Mr. Feynman's Quantum Mechanics

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Background material and photos of demos:

http://gibbs.physics.indiana.edu/smg

Inspiration:

QED: The Strange Theory of Light and Matter

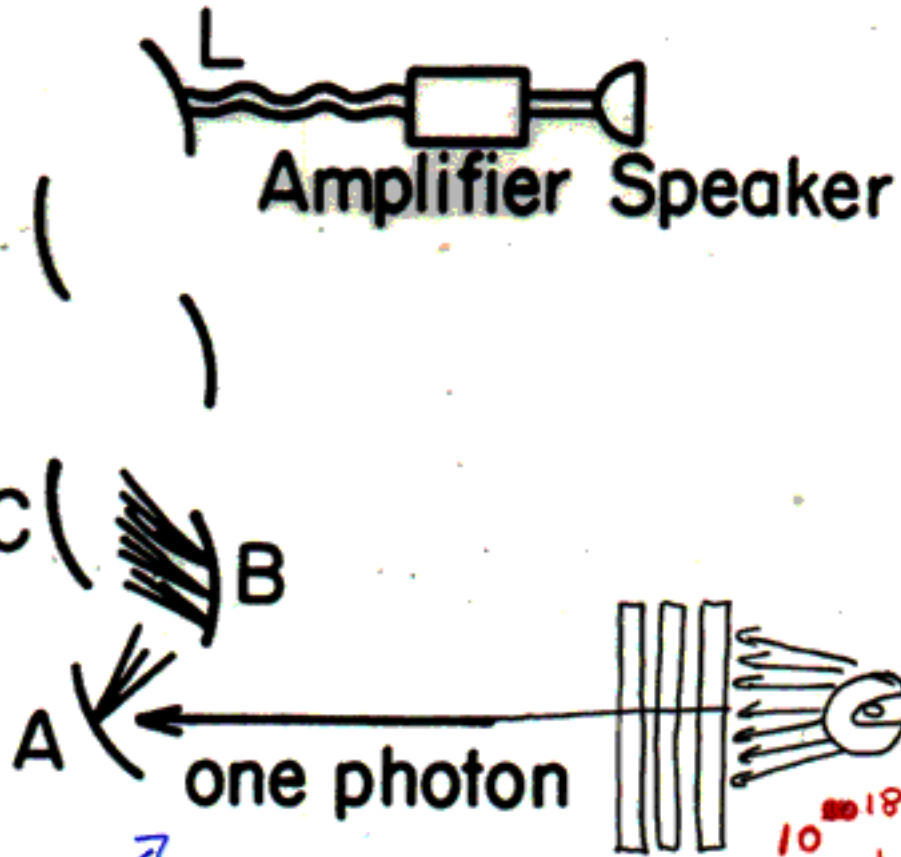
Richard P. Feynman

Princeton University Press, 1985


Du Perikles – Ka' Du sige mig – hvornaar smager en Tuborg bedst ?
Direkt efter ett föredrag om kvantfysik!

Light is made of particles that carry "lumps" of energy: photons

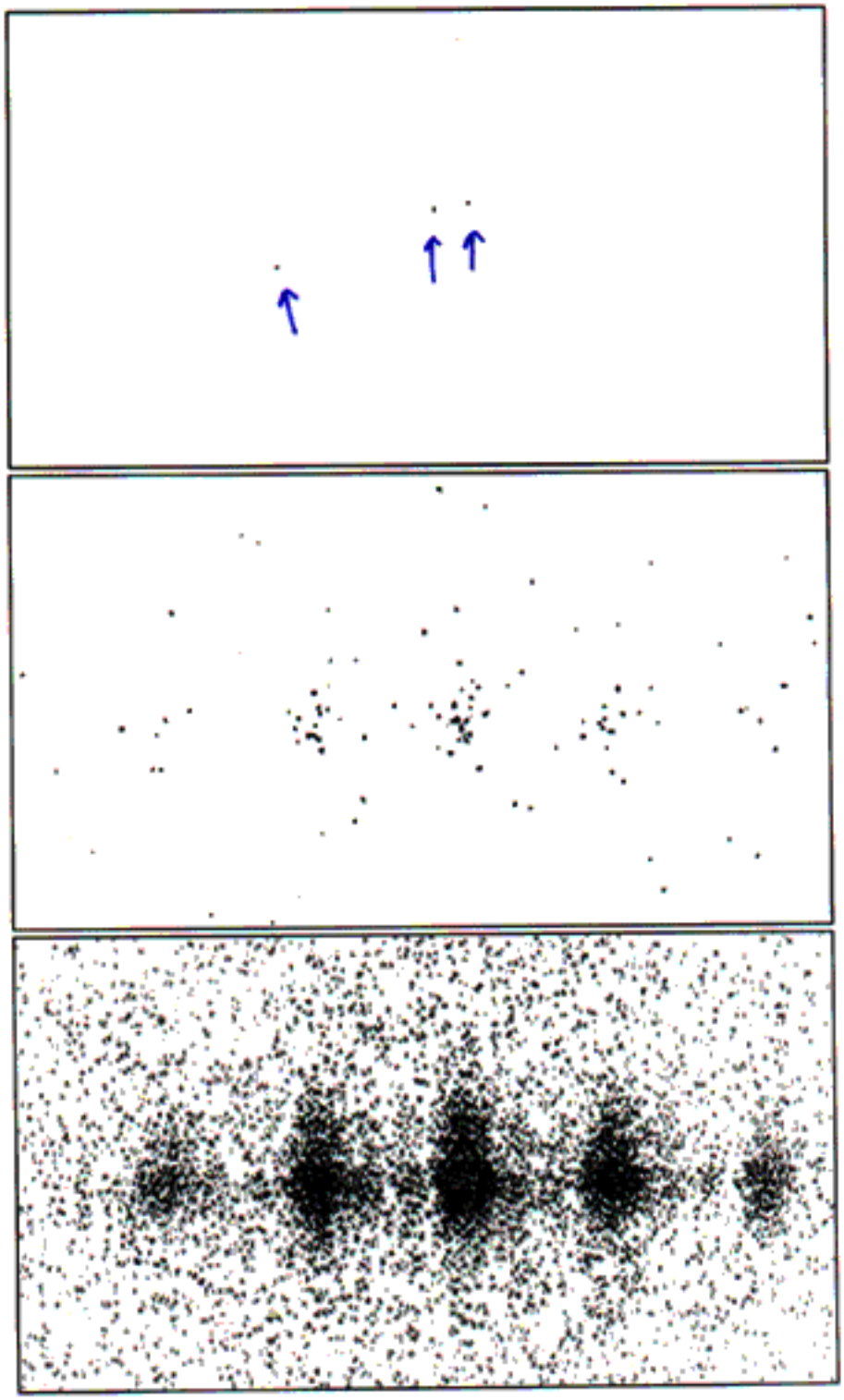
This energy can liberate electrons from metals: photo electric effect



average distance between photons ~ 2 km !

(Waves do not behave this way.)

Single photons detected by a CCD camera

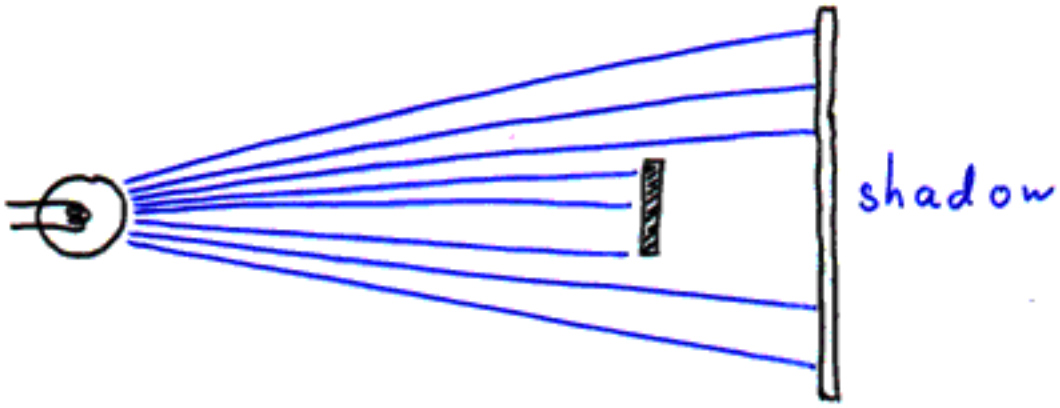


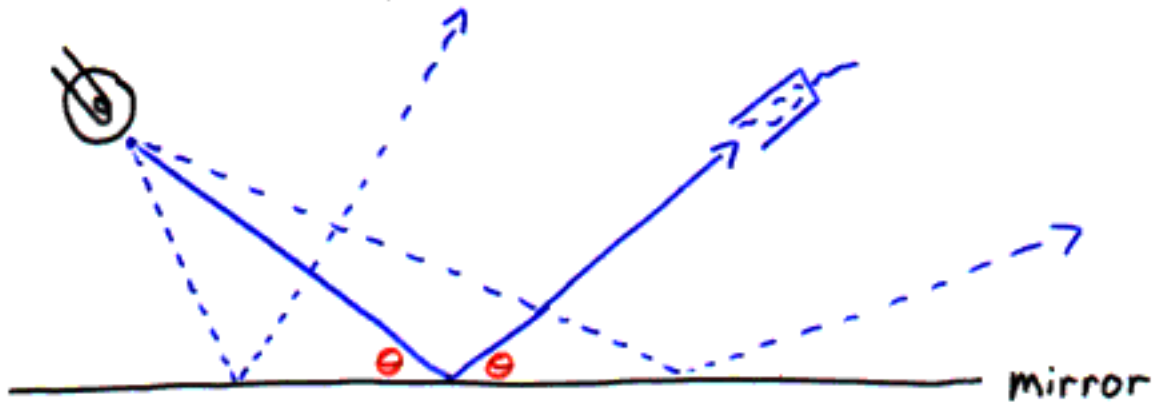
Lyman Page:
http://pupgg.princeton.edu/~page/single_photon.html

Simplest Classical Model

- particles of light travel in straight lines at speed $c \sim 3 \times 10^8$ m/s

"GEOMETRIC OPTICS"





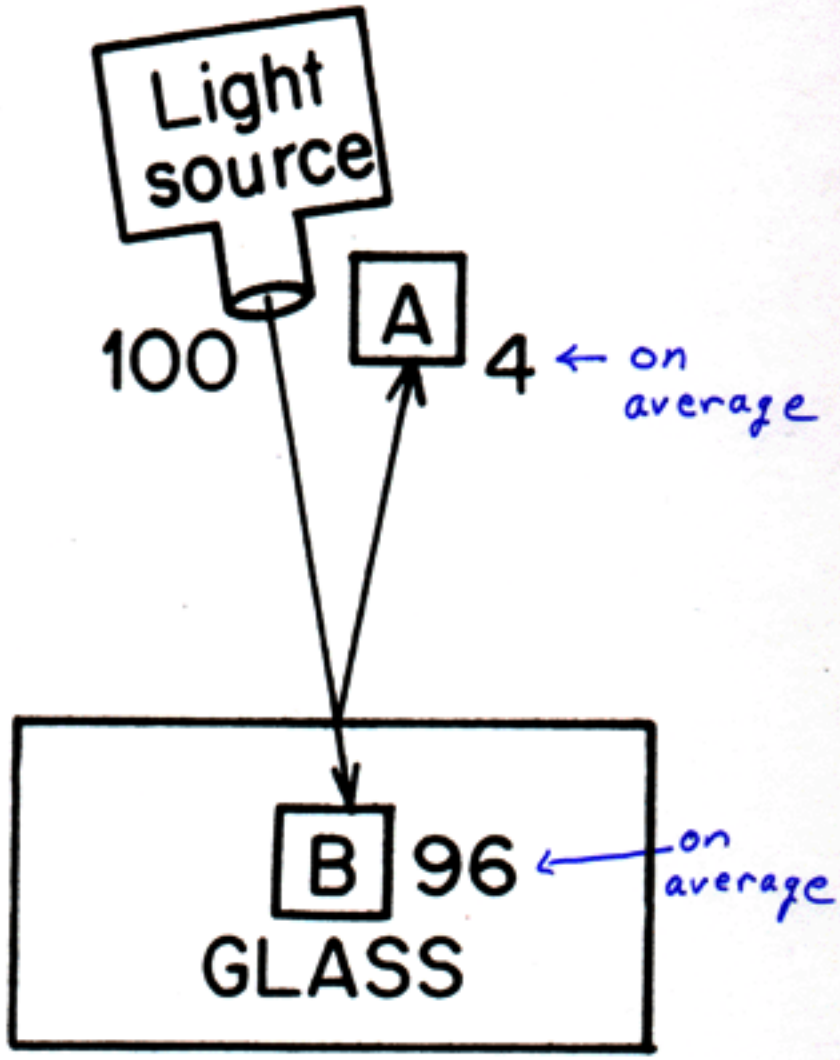
$\theta_i = \theta_r$

Works well in most cases, but...

Problems with the classical picture

1. partial reflection

photons seem to randomly "decide" to reflect or transmit

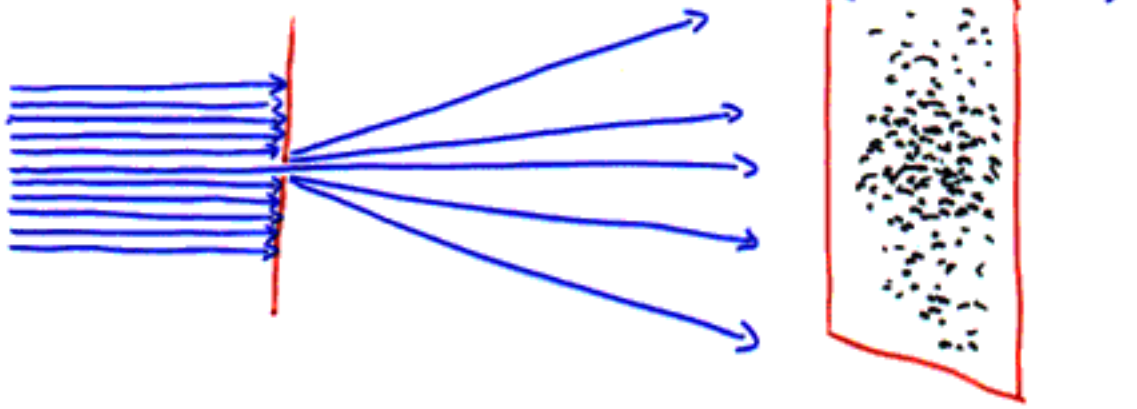


* Newton knew this was a problem for his particle theory of light.

Problems with classical model

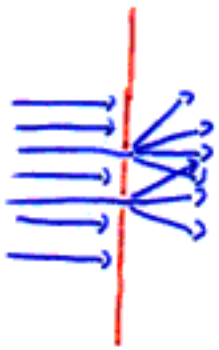
2. diffraction through narrow slits

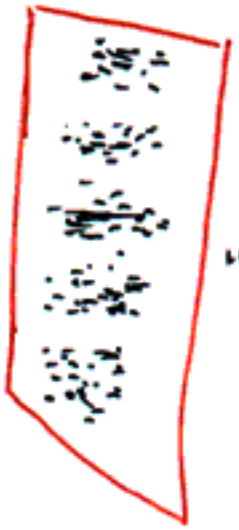
(10^{-5} - 10^{-6} m)



3. two-slit interference

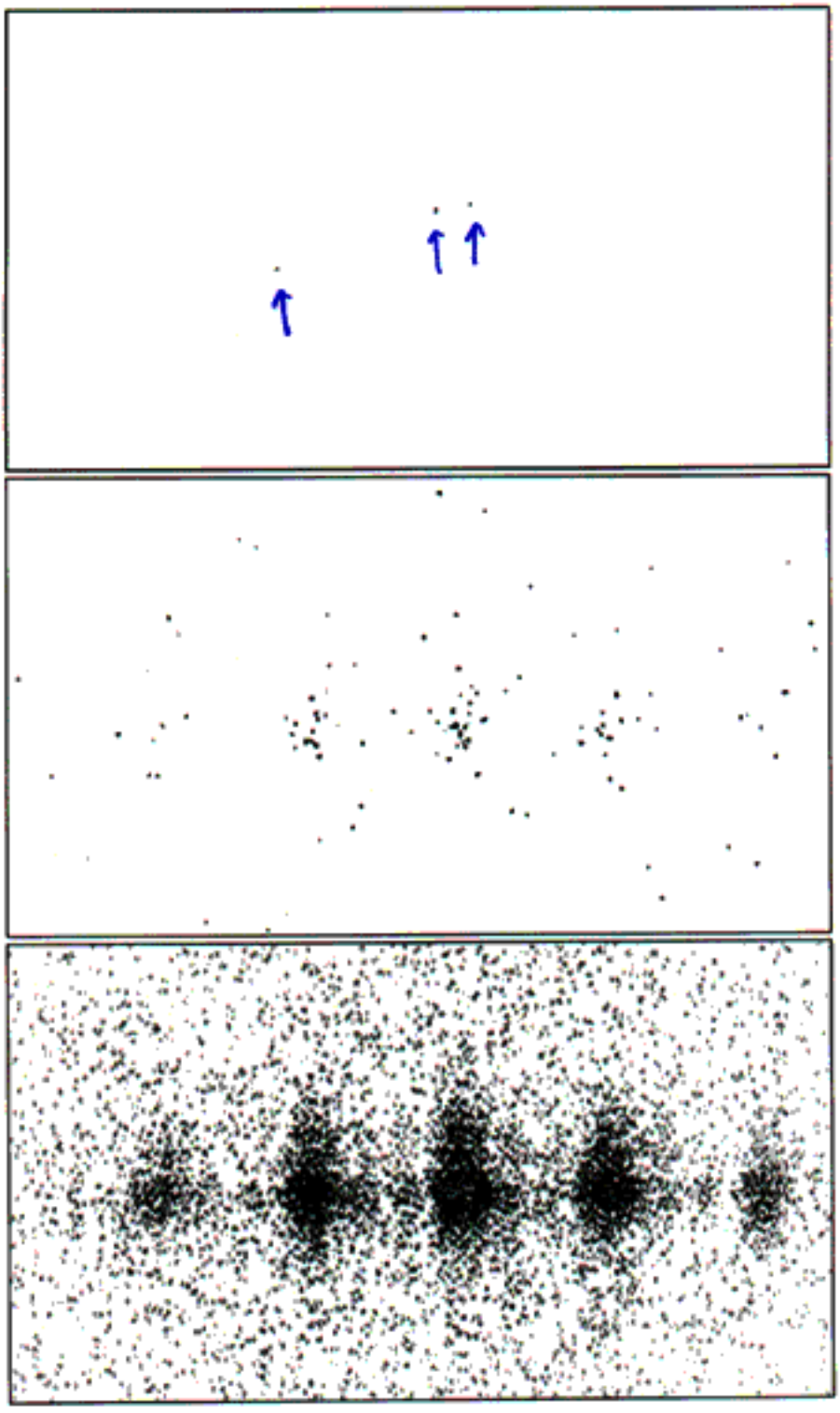
10μm



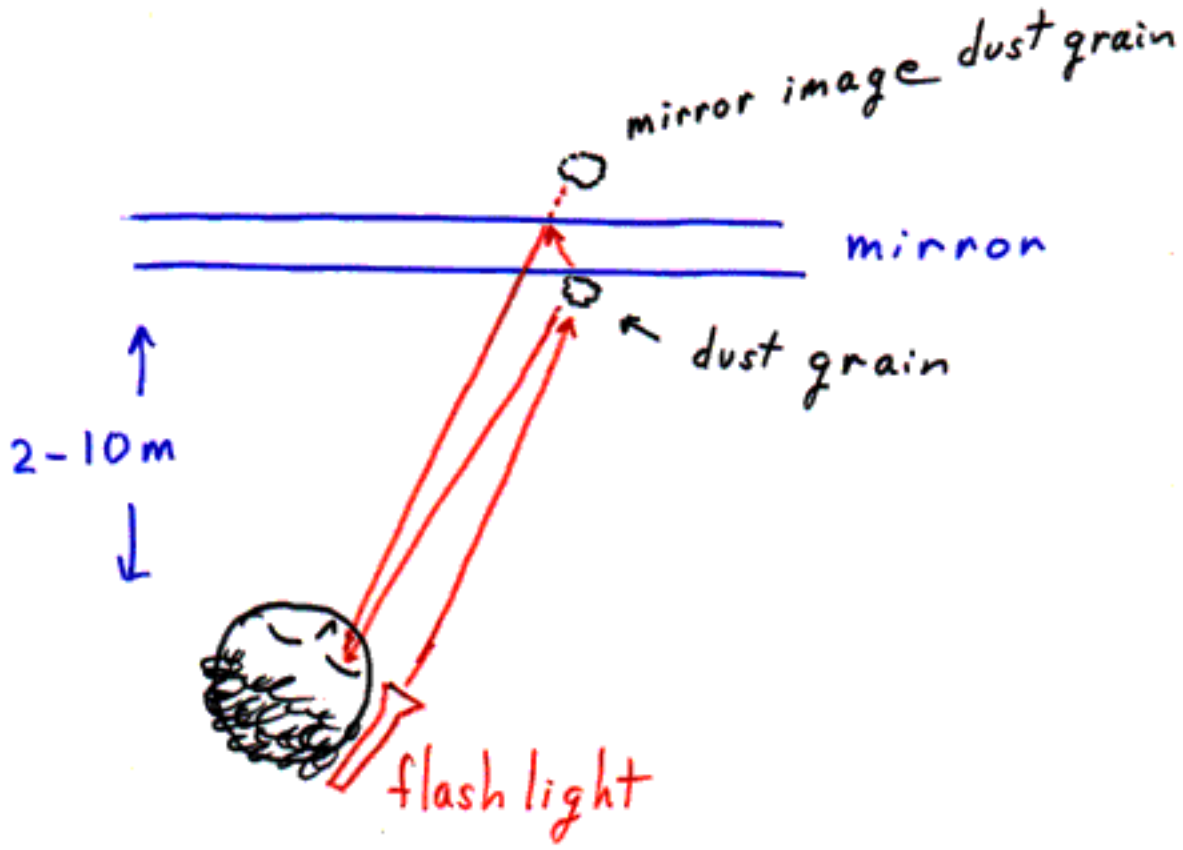


"fringes"

Something strange happens when the photon has two "choices" of paths to the same final position.

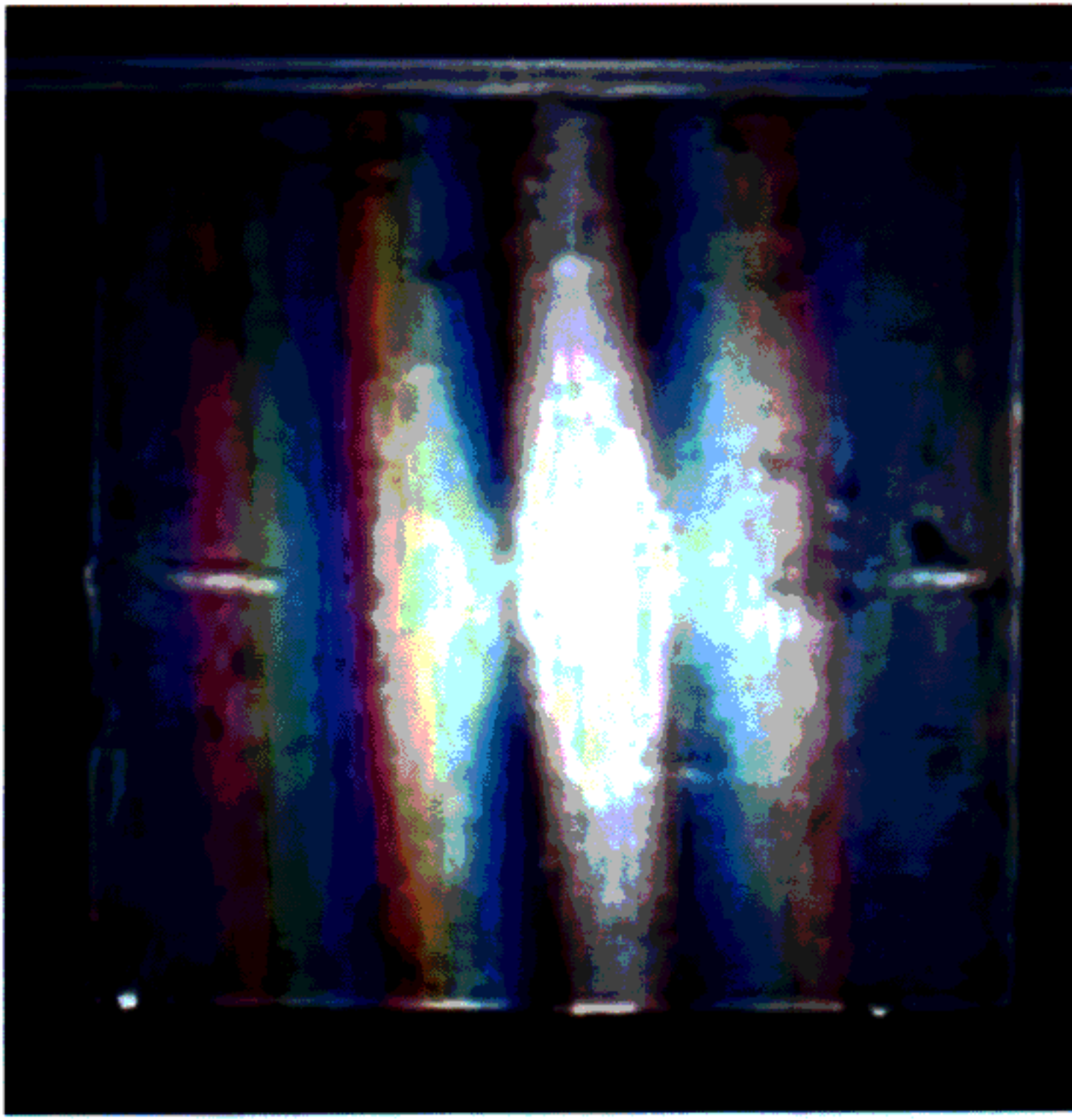


"Do it yourself" two-slit experiment

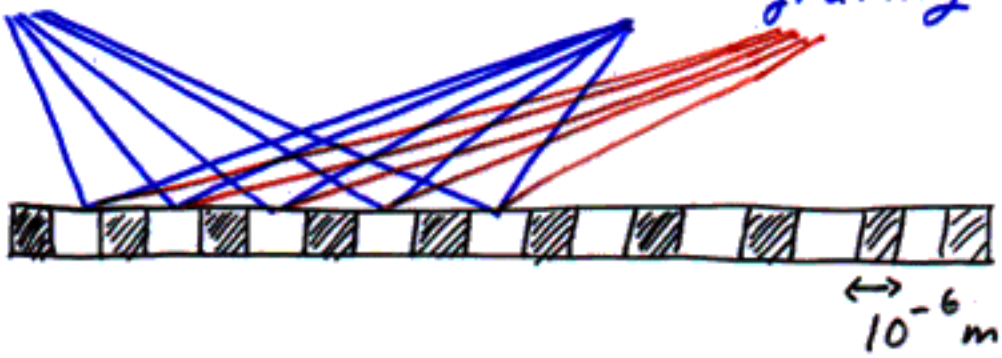


each dust grain and its mirror image act like a pair of slits*

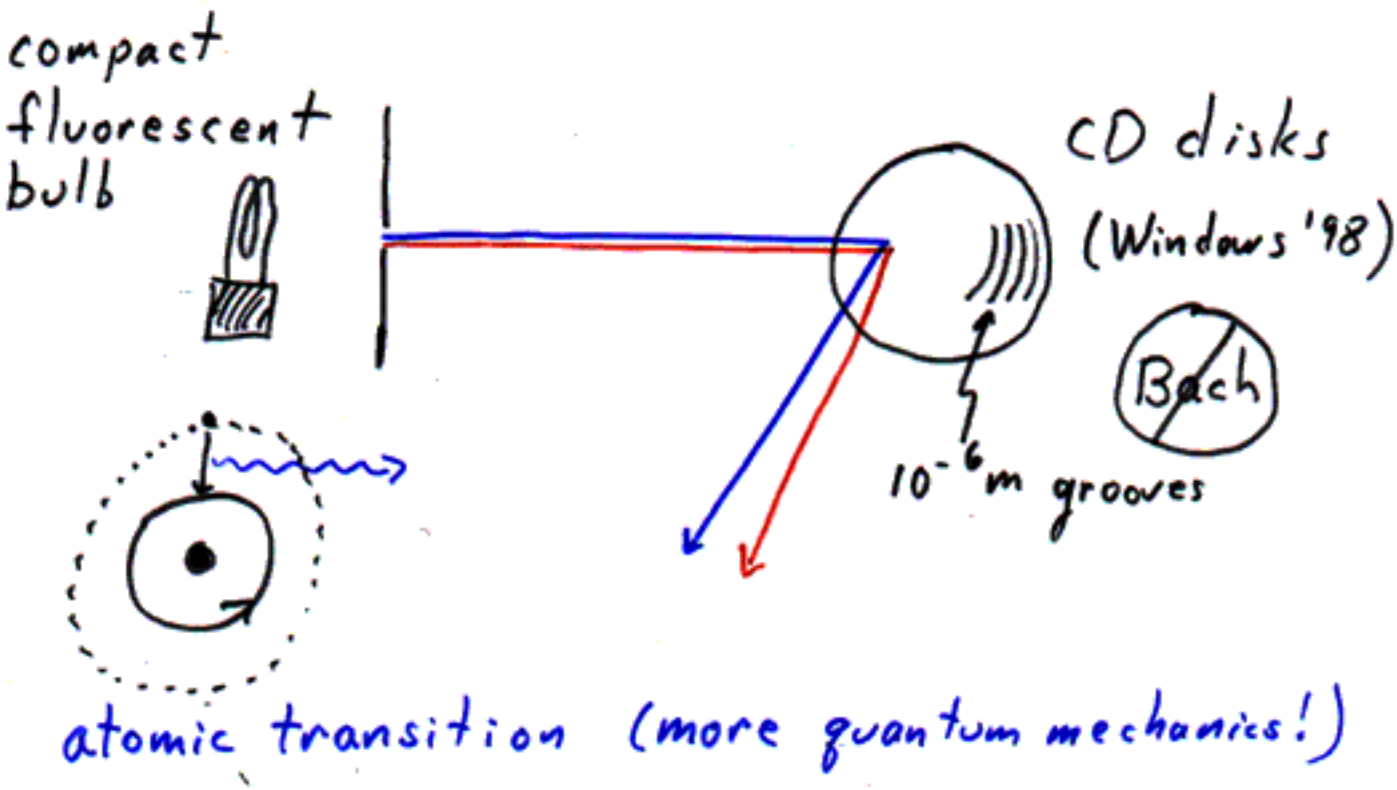
*. mirror image of flashight complicates this



two slits ⟶ many slits ≡ diffraction grating



different colors bounce off at different angles



atomic transition (more quantum mechanics!)

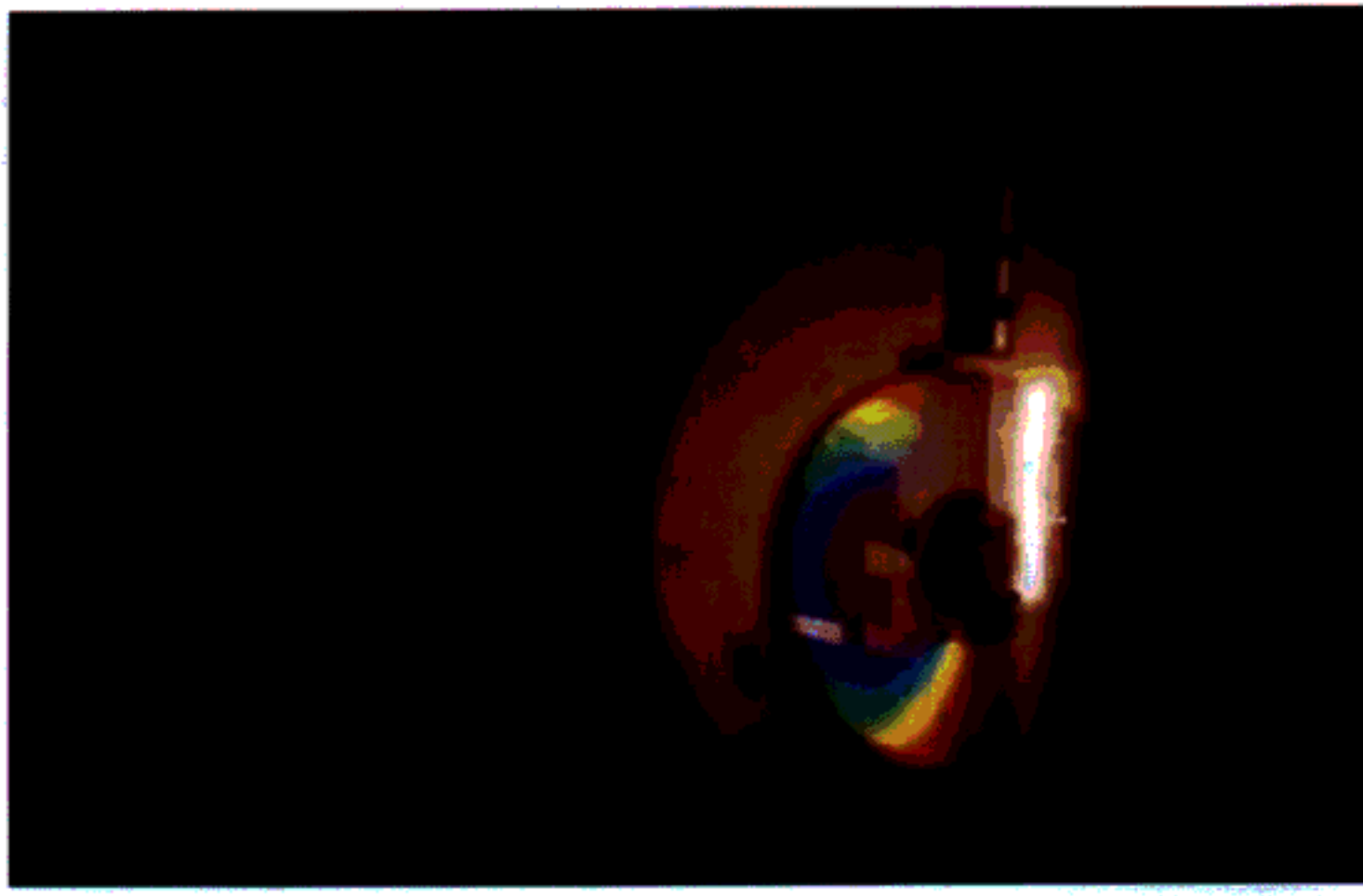
image of fluorescent bulb reflected in a CD disk

(Note specular beam on RHS)

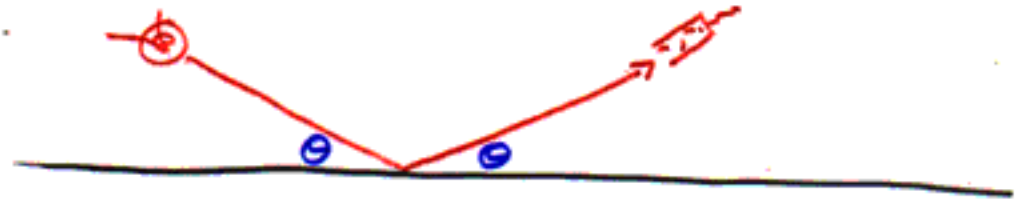
fluorescent lamp

incandescent bulb

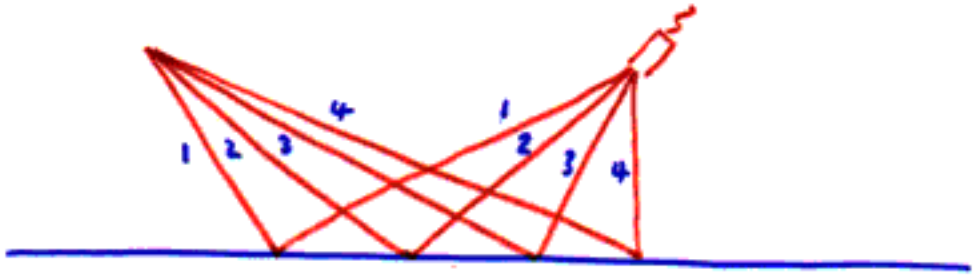
note spectrum is continuous



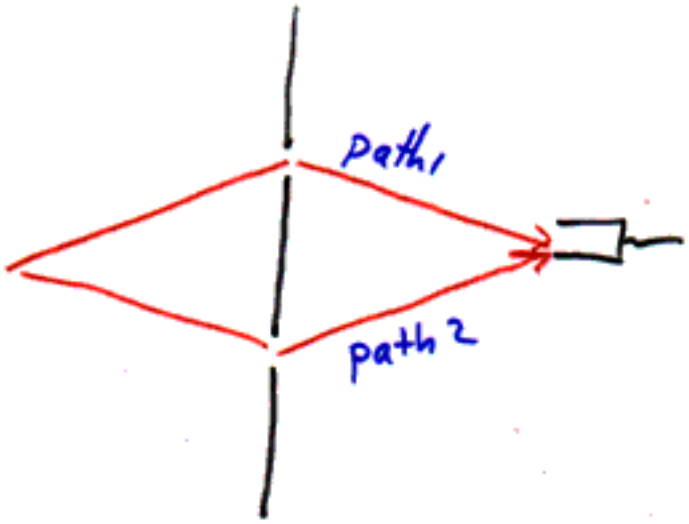
classical picture: single path



Feynman's "many paths" picture of quantum mechanics:



each photon "samples" all possible paths from source to detector



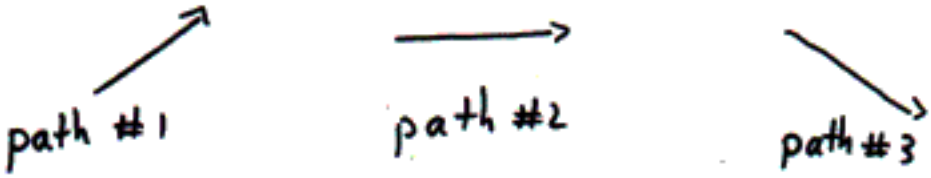
Strange Feature #1

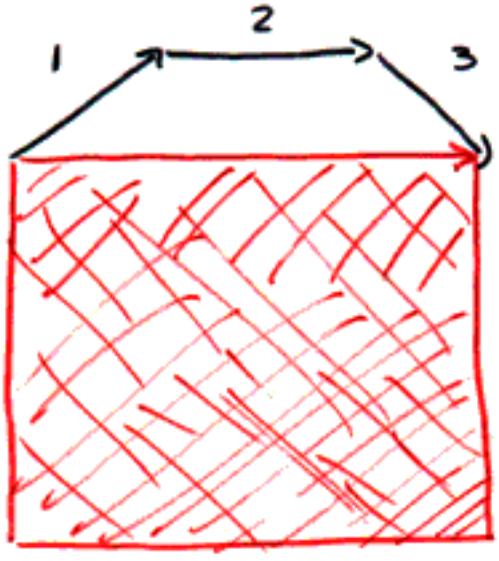
Each particle takes all possible paths to the detector.

Strange Feature #2

Each particle carries a "stop watch" which runs at a rate determined by the color (frequency) of the light.

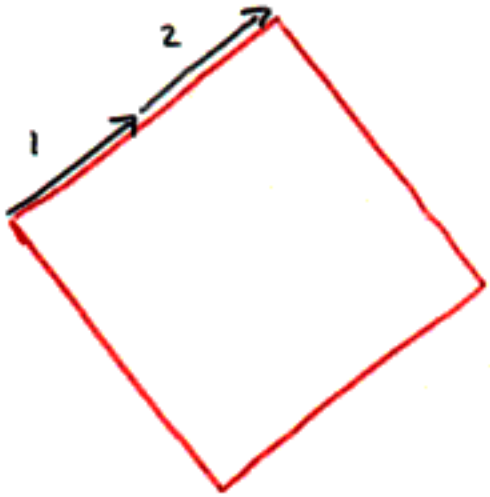
Crazy Rule: combine clock readings



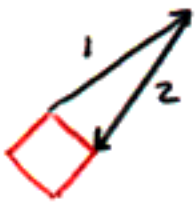


random probability of being detected $\propto$ area of square

Crazy Rule explains interference

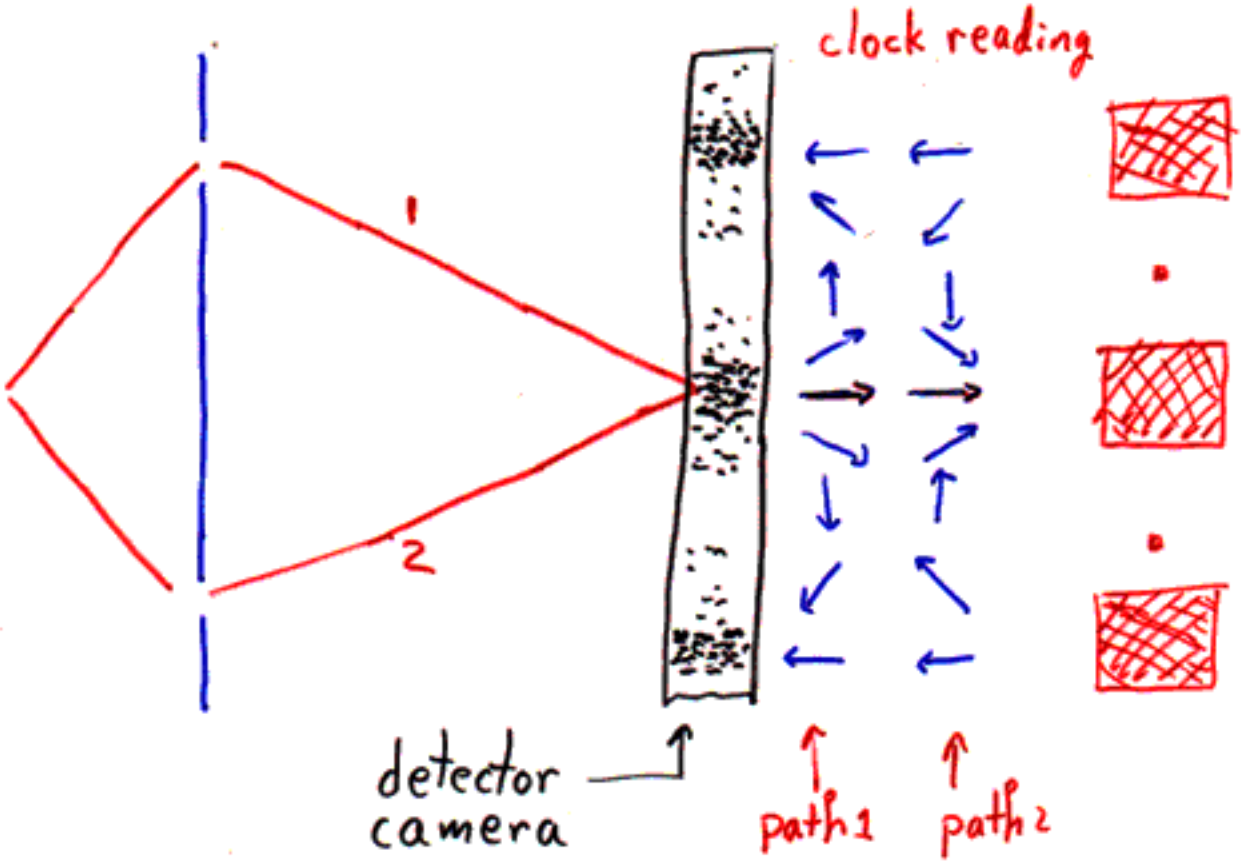


constructive
"in phase"



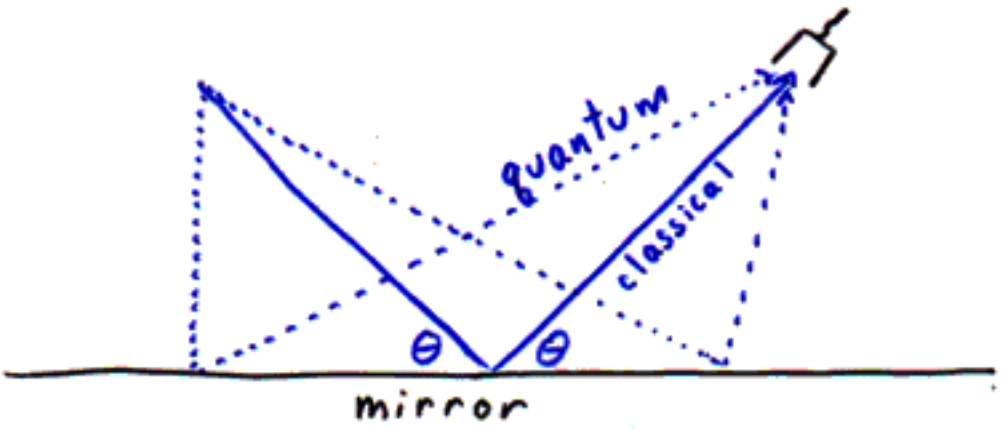
destructive
"out of phase"

Two-slit interference



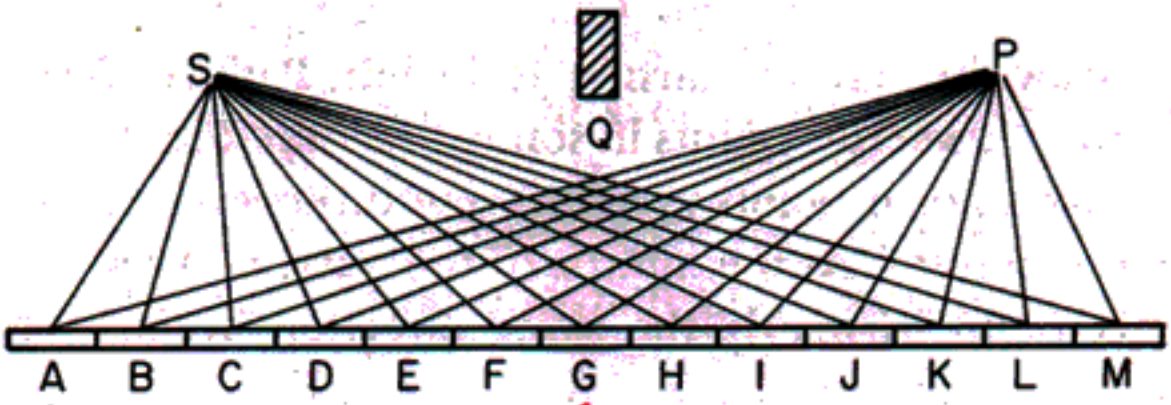
This crazy rule explains <u>all</u> quantum experiments. But....

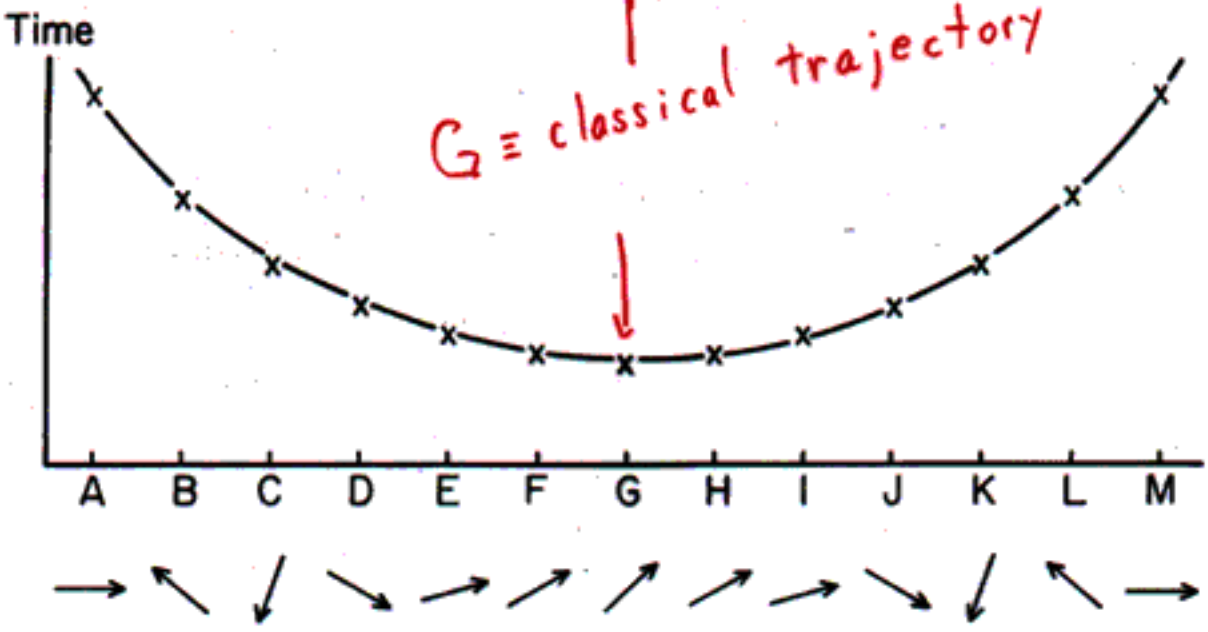
But it seems totally crazy!
How can it be consistent with geometric optics and everyday experience?

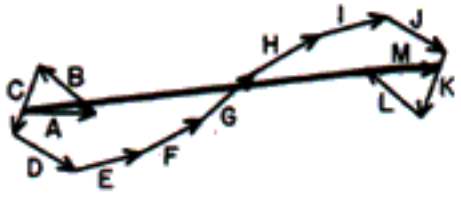


We know that 10 cm mirrors and 1 cm mirrors work equally well and obey geometric optics

Does the photon really sample all paths?

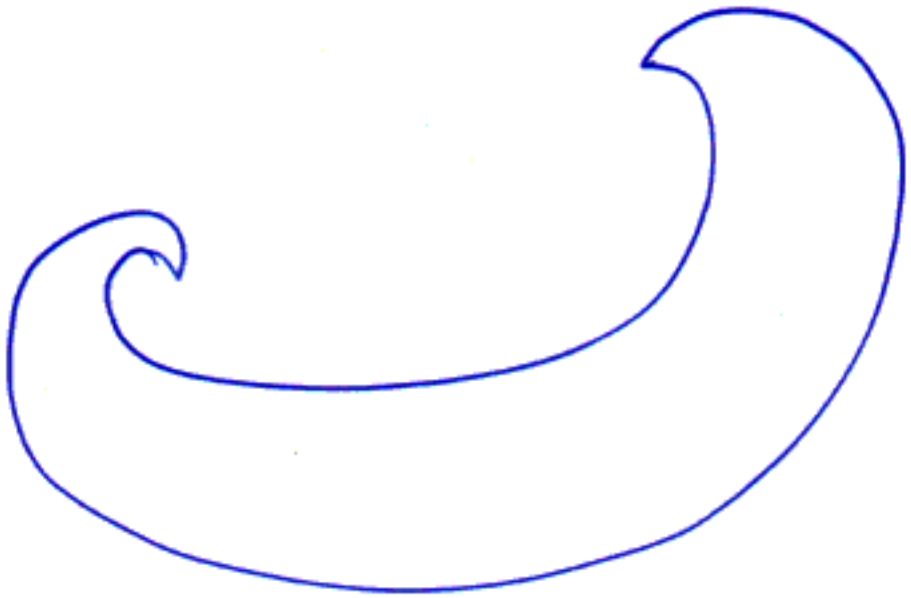






Principle of least time

Feynman's French Curve Theorem



Principle of least time

Mirages

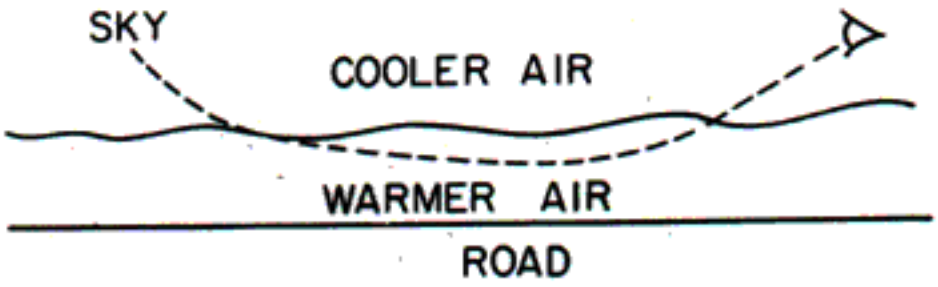


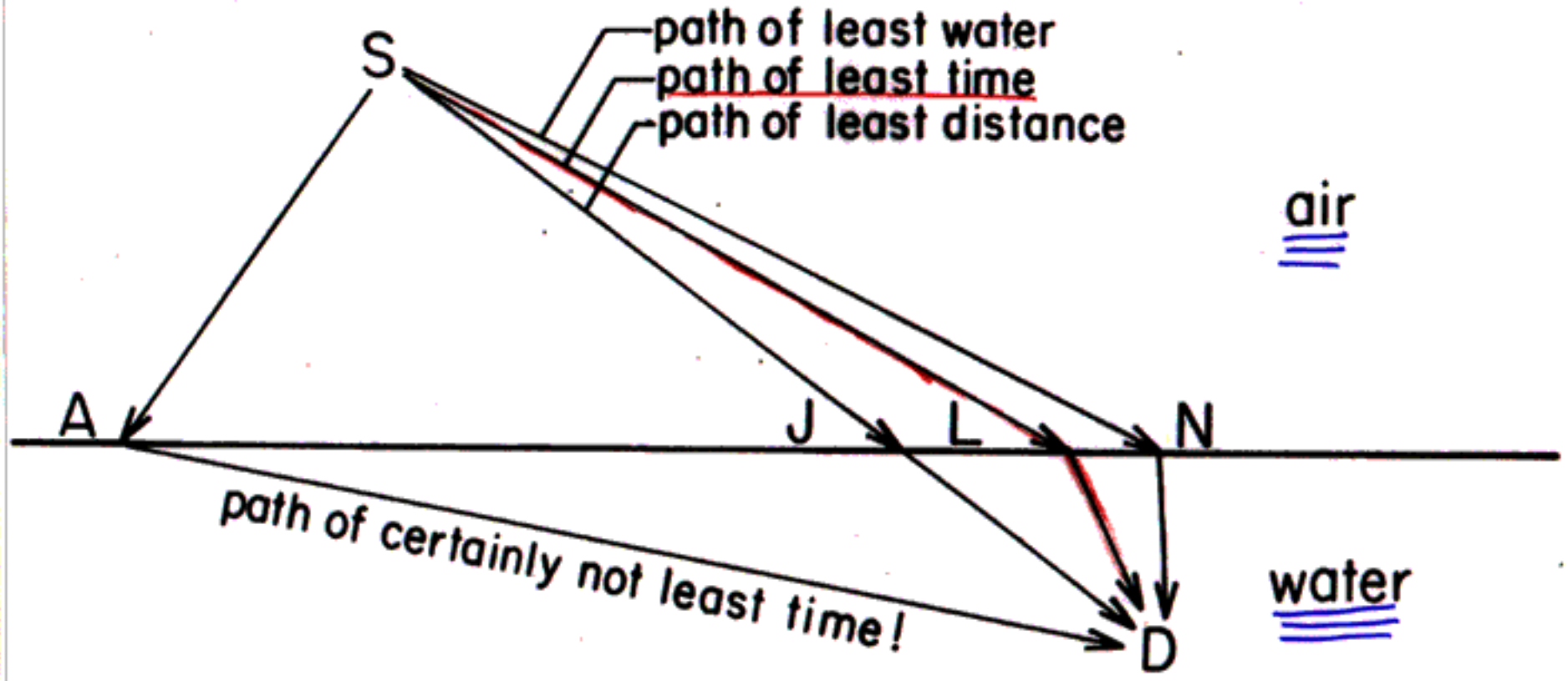
FIGURE 31. *Finding the path of least time explains how a mirage works. Light goes faster through warm air than through cool air. Some of the sky appears to be on the road because some of the light from the sky reaches the eye by coming up from the road. The only other time sky appears to be on the road is when water is reflecting it, and thus a mirage appears to be water.*

light travel faster in less dense (warmer) air

Principle of least time

Refraction

Snell's Law $n_1 \sin\theta_1 = n_2 \sin\theta_2$



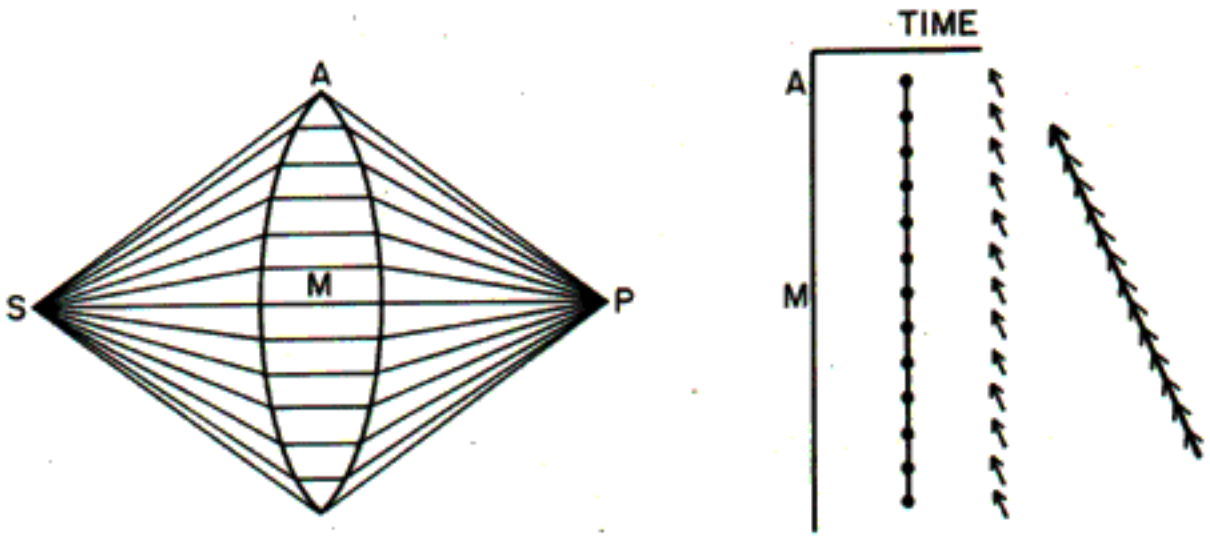
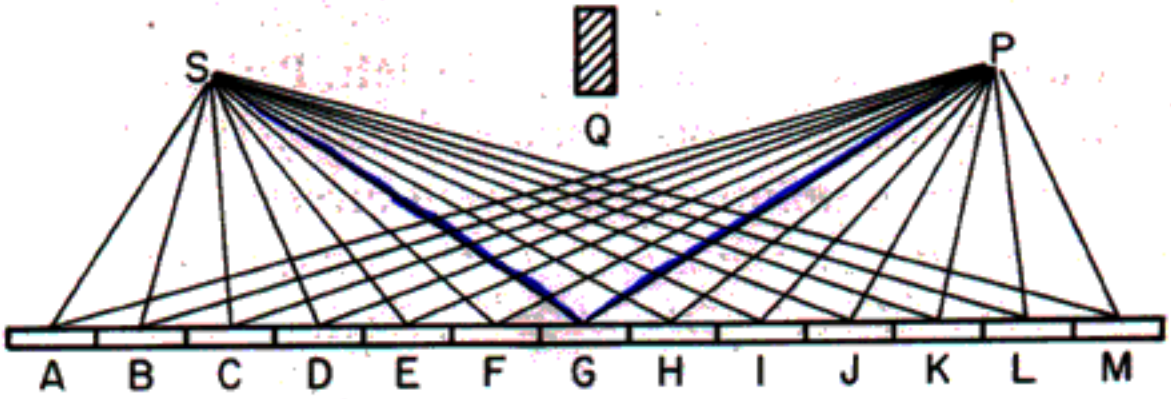
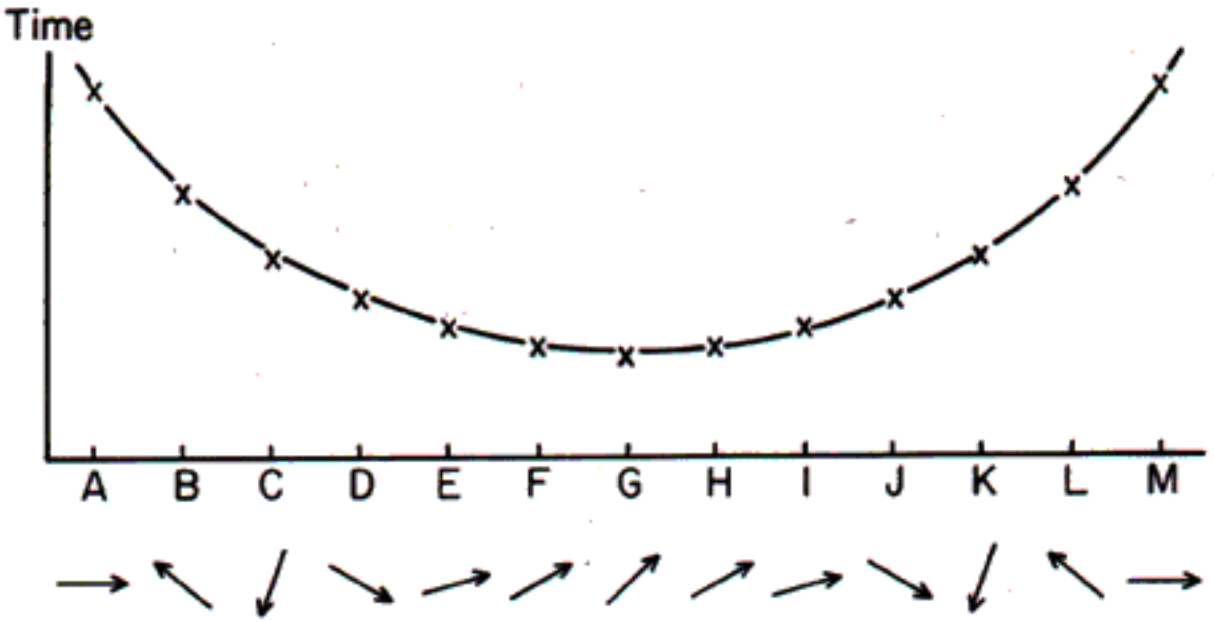
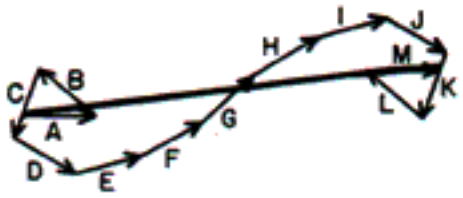


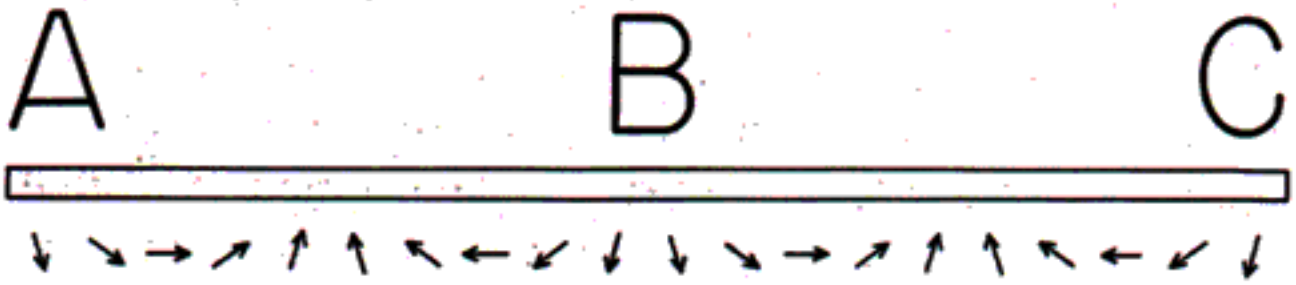
FIGURE 36. *A "trick" can be played on Nature by slowing down the light that takes shorter paths: glass of just the right thickness is inserted so that all the paths will take exactly the same time. This causes all of the arrows to point in the same direction, and to produce a whopping final arrow—lots of light! Such a piece of glass made to greatly increase the probability of light getting from a source to a single point is called a focusing lens.*

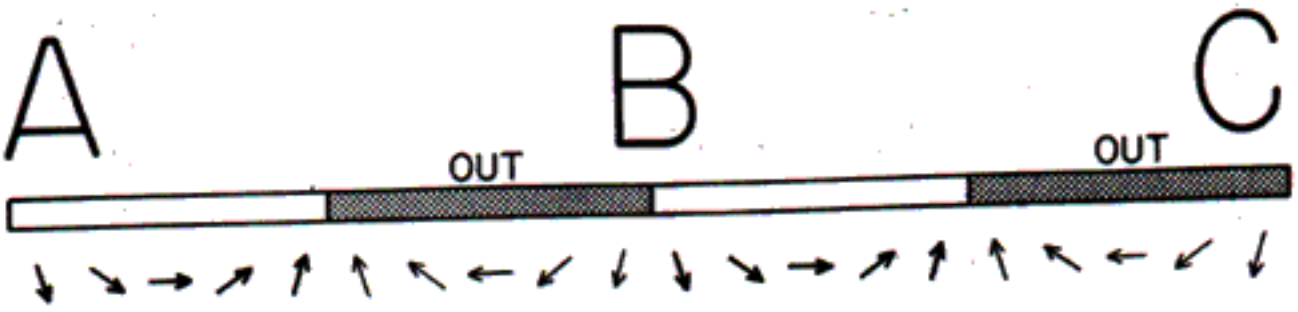


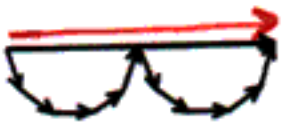




If the contributions from the non-classical paths all cancel each other, does the particle really go there?







blacken all portions of the mirror that give arrows pointing to the left.

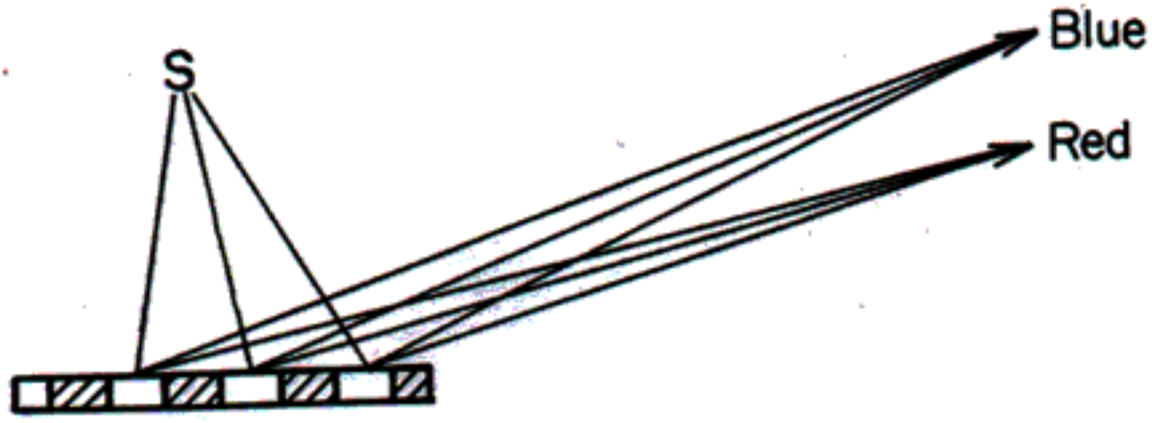
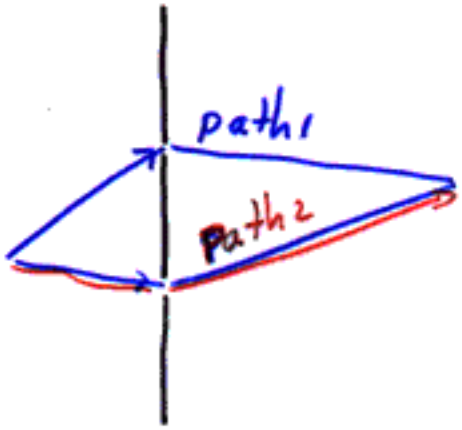


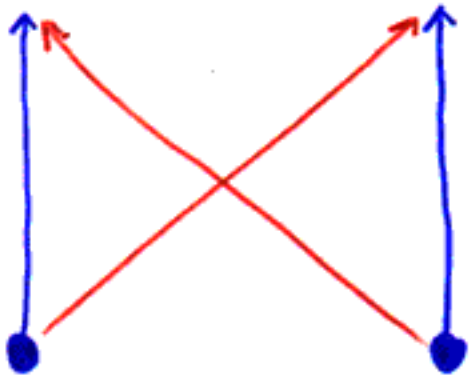
FIGURE 27. *A diffraction grating with grooves at the right distance for red light also works for other colors, if the detector is in a different place. Thus it is possible to see different colors reflecting from a grooved surface—such as a phonograph record—depending on the angle.*

Two paths to the same final state $\Longrightarrow$ interference



one particle
2 paths

Bose Einstein Condensation



$=$ path 1
$-$ path 2

For identical particles, (path 1) and (path 2) lead to the same final state.

constructive interference causes BEC

Quantum mechanics is very different from classical mechanics.—

– just as Danes are very different from Norwegians.

So, THAT'S the difference between Danes and Norwegians?