

QUANTUM STOCHASTIC PROCESSES

This course is for 4-5th year and graduate students. It is delivered in Department of Physics and ILC MSU since 1973. It is dedicated to systematic account of Quantum Stochastic Processes right in the form they are actually used in theoretical calculations of Quantum Open Systems. These methods turned to be the most useful in application to the problems of laser physics that is the reason why the most part of the specific examples are related to this field of applications of Quantum Theory. A specific feature of this course is that it is based on the most general concepts of mathematical theory of Stochastic Processes, being the same time adapted to the demands of students - physicists. This makes possible to get a systematic and very compact approach to the practically used technique. Some parts of course are based on original theoretical results obtained by the author, these parts being strictly fit to the general purpose of the course.

This course is distinguished among other approaches to the problems of Quantum Open Systems by its basic concept which proved to be an appropriate one to unify all the specific physical problems into a general theory and classify them as its specific applications.

The course consists of 12 up to 13 lectures, each is scheduled for two 45 minute classes.

REFERENCES

1. B. A. Grishanin, Quantum Electrodynamics for Radiophysicists, Moscow State University, Moscow, 1981.
2. L. Allen, J. Eberly, Optical Resonance and Two-Level Atoms, Dover, 1987.
3. J. A. Reissland, The Physics of Phonons, Wiley&Sons, London-New York-Sydney-Toronto, 1973.

The Lectures Program

LECTURE 1. Quantum probability theory as an essential element of quantum mechanics. Logic of quantum events. Calculation of probabilities and average values. Quantum probabilistic space. The most important representations of quantum systems. Hierarchy of quantum mathematical objects: state space, algebra of observables and algebra of superoperators.

LECTURE 2. Algebra of superoperators and its representations. Symbolic representation of superoperator transformations with use of substitution symbol. Algebraic rules of using symbolic representations of superoperator expressions, chronological ordering. Matrix representations. Application of Dirac notations to superoperator expressions.

LECTURE 3. The most important superoperators of quantum systems. Superoperator representation of two-level system dynamics. Wigner and Glauber representations. Quasiclassical asymptotics.

LECTURE 4. Open systems and quantum stochastic processes. Mathematical definition of an open system and quantum stochastic process. Markovian transition superoperator and calculation of single-instant average values within Heisenberg, Scrodinger and interaction representations. Necessary and sufficient conditions of physical realizability of a transition superoperator.

LECTURE 5. Markovian quantum stochastic processes. Formal definition of quantum markovian stochastic process. Quantum Smolukhovsky and Fokker-Plank Equations, generalized Liouvillian. Multi-instant averaging and multi-instant density matrices.

LECTURE 6. Markovian open systems. Temporal dynamics of reservoir, noise's correlation times, physical conditions of markovian dynamics. Calculation of the generalized Liouvillian for diffusion and jump types of quantum stochastic processes. Relativity of markovian approach and the role of an appropriate representation of dynamics. Physical meaning of classical and quantum noise models. The limitations of applicability of the classical model. Quantum specificity of non-markovian dynamics.

LECTURE 7. Application of general theory to a two-level atom. Dynamical model of the reservoir, interaction Hamiltonian and calculation of the relaxation operator. Bloch equations, calculation of fluorescence spectrum. Weak field limit.

LECTURE 8. Fluorescence spectrum of a two-level atom in a saturating laser field. Calculation of the fluorescence spectrum. Mollow spectrum structure and its experimental verification.

LECTURE 9. Redistribution of relaxation processes in a two-level system under the action of a strong laser field. Liouvillian of a two-level system in a strong laser field: markovian type of dynamics within the interaction representation. Laser field induced transformation of the relaxation parameters. Specific features of the fluorescence spectrum, suppression of collisional dephasing in gases and impurity centers. Inversion of a two-level atom by a purely monochromatic laser field and its experimental observation. The correspondence between the markovian and non-markovian interpretation of the effects of strong field induced effects of relaxation processes redistribution. Essentially non-markovian effects: Dicke narrowing, collapse of the rotational structure.

LECTURE 10. Quasiclassical approach to quantum fluctuations. Quasiclassical calculation of the open system Liouvillian and the responding Langevine equation. An application to dynamics of the electrically charged particles. Fluctuations, due to the recoil impulse, radiation excitation of betatron oscillations in accelerators. Recoil impulse effects in atoms.

LECTURE 11. Quantum measurement theory. The superoperators of non-demolition and destructive measurement procedures. A dynamical model of non-demolition quantum measurement device.

LECTURE 12. Phonon modes as open systems. Linear character of phonon modes' excitation. Anharmonicity as source of noise and relaxation. Quasiclassical nature of phonon damping and heat resistance. Quantum anharmonic excitations - biphonons, and its spectroscopic appearance.

LECTURE 13. Open systems in statistical physics. Gibbs distribution as a stationary state of an open system. Boltzmann equation for open systems.