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Abstract of the doctoral thesis

Tytuł: Nonlinear effects of quantum and classical dynamics due to the magneto-electric coupling in hybrid systems

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This doctoral dissertation is devoted to the study of selected hybrid systems in which coupling between different degrees of freedom gives rise to complex dynamical phenomena of both classical and quantum nature. The main objective of this work was to investigate the role of nonlinearity as well as magnetoelectric and optical interactions in the emergence of phenomena such as deterministic chaos, quantum entanglement, and effective thermalization.

In the first part of the dissertation, the nonlinear dynamics of a magnetoelectrically coupled system composed of a ferroelectric crystal and a magnetic nanodisk is analyzed. It is demonstrated that magnetoelectric coupling can induce parametric resonances, bifurcations, and deterministic chaos. Analytical tools such as the action--angle formalism, KAM theory, are employed to identify the transition from regular to chaotic dynamics. It is further shown that external control parameters enable tuning of the system’s dynamical behavior.

The second part focuses on a hybrid photon--magnon system with a photonic crystal structure. The semiclassical nonlinear dynamics is analyzed, and quantum correlations are investigated using logarithmic negativity as a measure of entanglement. A direct relationship between the phase-space structure and the generation of quantum correlations is established. It is found that maximal entanglement occurs near the boundaries separating different types of stationary points.

In the third part, the dynamics of a two-level atom coupled to a multimode optical system is studied. The atom is shown to act as a local probe of the thermalization process of optical modes. In the absence of thermalization, coherent dynamics with quantum revivals is observed, while for finite mode temperature decoherence and decay of the time-dependent part of the inversion occur. In the high-temperature limit, the system approaches an equilibrium state with equal population of atomic levels.

The obtained results demonstrate that coupling between different degrees of freedom in hybrid systems leads to the emergence of collective phenomena that can be controlled by appropriate choice of physical parameters. The dissertation provides a unified perspective on the transition from deterministic nonlinear dynamics to collective and statistical behavior in complex systems.