




**Physics or Philosophy?
Quantum Interpretations
in the Undergraduate Curriculum**

AAPT Summer Meeting
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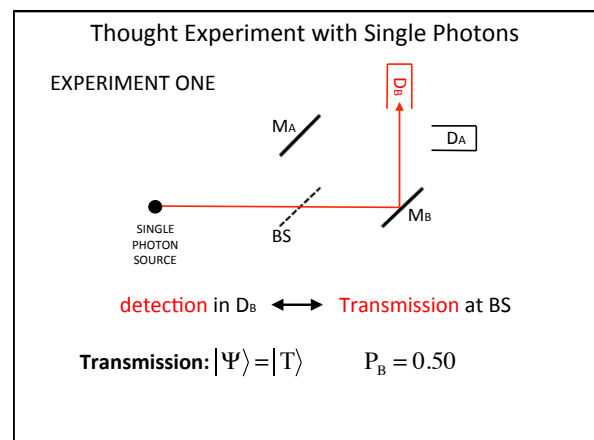
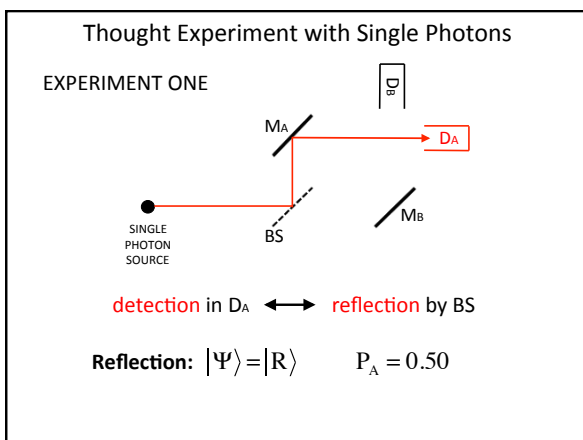
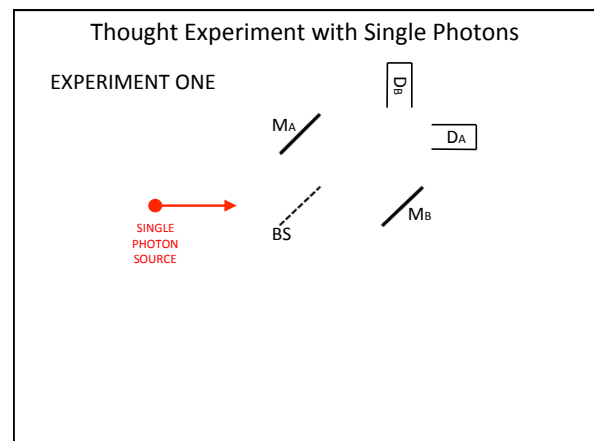
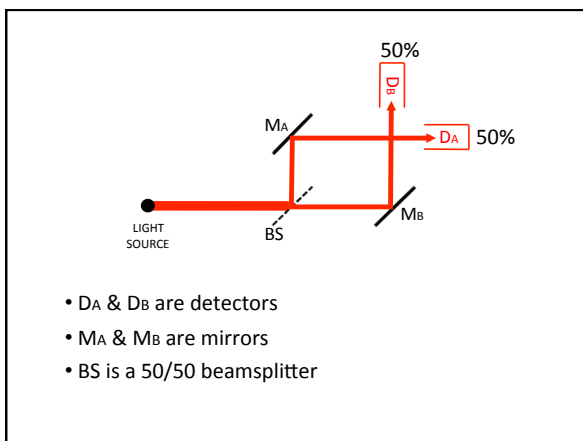
“Don’t worry about what $[\Psi]$ means, you’ll get used to it.”
- Willis E. Lamb, Jr. (1913-2008)

Develop mathematical tools first,
quantum intuition later??

Develop quantum intuition first,
mathematical tools later!!

Instructional choices impact student thinking

Interpretation is about sense-making



Thought Experiment with Single Photons

EXPERIMENT ONE

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

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

Thought Experiment with Single Photons

EXPERIMENT ONE

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

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

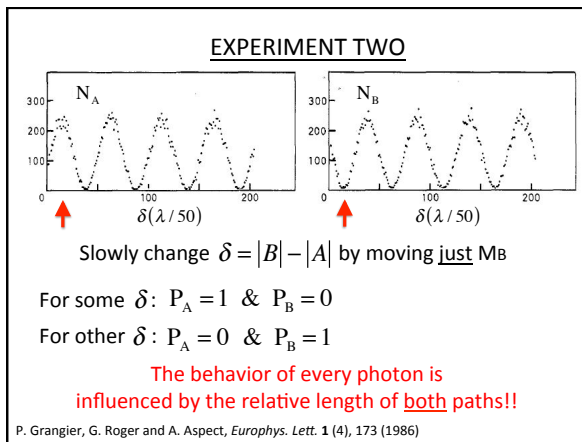
transmitted at BS1 and then reflected by BS2

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 $P_A = P_B = 0.5$

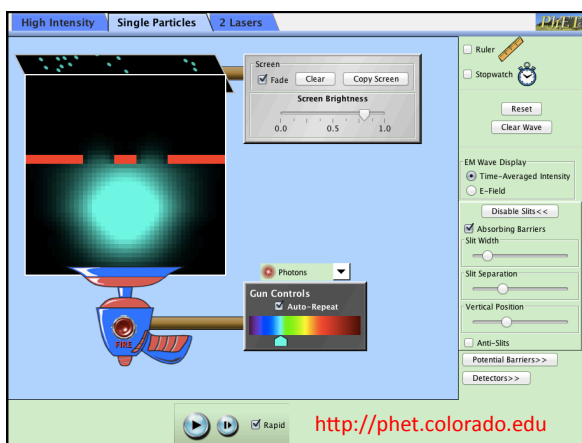


EXPERIMENT ONE

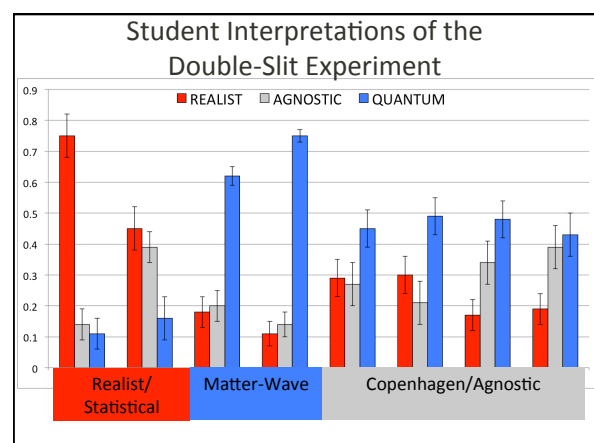
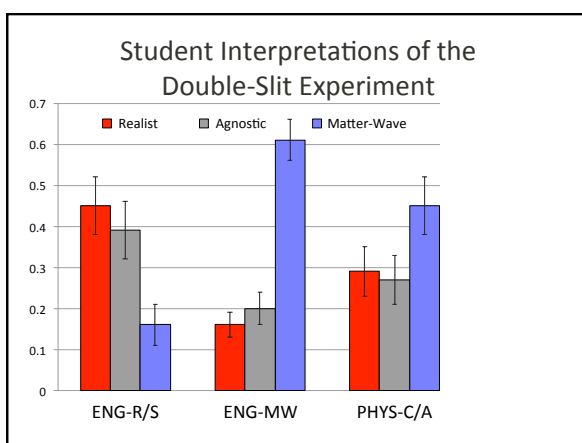
EXPERIMENT TWO

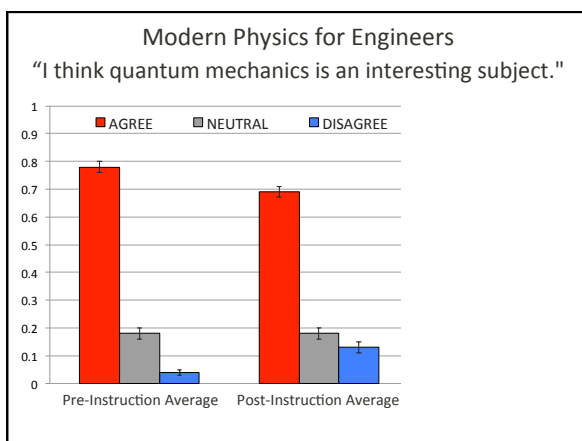
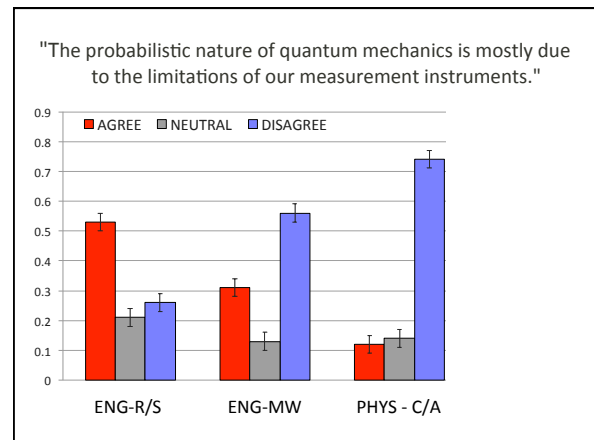
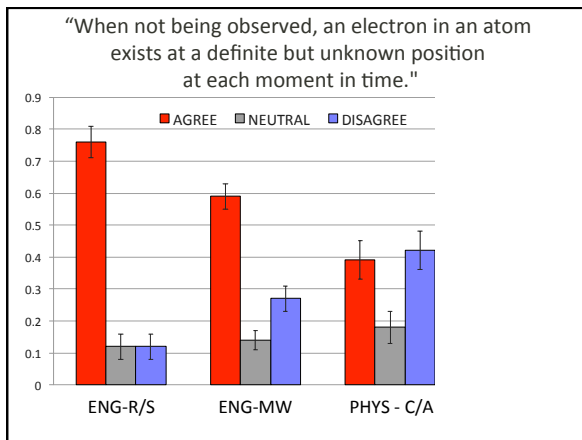
What happens when a single photon encounters the beam splitter?

- (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.





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

Modern Physics
COURSE MATERIALS

Home About the Course Browse Materials QM Sims Associated Research Download All Materials

Modern Physics Course Materials
Please contact Charles Bailly if you would like to be notified when these materials are updated.

Are you using these materials? Please contact us if you plan to use all or part of these course materials for your own modern physics course. If you have **already used** these materials, please fill out a **short survey** (~ 5 min.) about your experience. Your valuable feedback will help us understand where and how these materials are being used, and ways they might be improved.

Modern Physics is the third semester in our three-semester sequence of introductory physics courses. It comes in two flavors at CU: a course for engineering students (PHYS 2130), and one for physics majors (PHYS 2170). These course materials have been used in both environments.

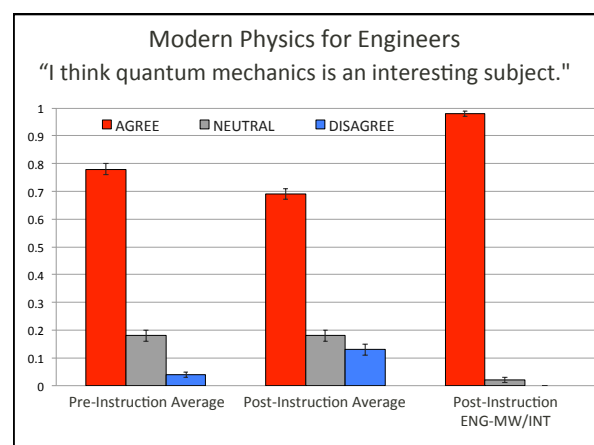
These materials were first developed and used by Carl Wieman, Kathy Perkins, and Sam McKagan in Fall 2005 and Spring 2006. They have seen significant additions and improvements over the years (see below), and the latest versions include the following topics:

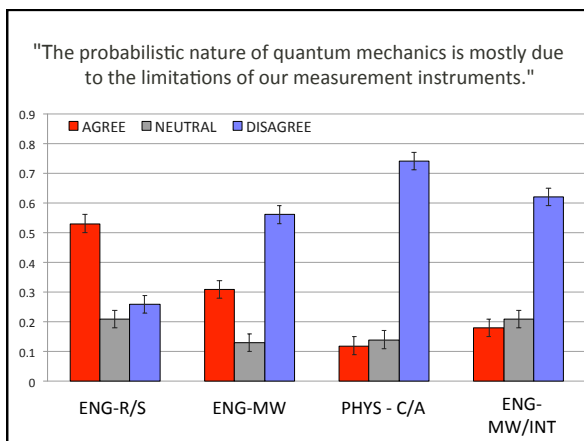
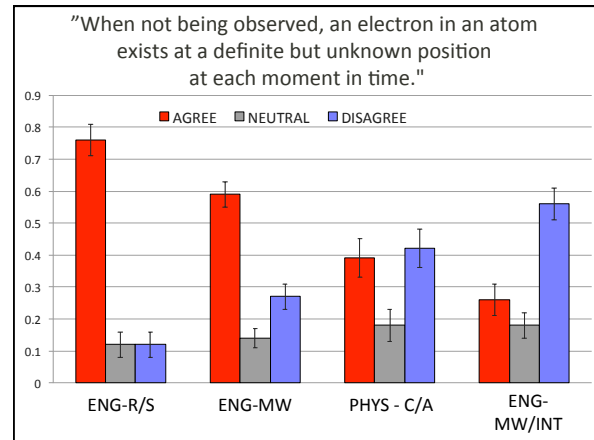
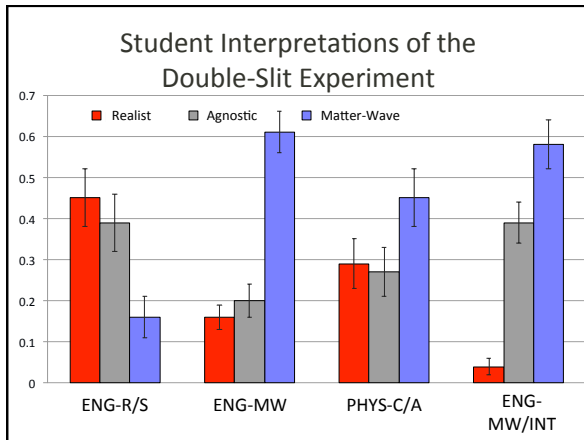
- Special relativity
- Photoelectric effect
- Atomic spectra and lasers
- Bohr and deBroglie models
- Stern-Gerlach, entanglement & single-quanta experiments
- Matter waves and the Schrödinger equation
- Tunneling, α -decay, STM's
- Hydrogen atom and molecular bonding
- Conductivity, semiconductors, BEC

<http://per.colorado.edu/ModernPhysics>

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Materials for other courses
Classical Mechanics
Electrostatics
Electrodynamics
Quantum Mechanics
Advanced Lab





Interpretation is about sense-making

We can strongly impact student thinking

Develop quantum intuition first,
mathematical tools later