Boolean) and Quantum logic of computation.
2. Dirac formulation of quantum theory. Canonical variables, projection postulate. Density matrix formalism.
3. Qubits and their physical realization in optics, atomic physics and solid state physics. No-cloning theorem. One qubit operations.
4. Entanglement and Einstein-Podolsky-Rosen (EPR) correlations as a main QI resource. Bell inequalities and Bell States. Experimental demonstrations of EPR paradox in Physics.
5. Quantum gates with two and more qubits. Decoherence problem for qubits; some important approaches.
6. Quantum mechanics of linear (photonic) elements in physics, Mach-Zehnder interferometers and quantum metrology approach.

2. Quantum information with continuous variables.

7. EPR paradox with Hermitial quadratures and its realization in quantum optics.
8. Fidelity of QI processing and Wigner function. Optimal cloning of continuous variables.
9. The entanglement criteria verification for various physical systems.
10. Schrodinger cat paradox and it feasibility in quantum physics.

3. Quantum algorithms

11. Discrete Fournier transform. Quantum search algorithm. Shor’s factorization algorithm.

12. Quantum teleportation with discrete and continuous variables.
13. Quantum key distribution and quantum cryptography.
14. Quantum optimization algorithms and quantum games.
15. Quantum walks and relevant algorithms.
16. Quantum Machine Learning and relevant algorithms

4. Quantum computers and current quantum technologies

17. Physical perspectives of Quantum computers. Criteria for QC realization. Photonic and plasmonic quantum simulators. Single photon sources and efficient detectors.
18. Quantum computers with atoms and ions. Quantum computers with superconductor circuits and solid state devices.

Literature

1. Michael A. Nielsen, Isaac L. Chuang, Quantum Computation and Quantum Information Cambridge University Press, 2000
2. Gregg Jaeger, Quantum Information, An Overview, Springer Science+Business Media, LLC, 2007
3. Christopher Gerry, Peter Knight, Introductory Quantum Optics, Cambridge University Press, 2005
4. L. Mandel and E. Wolf, Optical Coherence and Quantum Optics, Cambridge University Press, 1995.
5. D. F. Walls, Gerard J. Milburn Quantum Optics Springer Science & Business Media, 2008.
6. S. M. Barnett and P. M. Radmore, *Methods in Theoretical Quantum Optics*, Oxford, 1997
7. Anthony Sudbery. Quantum Mechanics and the Particles of Nature: An Outline for Mathematicians Cambridge University Press 1986

Additional Literature, Topical Reviews

1. R. Loudon, P. Knight, Squeezed Light, Journal of Modern Optics 34:709-759 (1987)
2. Roman Schnabel, Squeezed states of light and their applications in laser Interferometers, Physics Reports 684 1 (2017)
3. Luca Pezz`e , Augusto Smerzi, Markus K. Oberthaler, Roman Schmied and Philipp Treutlein, Quantum metrology with nonclassical states of atomic ensembles, Rev. Mod. Phys.90, 035005-1 (2018)
4. T. D. Ladd, F. Jelezko, R. Laflamme, Y. Nakamura, C. Monroe & J. L. O'Brien, Quantum computers, Nature, 464, pages 45–53 ((2010)
5. Howard E. Brandt, Qubit devices and the issue of quantum Decoherence, Progress in Quantum Electronics 22, 257–370 (1998)
6. Jacob Biamonte, Peter Wittek, Nicola Pancotti, Patrick Rebentrost, Nathan Wiebe & Seth Lloyd, Quantum machine learning, Nature, volume 549, pages 195–202 (2017)