Hi Rajneesh,

**DISCLAIMER**: The selection of colors in this illustration is completely arbitrary and is not intended to indicate any correspondence to actual colors in physical reality. The colors were selected merely to highlight the addition of amplitudes in Figure 4, segment “g”.

Next Phase. Aug 7, 2000

It is now desirable to introduce a **sine wave component** into both the model’s **particle** and its **line** modes of operation. The following table and diagrams (Figs. 1-4) illustrate importance of sine wave phase in the paradoxical and counterintuitive effects observed experimentally when light is physically manipulated by means of full and partial reflections and which we seek to more clearly illuminate by means of computer graphics..

**TWO PRINCIPLES OF PHASE:**

1) Each time light is reflected (by either a **full** or a **half silvered mirror**) its phase is retarded **90 degrees**. The reflected wave is phase shifted **90 degrees** relative to the incident wave, so that it lags the incident wave by **90 degrees**.

2) When light is transmitted through a **half silvered** mirror its phase remains unaffected.

**THE POSSIBLE PARTICLE DETECTION PROBABILITIES AT THE FIXED DETECTORS “X” & “Y”**

<table>
<thead>
<tr>
<th>Wave-Function or Particle Trajectory Blocked</th>
<th>Detector Lit Up</th>
<th>Probability of Individual Particle Detection</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Both Yellow and Blue</strong></td>
<td>no detector</td>
<td>0 at detector X &amp; 0 at detector Y</td>
</tr>
<tr>
<td>c and b or</td>
<td></td>
<td></td>
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<tr>
<td>c and d or</td>
<td></td>
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<tr>
<td>e and b or</td>
<td></td>
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<tr>
<td>e and d</td>
<td></td>
<td></td>
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<tr>
<td>Figure 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Segments “c” and/or “e”</strong></td>
<td>both detectors (&quot;X” and “Y”)</td>
<td>1/4 at detector “X” &amp; 1/4 at detector “Y”</td>
</tr>
<tr>
<td>“Yellow”</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Figure 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Segments “b” and/or “d”</strong></td>
<td>both detectors (&quot;X” and “Y”)</td>
<td>1/4 at detector “X” &amp; 1/4 at detector “Y”</td>
</tr>
<tr>
<td>“Blue”</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Figure 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>none</strong></td>
<td>detector “Y” (“Y” or nothing)</td>
<td>1/2 nothing &amp; 1/2 at detector “Y”</td>
</tr>
<tr>
<td>Figure 4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

A) If (as in Fig. 1) all possible paths to a detector are blocked, then neither detector “X” nor detector “Y” ever light up.
B) If (as in Fig. 2 & 3) **either one, but only one, of** the possible **yellow** or **blue** trajectories to the **2nd half silvered** mirror is blocked, then both of the detectors ("X" and "Y") light up individually half of the time (**on the average**) and never at the same time.

C) If (as in Fig. 4), none of the possible **yellow** or **blue** trajectories is blocked, then only detector "Y" lights up and even it lights up only **1/2** of the time (**on average**).

1) because of **destructive interference** between ‘Bf’ and ‘Yf’ which are **180 degrees** out of phase, detector “X” no longer lights up and
2) the **1/4 amplitude ‘Bf’** and the **1/4 amplitude ‘Yf’** interact by adding amplitudes through **constructive interference** to become the **1/2 amplitude ‘Gf’** at **segment ‘f’**. ‘Gf’ is observed when it strikes detector “Y”

**THE PARADOX (from the view point of classical physics):**

When (as in Fig. 1 following) all of the light is intercepted by **movable** photodetectors (m1 and m2) then the fixed photodetectors (X & Y) remain unlit and an individual photon is observed only by one, or the other, but never both, of the intercepting **movable** photodetectors

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**Figure 1** Both paths (yellow & blue) are intercepted by movable photo-detectors
Even though the wave packet goes simultaneously to both movable detectors (m1 and m2) the wave-packet of an individual particle is observed registering as a particle at only one movable photodetector or another. This fact illustrates the idea that the wave function is really just a potentiality, or at least its interpretation, is in terms of a potentiality (or potentia) for an event to occur.

Because even though the wave packet (if you follow the Schrödinger equation) splits and reaches both movable photodetectors, traversing both possible photon paths simultaneously, only one or the other of the movable photodetectors will fire. You know when you place your movable photodetectors to intercept both the blue and yellow segments, only one photodetector or the other will fire per individual photon traversing the apparatus.

When half of the light is intercepted by a movable photodetector then both fixed detectors (X & Y) light up but each separately and each only 1/4 of the time (on average). [See Figures 2 & 3 below]

![Diagram](image)

**Figure 2** The yellow path is intercepted by a movable photodetector.
Figure 3 The blue path is intercepted by a movable photo-detector.

When none of the light is intercepted by movable photodetectors only one fixed detector (Y) lights up and that only 1/2 of the time (on average). [Figure 4 next page]

Up until this stage everything has looked classical at least in the sense that the particle is either going one way or the other (i.e. taking the blue or the yellow path).

Now, in both segments “f” and “g” - is observed, not the sum of the two amplitudes from the yellow and blue paths (as you might expect from common sense) instead, the green sum is observed only in “g” while in “f” you get this strange cancellation.
THE PARADOX (from the view point of the Copenhagen Interpretation):

This strange cancellation occurs even with each individual photon traversing the apparatus one at a time.

Apparently the photon’s wave-function is interfering with itself independently of any measurements or observations. The Standard Copenhagen Interpretation of Quantum Mechanics states that the photon’s wave-function is only a representation of our knowledge about the photon. That it is a description of anything in the physical world is denied.

The Copenhagen Interpretation fails to account for how such a mere “representation of our knowledge” can interfere with itself, outside of, and independently of, our conscious minds.

However the von Neumann / Wigner interpretation does provide such an account. It suggests that we take the mathematical foundations of Quantum Theory seriously. It suggests that the photon’s wave-function actually models and corresponds to something that exists independently of our minds, in reality itself.

The von Neumann / Wigner interpretation seems a much more natural explanation of the wave-function’s interference effects in this experiment.

Figure 4 Neither the blue or yellow paths are intercepted and a mysterious cancellation occurs in segment “f.”
ILLUSTRATION OF THE RELATIONSHIP OF PHASE TO THE CONSTRUCTIVE AND DESTRUCTIVE INTERFERENCE IN SEGMENTS “F” AND “G”

Segment a:
This segment begins as a sine wave emanating out of the cone and ends with it striking the first half silvered mirror. This initial full amplitude wave-function (colored green) is 0 degrees out of phase with itself (of course) and has a probability amplitude of 1 (meaning that it always observed traversing segment a in any chosen experiment). Upon striking the first half-silvered mirror, the wave function of an individual photon splits into the superimposed possibilities of two different photon trajectories to the 2nd half-silvered mirror. These two superimposed path possibilities are represented in the illustration as the blue segments “b-d” and the yellow segments “c-e”.

Segment “b”
Segment “b” (colored blue) is transmitted through the half-silvered mirror as a sine wave 0 degrees out of phase with segment “a”, and carries one half of the amplitude carried by the sine wave in segment “a” (the not-segment “c” half). It finally strikes a full silvered mirror (lower right).

Segment “d”
Segment “d” is reflected by the full silvered mirror (lower right) as a sine wave. The wave-function is thus retarded so that it is 90 degrees out of phase with the phase of segment “a” and continues to carry an amplitude of 1/2.

Segment “c”
Segment “c” (colored yellow) is reflected by the half-silvered mirror as a sine wave and thus its phase is retarded 90 degrees relative to the phase of segment “a”. Segment “c” carries the other half of segment “a”’s amplitude (the not-segment “b” half). It finally strikes the full silvered mirror (upper left).

Segment “e”
The full silvered mirror reflects segment “c” into segment “e” and in the process retards its phase 90 degrees further. It is now 180 degrees out of phase with the phase of segment a but it still has an amplitude of 1/2.

When they reach the 2nd half-silvered mirror, both wave-packets of the two photon trajectories (segments b-d and segments c-e) again each split into two more wave-packets or possible photon trajectories. This creates a set of four superimposed wave-packets waiting for an observation (measurement) to collapse the set of possible states into one manifest actuality.

The blue and yellow wave functions each split so that they both occupy segments f and g simultaneously. Simultaneously with each other and with themselves.

An individual photon can only be observed traversing the spaces of either segments “b-d” or segments
“c-e” never both. The wave-function representing the possibility of finding this individual photon in either space is however at both spaces simultaneously until it is collapsed by a measurement into just one having traversed just one space.

This local/non-local relationship between the observable characteristics of an individual photon and its wave-function is also observed in the two possible trajectories represented by segment “f” and segment “g”.

Destructive and Constructive Interference in Segments “f” and “g”

An individual photon traversing segment d can be observed to be transmitted through the 2nd half-silvered mirror to detector X (at the end of segment “f”) [‘Bf’] or it can be observed to be reflected off of the 2nd half-silvered mirror to detector Y at the end of segment “g” [‘Bg’].

An individual photon traversing segment e can be observed to be reflected off of the 2nd half-silvered mirror towards detector X (at the end of segment “f”) [‘Yf’] or it can be observed to be transmitted through the 2nd half-silvered mirror to detector Y (at the end of segment “g”) [‘Yg’].

When (as in Fig. 4) none of the paths (trajectories) are blocked, the 4 possible states ( Bf, Bg, Yf, Yg ) of the wave function of even just one individual photon, manifest as “destructive interference” in segment “f” and as “constructive interference” in segment “g”.

‘Bf ’+ ‘Yf’ = nothing

Half of the time on average, when none of the trajectories are blocked, the 1/2 amplitude ‘Bd’ is “transmitted” and the 1/2 amplitude ‘Ye’ is “reflected” along segment “f” as the 1/4 amplitude ‘Bf’ and the 1/4 amplitude ‘Yf’. ‘Bf’ is 90 and ‘Yf’ 270 degrees out of phase with the phase of segment ‘a’ they are thus 180 degrees out phase with each other. Consequently ‘Bf’ and ‘Yf’ manifest complete “destructive interference” with each other, becoming when combined together, nothing, the result is an amplitude of zero. (they cancel each other out). You do not see anything.

‘Bg’ + ‘Yg’ = ‘Gg’

The other half of the time, when none of the trajectories are blocked, ‘Bd’ and ‘Ye’ are “reflected”, and “transmitted,” along segment “g” to become the 1/4 amplitude ‘Bg’ and the 1/4 amplitude ‘Yg’ respectively. Because ‘Bg’ and ‘Yg’ are both 180 degrees out of phase with the phase of segment ‘a’ they are 0 degrees out of phase with each other. Consequently ‘Bg’ and ‘Yg’ manifest complete “constructive interference” with each other, doubling their amplitude when combined to form the 1/2 amplitude ‘Gg’.

When (as in Fig. 2 & 3) one and only one of the paths (trajectories) are blocked, there is no interference (whether constructive or destructive)
between the 4 possible states (\(B_f, B_g, Y_f, Y_g\)) of the wave function of an individual photon,

\[
\begin{align*}
'B_f' + \text{nothing} &= 'B_f' \\
'B_g' + \text{nothing} &= 'B_g'
\end{align*}
\]

*When (as in Fig. 2) the yellow paths are blocked ['Yc' and/or ‘Ye’] so that only photons traversing the blue path ['Bd'] get through to the 2\textsuperscript{nd} half-silvered mirror, then each detector (X for ‘Bf’ and Y for ‘Bg’) lights up one half of the time, but never at the same time for any individual photon.*

\[
\begin{align*}
'Y_f' + \text{nothing} &= 'Y_f' \\
'Y_g' + \text{nothing} &= 'Y_g'
\end{align*}
\]

*When (as in Fig. 3) the blue paths are blocked ['Bb' and/or ‘Bd’] so that only photons traversing the yellow path ['Ye'] get through to the 2\textsuperscript{nd} half-silvered mirror, then each detector (X and Y) lights up one half of the time, but never at the same time for any individual photon.*

Unlike the individual photon which can only be observed to be reflected or transmitted, the wave-function of an individual photon traversing segment “d” is simultaneously both transmitted through the 2\textsuperscript{nd} half-silvered mirror to detector “X” (at the end of segment “f”) [\(B_f\)] and reflected off of the 2\textsuperscript{nd} half-silvered mirror to detector “Y” (at the end of segment “g”) [\(B_g\)].

Unlike the individual photon which can only be observed to be reflected or transmitted, the wave-function of an individual photon traversing segment “e” is both reflected off of the 2\textsuperscript{nd} half-silvered mirror to detector “X” (at the end of segment “f”) [\(Y_f\)] and simultaneously transmitted through the 2\textsuperscript{nd} half-silvered mirror to detector “Y” (at the end of segment “g”) [\(Y_g\)].

There is a lot here so let us know if you have any questions.

Thanks,

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