Lab 4b The Quantum Eraser - Week 10

Phys434L Quantum Mechanics Lab
2018

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1 Procedure

1. Set both half-wave plates to zero degrees relative to the horizontal (zero marking on top).

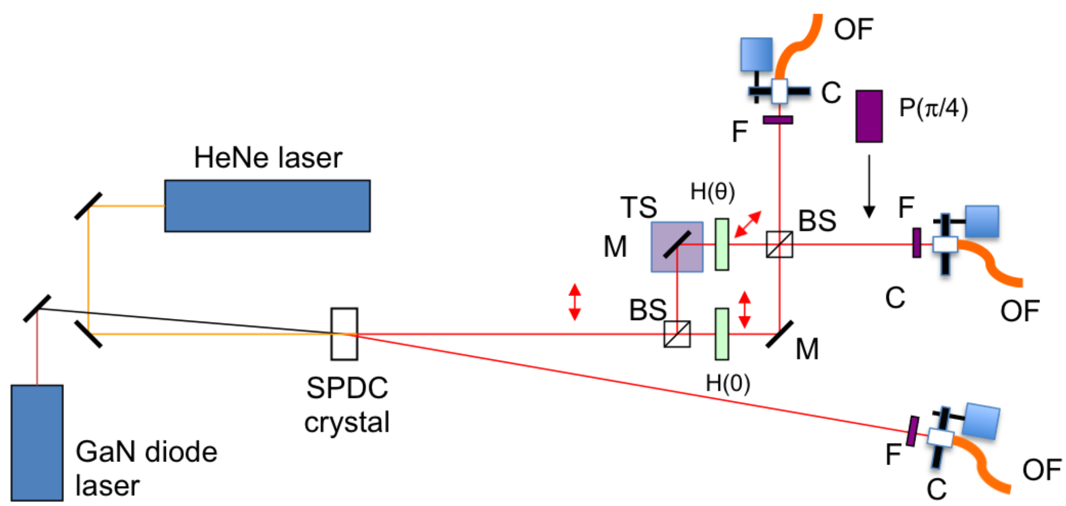

Figure 1: Apparatus to be used in the quantum eraser experiment. Optical elements of the interferometer are: beam splitters (BS); mirrors (M), with one of them mounted on a translation stage (TS); half-wave plates oriented an angle θ (H(θ)); and polarizer oriented by $\pi/4$ (P($\pi/4$)). The photon-collection system has a 40-nm band-pass filter (F), a lens-collimator (C), and an optical fiber (OF). Photons are sent throughout the fiber to the detectors.

2. Take a piezo scan to obtain the interference of the photons going through the interferometer. (Coincidences AB.)

3. Now rotate one of the half-waveplates to 15°leaving the other one unchanged and repeat the scan. Compare this results with the expected detection probability. Should there be any interference?

4. Repeat for the half-wave plate at 30°.

5. Finally rotate the half-waveplate to 45°. Because the new state after the rotated half-waveplate is now $|H\rangle$, it is orthogonal to the state of the light coming through the other arm. The paths are distinguishable and therefore we should not get any interference. Compare this with the result of the previous question and with your calculations.

   Notice that we don't even try to measure the polarization of the paths. Interference disappears even if *in principle* we can obtain the path information. Take a piezo scan to verify this.

6. Now place a polarizer after the interferometer with its transmission axis set to 45°(i.e., state $|D\rangle$).

   Question 1 Take-home: Find the vector for the final state, $|\phi_x, D\rangle$.

   Question 2 Take-home: Now find the probability of detecting the photon after the polarizer. That is, we want to measure the probability that the final state is $|\phi_x, D\rangle$.

   We can account for the eraser in the quantum mechanics algebra: we create a matrix that represents the eraser operation. It must project the polarization along the x-direction after the interferometer onto the state $|D\rangle$, or

$$\hat{P}_D = |D\rangle\langle D|. \tag{1}$$

   In the y-direction there is no eraser, so the matrix in the combined spaces is

$$\hat{E}_{xy} = \begin{pmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & 0 & 0 \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}, \tag{2}$$

   Notice that in the top-left we have the matrix for the projection along $|D\rangle$, to effect the projection in the x-subspace; and in the lower-right we have the identity matrix so that the polarization along the y-direction is left untouched. The operator for interferometer plus eraser will then be

$$\hat{E}_{xy}\hat{Z}. \tag{3}$$

7. Take a scan and compare the results with your predictions.
8. Based on the above analysis comment on the coincidences AC.

The last part is called the "quantum eraser." By placing the polarizer after the interferometer we erase the path-labeling information, and thus we regain interference. It is striking that we decide whether to get or not the interference *after* the photon goes through the interferometer.