ABSTRACT

A state of radiation field which cannot be described by a non-negative and well defined Glauber Sudarshan P-function is called nonclassical state. Squeezed state and antibunched state, which have been extensively studied in the last few decades, are examples of lowest order nonclassical state. Higher order nonclassicalities (e.g. higher order antibunching (HOA), higher order sub- Poissonian photon statistics (HOSPS), higher order squeezing (HOS)) are not yet studied rigorously. Different kind of higher order nonclassical phenomena are studied in the present thesis. The study is mainly focused on a particular class of quantum states which are known as intermediate states. Mutual relationship between different criteria of higher order nonclassicality is also studied. In that study it is found that the HOA, HOSPS and HOS are independent phenomenon.

Since the introduction of binomial state as an intermediate state, different intermediate states have been proposed in the literature. Different nonclassical effects have also been reported in these intermediate states but most of these reports are limited to lower order nonclassicality. Before the present study, higher order antibunching was predicted in only one type of intermediate state, which is known as shadowed negative binomial state. In the present thesis it is shown that the higher order antibunching can be seen in different intermediate states, such as binomial state, reciprocal binomial state, hypergeometric state, generalized binomial state, negative binomial state and photon added coherent state. We have also studied the possibility of observing the higher order antibunching in different limits of intermediate states. The effects of different control parameters on the depth of nonclassicality have also been studied in this connection and it has been shown that the depth of nonclassicality can be tuned by controlling various physical parameters. Potential single photon sources are expected to satisfy the criterion of HOA. As the intermediate states
mentioned above are shown to satisfy the condition of HOA, they form a set of potential SPSs. A quantitative measure of quality of single photon source is introduced here and different intermediate states are compared using that measure. Further, since the experimental generation of intermediate states is difficult, we have also shown existence of HOA in some simple optical systems (many wave mixing processes).

To study other criterion of higher order nonclassicality in general, a notion of higher order nonclassicality (in terms of higher order moments) is introduced. Under this generalized framework, conditions of HOS and HOSPS are derived. A simpler form of the HOS (Hong-Mandel type) criterion is derived by using an operator ordering theorem introduced by Pathak in [J. Phys. A 33, 5607, 2000]. It is also generalized for multi-photon Bose operators of Brandt and Greenberg type. Similarly, condition for higher order subpoissonian photon statistics (HOSPS) is derived by normal ordering of higher powers of number operator. Further, with the help of simple density matrices, it is shown that the HOA and HOSPS are not the manifestation of the same phenomenon and consequently it is incorrect to use the condition of HOA as a test of HOSPS. It is also shown that the HOA and HOSPS may exist even in absence of the corresponding lower order phenomenon.

Simpler criteria for the HOS (Hong-Mandel) and HOSPS are used further to study the possibilities of observing HOSPS and HOS in different intermediate states. It is shown that the binomial state, generalized binomial state, negative binomial state, photon added coherent state, hypergeometric state, e nonlinear first order excited squeezed state (NLESS) and nonlinear vacuum squeezed state (NLVSS) may show the characteristics of HOS and HOSPS. It is also shown that the Binomial state which is always antibunched, is not always higher order squeezed and NLVSS which shows higher order squeezing does not show HOSPS and HOA. The opposite is observed in NLESS and consequently it is established that the HOSPS and HOS are two independent signatures of
higher order nonclassicality. Similar characteristics have been observed in other intermediate states too. Recently Gupta and Pathak [Phys. Lett. A 365 (2007) 393] had shown that the reduction of the Carruthers-Nieto symmetric quantum phase fluctuation parameter \( U \) with respect to its coherent state value corresponds to an antibunched state, but the converse is not true. Consequently reduction of \( U \) is a stronger criterion of nonclassicality than the lowest order antibunching. Here we have studied the possibilities of reduction of \( U \) in intermediate states by using the Barnett Pegg formalism. We have shown that the reduction of phase fluctuation parameter \( U \) can be observed in different intermediate states, such as binomial state, generalized binomial state, hypergeometric state, negative binomial state, and photon added coherent state. It is also shown that the depth of nonclassicality can be controlled by various parameters related to intermediate states. Further, in this chapter we have provided specific examples of antibunched states, for which \( U \) is greater than its poissonian state value. In the present work, we have observed different interesting facts regarding higher order nonclassicality of light in general and possibilities of observing higher order nonclassical effects in different physical systems (intermediate states and many wave mixing processes) in particular. Possibility of experimental detection of higher order nonclassicalities is also discussed.