University of Calgary
Fall semester 2008

PHYS 673: Quantum and Nonlinear Optics

Homework assignment 4

Due November 4, 2008. Computers are not allowed except in Problem 4.4.

Problem 4.1.

a) Calculate $\langle \Delta X_\theta^2 \rangle$ for the n-photon Fock state and verify that this state is not squeezed. **Note:** because Fock states are phase invariant, you need to check only one phase.

b) Calculate $g^{(2)}$ for the squeezed vacuum state ($\langle X^2 \rangle = e^{-2r}/2$) and verify that this state is not antibunched.

Problem 4.2. Read the paper "Nonlocality of a single photon revisited" by L. Hardy, Phys. Rev. Lett. **73**, 2279 (1994) as well as comments by L. Vaidman, Phys. Rev. Lett. **75**, 2063 (1995), D. M. Greenberger *et al.,* Phys. Rev. Lett. **75**, 2064 (1995) and the reply by L. Hardy, Phys. Rev. Lett. **75**, 2065 (1995).

a) Find the probability of the event $F_1 = 1$ in Eq. (10) of the original paper.

b) Would you agree with Hardy or his opponents?

Problem 4.3. Read the paper "Generating optical Schrödinger kittens for quantum information processing" by A. Ourjoumtsev *et al.,* Science **312**, 83 (2006). Reproduce the theoretical calculations using simplifying assumptions $\gamma = 0$, $\xi = 1$. Use other parameters as listed in the paper.

a) Find the Fock basis expansion of the squeezed state after the DOPA with $s = 0.56$ (e.g. up to $n = 6$).

b) Calculate the photon number expansion of the two-mode state after the first beam splitter.

c) Determine the signal state conditioned on the APD click (assume that the APD projects onto the single-photon state).

d) Account for the homodyne detector efficiency by introducing an additional absorber. Find the density matrix in the Fock basis.

e) Using your program from homework 3, calculate a table of Wigner functions of operators $|m\rangle\langle n|$ (where $|m\rangle$, $|n\rangle$ are Fock states).

f) Produce a set of theoretical plots analogous to Fig. 3 in the paper.