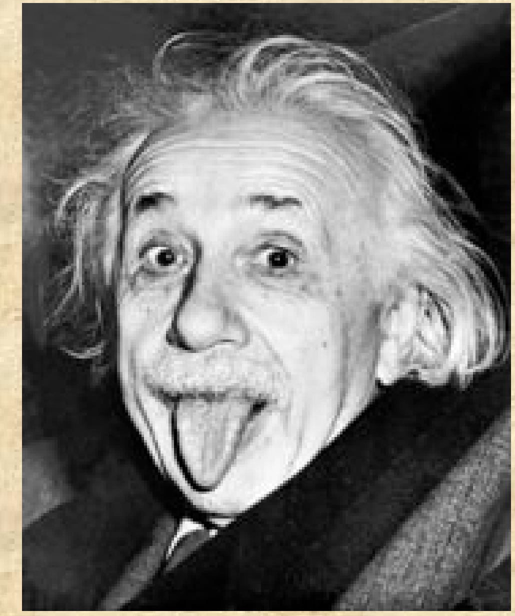
Misconceptions about Quantum Physics



Bill Poirier

MVJS Mini-Conference

Lawrence Hall of Science

July 9, 2015

Some Notable Quotes

"If we knew what we were doing, it wouldn't be called 'research' "
—Albert Einstein

"The paradox is only a conflict between reality and your feeling of what reality ought to be" —Richard Feynman

"I think I can safely say that nobody understands quantum mechanics"
—Richard Feynman

"Richard Feynman is probably the most gifted practitioner of quantum mechanics in the first generation to have grown up with it"
—David Mermin

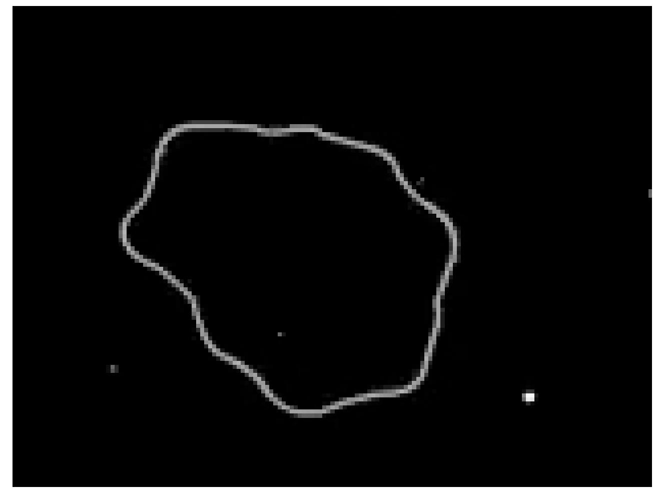
So What Hope Is There??

Einstein got it wrong.

Feynman says nobody can understand it.

Physicists keep arguing about it with no end in sight.

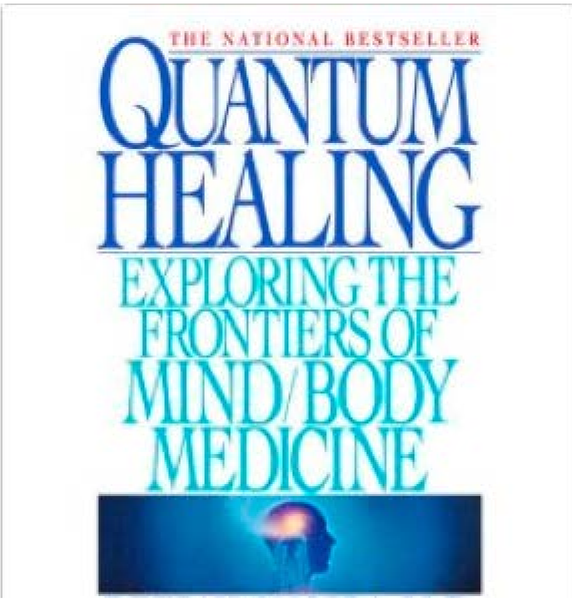
So What Hope Is There??



“Explaining string theory is easy; everybody at least understands the concept of a string. Quantum physics, on the other hand, is the hardest.”

—Brian Greene

Become a “smart” quantum consumer



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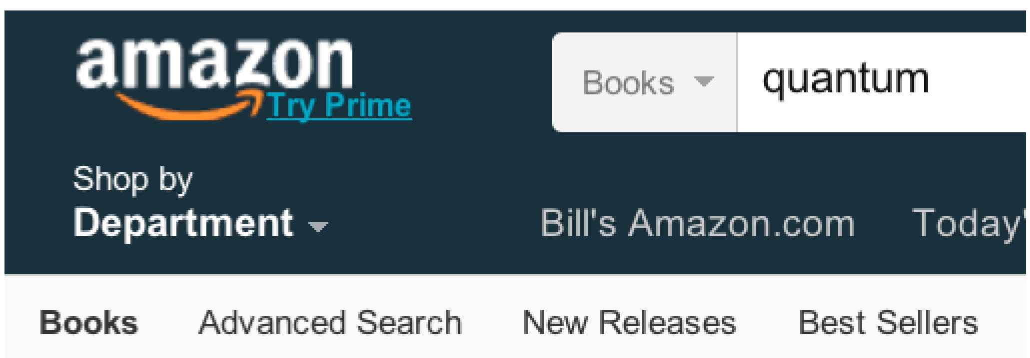


1-12 of 37,518 results for **Books** : "quantum"

Overview

- Wave Particle Duality
- Quantum Probability Wave
- Heisenberg Uncertainty Principle
- Double Slit Experiment
- Wavefunction Revisited:
  - many particle wavefunction
  - wavefunction measurement
  - collapse and Schrödinger's cat
- Interpretations
- Popular Depictions

No time for:

EPR experiments

Bell's Theorem

Nonlocality

Wave Particle Duality

- Misconception: *Tiny objects are both waves and particles at the same time.*
  - particles are localized in space (like single points).
  - waves are spread out and continuous (across many points).
- More accurate: *Tiny objects sometimes behave like waves, and other times like particles.*
  - not well described by either wave or particle concept.
- Lesson: Accept the weird, but don't accept the logically inconsistent.

Wave Particle Duality

- Misconception: *There is nothing mysterious about the wave particle duality.*

  "A man may have many aspects: husband, father, friend, businessman...You would not expect him to exhibit his husbandly behavior toward a customer or his business-like behavior towards his wife." —Isaac Asimov*

- More accurate: *Wave particle duality is very weird.*
- Lesson: Accept the weird in quantum physics; don't accept the notion that the weirdness can be entirely "explained away." It cannot be.

* from *The New Intelligent Man's Guide to Science* (Basic Books, New York, 1965)

Quantum Probability Wave

Some facts about the "wavefunction"

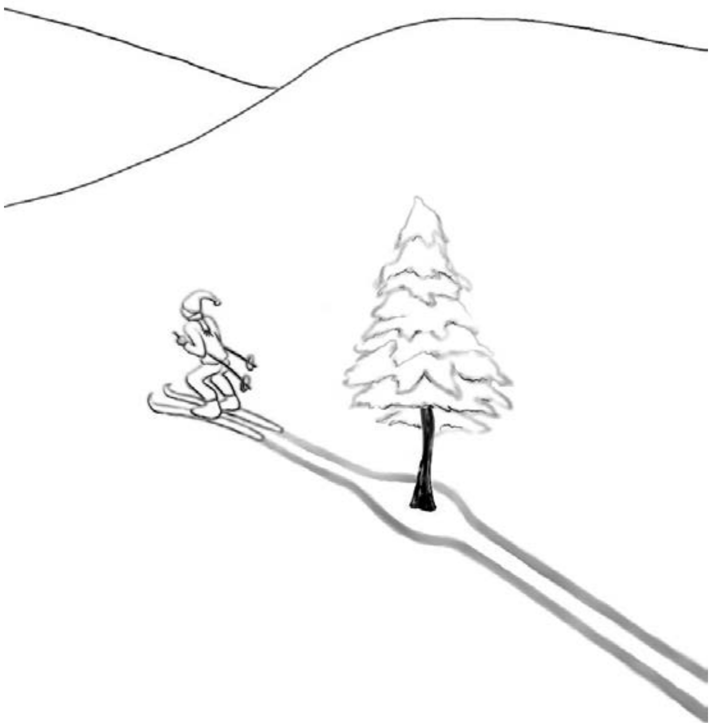
- The wavefunction is a theoretical construct, used to describe the particle motion when it is *not* being observed.
  - delocalized "wave of probability" spanning all possible particle positions throughout space ("superposition" of position states).
  - evolves according to well prescribed rules (Schrödinger eqn.)
- The wavefunction *also* tells us what happens when the particle is "observed" (or measured).
  - it is *always* observed as a single particle in a definite position, *never* as a wave, or as multiple particles.
  - wavefunction "collapses" to observed position randomly, but with well-defined probability.

Quantum Probability Wave

- Lesson: Quantum physics is all about exploring all possibilities.
  - when they are not being observed, quantum particles explore all possible states available to them, such as positions in space.
- Misconception: *Quantum physics is* so *weird that "anything can happen," and nothing is certain.*
- More accurate: *Quantum physics is* the *most reliably accurate predictive scientific theory ever devised.*
- Lesson: Any physical theory must agree with experimental observations, or it has to be discarded.

Quantum Probability Wave

- Lesson: Quantum physics is all about exploring all possibilities.



"When you come to a fork in the road, take it!"

—Yogi Berra

with apologies to Charles Addams and *The New York Times* (December 3, 2006)

Heisenberg Uncertainty Principle

- Misconception: *No measurement can be made of a quantum particle without affecting that particle.*
- The above is *always* true in physics, and has nothing to do with quantum mechanics *per se*!
- Nevertheless, HUP does imply that quantum measurement is very different from classical measurement.
  - particle *can* be greatly affected, but...
  - measurement device can be *even more* greatly affected.
- Fundamental property about quantum systems, rather than statement about limits of experimental apparatuses.

Heisenberg Uncertainty Principle

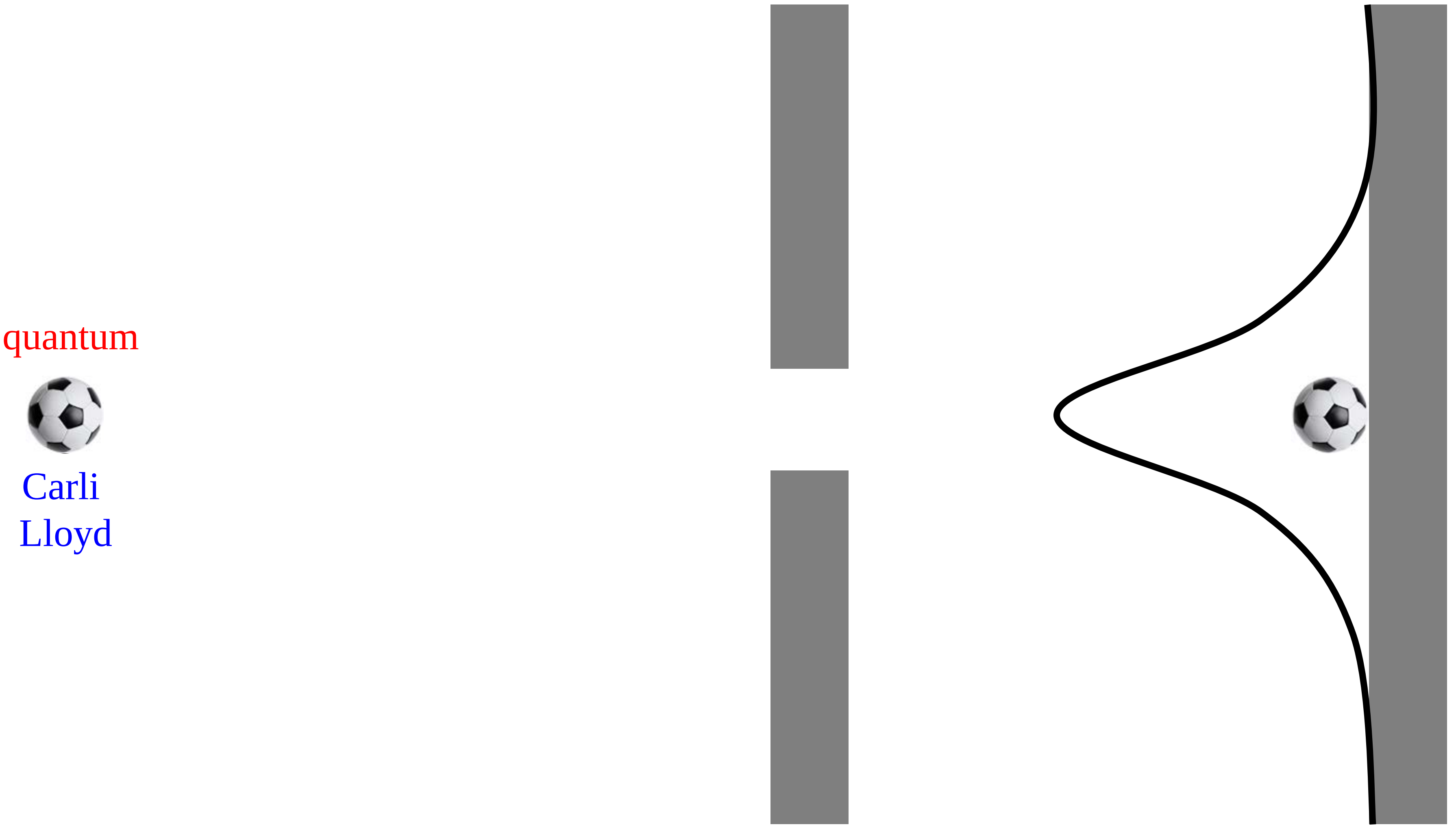
- More accurate: *There is a fundamental limit to the precision with which both a particle's* position *and its* velocity *can be known simultaneously.*
  - The better we know position, the less well we know velocity.
- A particle must possess *both* attributes in order to remain a "particle" (i.e. localized) over time.
  - HUP is a feature of the *wavelike* aspect of quantum physics.
- Lesson: We cannot "see" all attributes of quantum particles, the way we can for classical particles.
  - they may or may not even exist (hidden variables).

Single Slit Experiment (classical):

Explained as a game of soccer

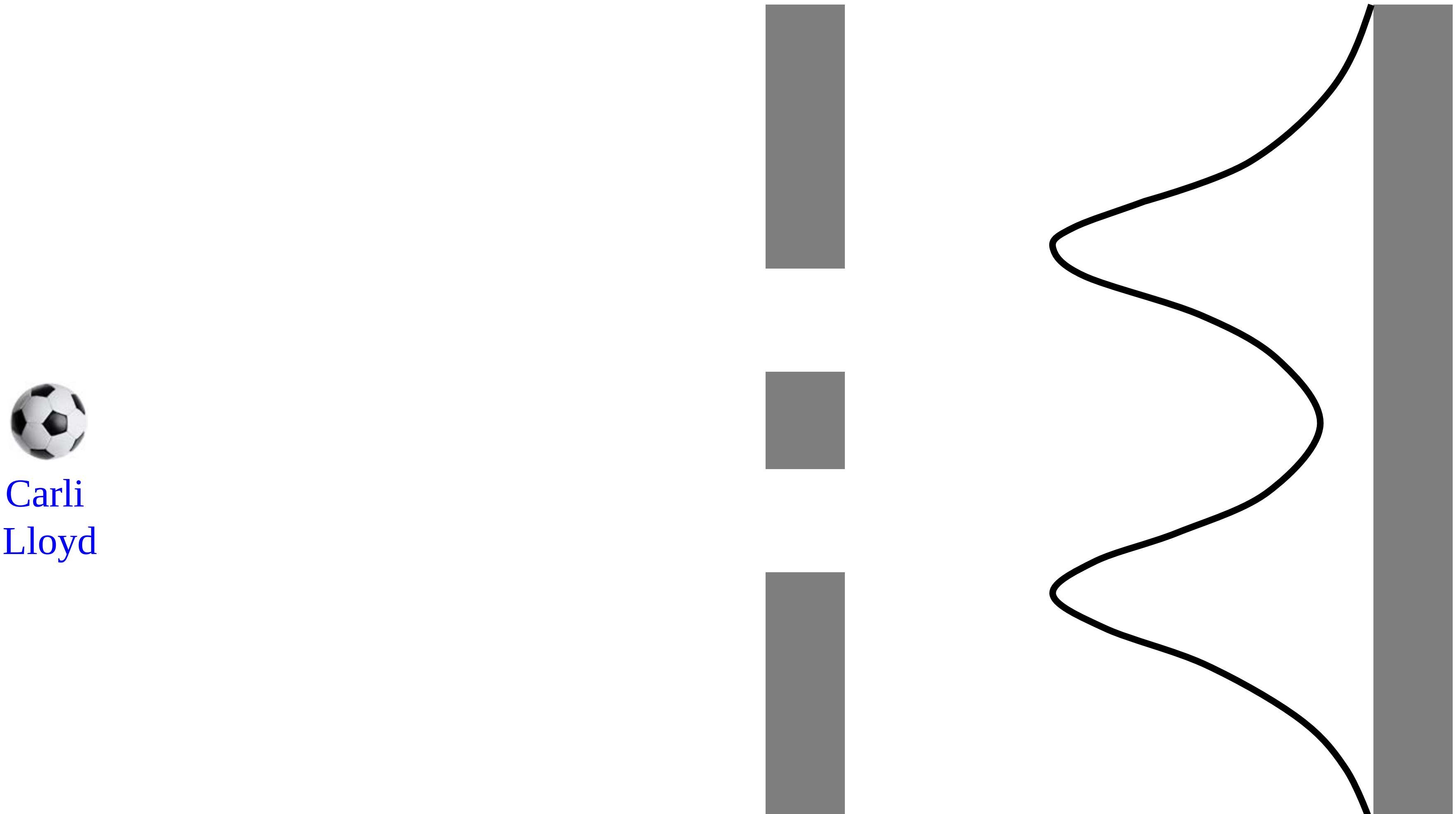
Single Slit Experiment (*quantum*):

Explained as a game of soccer



Double Slit Experiment (classical):

Explained as a game of soccer

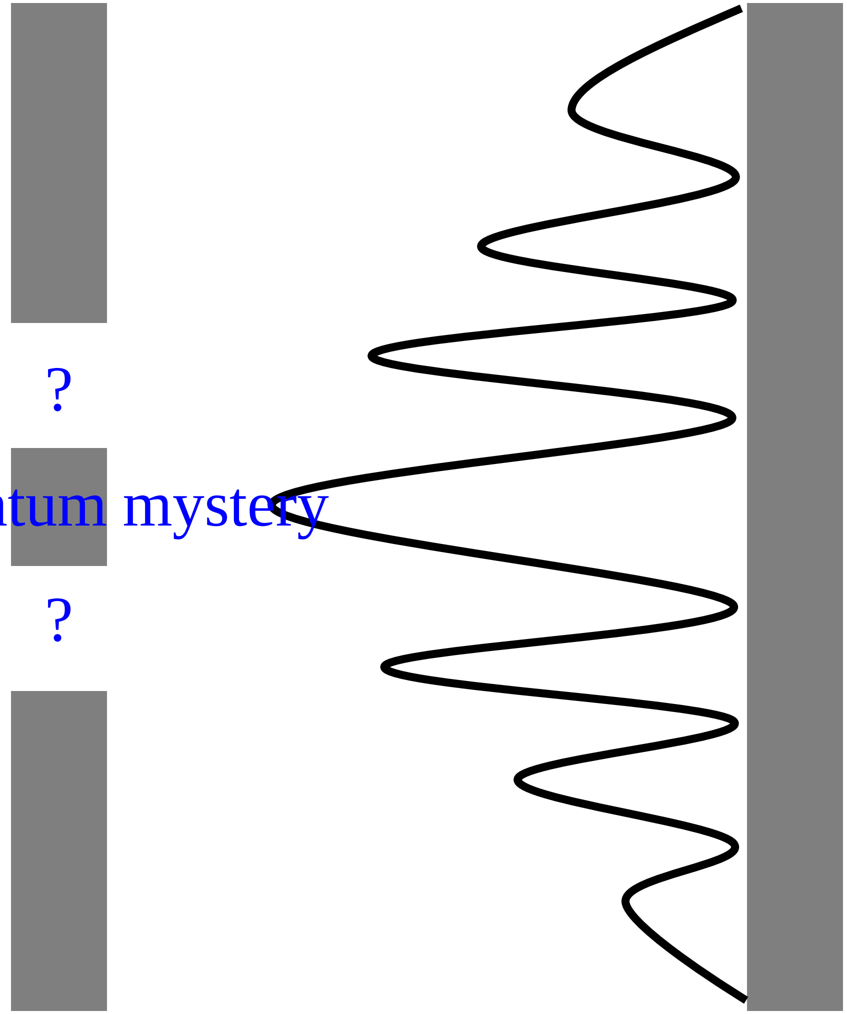


Double Slit Experiment (*quantum*):

Explained as a game of soccer

quantum

Carli
Lloyd

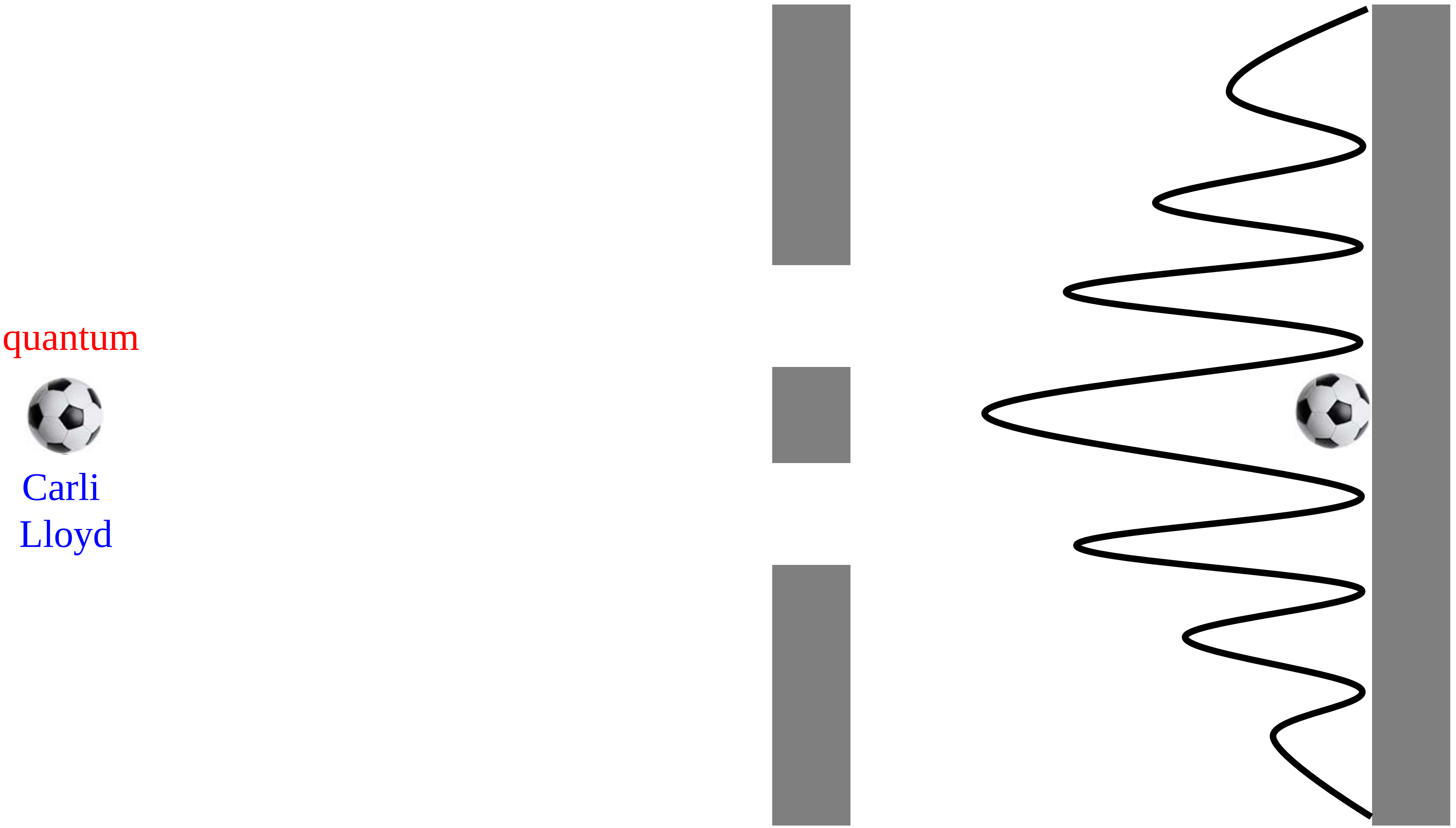


"[this] has in it the heart of quantum mechanics. In reality, it contains the only mystery."

—Richard Feynman

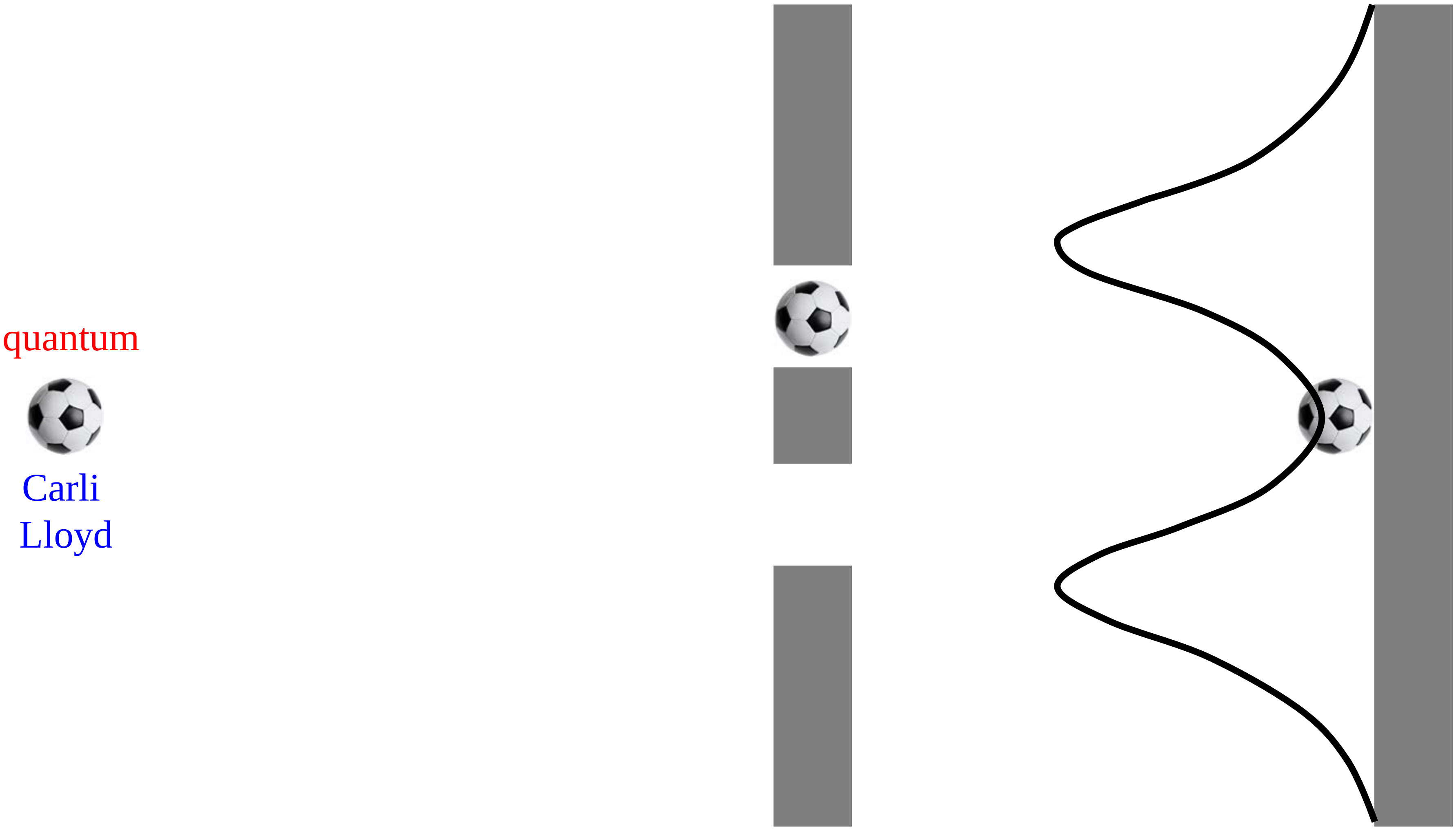
Double Slit Experiment (*quantum*):

Explained as a game of soccer



Double Slit Experiment (*quantum*):

Explained as a game of soccer



Quantum Wavefunction Revisited

- Misconception: *The quantum wavefunction describes individual quantum particles.*
- More accurate: *The quantum wavefunction describes the "quantum system," generally consisting of many particles.*

- question: does the "system" include any measurement devices?

- Lesson: Be wary of any description of a "wavefunction" that refers to a single particle only.

Quantum Wavefunction Revisited

"Measuring" the wavefunction itself

- Misconception: *The quantum wavefunction can be directly measured in the laboratory.*
- More accurate: *An "effective"single-particle wave-function can be mostly inferred, from a large sequence of separate experiments on completely different particles.*
- (quantum tomography & weak measurement experiments).
- These experiments do not "prove" the existence of the wavefunction in any sense.
- Lesson: The wavefunction cannot be directly observed.
- known since Max Born.

Quantum Wavefunction Revisited

The role of "context"

- Misconception?: *A quantum system forms an "undivided whole" whose pieces have no separate existence.*
- More accurate: *The context (environment) of a quantum particle influences its behavior in a way that is totally different from our intuition about the physical world.*
- nonlocality is observed experimentally.
- difficult to distinguish "observer" from "observed."
- difficult to pin anything down; great care must be taken.
- Lesson: Quantum physics is all about context.

Where Does It All End?

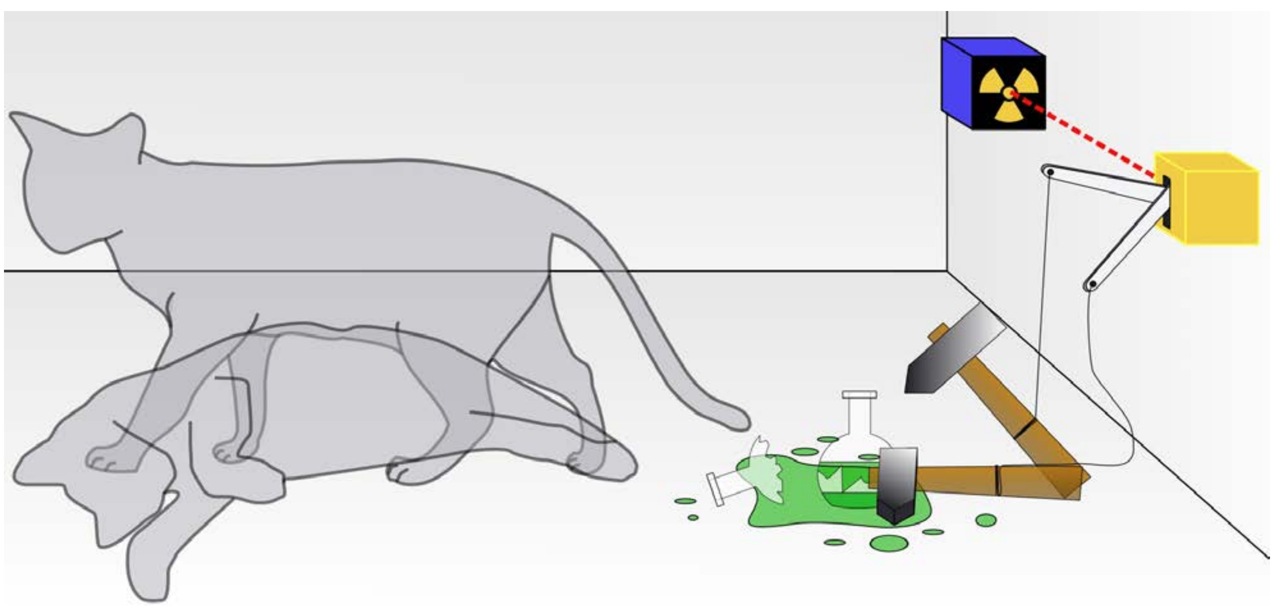
Wavefunction collapse & Schrödinger's cat

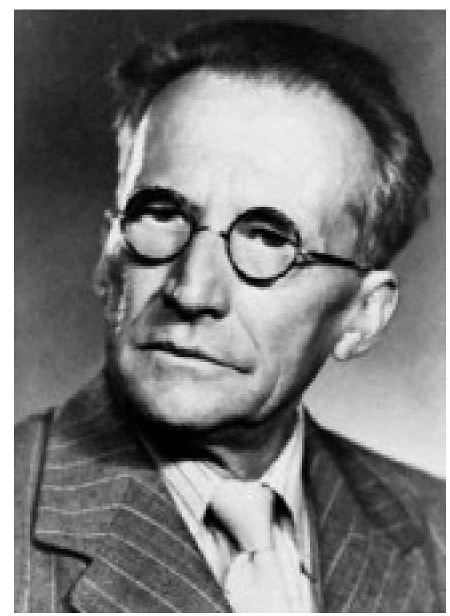
- Quantum theory does not explain *how* the wavefunction collapses when measurement occurs. However...
  - this must be caused by something *outside* the quantum system.
  - different physics than what happens *inside* the system.
- Problem: How does one divide the world into the "quantum system" and everything else?
  - the division is arbitrary, yet different physics used for each part.
- Leads to Schrödinger's cat dilemma.

Where Does It All End?

Wavefunction collapse & Schrödinger's cat

- Leads to Schrödinger's cat dilemma.
  - macroscopic objects exist in a wave of many possibilities.
  - cat is in a superposition of "live" and "dead" states.
  - such things are *never observed* in nature.





Where Does It All End?

More recent insights

- Early debate mainly centered on one of two possibilities:
  1. Wavefunction must somehow "collapse" long before the macroscopic scale is ever reached.
  2. Quantum theory must be incomplete (e.g. hidden variables).
- What the founding fathers did not (fully) know:
  1. Even if an observer *were* a part of the quantum system, other macroscopic objects would still *appear* to be in definite states.
  2. Larger and larger objects have been placed into superposition states (manifest by self-interference in double slit experiments).

Where The Weird Things Are:

Interpretations of Quantum Mechanics

Danger!!
We are now entering
the realm of
METAPHYSICS!!

*"What cannot be seen
should not be discussed."*

—Niels Bohr

Where The Weird Things Are:

Interpretations of Quantum Mechanics

1. Collapse occurs randomly at some small threshold scale, due to new physics that has yet to be observed.
   - "collapse" theories, GRW, Penrose.
2. Collapse occurs with the first conscious observer.
   - von Neumann, also Penrose, many popular depictions.
3. Collapse *never* occurs. Everything, including observers, is a part of the quantum system.
   - Everett "many worlds" interpretation.

Where The Weird Things Are:

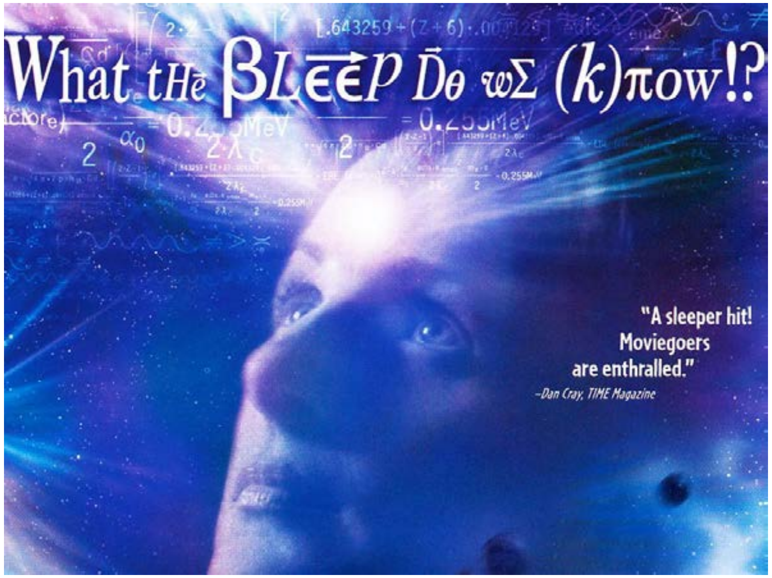
Interpretations of Quantum Mechanics

- Misconception: *Quantum physics (i.e. experiments) "prove" the existence of aspect x from interpretation y.*
- More accurate: *The different interpretations (mostly) make the same predictions, and therefore cannot be experimentally "proven."*
- Misconception: *The different interpretations of quantum mechanics are all true at the same time.*
- More accurate: *Each provides a consistent framework on its own, but they cannot be "mixed and matched."*

Popular Depictions of Quantum Physics

Do they inform, or just sensationalize?

- Quantum physics should not be just for the physicists, *but...the reality is mysterious and wonderful enough on its own, without the need for embellishing hype.*
- Speculation is fine, *but...it should not hide behind the mantle of "hard scientific fact."*



- People seem to have a need for modern science to provide meaning in their lives, and/or to rationalize their world views.
- Top 10 List of Cringeworthy Quotes available on request...

Thank You !!

Calvin and Hobbes by Bill Watterson October 29, 1989