Quantum Optics, Exercise (2)

March 24, 2025

Problem 1

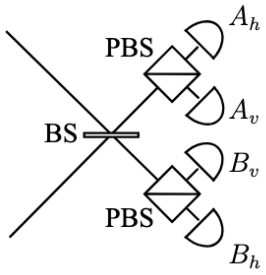
Consider two-mode states incident on a measurement setup, as shown in the figure below. The action of the 50/50 beam splitter (BS) is polarization-independent, meaning it performs the same transformation on horizontally (H) and vertically (V) polarized photons, without altering their polarization.

The two polarizing beam splitters (PBS) direct the H and V polarizations to their respective detector pairs: A_h and A_v, or B_h and B_v. Your task is to distinguish between the two Bell states in the polarization basis:

$$|\Phi_+\rangle = \frac{1}{\sqrt{2}} \left(|V\rangle_1 |V\rangle_2 + |H\rangle_1 |H\rangle_2 \right),$$

and

$$|\Psi_-\rangle = \frac{1}{\sqrt{2}} \left(|V\rangle_1 |H\rangle_2 - |H\rangle_1 |V\rangle_2 \right).$$



(a) Express both states as the action of creation operators (which create photons of the appropriate polarizations) on the vacuum input modes.

(b) Which detectors will click (and with what probability) if the incident state $|\Phi_+\rangle$?

(c) Which detectors will click (and with what probability) if the incident state $|\Psi_-\rangle$?

(d) Comment on the distinguishability of the two scenarios. Is it necessary for the detectors to distinguish between one-photon and two-photon events in order to differentiate between these two Bell states?

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