What is Real?
How the History and Personalities of Quantum Mechanics Affect our Understanding of Reality

By: Fraser Turner

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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

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

The people
The problems
The physics

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An Embarrassment…

See the video by Sean Carroll (first minute)

3

Where does Quantum Physics come from?

QUANTUM PHYSICS for babies

Chris Ferrie
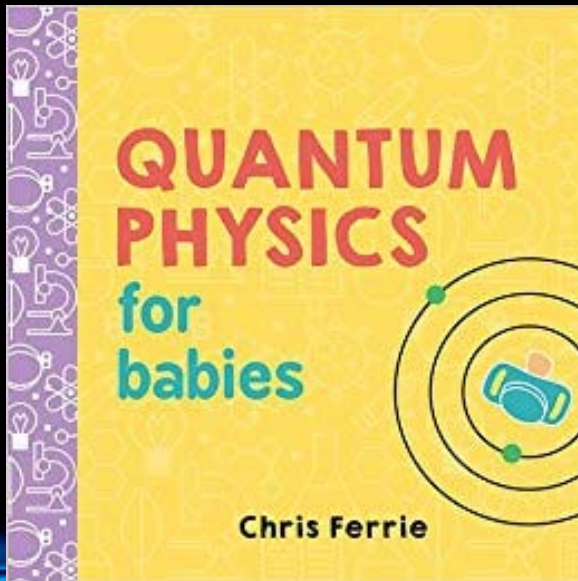
~~Starting our derivation with Schrödinger…~~

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.

5

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
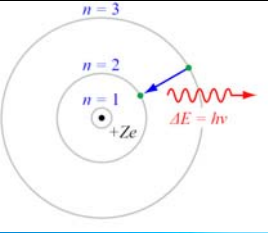

An electron can take energy | to jump up. | And it must give energy | to fall down.

7

This amount of energy is a quantum.

Now you are a
QUANTUM
PHYSICIST!

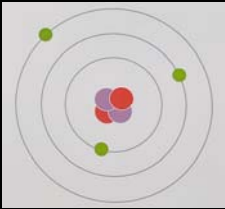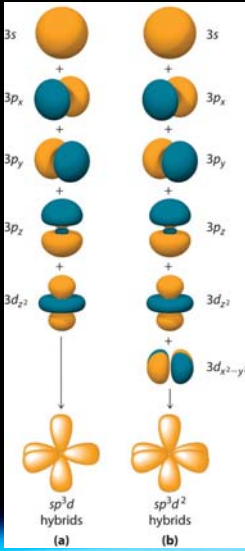1922 Nobel Prize in Physics: Niels Bohr

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Electrons (and everything else) as waves
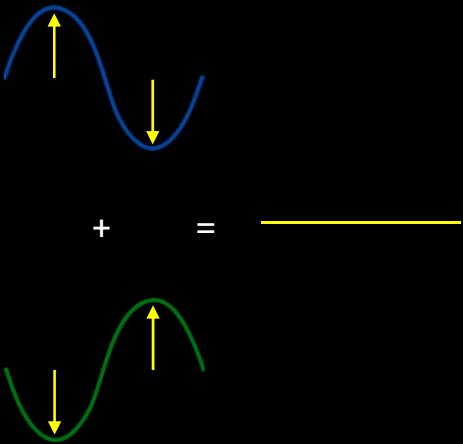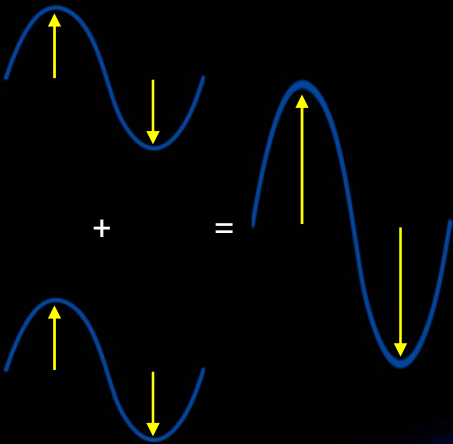
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Wave Interference

+ = ——————

Waves cancel out

+ =

Waves get stronger

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Wave Interference

In-between phase difference
Doesn't cancel or double

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Wave-Particle Duality: with Lasers!
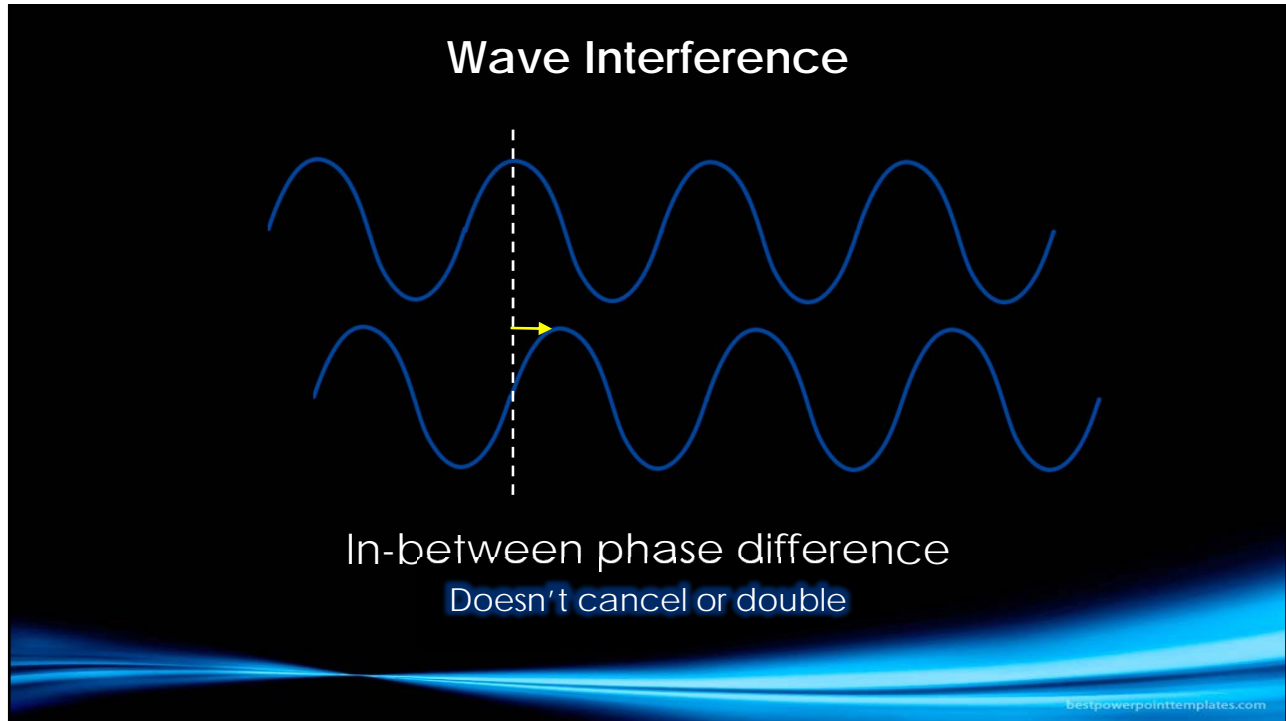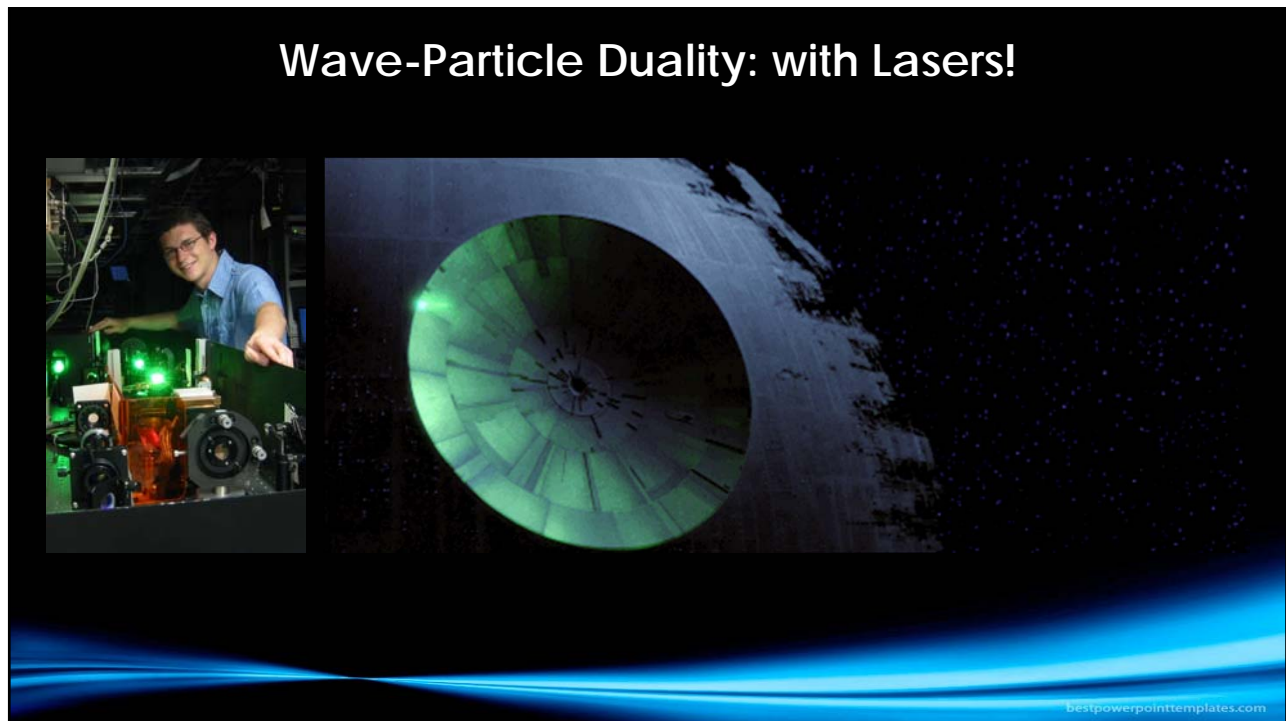
12
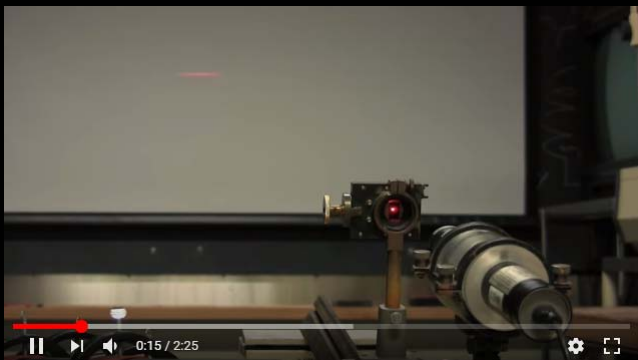
Double Slit Experiment
One slit open

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

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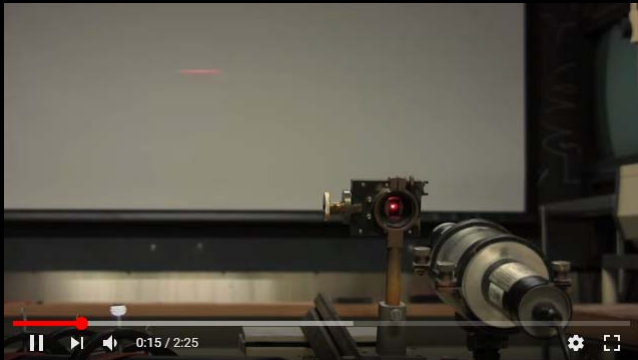
Double Slit Experiment
The other open

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

14
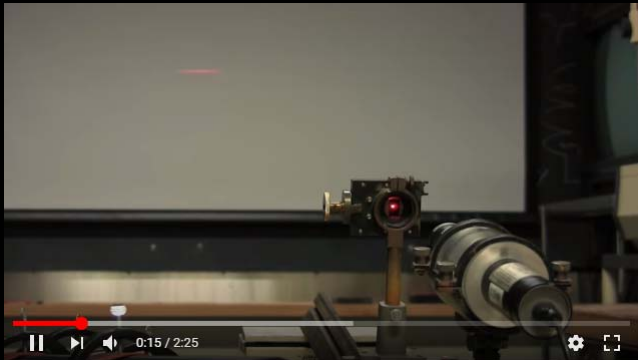
Double Slit Experiment
If light were made of particles...

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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Wave-particle Duality

Light can act like a wave or a particle

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

Brightness

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
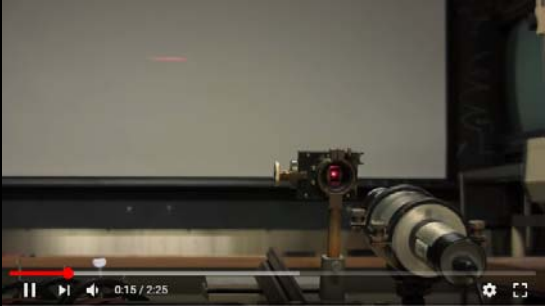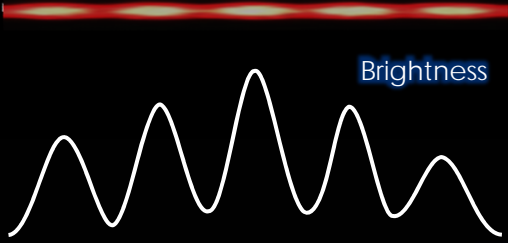
The Electron Particle
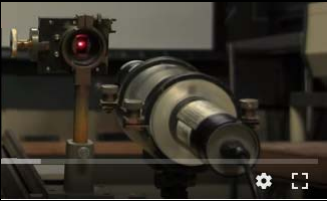
Objects travel as waves, but interact as particles
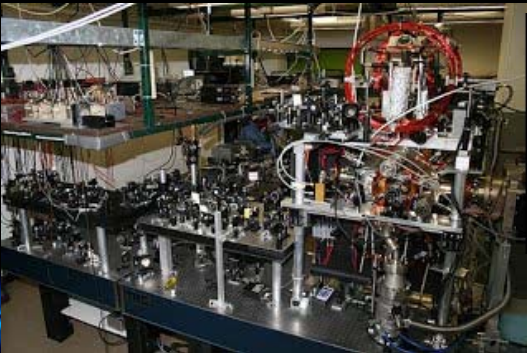
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Looking for Quantum Effects

Quantum Light

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

Quantum Electrons

Quantum Atoms

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Interpreting the collapse of the Wavefunction

Probability

1) It travels like a wave until we take a "measurement"

2) It appears in one place, but at random (within the distribution)

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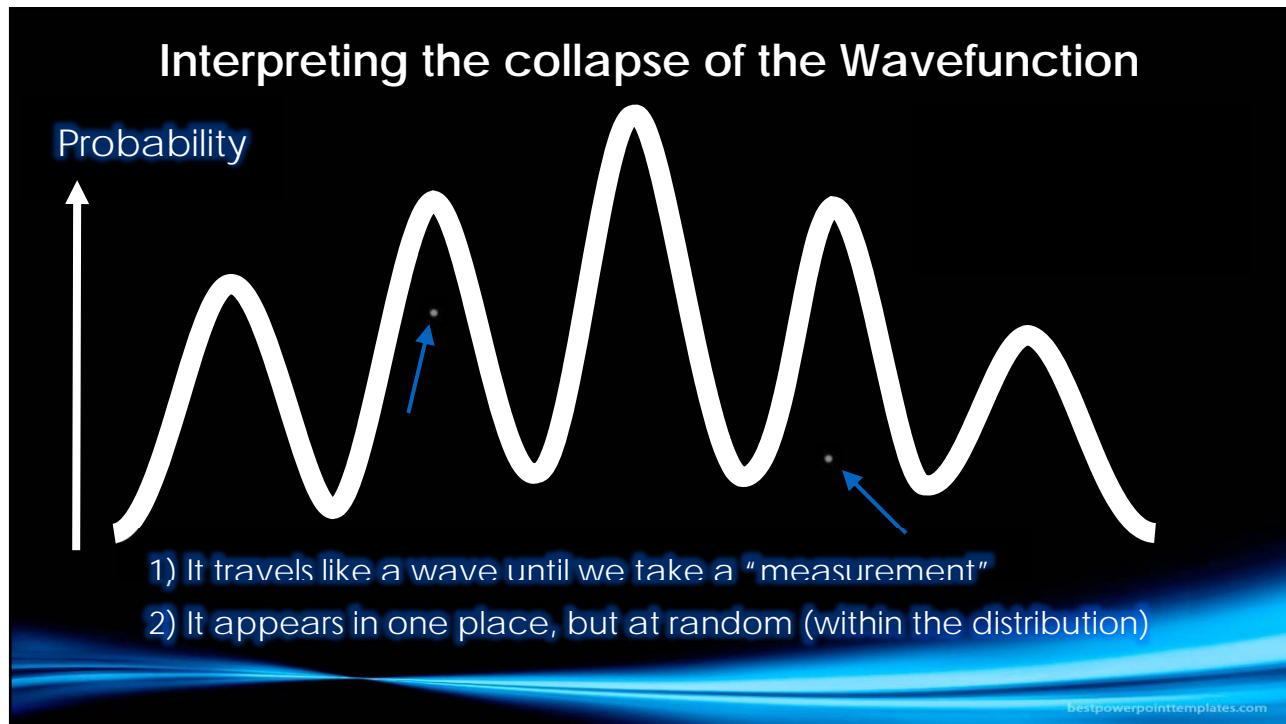# The Copenhagen Interpretation

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

2

1

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**
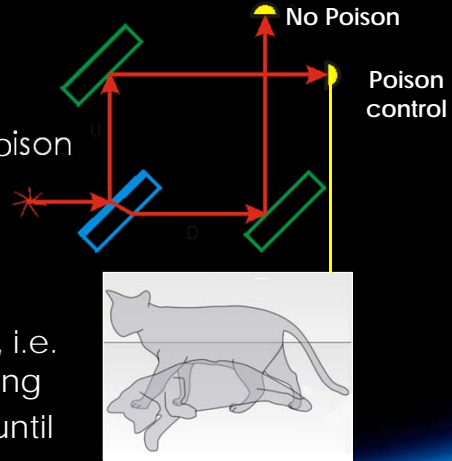
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Slide 25

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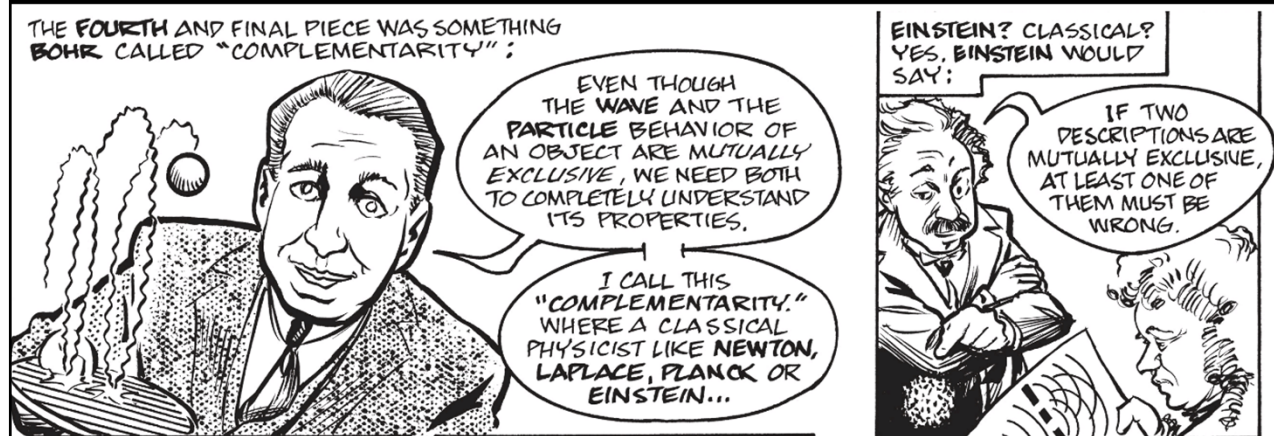
Interpretation
1. You can't ask that question until you look, i.e. there is no objective reality before measuring
2. It is *in a superposition* of alive and dead, until you measure it's aliveness by looking

No Poison

Poison control

Bohr and Einstein

THE **FOURTH** AND FINAL PIECE WAS SOMETHING **BOHR** CALLED "COMPLEMENTARITY":

EVEN THOUGH THE **WAVE** AND THE **PARTICLE** BEHAVIOR OF AN OBJECT ARE MUTUALLY EXCLUSIVE, WE NEED BOTH TO COMPLETELY UNDERSTAND ITS PROPERTIES.

I CALL THIS "COMPLEMENTARITY." WHERE A CLASSICAL PHYSICIST LIKE **NEWTON**, LAPLACE, PLANCK OR EINSTEIN...

EINSTEIN? CLASSICAL? YES, EINSTEIN WOULD SAY:

IF TWO DESCRIPTIONS ARE MUTUALLY EXCLUSIVE, AT LEAST ONE OF THEM MUST BE WRONG.

Suspended in Language: Graphic Novel about Neils Bohr

Sean Carroll on The Copenhagen Interpretation

See the video by Sean Carroll

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Everett Interpretation: Many Worlds

No Poison

Poison

Interpretation
- The total quantum system (Universe) splits into two equal halves; no special "collapse"

Problems:
- An infinity of Universes?
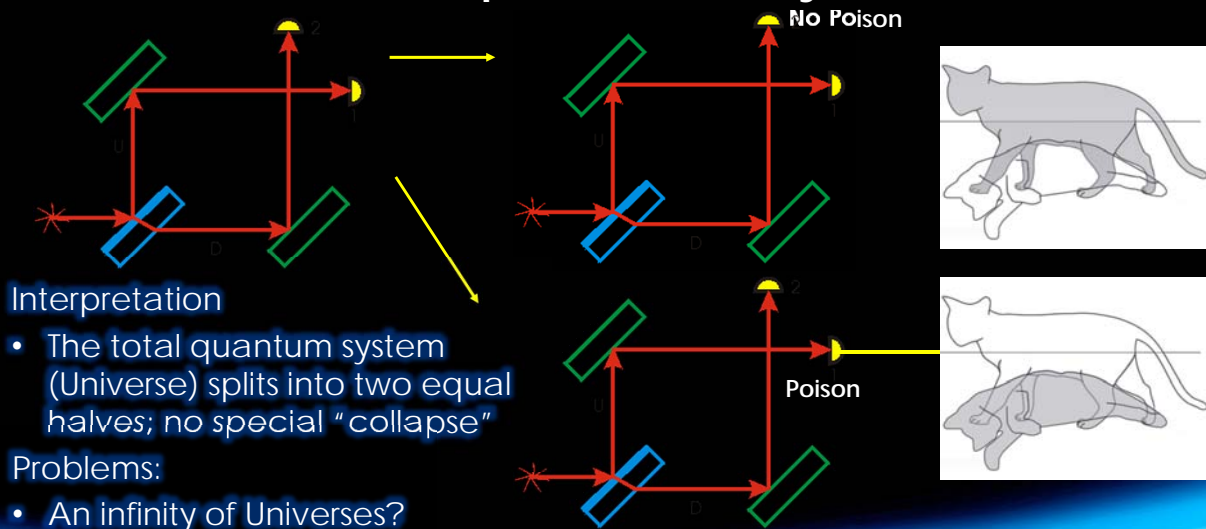
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Sean Carroll on The Many Worlds Interpretation

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.
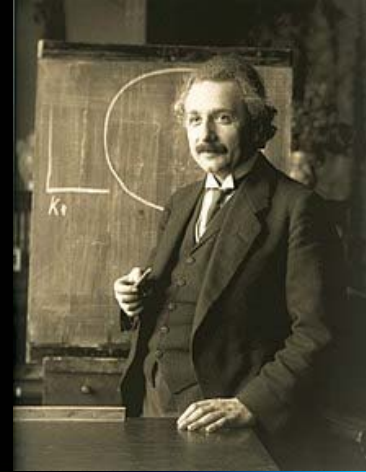
— RICHARD FEYNMAN IN
THE CHARACTER OF PHYSICAL LAW

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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
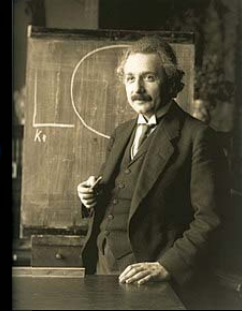
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Tale 1: The Pope and the Misfit

- 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!

FIELDS ARRANGED BY PURITY

MORE PURE →

SOCIOLOGY IS JUST APPLIED PSYCHOLOGY

PSYCHOLOGY IS JUST APPLIED BIOLOGY.

BIOLOGY IS JUST APPLIED CHEMISTRY

WHICH IS JUST APPLIED PHYSICS. IT'S NICE TO BE ON TOP.

OH, HEY, I DIDN'T SEE YOU GUYS ALL THE WAY OVER THERE.

SOCIOLOGISTS PSYCHOLOGISTS BIOLOGISTS CHEMISTS PHYSICISTS MATHEMATICIANS
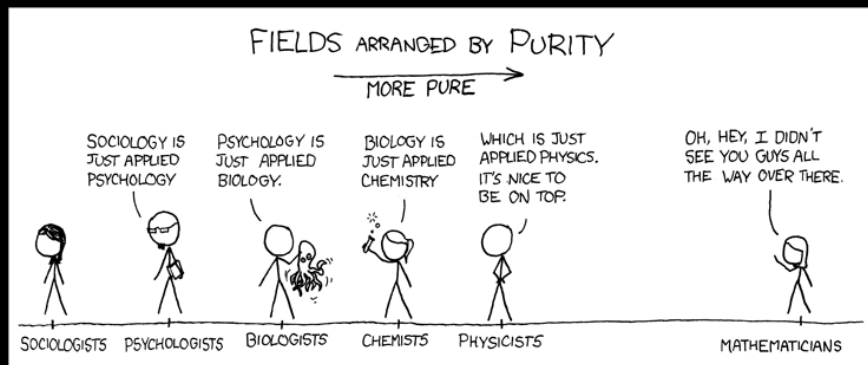
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Videos and References

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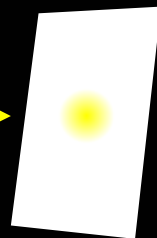# Your Quantum Nose? But that's Warm and Wet!

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One way to look at it

45

Path Integrals and Choices
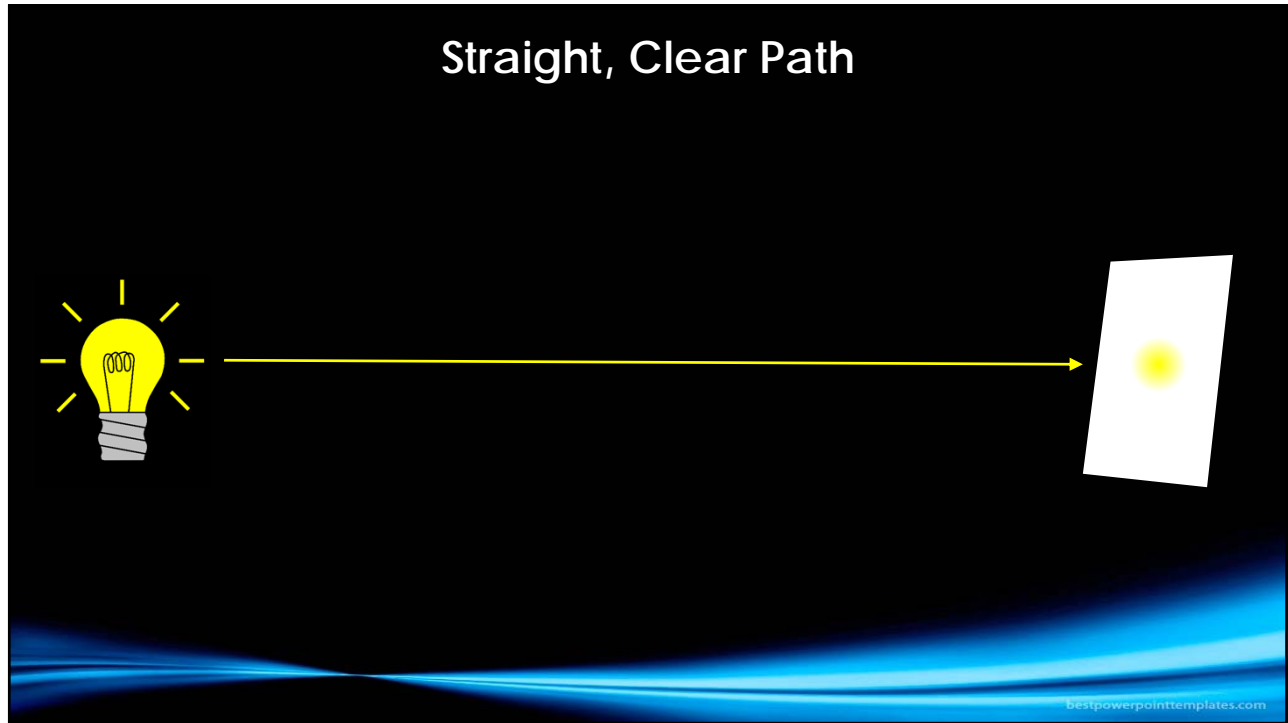
How does light travel?
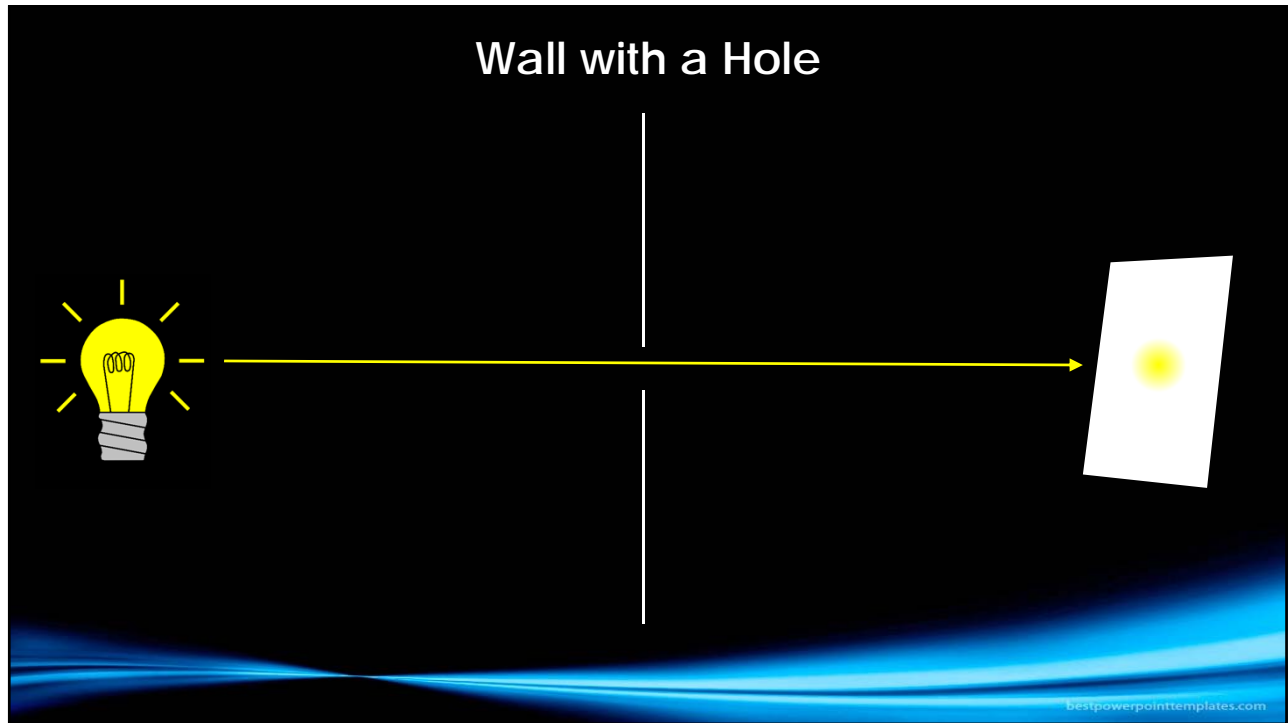

A) Along one straight path?
B) Along every possible path?

A) and B) give the *same result*!
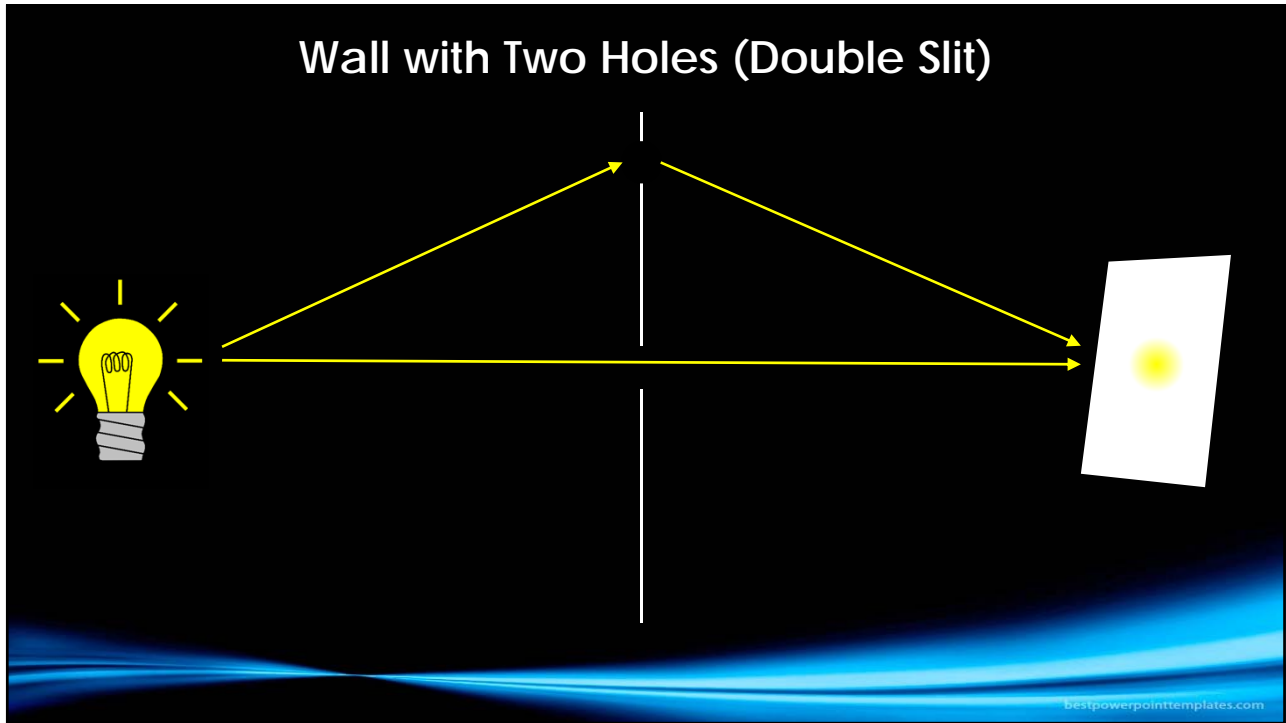
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Straight, Clear Path

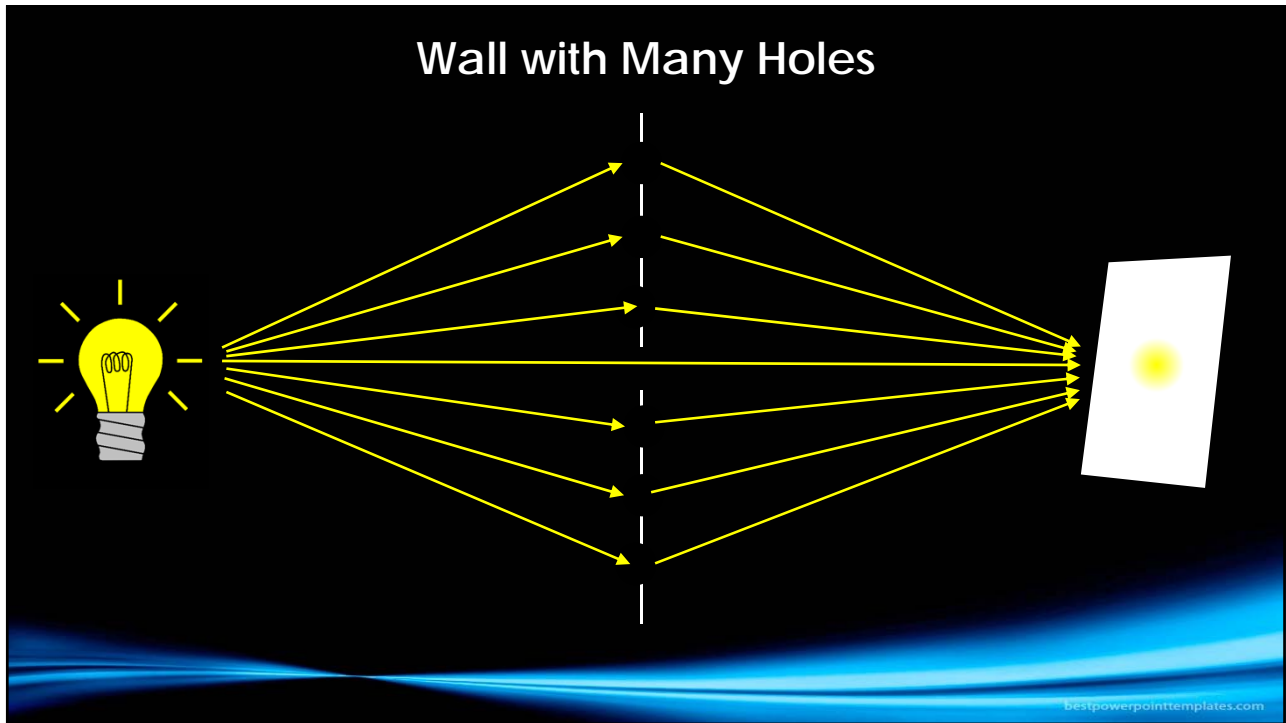47

Wall with a Hole

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Wall with Two Holes (Double Slit)

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Wall with Many Holes

50
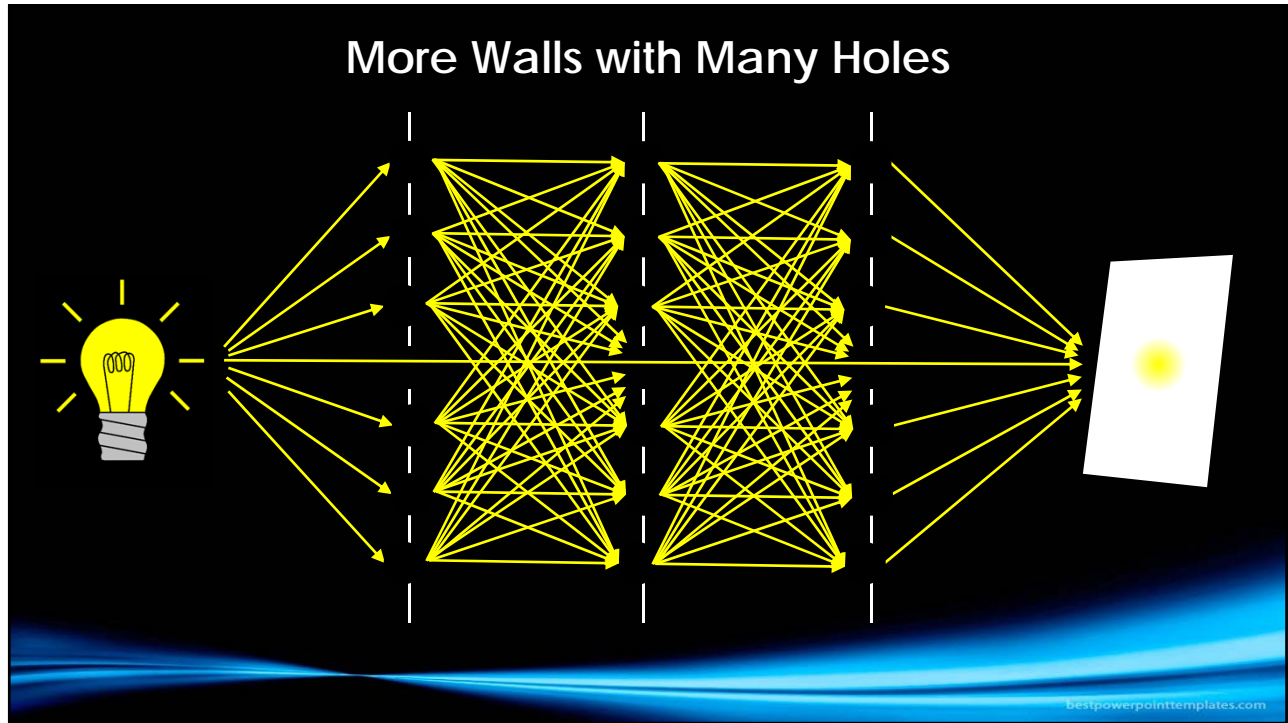
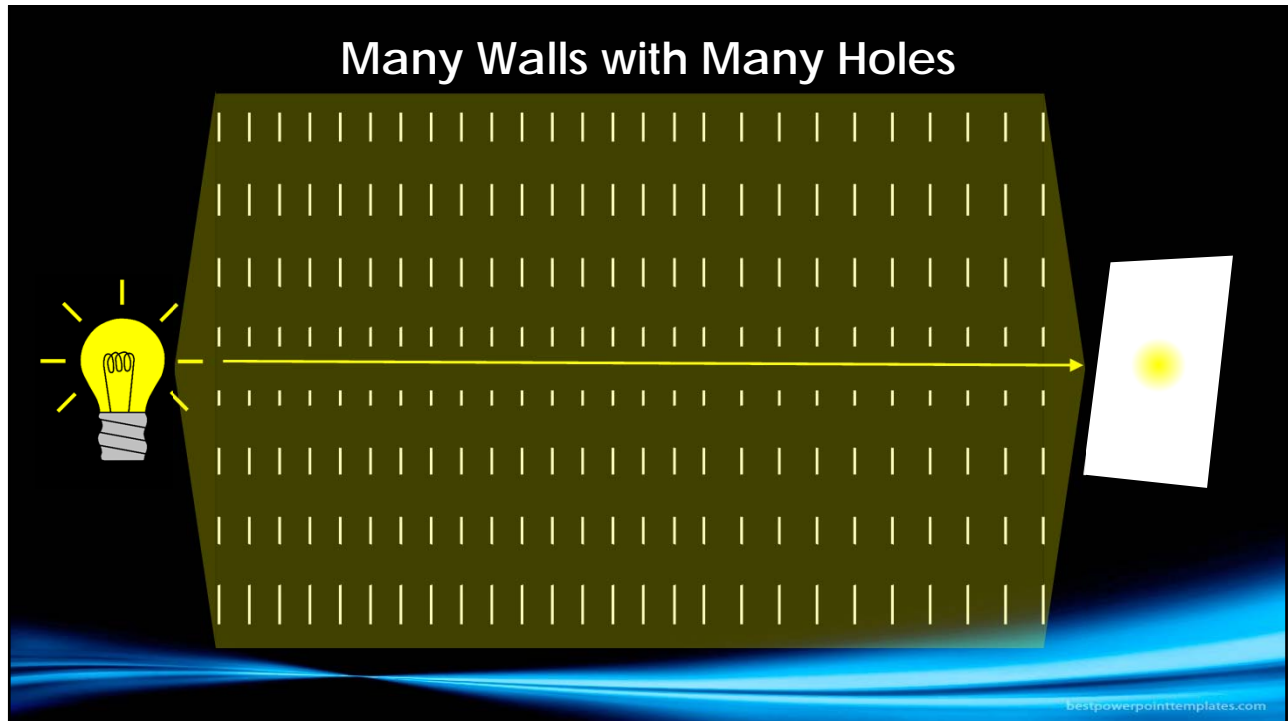More Walls with Many Holes
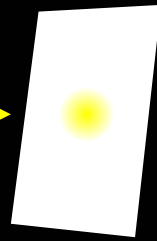
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Many Walls with Many Holes

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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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