

1

FIELDS ARRANGED BY PURITY
 MORE PURE →

SOCIOLGISTS: SOCIOLGY IS JUST APPLIED PSYCHOLOGY
 PSYCHOLOGISTS: PSYCHOLOGY IS JUST APPLIED BIOLOGY.
 BIOLOGISTS: BIOLOGY IS JUST APPLIED CHEMISTRY
 CHEMISTS: WHICH IS JUST APPLIED PHYSICS. IT'S NICE TO BE ON TOP.
 PHYSICISTS: OH, HEY, I DIDN'T SEE YOU GUYS ALL THE WAY OVER THERE.
 MATHEMATICIANS

Objectives and Outline

- Participants will be able to use an intuitive rule of thumb to describe quantum behaviour.
- Participants will gain an appreciation of the scale over which you can observe quantum effects.
- Participants will explore how personalities and politics can influence scientific understanding

The people
 The problems
 The physics

<https://www.xkcd.com/435/>

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An Embarrassment...

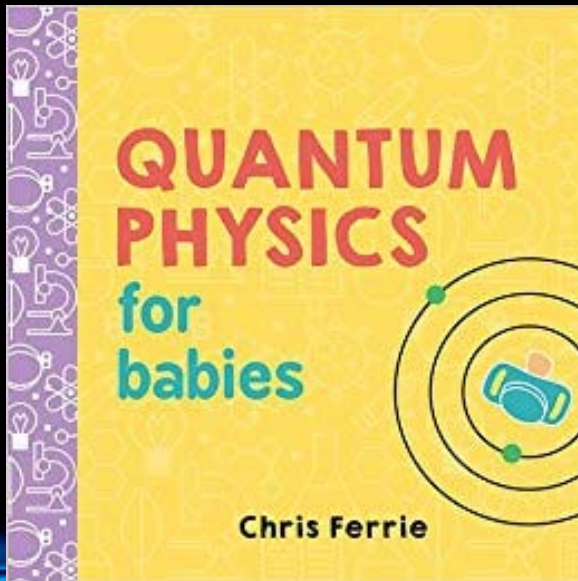


See the video by Sean Carroll (first minute)

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Where does Quantum Physics come from?



~~Starting our derivation
with Schrodinger...~~

Maybe an introductory
text instead.

(Thanks Chris!)



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Intro to Quantum Physics

All balls are made of atoms.

There are **neutrons**.

And **protons**.

And **electrons**.

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Intro to Quantum Physics

An **electron** can be here.

Or here.

Or here.

But an **electron** cannot be here.

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Intro to Quantum Physics


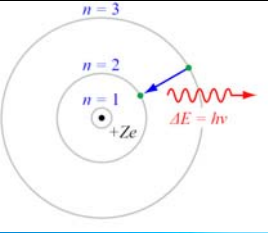
An electron can take energy to jump up. And it must give energy to fall down.

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This amount of energy is a quantum.

Now you are a
QUANTUM PHYSICIST!

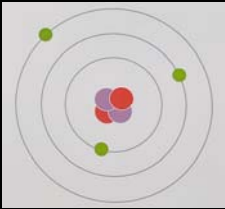
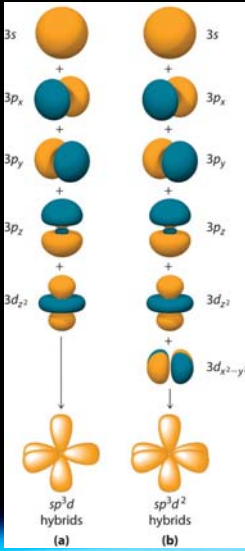



1922 Nobel Prize in Physics: Niels Bohr

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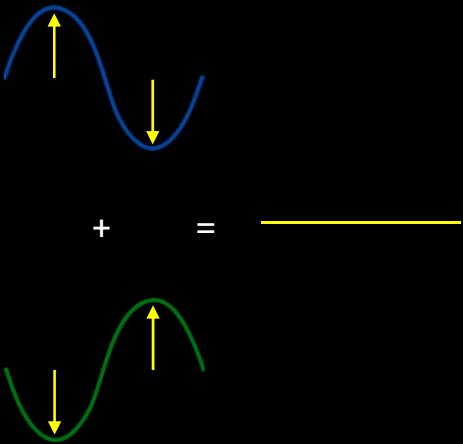
Electrons (and everything else) as waves

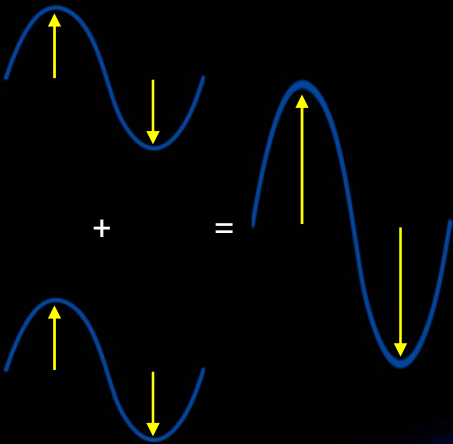
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Wave Interference



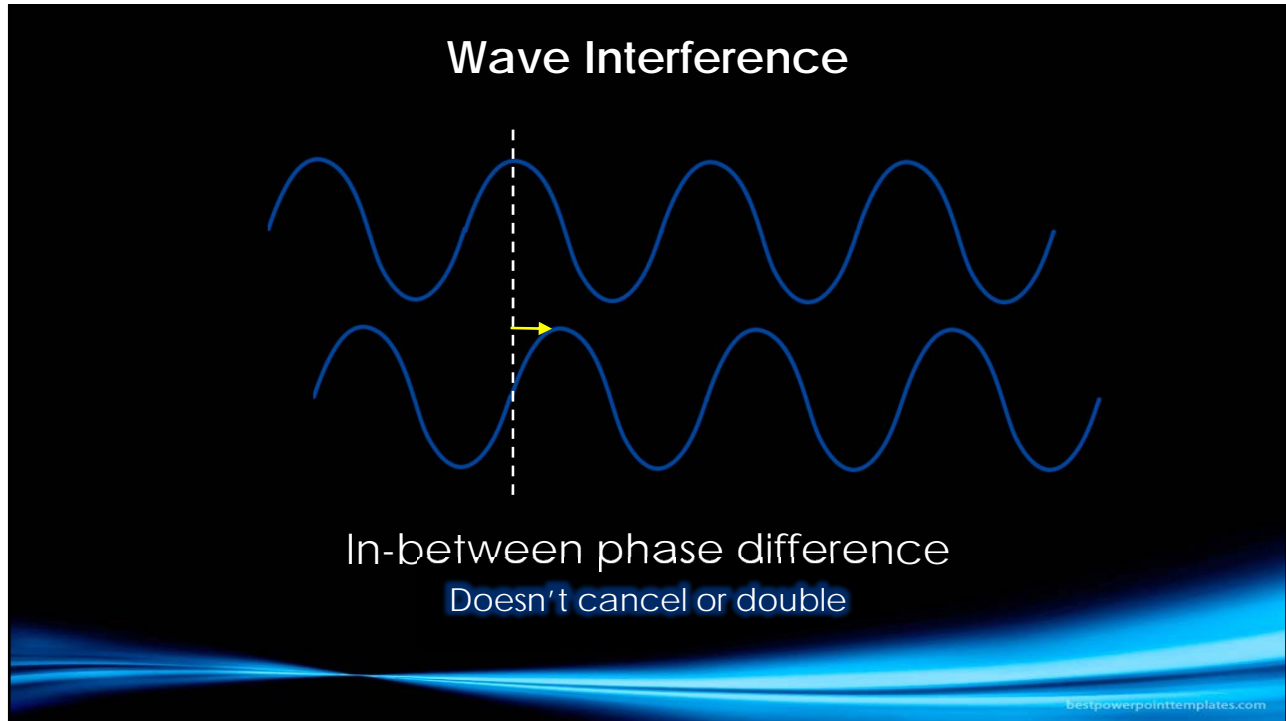
Waves cancel out



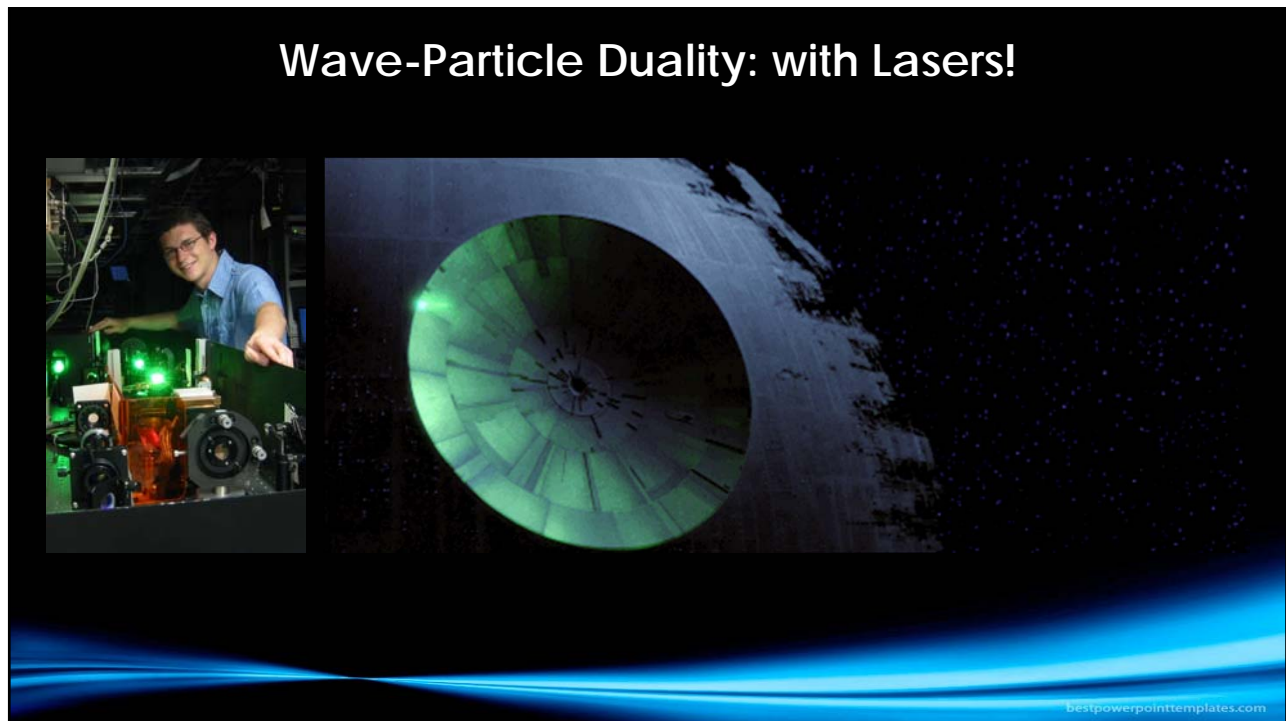
Waves get stronger

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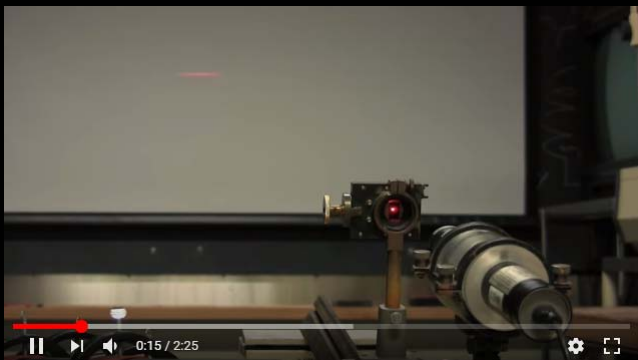
Double Slit Experiment
One slit open





<https://www.youtube.com/watch?v=9D8cPrEAGyc>
TSG Physics: Laser Diffraction and Interference

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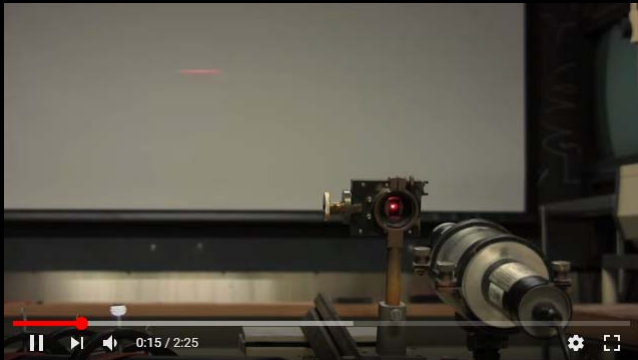
Double Slit Experiment
The other open





<https://www.youtube.com/watch?v=9D8cPrEAGyc>
TSG Physics: Laser Diffraction and Interference

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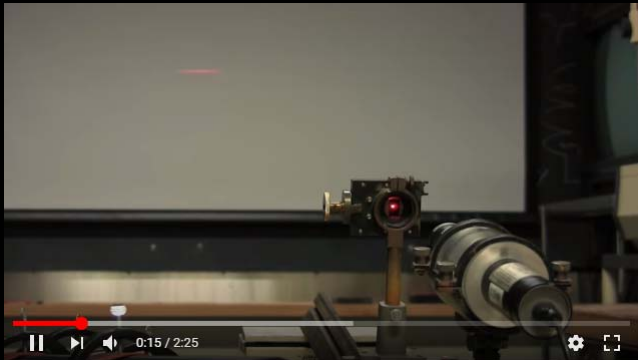
Double Slit Experiment
If light were made of particles...





<https://www.youtube.com/watch?v=9D8cPrEAGyc>
TSG Physics: Laser Diffraction and Interference

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Double Slit Experiment
...but no.




<https://www.youtube.com/watch?v=9D8cPrEAGyc>
TSG Physics: Laser Diffraction and Interference

So light acts like a wave!
Except, when it doesn't.

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Light as Packets of Energy



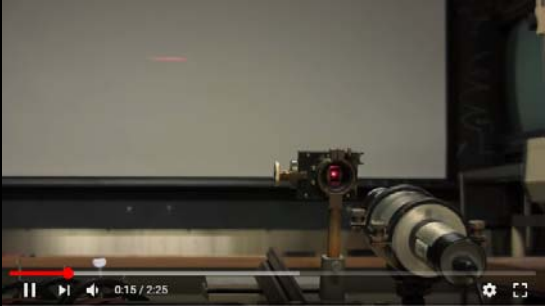
See the Nobel Lecture by Donna Strickland

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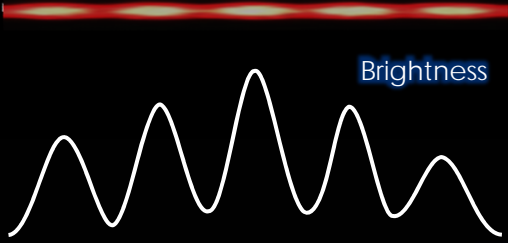
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Wave-particle Duality

Light can act like a wave or a particle



Can matter act as a wave or a particle? Try Electrons.



See the video of electron interference

<http://iopscience.iop.org/article/10.1088/1367-2630/15/3/033018/meta>

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Wave-Particle Dualism

Brightness, or Probability The Real Electron Wave

It looks like the "Wave" collapses to a single point when we measure the electron. This has been called the Collapse of the Wavefunction.

Objects travel as waves, but interact as particles

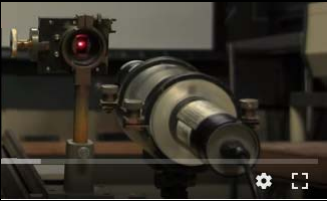
The Electron Particle

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Looking for Quantum Effects

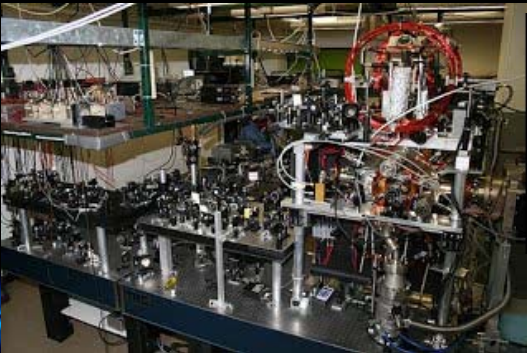
Quantum Light



Seeing Quantum Effects is **HARD!!**
It's easier if objects are **cold and isolated**

Quantum Electrons





Quantum Atoms

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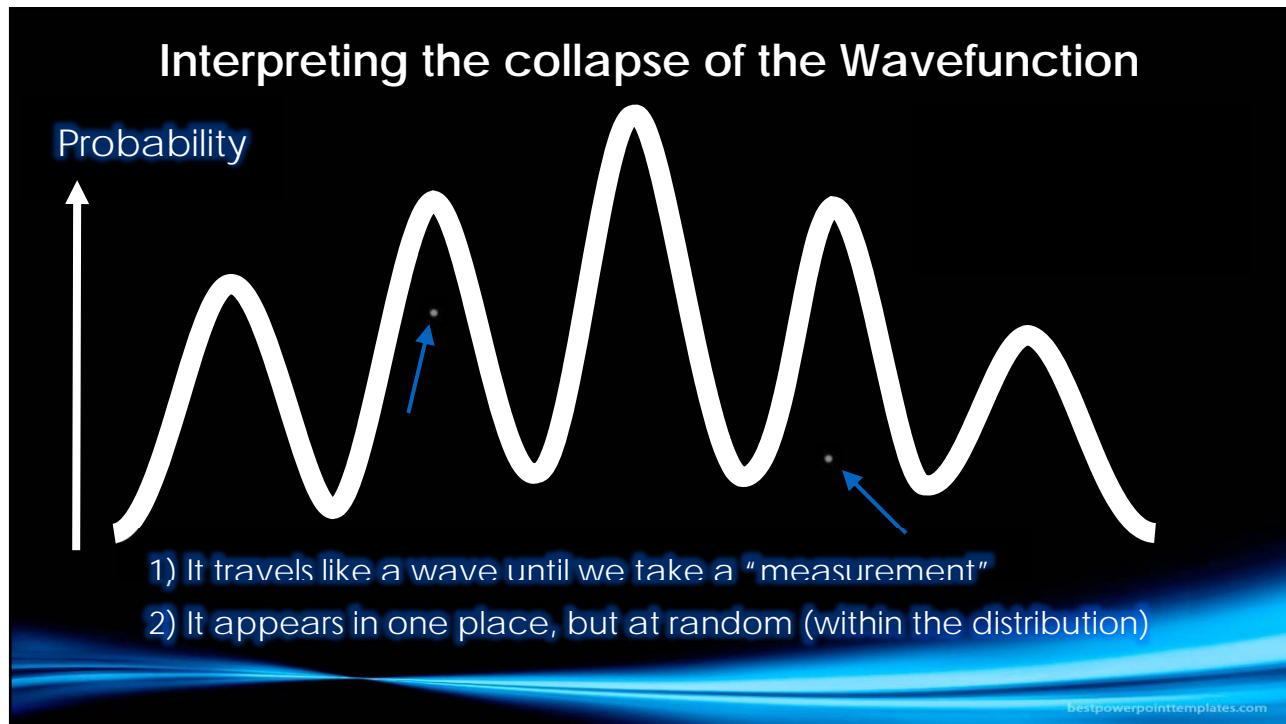
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The Copenhagen Interpretation

Wave-Particle Duality

- Left alone: Travels as Wave
- Look at it: Interacts as Particle

50/50 Beamsplitter

Imagine the beam is weak, so only "one photon will go at a time"

- The "wave" splits 50/50 and arrives at both detectors
- When we look, either detector 1 or 2 registers the photon, not both
- Interpretation: it actually **only** went along path 1 or path 2

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The Copenhagen Interpretation(s)

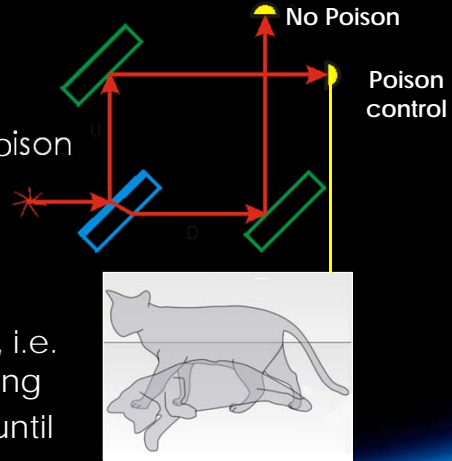
Schrodinger's Thought Experiment

- Imagine a cat in a box
- Take a 50/50 Quantum Event
- Use only one detector to trigger a poison

Q: Is the cat alive or dead?

Interpretation

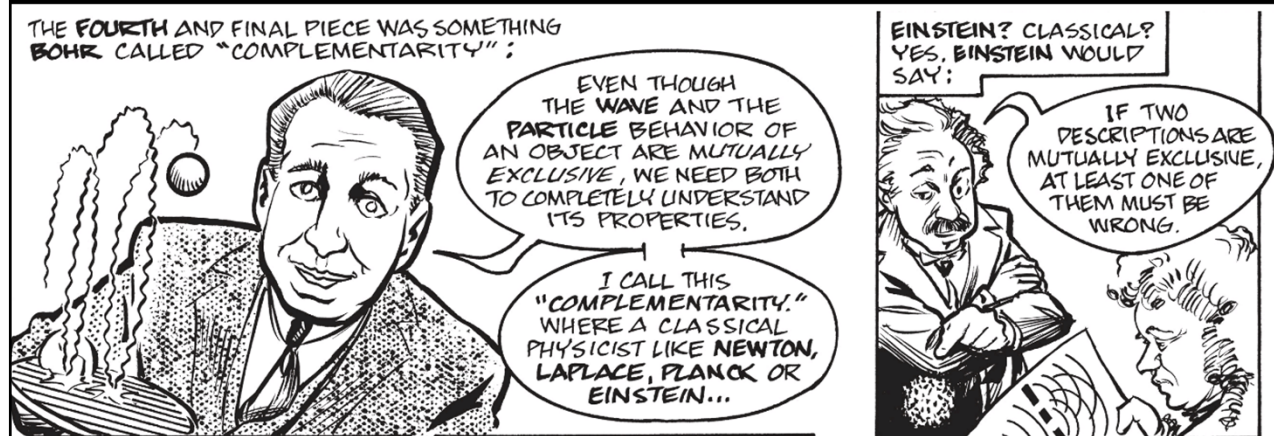
1. You can't ask that question until you look, i.e. there is no objective reality before measuring
2. It is *in a superposition* of alive and dead, until you measure it's aliveness by looking



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Bohr and Einstein



Suspended in Language: Graphic Novel about Neils Bohr

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Sean Carroll on The Copenhagen Interpretation

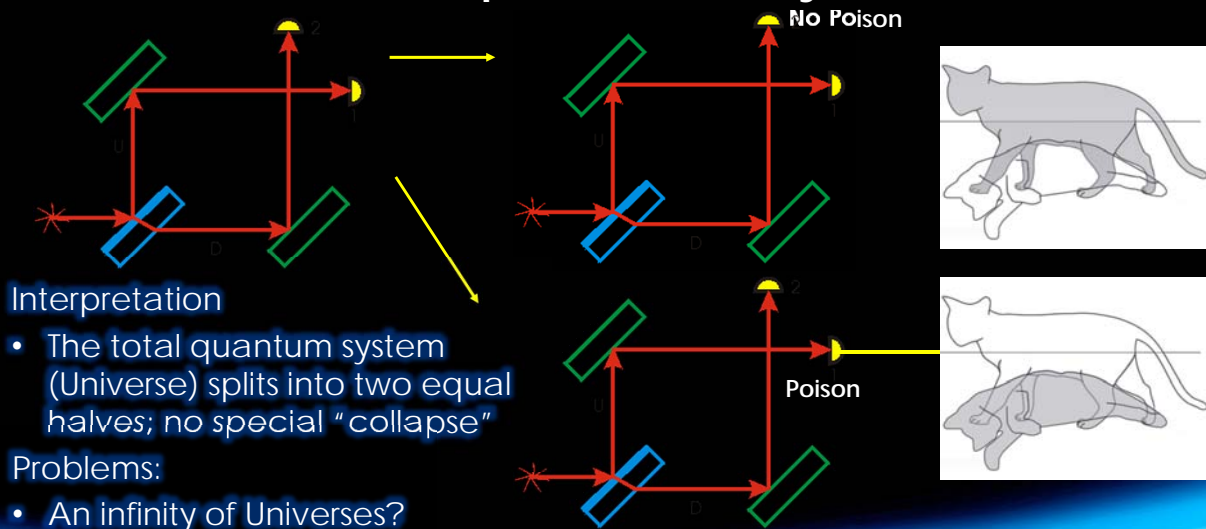


See the video by Sean Carroll

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Everett Interpretation: Many Worlds



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Sean Carroll on The Many Worlds Interpretation



See the video by Sean Carroll

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Throw in the Towel?

THERE WAS A TIME WHEN THE NEWSPAPERS SAID THAT ONLY TWELVE MEN UNDERSTOOD THE THEORY OF RELATIVITY. I DO NOT BELIEVE THERE WAS EVER SUCH A TIME. THERE MIGHT HAVE BEEN A TIME WHEN ONLY [EINSTEIN] DID, BECAUSE HE WAS THE ONLY GUY WHO CAUGHT ON, BEFORE HE WROTE HIS PAPER. BUT AFTER PEOPLE READ THE PAPER A LOT OF PEOPLE UNDERSTOOD THE THEORY OF RELATIVITY IN SOME WAY OR OTHER, CERTAINLY MORE THAN TWELVE. ON THE OTHER HAND, I THINK I CAN SAFELY SAY THAT NO ONE UNDERSTANDS QUANTUM MECHANICS. SO, DO NOT KEEP SAYING TO YOURSELF, IF YOU CAN POSSIBLY AVOID IT, 'BUT HOW CAN IT BE LIKE THAT?'

NOBODY KNOWS HOW IT CAN BE LIKE THAT.

— RICHARD FEYNMAN IN
THE CHARACTER OF PHYSICAL LAW



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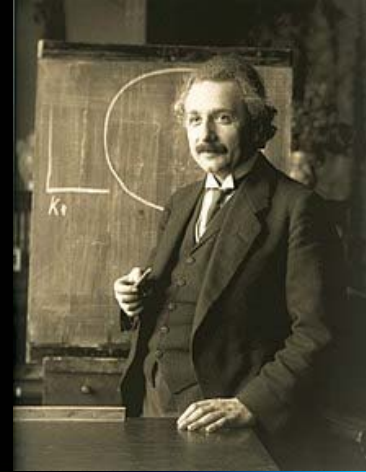
30

Rebuttal

"The theory decides
what we can observe"
- Albert Einstein

[or think to observe]

e.g. Galileo pointing a telescope at Jupiter



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The People

3 Cautionary Tales

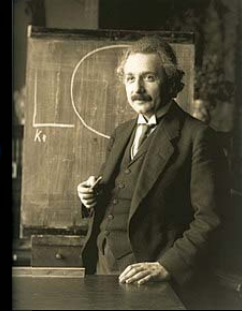
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Tale 1: The Pope and the Misfit



- Father of the Quantum Atom
- Collaborated with and mentored dozens of physicists
- Copenhagen Interpretation
- Father of Relativity (not popular at the time)
- Mostly Worked Solo
- Believed Quantum Mechanics was Incomplete



Continual (Collegial) Engagements between the two with Thought Experiments
Culminating in the Einstein-Podolsky-Rosen "Paradox"

Treated with Reverence

Treated as Esoteric

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Tale 1: The Pope and the Misfit



- John von Neumann
- Knew Calculus by 8
- Published by 19
- "von Neumann can prove anything, and anything he proves is correct"
- Grete Hermann
- Established the Foundation of Computer Algorithms and Algebra
- Proved that von Neumann made a mistake



von Neumann proved that the Copenhagen interpretation was the only possible interpretation of Quantum Mechanics

Grete proved otherwise, but was ignored for decades

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Tale 2: Money and War



J. Robert Oppenheimer

- Leader in the Manhattan Project
 - "If Bohr was God, 'Oppie' was his prophet"
 - "If we cannot disprove Bohm, then we must agree to ignore him"

David Bohm

- Pilot-Wave Interpretation
 - Joined the Communist Party in Berkeley
 - Was persecuted and fled to Brazil
 - Upset both Bohr AND Einstein with non-locality



John Bell (and experimentalists) proved that both Quantum Mechanics and Relativity could not be correct as is

Incidentally proving Bohm's non-local Pilot-Wave description was valid

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Tale 3: The Mystic and the Pragmatist

(Not that mystic but it follows the pattern for my talk!)



John Wheeler

- Worked with Bohr in Nuclear Fission
- Tried to marry Relativity with Quantum Mechanics
- Interpreted Copenhagen to imply consciousness plays a role

Hugh Everett

- Treated the Universe as Quantum
- Resulted in many-worlds
- Revised his thesis to pass muster by Bohr & Wheeler
- Left academia to work for the American Military as a consultant in the Cold War



Many felt Quantum Interpretations was a waste of time, as the atomic bomb proved how useful QM was.

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Why are there still disagreements?

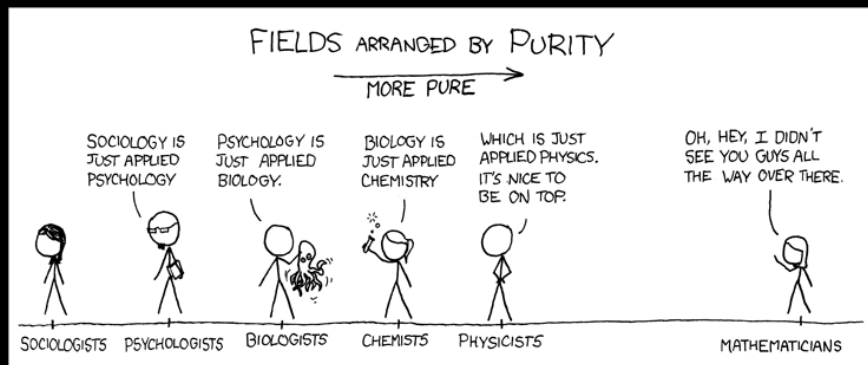


See the video by Sean Carroll

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The End Thank you!



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Videos and References

Sean Carroll Sixty Symbols: <https://youtu.be/ZacggH9wB7Y>

Donna Strickland Nobel Presentation: https://www.youtube.com/watch?v=sl_e7c085LM

Double Slit Interference with Lasers: <https://www.youtube.com/watch?v=9D8cPrEAGyc>

Double Slit Interference with Electrons:

<http://iopscience.iop.org/article/10.1088/1367-2630/15/3/033018/meta>

Dominic Walliman (General Quantum): <https://www.youtube.com/watch?v=ARWBdfWpDyc>

Dominic Walliman (Quantum Nose): <https://www.youtube.com/watch?v=DJsJIVXkrGQ>

Based on the Texts:

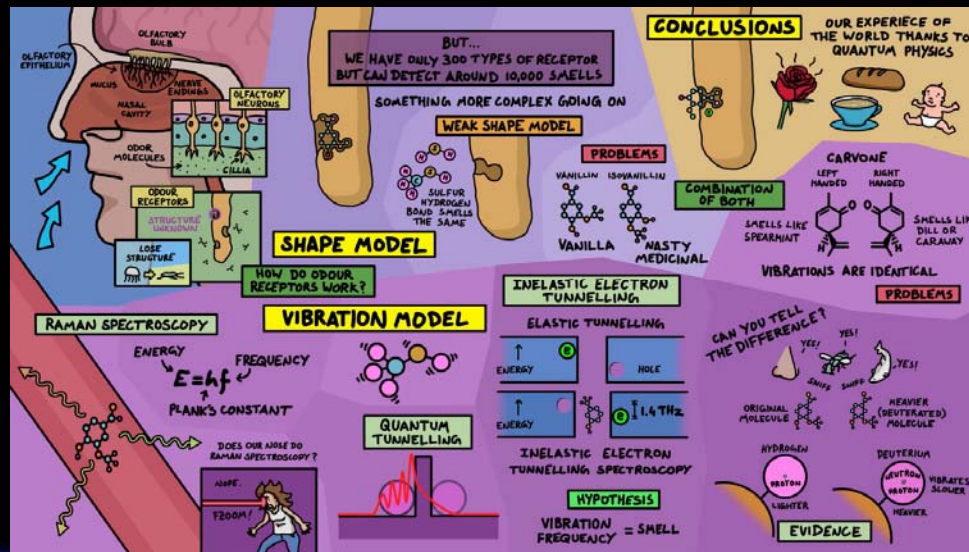
Becker, A (2018) **What is Real?: The Unfinished Quest for the Meaning of Quantum Physics.**
New York, NY: Basic Books

Ottaviani, J (2009) **Suspended in Language: Niels Bohr's Life, Discoveries, and the Century he Shaped.** G.T. Labs

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Your Quantum Nose? But that's Warm and Wet!




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Wave-Particle Duality


Waves



Particles



We've seen this behaviour in objects as large as C_{60}

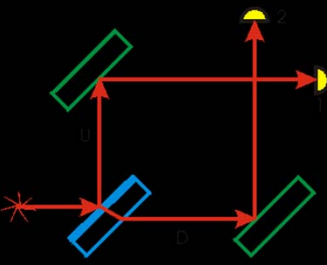


Objects travel as waves,
but interact like particles

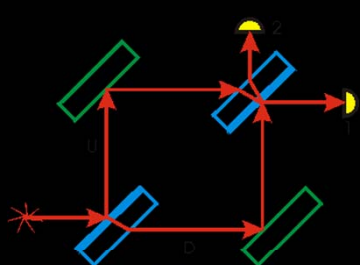
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Delayed choice



50/50 Either detector




Design it so it always goes up

Wait until the photon is halfway through the
device before putting the second splitter in

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Bell's Inequality: No slower-than-light hidden variables



Cornell University
Library

We gratefully acknowledge support from the Simons Foundation and member institutions

arXiv.org > quant-ph > arXiv:1508.05949

All papers

Quantum Physics

Experimental loophole-free violation of a Bell inequality using entangled electron spins separated by 1.3 km

B. Hensen, H. Bernien, A.E. Dréau, A. Reiserer, N. Kalb, M.S. Blok, J. Ruitenberg, R.F.L. Vermeulen, R.N. Schouten, C. Abellán, W. Amaya, V. Pruneri, M. W. Mitchell, M. Markham, D.J. Twitchen, D. Elkouss, S. Wehner, T.H. Taminiau, R. Hanson

(Submitted on 24 Aug 2015)

For more than 80 years, the counterintuitive predictions of quantum theory have stimulated debate about the nature of reality. In his seminal work, John Bell proved that no theory of nature that obeys locality and realism can reproduce all the predictions of quantum theory. Bell showed that in any local realist theory the correlations between distant measurements satisfy an inequality and, moreover, that this inequality can be violated according to quantum theory. This provided a recipe for experimental tests of the fundamental principles underlying the laws of nature. In the past decades, numerous ingenious Bell inequality tests have been reported. However, because of experimental limitations, all experiments to date required additional assumptions to obtain a contradiction with local realism, resulting in loopholes. Here we report on a Bell experiment that is free of any such additional assumption and thus directly tests the principles underlying Bell's inequality. We employ an event-ready scheme that enables the generation of high-fidelity entanglement between distant electron spins. Efficient spin readout avoids the fair sampling assumption (detection loophole), while the use of fast random basis selection and readout combined with a spatial separation of 1.3 km ensure the required locality conditions. We perform 245 trials testing the CHSH-Bell inequality $S \leq 2$ and find $S = 2.42 \pm 0.20$. A null hypothesis test yields a probability of $p = 0.039$ that a local-realist model for space-like separated sites produces data with a violation at least as large as observed, even when allowing for memory in the devices. This result rules out large classes of local realist theories, and paves the way for implementing device-independent quantum-secure communication and randomness certification.

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References & Citations

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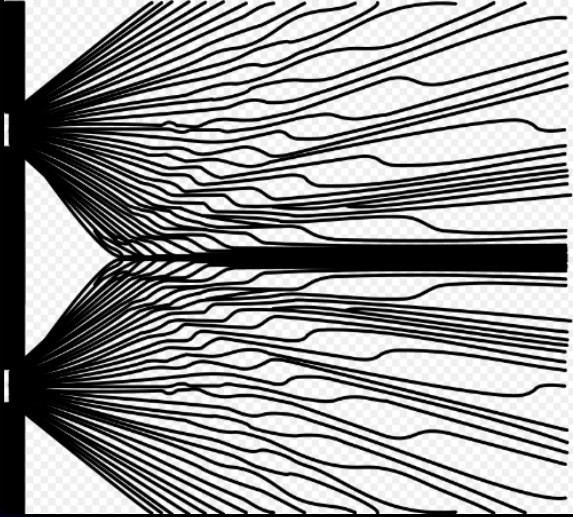
[11 blog links](#) (what is this?)

Bookmark (what is this?)

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Bell's Inequality: No slower-than-light hidden variables



Instantaneous Pilot Waves

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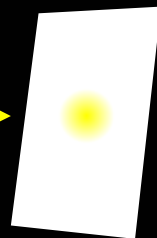
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One way to look at it

45

Path Integrals and Choices

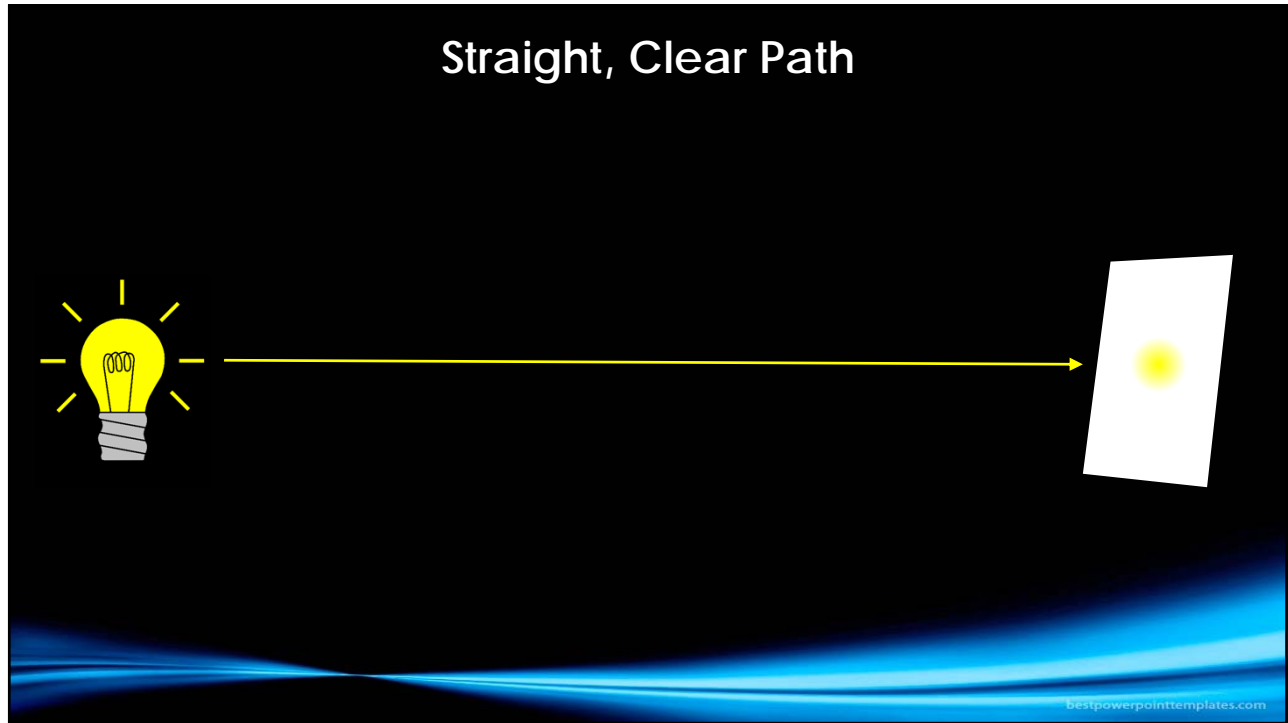
How does light travel?



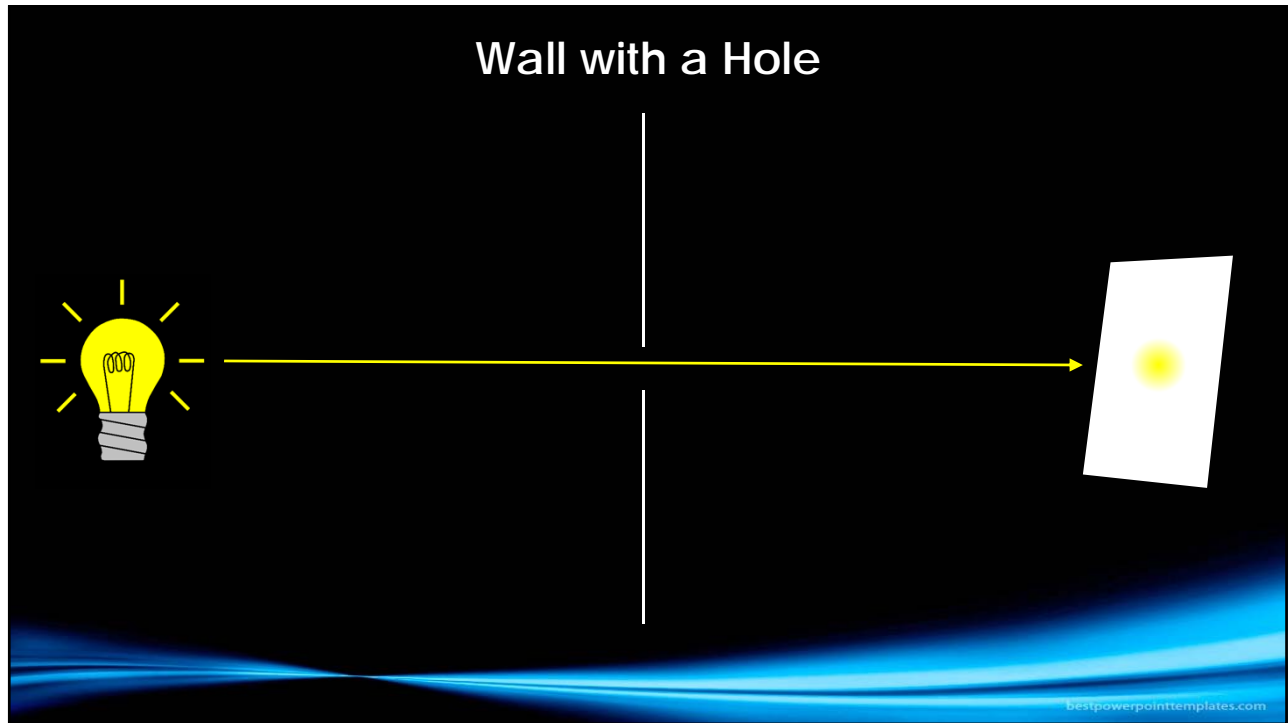
- A) Along one straight path?
- B) Along every possible path?

A) and B) give the *same result!*

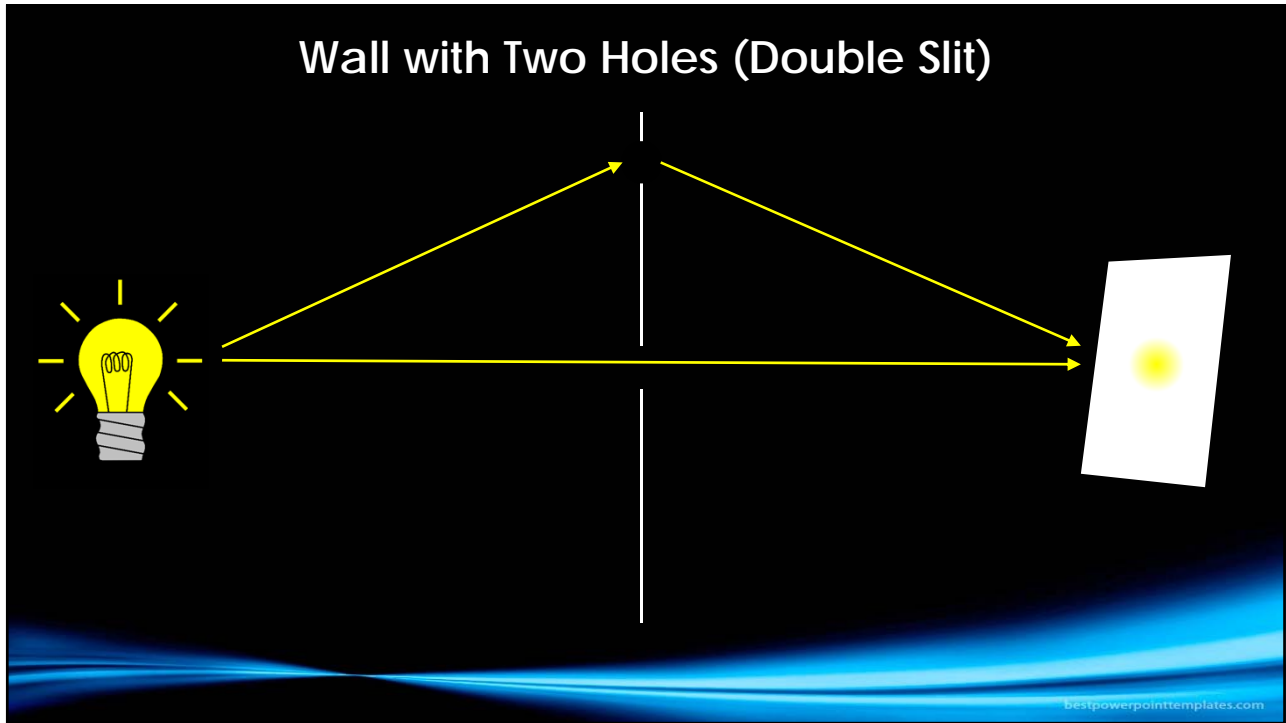
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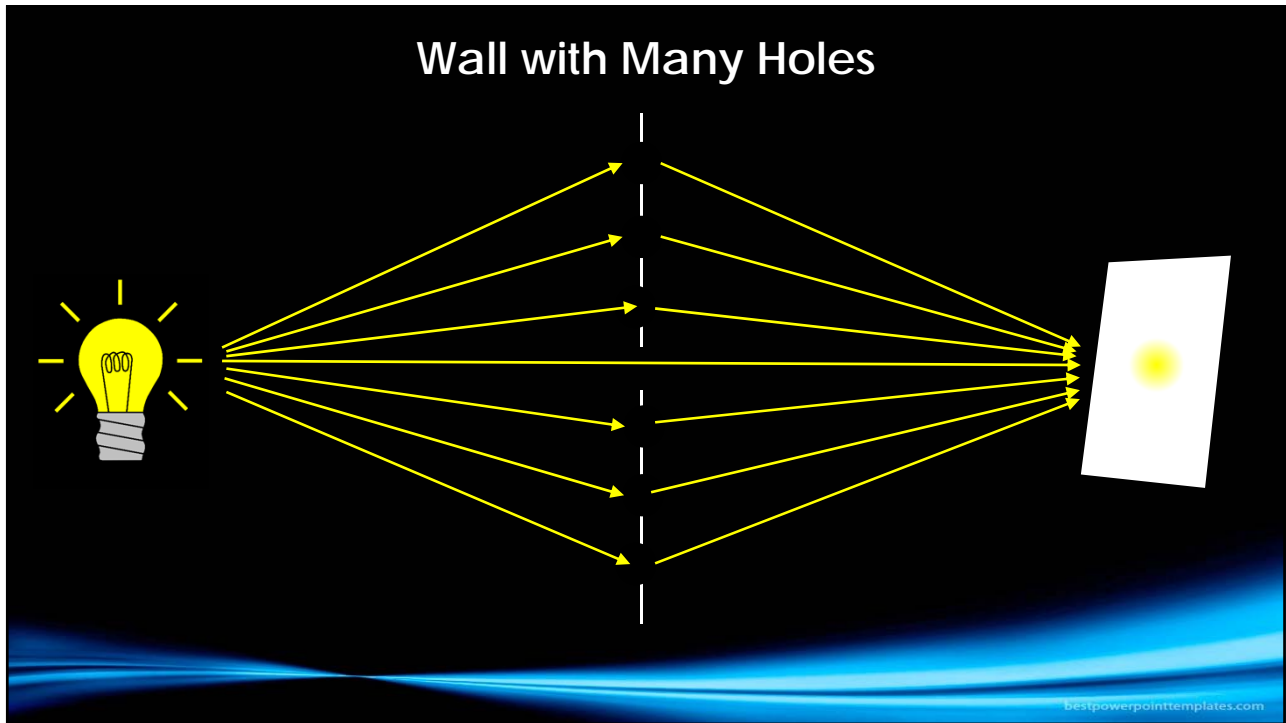
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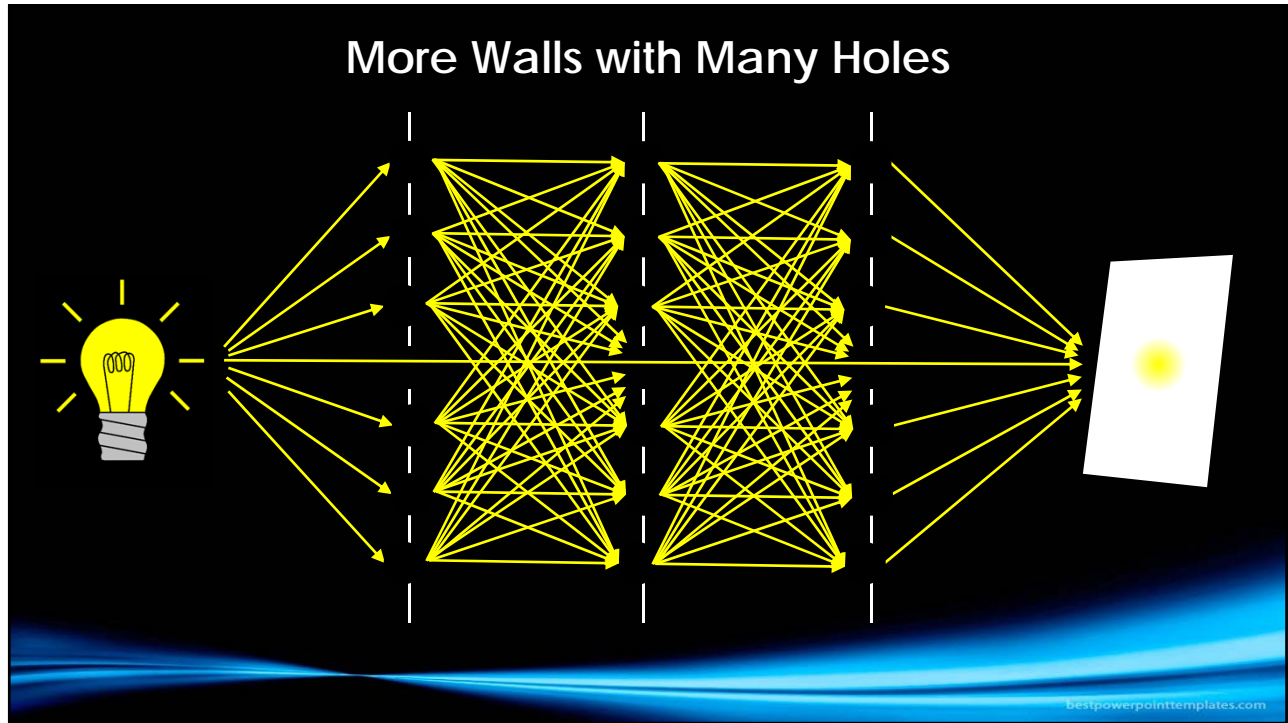
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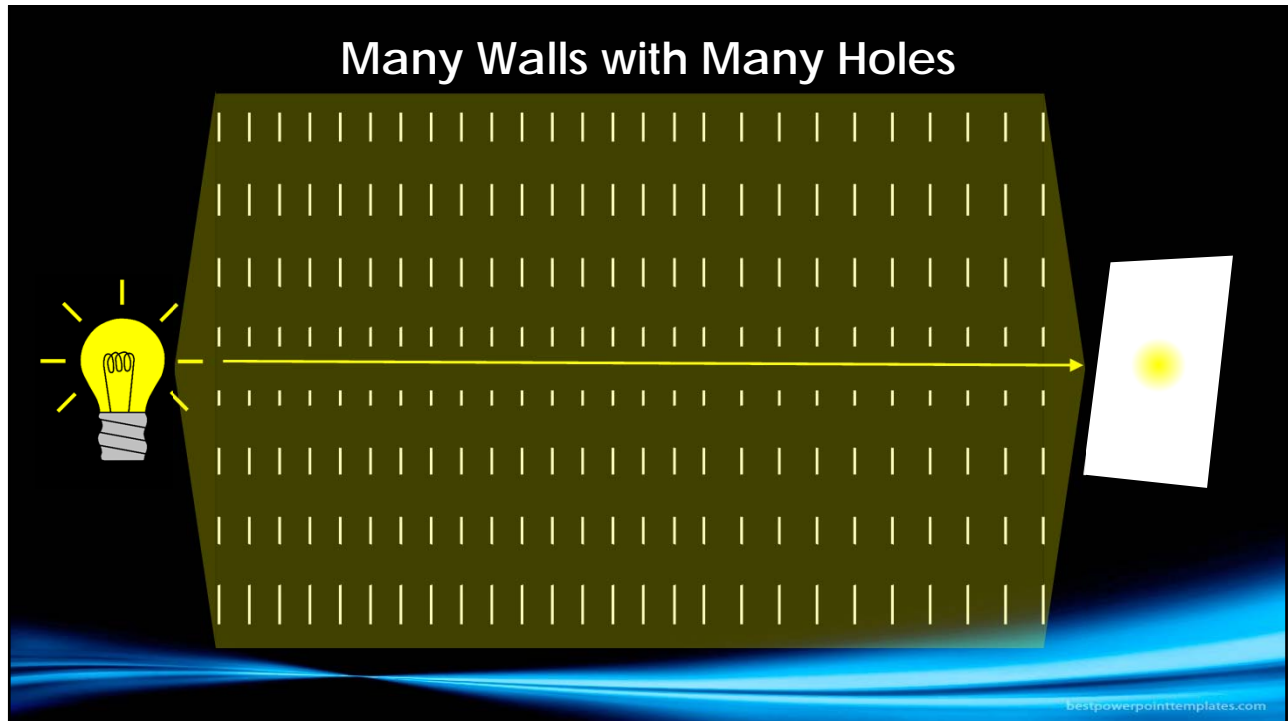
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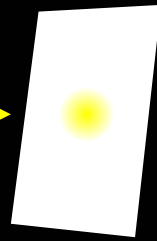
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Infinite Walls with Infinite Holes (i.e. A Straight, Clear Path)

Myriad possible paths interfere to
behave like a single path



Myriad possible choices interfere to
behave like a single "decision"?

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