Interference

To examine the concept of interference, we consider what is known as the polarizing beam splitter for single-photons. Photons are straightforwardly generated and controlled with linear optical elements such as wave plates and beam splitters so they are convenient to use for encoding a quantum system that consists of two levels called a quantum bit or *qubit*, and as well to implement unitary transformations. A classical bit has a state of either *0* or *1*. A qubit also has two possible states $|0\rangle$ and $|1\rangle$; however, it differs from a classical bit in that it can be in states other than $|0\rangle$ and $|1\rangle$ such as the linear superposition $a|0\rangle + b|1\rangle$. This quantum property enables qubits to interfere.

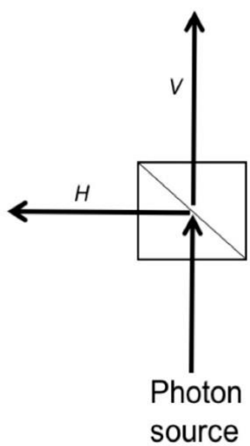

Figure 2.1: Single photon sent into a 50-50 polarizing beam splitter which allows horizontal (*H*) or vertical (*V*) polarization.

A polarization qubit uses two orthogonal polarization states; e.g., horizontal polarization with the logical value H and vertical polarization with value V. A superposition of these can then be used to represent an arbitrary polarization. A coherent superposition of horizontal and vertical polarization represents a 45-degree diagonal polarization, and it will be transmitted with 100% probability by a polarizer set at that angle, Figure 2.1. However, an incoherent mixture will be transmitted with only 50% probability.

A polarization beam splitter, consisting of a semi-reflective mirror, transmits one polarization mode and reflects the other. A polarization rotation can be physically implemented using quarter and half-wave optical plates. For a 50-50 beam splitter with θ = 45 degrees, we can use the general unitary operator for rotating a qubit given in Equation (2.16) to generate linear polarization along ± 45 degrees with $\hat{n} \cdot \bar{\sigma} = \sigma_x$,

$$|+45\rangle = (|H\rangle + |V\rangle)/\sqrt{2}, \; |-45\rangle = (|H\rangle - |V\rangle)/\sqrt{2}. \tag{2.4}$$

Or with $\hat{n} \cdot \bar{\sigma} = \sigma_y$, generate left ($L$) and right ($R$) handed *circular polarization*

$$|L\rangle = (|H\rangle + i|V\rangle)/\sqrt{2}\,, |R\rangle = (|H\rangle - i|V\rangle)/\sqrt{2}\,. \tag{2.5}$$

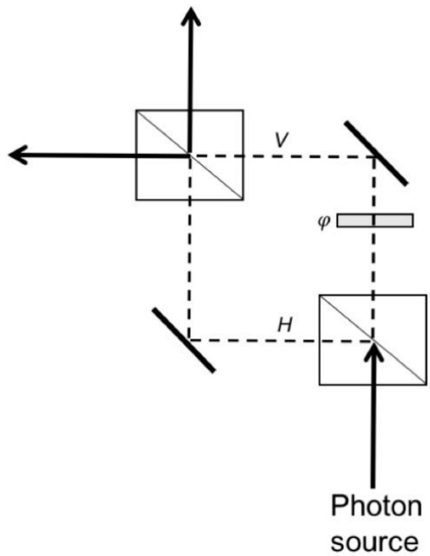

Figure 2.2: Single photon sent into an interferometer with a 50-50 polarizing beam splitter, a phase shifter, and a second beam splitter to allow interference. The mirrors are assumed sufficiently massive that there is little observable mirror recoil due to the reflection of a photon.

A second beam splitter can also be added, along with a phase-shifter to vary the effective path-length to form a Mach-Zehnder interferometer, allowing the beams to

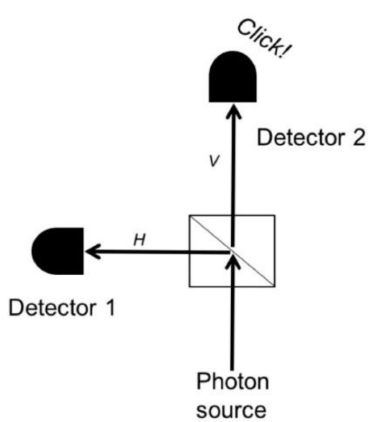

Figure 2.3: Single photon sent into a 50-50 polarizing beam splitter with click detectors that will register either horizontal (H) or vertical (V) polarization.

recombine and interfere, Figure 2.2. In this case, a single photon *interferes with itself* or more precisely with the two paths the photon can take to the detector. Detectors are added to the polarizing beam splitter arrangement to make a measurement. However, photons cannot be split, therefore only one detector or the other will *click* as the photon is destroyed during the measurement process, Figure 2.3.