Tutorial 4: Photon Paths

1. Introduction

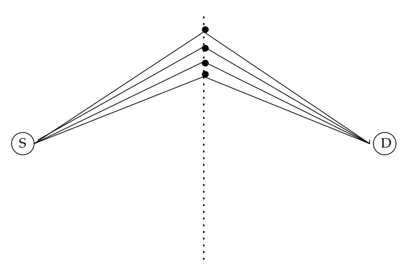
Recall that in order to compute the probability of a photon travelling from the source to the detector, we must assign a probability arrow (or amplitude) to each path the photon can take. Then we add the arrows, and square the length of the final arrow to compute the overall probability. If the photon is just travelling through air, the length of the arrow is the same for each path, while the direction of the arrow is given by the direction of the stopwatch hand.

Start up the ONEPRT program: double click on the ct.exe icon and select oneprt.ctb from the menu. Click on 'INTRODUCTION.'

There is one word of caution—whenever the screensaver kicks in you will lose whatever work was on the screen.

Carry out the introduction unit of the program. Examine what happens to the stopwatch hand as the photon runs along the path you chose. Describe in words what the program is calculating when many paths go from the source to the detector.

2. Straight-line Motion



Click on DONE INTRO to exit the introduction. Click on a series of points along the dotted vertical line between the source and the detector. You should have 21 or so equally space points going from the top of the screen to the bottom (ten above, ten below, and one straight line). For each point, the computer draws a path from the source to the detector that passes through the point. It computes how much the stopwatch hand turns for that path, and transfers the arrow for that path to the window on the right side of the screen. As you explore additional paths, the arrows on the right side of the screen are lined up head to tail so they can be added.

Note that you can click on the points in any order, but if you place the points sequentially from top to bottom or vice versa, the little arrows adding up in the right-hand window will approximate a famous S-shaped curve in your textbook (it's called the Cornu spiral for jargon lovers).

©We would like to acknowledge Edwin Taylor for much of the material in this tutorial and for the computer programs.

Note that if you make a mistake, then just click again on the midpoint of the mistaken path, and it will be erased.

Click on the 'RESULTING ARROW' button to see the final arrow. The overall probability that the photon will travel from S to D along these paths is equal to the square of the length of the final arrow.

1. Two students, Daria and Quinn, are discussing this computer experiment.

   – Daria: *Each arrow has the same length, but their direction matters in finding the total probability. Some arrows tend to cancel others when you line them up, and the final arrow is not necessarily 21 times the length of the individual arrows.*

   – Quinn: *Nuh uh Daria. Each arrow is the same length. Therefore each path contributes the same amount to the final arrow. If there are 21 paths, the length of the final arrow will be 21 times the length of each individual arrow.*

   With which (if either) of the students do you agree and why?

   If we are adding twenty-one arrows each of length L, what is the maximum possible length for the final arrow? What is the minimum possible length for the final arrow?

2. Which paths contribute the most to the final arrow on the right side of the screen? (Repeat the construction as many times as needed to answer this question.)

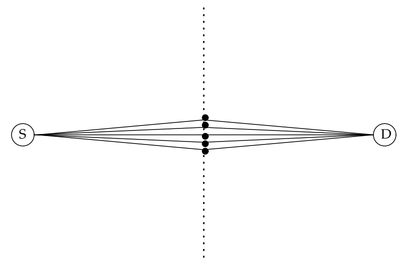
3. Use the stopwatch model to explain *why* those particular paths give a sizable contribution to the final arrow. (You will need to draw some kind of diagram to explain this.)

Click on 'ADD DETECTORS.' The final arrow is copied from the right-hand window to the position of the original detector. Now click on a point near the top of the screen that lies on the vertical line passing through the original detector.

4. For this new detector, do the paths that contribute significantly to the final arrow pass through the same midpoints as those that contributed the most for the original detector? Explain why or why not.

3. Narrow and Wide Slits

Click on 'NEW CASE.' Place five points very close to each other along the vertical dotted line, centered between S and D. This mimics light passing through a narrow slit.



Press the 'ADD DETECTORS' button and click on different locations along the dotted vertical line passing through the original detector. For each new detector location, the final arrow in the right-hand window is copied to the position of the detector. You can use the 'CLEAR PATHS' button to redraw the final arrows for each detector without showing the paths. Include a detector near the bottom of the screen.

1. With a ruler, measure on the screen the lengths of the final arrows for the central detector and for the detector near the bottom of the screen. Calculate the ratio of the arrow lengths:

$$\frac{(\text{Length of arrow})_{\text{bottom}}}{(\text{Length of arrow})_{\text{center}}} =$$

2. What is the corresponding ratio of the probabilities for detecting photons at the two locations?

$$\frac{\text{Prob.(detection at bottom)}}{\text{Prob.(detection at center)}} =$$

Now let's mimic a wider slit. Press 'NEW CASE' to clear the screen. Now place nine closely spaced points along the center vertical line. (This slit should be about twice the size of the narrow one above.)

Place additional detectors above and below the original one.

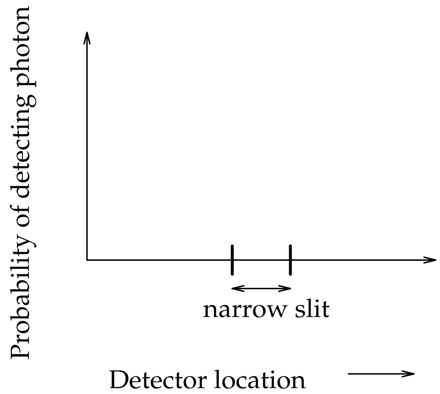
3. With a ruler, measure on the screen the lengths of the final arrows for the central detector and for the detector near the bottom of the screen. Calculate the ratio of the arrow lengths:

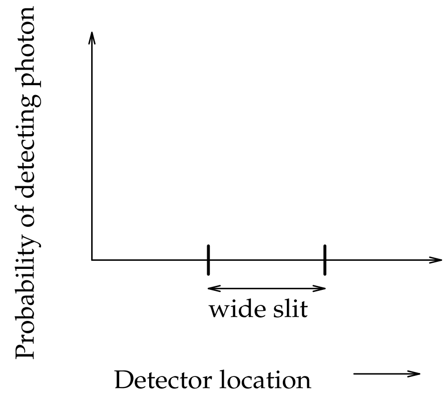
$$\frac{(\text{Length of arrow})_{\text{bottom}}}{(\text{Length of arrow})_{\text{center}}} =$$

4. What is the corresponding ratio of the probabilities for detecting photons at the two locations?

$$\frac{\text{Prob.(detection at bottom)}}{\text{Prob.(detection at center)}} =$$

5. For both the narrow and wide slits, make a plot (on the next page) of the probability for detecting a photon as a function of detector location.

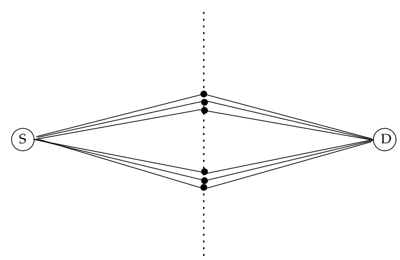




4. Two-Slit Interference

Start a 'NEW CASE.' Create two very narrow slits by placing two sets of three closely spaced dots along the central vertical line. Put your two slits about equal distance above and below the central horizontal line (put the edge 4 dots above and below the center line).

Use 'ADD DETECTOR' to examine what happens at locations above and below the original detector.



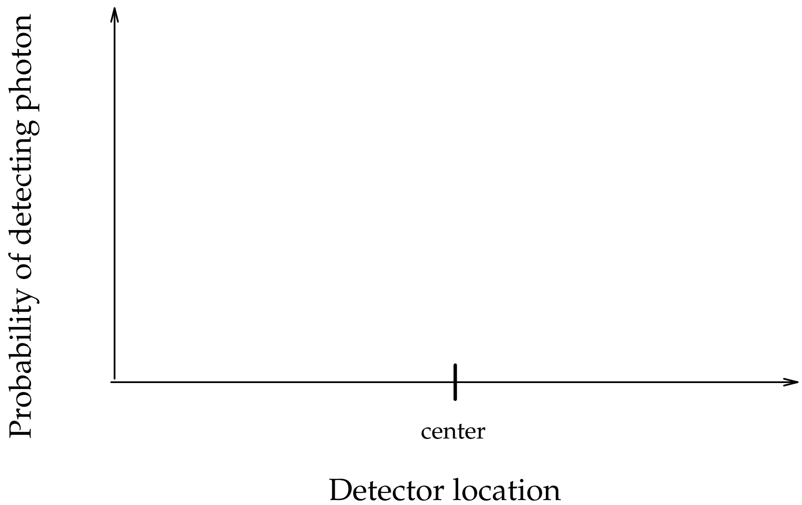
1. Find a location above or below the original detector where there is essentially no probability of detecting a photon.

   Sketch the arrows corresponding to the three paths going through the lower slit. Draw the arrow found by adding these three arrows.

   Sketch the arrows corresponding to the three paths going through the upper slit. Draw the arrow found by adding these three arrows.

   How do the arrows for the lower and upper slits compare?

2. Sketch (on the next page) how the probability for detecting a photon varies with detector location.

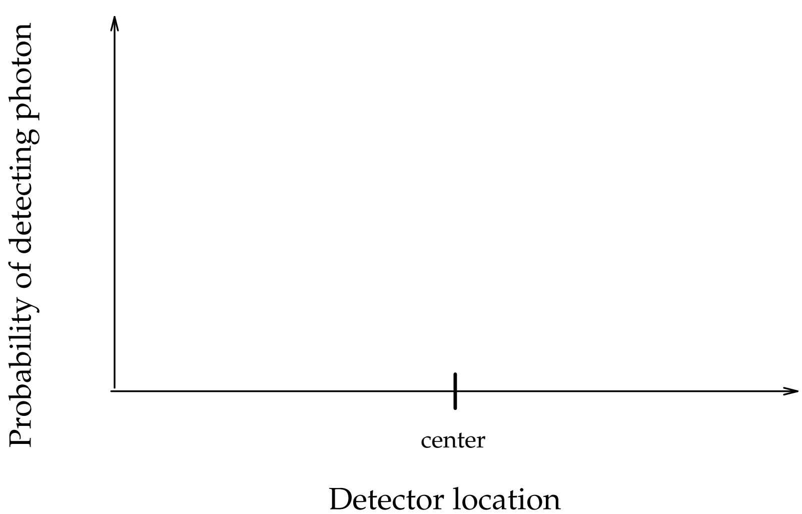


Start a 'NEW CASE.' Now we will increase the separation between the slits. Create two very narrow slits by placing two sets of three closely spaced dots along the central vertical line. Put your two slits about equal distance above and below the central horizontal line (now place them 9 dots above and below the center).

Use 'ADD DETECTOR' to examine what happens at locations above and below the original detector.

3. Find a location above or below the original detector where there is essentially no probability of detecting a photon.

4. Sketch how the probability for detecting a photon varies with detector location.



5. Explain in your own words what the difference is between these two curves. Use the quantum model developed in class to explain why this difference occurs.