Physics or Philosophy? Quantum Interpretations in the Undergraduate Curriculum

AAPT Summer Meeting

July 17, 2013

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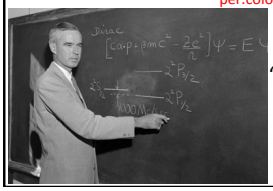


"Don't worry about what [Ψ] means, you'll get used to it."

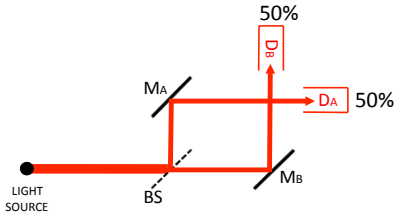
- Willis E. Lamb, Jr. (1913-2008)

Develop mathematical tools first, quantum intuition later??

Develop quantum intuition first, mathematical tools later!!

Instructional choices impact student thinking

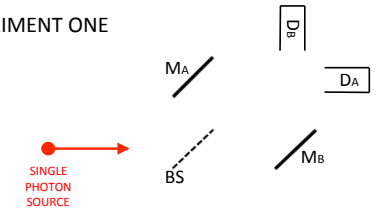
Interpretation is about sense-making



- DA & DB are detectors
- MA & MB are mirrors
- BS is a 50/50 beamsplitter

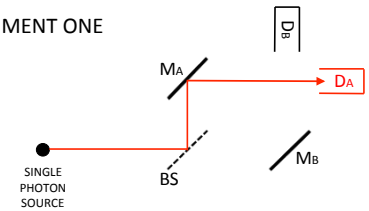
Thought Experiment with Single Photons

EXPERIMENT ONE



Thought Experiment with Single Photons

EXPERIMENT ONE

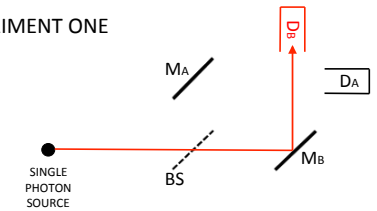


detection in DA ⟷ reflection by BS

Reflection: $|\Psi\rangle = |R\rangle$ $\quad P_A = 0.50$

Thought Experiment with Single Photons

EXPERIMENT ONE

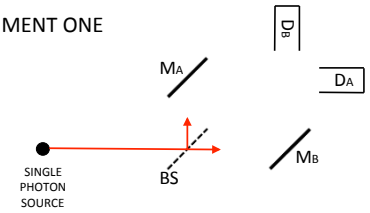


detection in DB ⟷ Transmission at BS

Transmission: $|\Psi\rangle = |T\rangle$ $\quad P_B = 0.50$

Thought Experiment with Single Photons

EXPERIMENT ONE



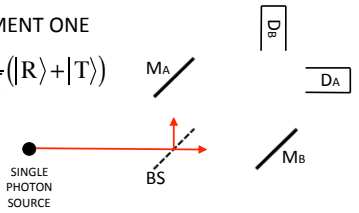
$$|\Psi\rangle = \frac{1}{\sqrt{2}}\left(|\mathrm{R}\rangle + |\mathrm{T}\rangle\right)$$

Single photons trigger **either DA or DB**, but not both!!

Thought Experiment with Single Photons

EXPERIMENT ONE

$$|\Psi\rangle = \frac{1}{\sqrt{2}}\left(|\mathrm{R}\rangle + |\mathrm{T}\rangle\right)$$

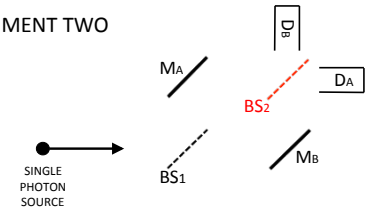


What happens when a single photon encounters the beam splitter?

(A) Each photon is either reflected or transmitted.
(B) Each photon is both reflected and transmitted.
(C) There's no way of knowing.
(D) None of the above.

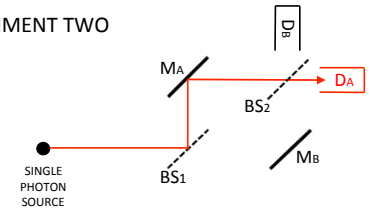
Thought Experiment with Single Photons

EXPERIMENT TWO



Thought Experiment with Single Photons

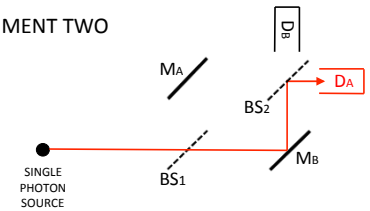
EXPERIMENT TWO



If detected in DA, the photon *could have* been reflected at BS1 and then transmitted by BS2

Thought Experiment with Single Photons

EXPERIMENT TWO



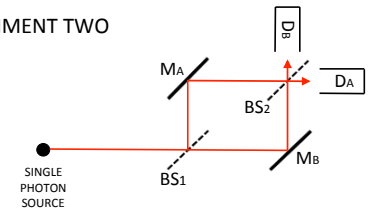
If detected in DA, the photon *could have* been reflected by BS1 and then transmitted at BS2

OR

transmitted at BS1 and then reflected by BS2

Thought Experiment with Single Photons

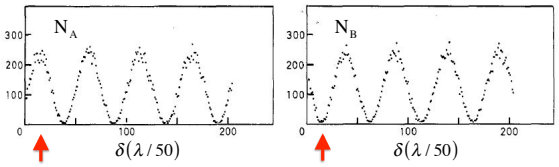
EXPERIMENT TWO



Whether detected in DA or DB, we have no information about which path the photon might have taken.

When the path length difference $\delta = |B| - |A| = 0$, then $\mathrm{P_A} = \mathrm{P_B} = 0.5$

EXPERIMENT TWO



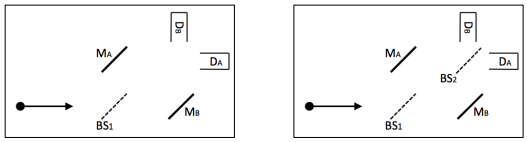
Slowly change $\delta = |B| - |A|$ by moving just MB

For some δ: $P_A = 1$ & $P_B = 0$

For other δ: $P_A = 0$ & $P_B = 1$

The behavior of every photon is influenced by the relative length of both paths!!

P. Grangier, G. Roger and A. Aspect, *Europhys. Lett.* **1** (4), 173 (1986)



EXPERIMENT ONE EXPERIMENT TWO

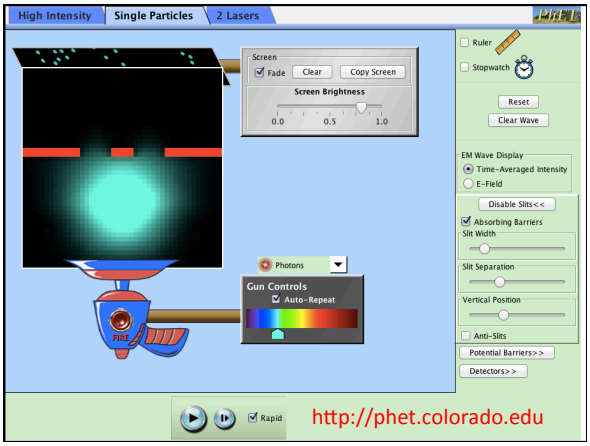
What happens when a single photon encounters the beam splitter?

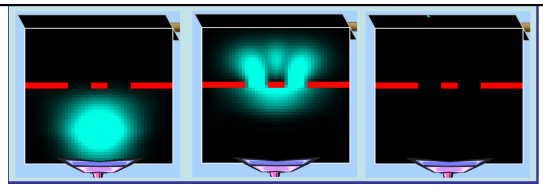
(A) Each photon is either reflected or transmitted.

(B) Each photon is both reflected and transmitted.

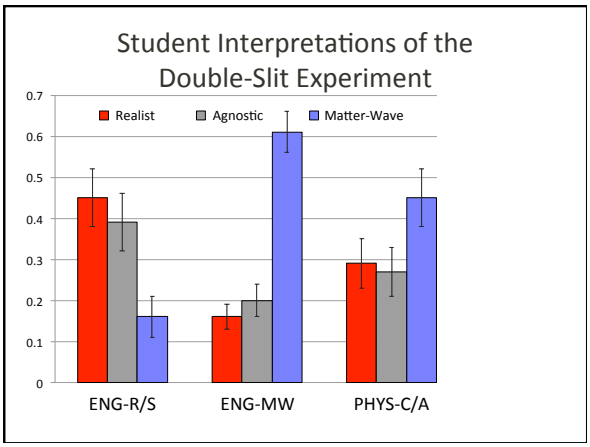
(C) It depends on whether we're conducting Experiment One or Experiment Two.

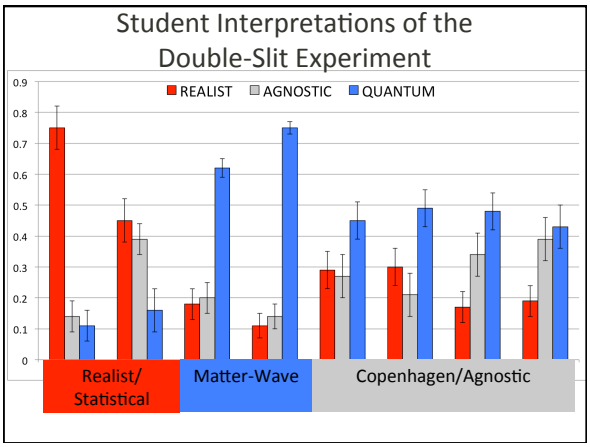
(D) None of the above.



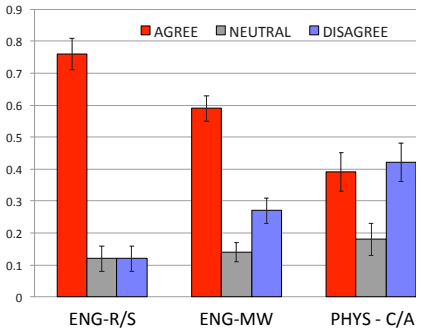


- **[Realist/Statistical]** Each electron is a particle that went through one slit or the other.
- **[Matter-Wave]** Each electron went through both slits and interfered with itself.
- **[Copenhagen/Agnostic]** We can't say what an electron does between emission and detection.

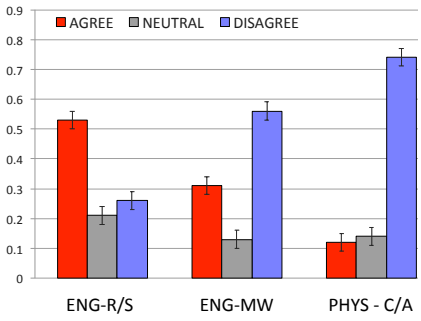




"When not being observed, an electron in an atom exists at a definite but unknown position at each moment in time."

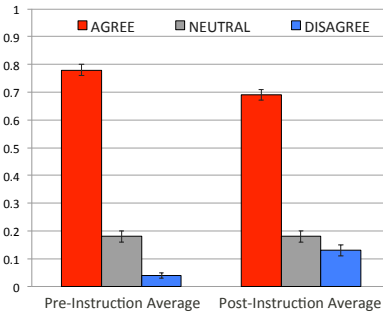


"The probabilistic nature of quantum mechanics is mostly due to the limitations of our measurement instruments."



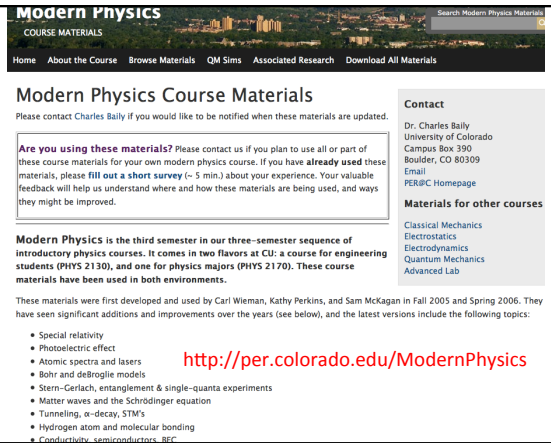
Modern Physics for Engineers

"I think quantum mechanics is an interesting subject."



Incorporating Interpretation into QM

- "Spins first" approach (Stern-Gerlach Experiments)
- Give students the tools to articulate their beliefs
  - Local realism
  - Complementarity/wave-particle duality
  - Entanglement/non-locality
- Make connections with experiment
  - Single-quanta experiments
  - Distant correlated measurements
  - Quantum cryptography/computing



http://per.colorado.edu/ModernPhysics

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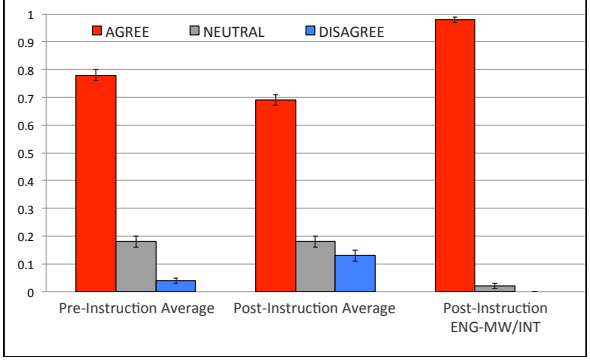

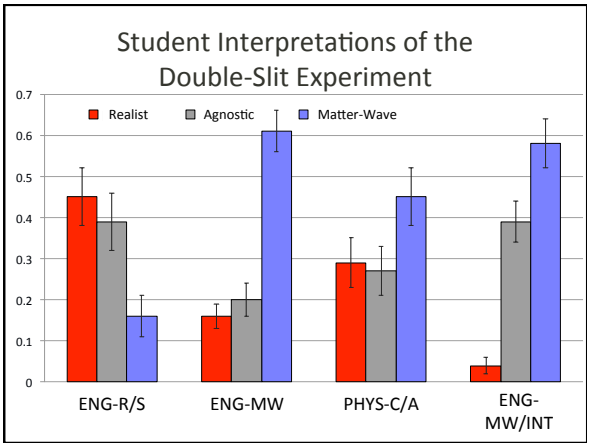

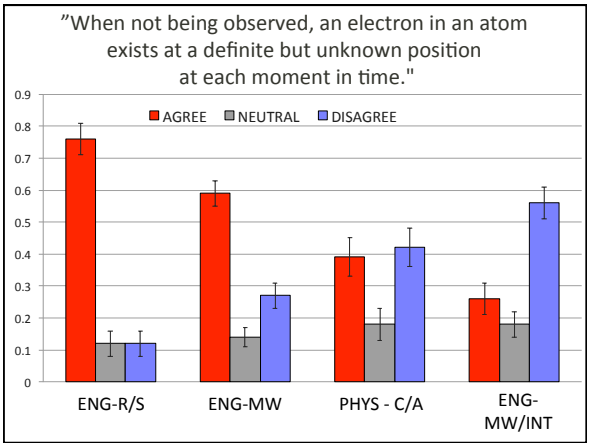

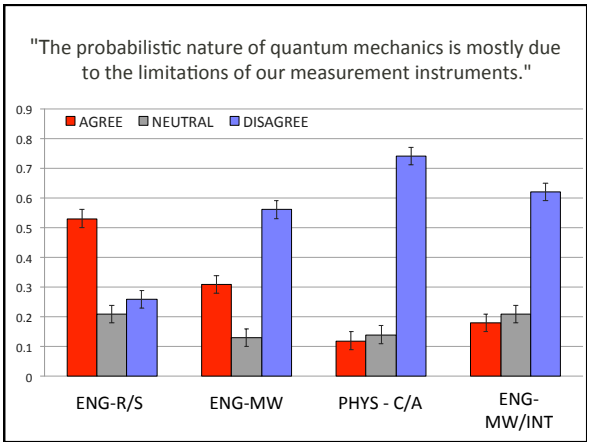

Interpretation is about sense-making

We can strongly impact student thinking

Develop quantum intuition first, mathematical tools later