The Quantum Eraser

Physics P371 – Quantum Mechanics

Spring 2009

In this lab we are going to use a very clever experiment as an exercise in state-vector algebra and to ponder further about the meaning of superposition and measurement.

1 Polarization-Interferometer Operators

Consider the interferometer shown in the figure. Light is traveling along the x-direction with vertical polarization, encounters the interferometer, which has non-polarizing 50-50 beams splitters. The arms have half-wave plates initially with their fast axes aligned with the horizontal axis. That is, the wave plates do not alter the polarization of the light. One wave plate we are going to move. The other one is a dummy one.

Figure 1: A schematic of the apparatus.
A thorough description of the experiment is done by using a formalism that combines the space of spatial directions and polarization: $|\phi_x, H\rangle$, $|\phi_x, V\rangle$, $|\phi_y, H\rangle$ and $|\phi_y, V\rangle$.

**Question 1** Using the matrix formalism calculate the probability of photons exiting the interferometer through the x-axis.

The matrix representing the half wave plate in the upper arm and none in the lower arm is:

$$W_{\lambda/2}(\theta) = \begin{pmatrix}
\cos 2\theta & \sin 2\theta & 0 & 0 \\
\sin 2\theta & -\cos 2\theta & 0 & 0 \\
0 & 0 & 1 & 0 \\
0 & 0 & 0 & 1
\end{pmatrix},$$  

(1)

**Question 2** Find the state of the light when the wave plate is rotated an angle $\theta$.

**Question 3** Find the probability of the photon leaving the interferometer as a function of $\theta$.

### 1.1 Experiment: Quantum interference

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

2. Take a piezo scan to obtain the interference of the photons going through the interferometer. Use the Dynamical Phase program.

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 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 $45^\circ$ (i.e., state $|D\rangle$). Now find the probability of detecting the photon after this polarizer.

7. Take a scan and compare the results with your predictions.

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. Such a scheme has been argued extensively in the literature, and has been labeled a “delayed choice” experiment.

Finally, note that we erase the path-distinguishing information by manipulating the states of the system. This is in contrast to Feynman’s double-slit experiment where the interference was destroyed by disturbing the system in an uncontrollable and unpredictable way.