Abstract

Quantum mechanics introduced new terms to the scientific world, like quantum superposition and entanglement. These phenomena have no equivalents in classical physics. Exploration of these new resources has a fundamental role in the understanding of the quantum nature of the world. Application of these phenomena allows scientists to implement protocols that were never possible before, such as quantum teleportation and measurement without interaction. Quantum entanglement and nonclassical correlations of quantum states can be also used to design secure information processin protocols -- quantum cryptography and communication. Therefore it is very important to use proper tools for detecting nonclassical properties of quantum states and which guarantees effectiveness of all the above tasks.

The main goals of presented dissertation are investigation, development and implementation of new criteria for detecting quantum entanglement or nonexistence of classical description of correlation of quantum states.

The introduction describes the historical view of research on theory of quantum information and basic formalism. The next four chapters compose the main body of the dissertation. They are based on the following articles:
[A] K. Kostrzewa, W. Laskowski, T. Vertesi, „Closing the detection loophole in multipartite Bell experiments with a limited number of efficient detectors", Phys. Rev. A 98, 012138 (2018) [this paper was presented on the editorial list of suggested articles];
[B] M. Markiewicz, K. Kostrzewa, A. Kołodziejski, P. Kurzyński, W. Laskowski, „Investigating nonclassicality of many qutrits by symmetric twoqubit operators", Phys. Rev. A 94, 032119 (2016);
[C] K. Rosołek, K. Kostrzewa, A. Dutta, W. Laskowski, M. Wieśniak, M. Żukowski, „Clearer visibility Hong-Ou-Mandel effect with correlation function based on rates rather than intensities", Phys. Rev. A 95, 042119 (2017);
[D] W. Laskowski, M. Markiewicz, D. Rosseau, T. Byrnes, K. Kostrzewa, A. Kołodziejski, „Correlation-based entanglement criterion in bipartite multiboson systems", Phys. Rev. A 92, 022339 (2015).

Chapter three is dedicated to the new family of N-particles Bell inequalities with additional assumption that there are only k (k<N) effective detectors available. It presents also conditions which one must satisfy to violate such inequalities and the tradeoff relation between low efficiency and the time of experiment. Finally the scenario is considered in which some number of unknown detectors are completly destroyed.

The properties of the three level systems - qutrits are investigated in chapter three. New method of describing qutrits is based on the isomorphic relation between Hilbert space of single qutrit and the symmetric subspace of two - qubit Hilbert space. Such a transformation significantly simplifies mathematical description of a problem. New methods can be used to investigate nonlaclassical properties and entanglement of qutrit states.

Chapter four discusses new version of the Hong - Ou - Mandel (HOM) experiment. Classical description of this experiment puts some bound for visibility which can be obtained. It means that

visibillity can be a measure of nonclassicality of phenomena which occur in the experiment. Here, one proposes a new quantum description of HOM experiment which is based on redefinition of functions of correlations of results of measurements. New method is used to describe HOM experiment for the multiphoton state from parametric down conversion process. New description leads to the value of visibillity parameter higher than the classical limit and it will always exceed the latter in the traditional case.

Last chapter introduces the criterion of entanglement in multiboson system. The condition is based on geometrical criterion in terms of correlation tensor formalism. One can present a state of many bosons as a state of a single qudit (d-level system). Examples show that the new criterion is stronger than its spin equivalent.

At the very end of the dissertation there is a summary where the most important results are presented.