Abstract

With emerging quantum technologies and the progress in detection schemes it is nowadays of a broad scientific interest (and most probably it will be so in the future) to investigate the phenomena of entanglement of quantum light. This PhD dissertation is a contribution to this endeavour. It comprises of four papers preceded by an introduction. The papers are listed in PhD Series and contain results to which I contributed during my PhD studies. The introduction gives a brief description of new concepts proposed in aforementioned papers. The subject of the research is focused on analyzing nonclassical correlations of quantum optical states using the intensity measurements in context of polarisation and homodyne measurements. The papers are related with each other.

The first one "General mapping of multiqudit entanglement conditions to nonseparability indicators for quantum-optical fields" opens the series. The paper describes a general method that allows to construct a certain class of quantum-optical nonseparability indicators that use intensity-based correlations. The method is based on mappings between entanglement witnesses and Bell inequalities for qudits and analogous nonclassicality indicators for optical fields. The main idea of this concept is to replace the probabilities of the coincidence detection of a particle in a given detection channel by the ratio of intensity of the optical field registered in analogous channel divided by total local intensity. Mathematically speaking, the mapping replaces average values of Pauli observables, or of their correlations, by averages of standard and normalized Stokes observables, or of their correlations. In such a way we obtain methods of quantum-optical entanglement detection that nowadays are experimentally feasible. Also, it is noted in the paper that in the case of Bell's inequality our method is suitable only for normalized observables. The strategy for constructing Bell's inequalities for standard Stokes operators must be radically different, and is not discussed in the dissertation. The nonclassicity identifiers obtained in this way are tested for four-mode bright squeezed vacuum (BSV) and its generalization to states with a greater number of optical modes. Results presented in this paper make a significant contribution in the investigation of problems discussed in the three following papers.

The second paper "Simplified quantum optical Stokes observables and Bell's theorem" also presents new tools for detecting nonclassical correlations of optical fields. We proposed new observables – simplified Stokes operators – for Bell experiments. The idea of new observables is very simple and consists of on a comparison in which local detector related e.g. with the measurement of horizontal and vertical polarisation a higher intensity of light was recorded. Depending on the result, the value of ± 1 is assigned to such a measurement. When both local detectors register the same intensity, 0 is assigned. The new observables turn out to perform better than the normalized Stokes operators in the case of BSV and for the third-order radiation from parametric source i.e. so called "macroscopic GHZ state". It is worth noting that the proposed observables are experimentally realizable and their physical meaning is intuitive. Unfortunately, our observables are not useful for entanglement

witnesses,

Papers "Can single photon excitation of two spatially separated modes lead to a violation of Bell inequality via weak-field homodyne measurements?" and "Wave–particle complementarity: detecting violation of local realism with photon-number resolving weak-field homodyne measurements" concern the analysis and verification of statements regarding the nonclassicality of a single photon, aka "single-photon non-locality", using weak field homodyne measurements. We analysed two emblematic thought experiments: one proposed by Tan Walls and Collett (TWC) and the so called Hardy paradox. The general mapping from the first paper was used to check the validity of TWC and Hardy's claims. Now, when such experiments are not only gedanken anymore and turned real, it is relevant to clarify the controversy concerning the violation of Bell's inequalities by a single photon Solving this problem once for all has, apart from fundamental, also practical consequences. Single photon nonclassical properties could be used in device-independent quantum protocols. Hardy's experiment is indisputably correct, while in the case of TWC the hypothesis turned out to be erroneous. We present a model of local hidden variables for the TWC experiment, which means a no-go statement for unconditionally secure quantum cryptography with the setup and closes the problem of TWC experiment once for all. Still TWC correlations can be used to derive entanglement witnesses, that is done using the general mapping from the first paper. Apart from that, we present schemes enabling witnessing of non-locality of single photon that are modified versions of the TWC and Hardy experiments. It turns out that the violation of the Bell inequality by a single photon occurs only with very specific settings of tunable beamsplitters and also tunable amplitudes of the coherent states of the local oscillators.

The introduction to the papers is organized as follows. First four sections contain general remarks about observables for optical fields and bright squeezed vacuum. Sections 5-7 summarise new results from aforementioned publications. In section 5 is about the general mapping betwwen non-separability indicators for qudits and optical fields. Section 6 discusses simplified Stokes observables. Section 7 analyzes gedankenexperiments of Tan, Wall and Colett (TWC) and Hardy. Last section contains short description of possible continuation of the research line presented in this thesis.