

PHOTON EXERCISES FOR THE "ONEPARTICLE" SOFTWARE PROGRAM

Edwin F. Taylor
July 2000

READING for Sections A through E: Feynman, *QED*, Chapter 2, pages 36 to 54

A. INTRODUCTION

The **OneParticle** program is designed to simulate the sum over paths theory of quantum mechanics described by Richard P. Feynman (with Ralph Leighton) in the book *QED: The Strange Theory of Light and Matter* (Princeton University Press, 1985).

The following exercises make use of the "red photon" and "blue photon" particles, ignoring the "electron" particle for now.

Carry out the Introduction unit of the OneParticle program. This presents the fundamental theory:

1. The photon explores each alternative path while the fictional quantum stopwatch meters the rotation of the little arrow for that path.
2. The resultant arrow constructed by adding, head-to-tail, the little arrows for alternative paths.
3. (Not part of this display) The probability for detection reckoned from the squared magnitude of the resulting arrow.

After completing the introduction, play with the main program, checking out the various features, including those available in the menus at the top of the screen.

B. "STRAIGHT-LINE" MOTION?

Exit the introduction.

Check to see that the label RED PHOTON appears at the top of the screen.

Select "Advanced" from the "Basic/Advanced" menu at the top of the screen.

Click on the button CHAIN OF MIDPOINTS.

Click on the vertical center near the top of the screen.

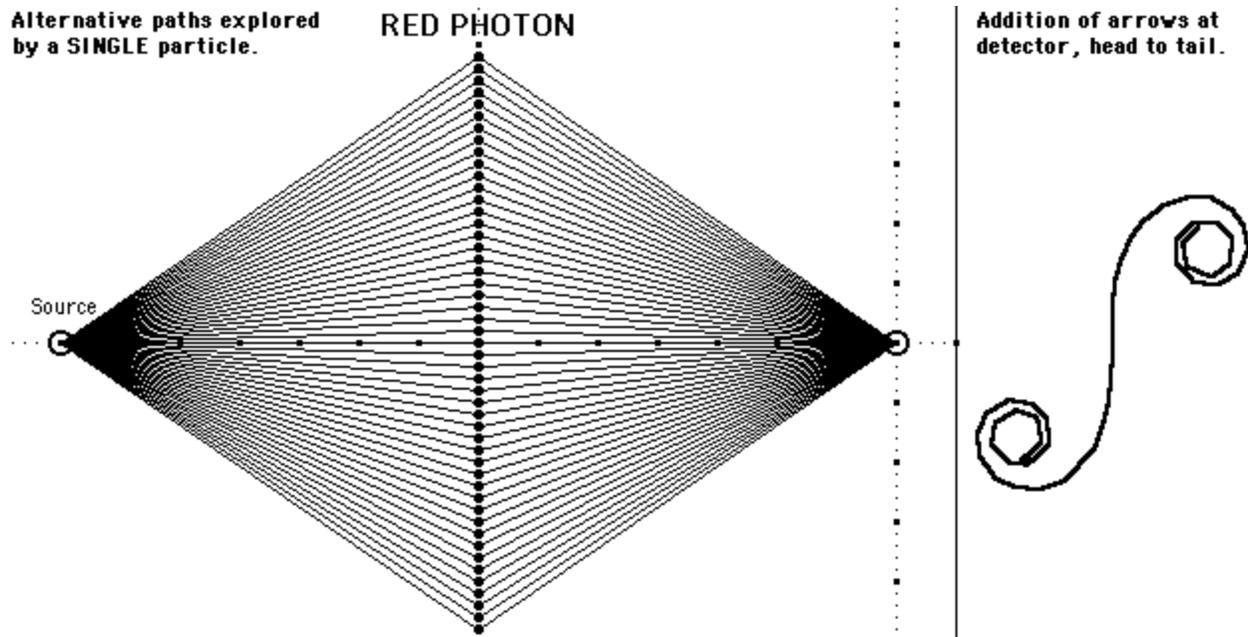
Click on the button labeled SYMMETRIC ACROSS HORIZONTAL CENTERLINE

The result should be similar to the figure on the top of the next page.

You can see the **resulting arrow** in the right hand window by clicking on the button labeled RESULTING ARROW. The little stopwatch-hands for all the paths you have chosen add up (head-to-tail). The tail of the resulting arrow is at the original dot and its head is at the head-end of the most recently added little stopwatch hand.

The overall probability that the photon will travel from Source to Detector along this collection of paths is proportional to the square of this resulting arrow.

The scroll-shaped (S-shaped) figure on the right is called a **Cornu Spiral**.



Now investigate which of the alternative paths contribute most to the resulting arrow. One way to do this is to erase some of the paths by clicking on the midpoint.

Questions:

B1. Which paths make negligible contribution to the resulting arrow in the right-hand window? Explain in one or two sentences the *reason* for this lack of contribution.

B2. In two sentences, explain how it can be that certain paths contribute more than others to the resulting arrow, since the little stopwatch hands all have the same length.

B3. Start again and restore the initial construction shown above.

Click on the button ADD DETECTORS and click on different points on the right-hand vertical dotted line that passes through the original detector.

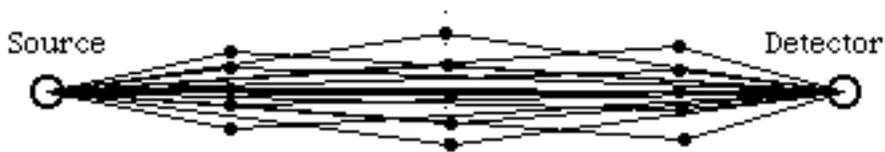
How does the Cornu spiral for these detectors differ from the Cornu spiral for the original detector? Explain these differences in a sentence or two.

Discussion question: A profound difficulty, for thought now and later:

B5. Rachel says, "This whole setup is absurd. Suppose the intermediate points include EVERY point along the vertical dotted line shown above. The photon *must* cross this vertical dotted line on its way from Source to Detector. There are an infinite number of these intermediate points. Each one contributes to the resulting arrow. Therefore this resulting arrow will be infinitely long, and its square will also be infinite. This predicts an infinite probability that the photon will arrive at the detector. But there is only one photon exploring all these paths! This absurd result shows that this whole construction cannot represent Nature." Analyze Rachel's difficulty. Resolve it if possible -- no hurry about this!

C. MANY PATHS?

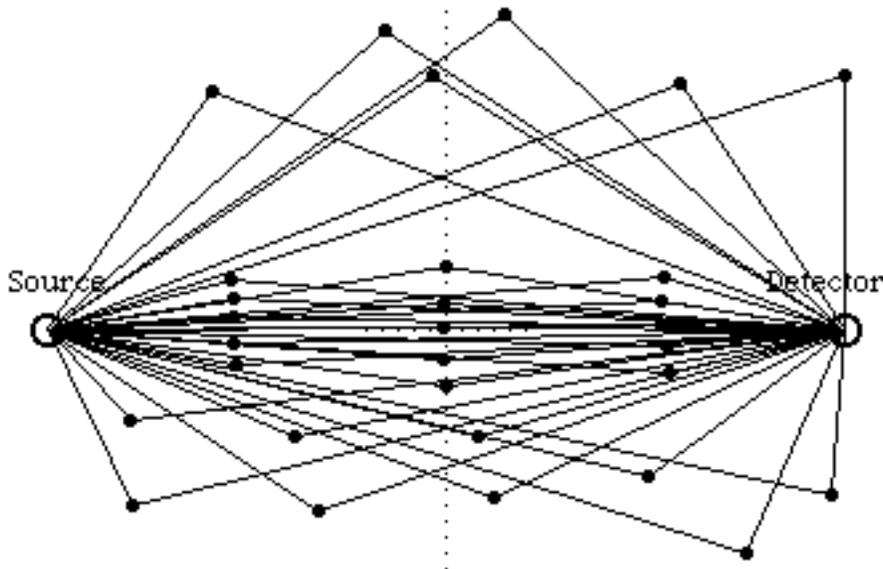
Click on the NEW CASE button. Imagine a straight line connecting Source and Detector. Click on a lot of points that lie *on or near* this line, as follows:



Question:

C1. What do you observe about the resulting arrow from all the little stopwatch hands added together in the right-hand window? Explain this result in a sentence or two.

Now add a lot more intermediate points that lie *far* from the centerline between source and detector, as follows:

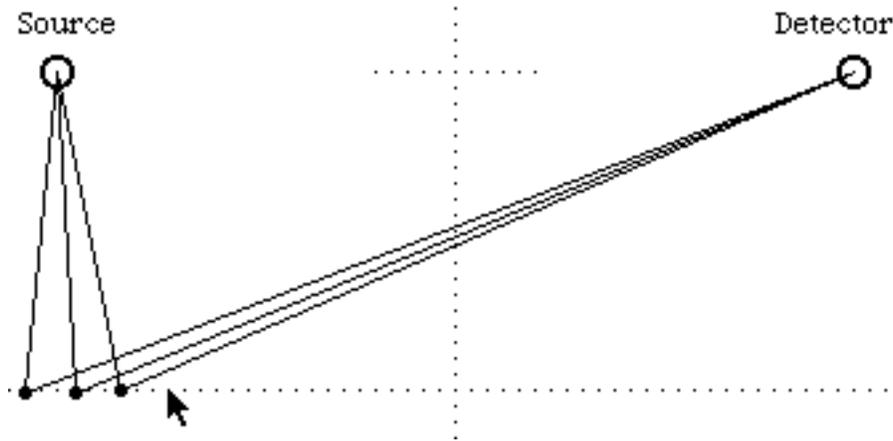


Question:

C2. How is the *resulting* arrow in the right-hand window affected by the addition of these far-from-centerline points? That is, how much have the addition of these far-from-centerline points changed the length of the resulting arrow in the right hand window? Briefly explain the reason for this result.

D. MIRROR

Which portions of a mirror contribute most to the reflection at the detector? Click on the NEW CASE button. Duplicate Figure 20, page 40 of QED by clicking on a long string of intermediate points along the lower dotted horizontal line lying along the bottom of the left-hand window. Here is a possible beginning stage of the construction of Figure 20:



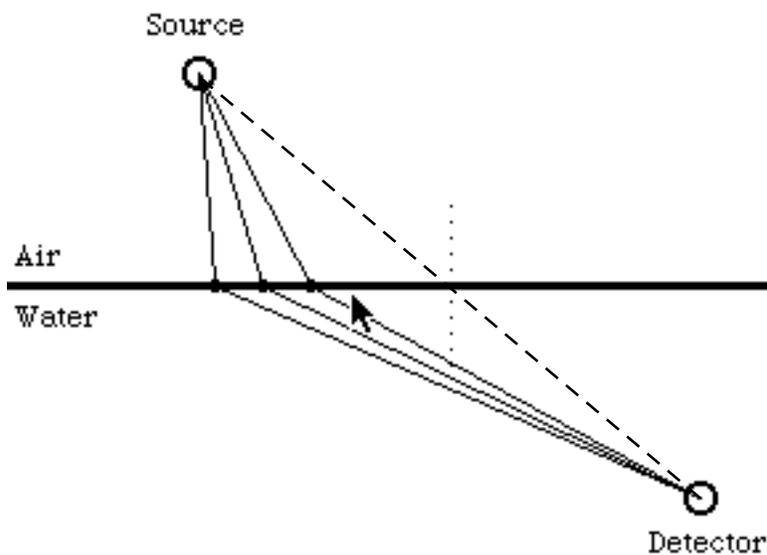
Question:

D1. For what intermediate points along the length of the "mirror" dotted line do the "stopwatch hands" in the right-hand window add up more or less in the same direction? Which portion of the mirror contributes most to the resulting arrow at the detector?

E. WATER

Which paths across the surface of water contribute most to the resulting arrow at a detector under the water? Press the NEW CASE button and then the WATER button. Place intermediate points sequentially along the water's surface from left to right. The following figure shows the beginning of this process. To help you answer the following questions, observe the hand on the clock at the top of the screen as you add the dots in sequence.

Note: This part of the program allows you to place intermediate points *only* at the water's surface.



Questions:

E1. Describe or name the figure that you see in the right-hand panel when these dots are all placed.

E2. Describe the locations of intermediate points along the air-water interface for which the stopwatch hands in the right-hand window add up more or less in the same direction. Do these particular intermediate points lie to the *right* or to the *left* of the straight line between Source and Detector (shown as a slanted dashed line in the figure above)?

READING for Sections G and H: Feynman QED, Chapter 3, pages 77 thru 83

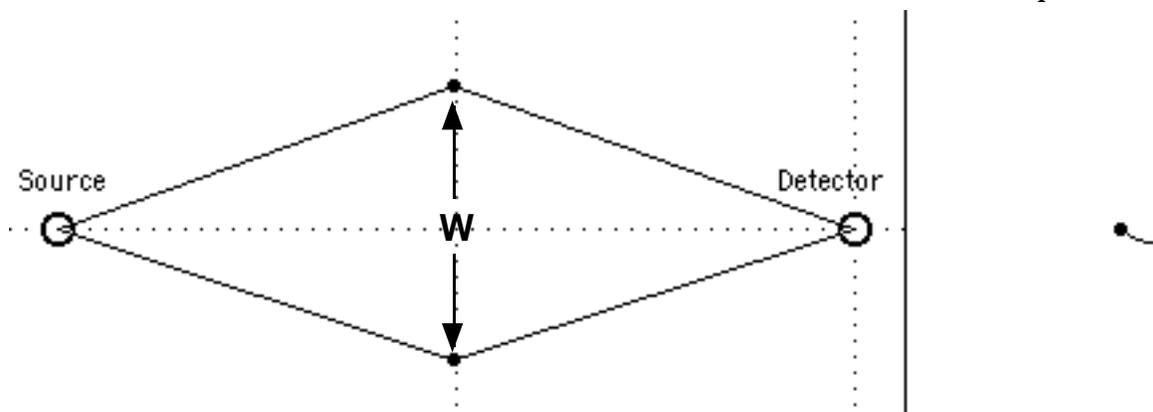
G. TWO-SLIT INTERFERENCE

Click on NEW CASE. Create two “slits” by the following method:

Click on a point on the vertical center line between Source and Detector

Click on the button REFLECT ACROSS CENTERLINE.

Now click on the ADD DETECTORS button, the CHANGE TO COLOR button and the MANY DETECTORS button to see what we call the "two-slit interference pattern."



Questions:

G1. Describe the interference pattern that results from this set of detectors.

G2. Experiment with different vertical separations W between “slits.” How is the interference pattern of resulting arrows different for a small W than a large W ? Be as specific as you can in your answer.

H. MULTI-SLIT INTERFERENCE

Using the questions below, investigate the results of employing multiple slits to create an interference pattern. Use only one intermediate dot per “slit.”

Questions:

H1. Place and delete a single dot (“slit”) along the vertical dotted line half-way between Source and Detector until you find a location for which the number of rotations is 10.5 (clock in upper right corner of the left panel). Then click on the button REFLECT

ACROSS CENTERLINE. Use CHANGE TO COLOR and MANY DETECTORS to show the interference pattern. Count the number of dot-detectors from zero intensity to zero intensity across the CENTRAL peak for this "two-slit" system, that is, count these detectors in a vertical direction on your computer screen.

H2. Next place on the vertical dotted line above the center line two dots ("slits") that yield rotations of 10.5 and 11.5 respectively. Then click on REFLECT ACROSS CENTERLINE. Now for the central detector all four little stopwatch hands in the right-hand window lie nearly along a straight line. Click on CHANGE TO COLOR and MANY DETECTORS. Now how many detector-dots are there across the top-to-bottom width of the CENTRAL interference peak for this "four-slit" system?

H3. Create a similar set of three "slits" above and below the centerline. For this case how many detector-dots are there across the top-to-bottom width of the CENTRAL interference peak?

H4. Draw a general conclusion: How does the width of the central peak change as you add more and more outlying slits, each located to give an extra complete revolution of the clock?

I. CONFUSION ABOUT FIGURES 47 AND 48 (pages 73 and 74) OF QED

A STUDENT ASKS:

I do not understand the diagrams at the bottom of figure 48 (page 74). The arrows labeled "X to A and Y to B (first way)" at the bottom left of figure 48 does not match the arrows labeled "X to A and Y to B" in the lower right of figure 47 (page 73). I also do not understand where the two sets of vector additions at the bottom of figure 48 come from. Maybe in time we will understand it.

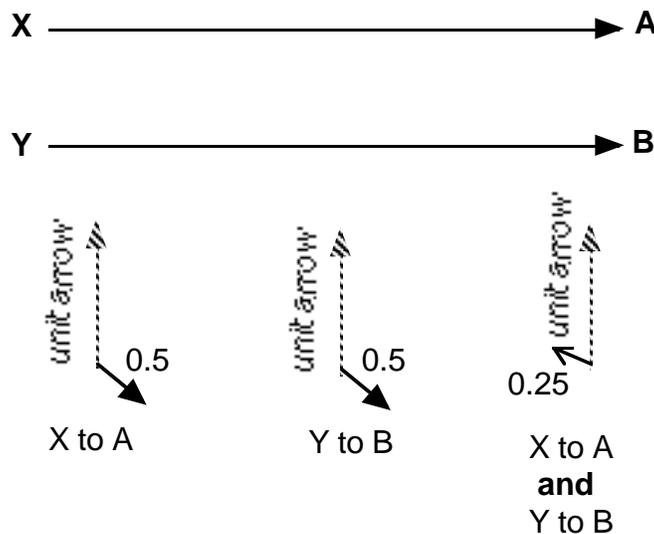


Figure 47, page 73 ("first way")

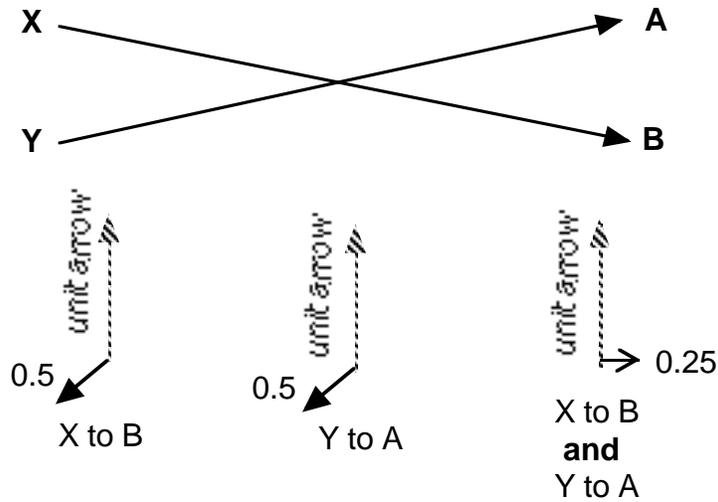
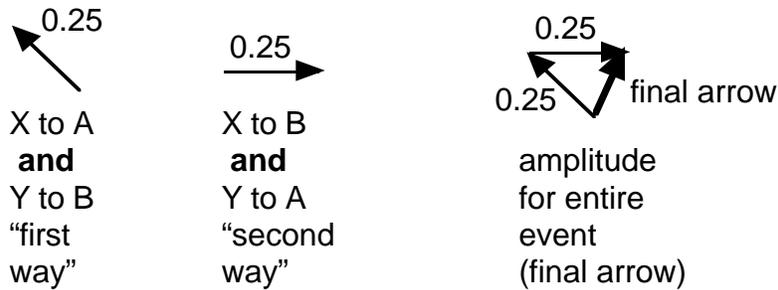


Figure 48, page 74 (“second way”)

ARROWS MAGNIFIED



Summary (Bottom of Figure 48)

REPLY: It IS a bit confusing. First of all, look at the left-hand panels of the MIDDLE rows in Figures 47 and 48.

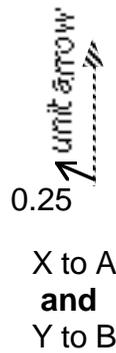


From Figure 47

From Figure 48

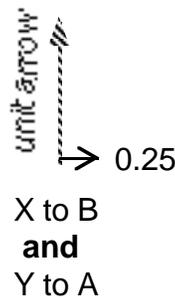
The arrow labeled “X to B” from Figure 48 rotates further than the arrow labeled “X to A” from the earlier Figure 47—because the distance from X to B (Figure 48) is greater than the distance from X to A (Figure 47).

Second, look at the set of arrows in the lower right diagram of Figure 47, labeled "X to A and Y to B."



The resulting arrow is the little one marked 0.25 pointing in the 10 o'clock direction. (This is the "product" of the two earlier arrows to the left of that—shrink and turn.) This little arrow has been reproduced at the left of the summary diagram at the bottom of Figure 48.

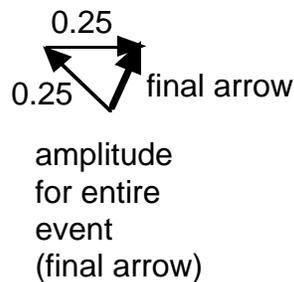
Third, look at the set of arrows in the right hand panel of the MIDDLE row in Figure 48.



The resulting arrow is the little one marked 0.25 pointing in the 3 o'clock direction. (This is the "product" of the two earlier arrows to the left of that—shrink and turn.) This little arrow is reproduced in the middle of the summary diagram at the bottom of Figure 48.

Fourth, the right-hand bottom diagram in Figure 48 comes from ADDING UP the two little arrows to the left of that.

ARROWS MAGNIFIED



This is the final (resulting) arrow for BOTH alternative ways of getting two photons from X and Y to detectors at A and B.

Does this make sense? Edwin

Copyright © 2000 Edwin F. Taylor

This page intentionally blank.