Review: wrapping it up

We are proud of what you have accomplished this semester
- Andreas Becker &
Noah Finkelstein

Phys 2130, Last Day:
Questions?
Review

Reminders:
Final on May 3
1:30p this room.
Accommodations G1b31

Exam Info

Final Period is is **May 3, 1:30p**

Bring **3** 3x5 cards full of information! Also calculator and pencils.

Final is cumulative. Multiple choice (90%) & brief (10%) long answers.

Best way to study:

Review HW, lecture notes, prior & practice midterms.

Can you explain reasoning for answers to others?

What if you change something, what would happen?

Today Review of particular content / your questions.
(note some of review will show up on exam ;)

LOTS of INFO on Web

- Review Topics
- Structure of exam
- Previous review materials
- Sample questions posted.

- Your Course Score to-date is on D2L

We are here for you …

- Please collect your HW after class

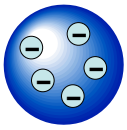
- Special Office Hrs. With Prof. Becker Mon May 2, 10a-noon, JILA X350

Recent Materials (2nd Half)

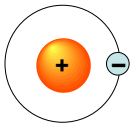
- **Potential Wells: finite and infinite square wells**
- **Tunneling:** wave function in various energy regions, alpha decay and STM
- **Nuclear physics**: alpha decay, fission, fusion
- **Lasers:** properties of lasers, conditions of making laser
- **Bonding**: covalent bond, what explains bonding/anti-bonding
- **Band Structure**: where do bands come from? What about band structure explains conductors, insulators, semiconductors?
- **Semiconductors**: how can make semiconductor? What does this mean with energy levels? What is N-type? P-type?
- **Diodes:** What is NP junction and how does this make diode?
- **Disproving Einstein:** EPR paradox, Interpretation, Local Realism Single Photon Expt.

SEE WEB!!!

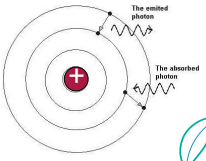
Models of the Atom



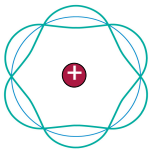
- Thomson – Plum Pudding
  - Why? Known that negative charges can be removed from atom.
  - Problem: just a random guess
- Rutherford – Solar System
  - Why? Scattering showed hard core.
  - Problem: electrons should spiral into nucleus in ~10^{-11} sec.



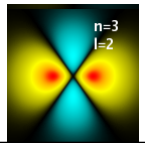
- Bohr – fixed energy levels
  - Why? Explains spectral lines.
  - Problem: No reason for fixed energy levels



- deBroglie – electron standing waves
  - Why? Explains fixed energy levels
  - Problem: still only works for Hydrogen.



- Schrodinger – quantum wave functions
  - Why? Explains everything!
  - Problem: None (except that it's hard to understand)



Questions 1 through 4 refer to the following two experiments:

In one experiment electrons are traveling from a source to a detecting screen.
In a second experiment light is traveling from a source to a photographic plate.

For each question, choose from the options A through D below the most appropriate answer according to quantum physics.

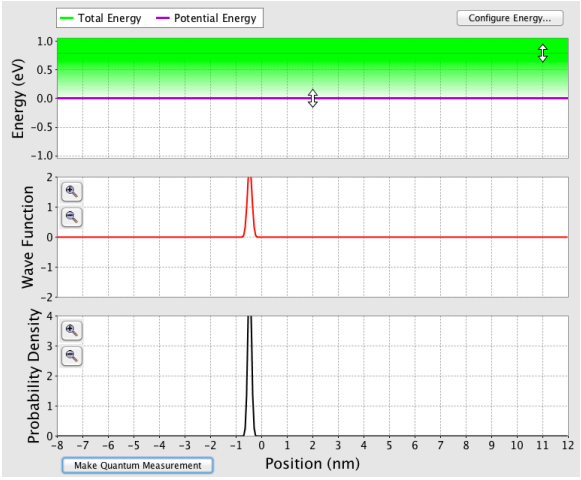
A. It is behaving like a particle.
B. It is behaving like a wave.
C. It is behaving like both a particle and a wave.
D. You cannot tell if it is behaving like a particle or a wave.

How is the particle/wave behaving when…

1. ...an electron is traveling from the source to the detecting screen?

A. It is behaving like a particle.
B. It is behaving like a wave.
C. It is behaving like both a particle and a wave.
D. You cannot tell if it is behaving like a particle or a wave.

Check out the tunneling sim



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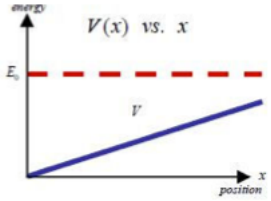
A. It is behaving like a particle.
B. It is behaving like a wave.
C. It is behaving like both a particle and a wave.
D. You cannot tell if it is behaving like a particle or a wave.

For each question 18 through 20, choose the most appropriate answer from A through C.

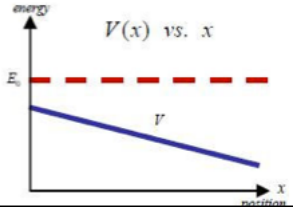
A. The de Broglie wavelength of the particle will increase.
B. The de Broglie wavelength of the particle will decrease.
C. The de Broglie wavelength of the particle will remain the same.

What will happen when a quantum particle is traveling from left to right with constant total energy (dashed line: E_0), in a region in which the potential energy (solid line: V(x)) is…

19. _____ Increasing?



20. _____ Decreasing?



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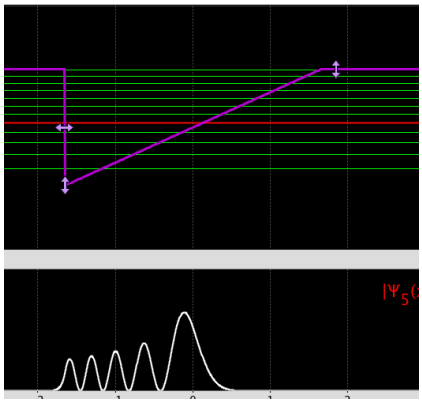

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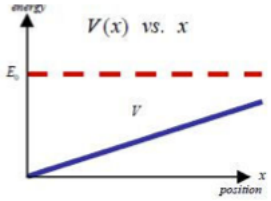
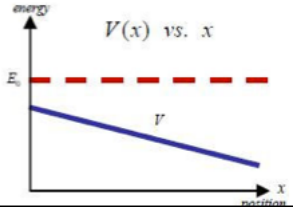
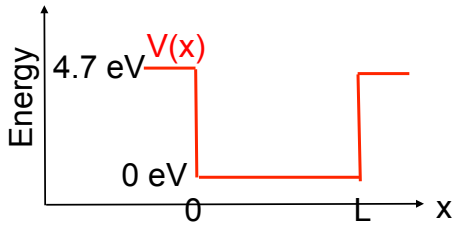


20. B Decreasing?

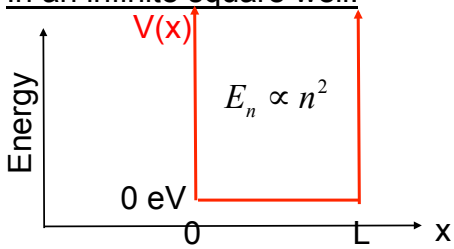


1. Figure out what V(x,t) is, for situation given.
   V(x,t) = potential energy of the electron
   → What is it as a function of position?
   → Is it changing with time? (Too complicated)

In a wire:

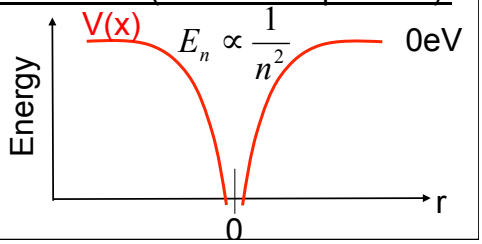


In an infinite square well:

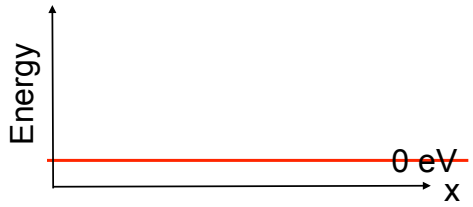


In free space, really long wire:

In H-atom (3-D … complicated):

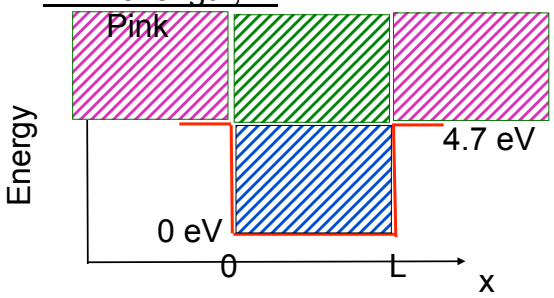


In free space:



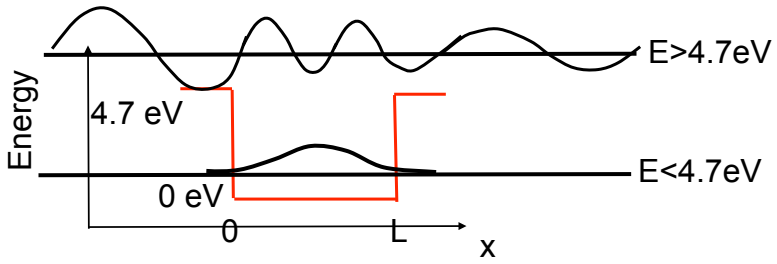
For the case of an electron in free space (E> V=0), what energies are allowed?
A. Any energy is allowed
B. Only certain specific energies are allowed.

In wire length, L:



In which regimes is an electron allowed to have only specific fixed energies (quantized energy levels)? (In the other regimes… any energy is allowed)
A. Green only
B. Blue only
C. Pink only
D. Green and Blue
B. Green, Blue, and Pink

In wire length, L:



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A. Green only
B. Blue only
C. Pink only
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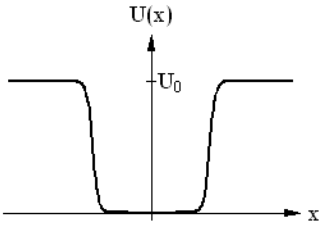
B. Green, Blue, and Pink

Question 26

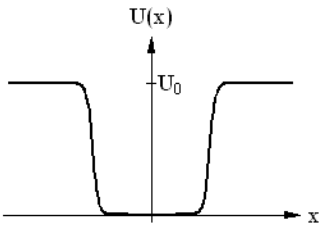
Are there any allowed values of the particle's total energy E with $E < U_0$, and if so, are all values allowed or only a discrete set of energy values?



A. There are no allowed values of energy in this range.
B. Only certain discrete values of energy in this range are allowed.
C. All values of energy in this range are allowed.

Question 27

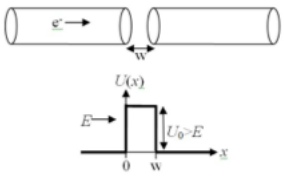
Are there any allowed values of the particle's total energy E with $E > U_0$, and if so, are all values allowed or only a discrete set of energy values?

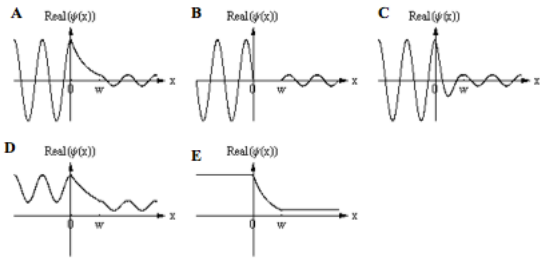


A. There are no allowed values of energy in this range.
B. Only certain discrete values of energy in this range are allowed.
C. All values of energy in this range are allowed.

Question 28

28. An electron with energy E is traveling through a conducting wire when it encounters a small gap in the wire of width w. The potential energy of the electron as a function of position is given by the plot at right, where $U_0 > E$. Which of the following sketches most accurately describes a snapshot of the real part of the wave function of this electron?

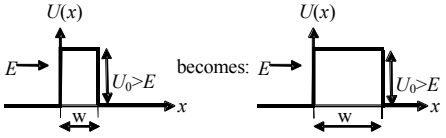




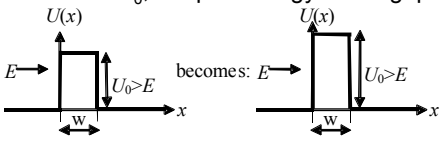
Question 29

Suppose that in the experiment described in the previous question, you would like to decrease the speed of the electron coming out on the right side. Which of the following changes to the experimental set-up would decrease this speed?

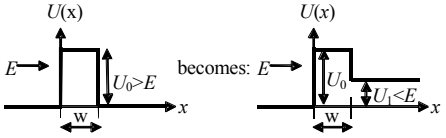
A. Increase the width w of the gap:



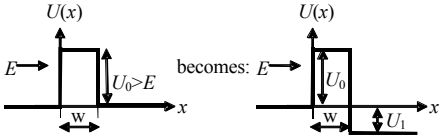
B. Increase U_0, the pot. energy of the gap:



C. Increase pot. energy right of the gap:

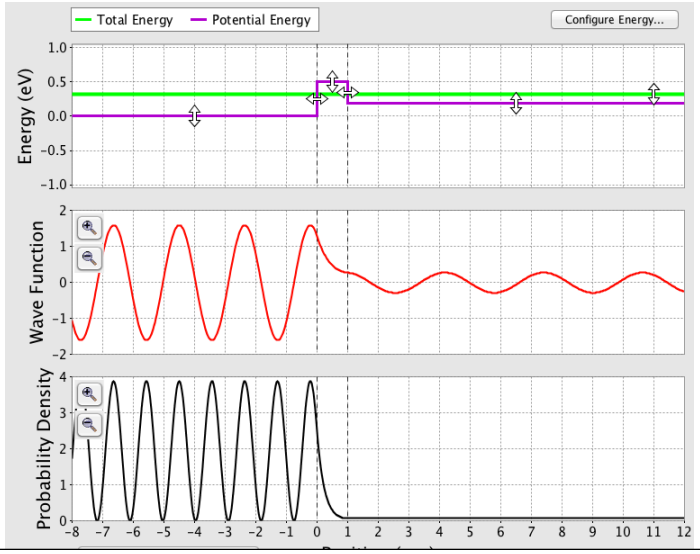


D. Decrease pot. energy right of the gap:



E. More than one of the changes above would decrease the speed of the electron.

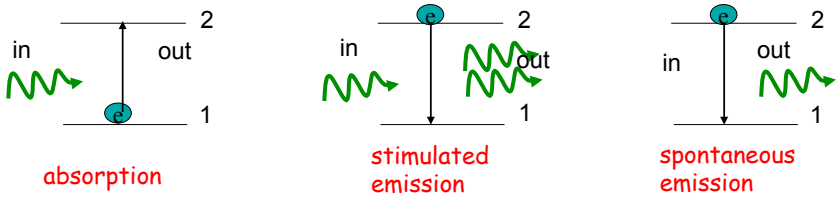
Go to the sim!



LASER - Light Amplification by Stimulated Emission of Radiation

Need to clone lots of photons → LOTS of identical light.

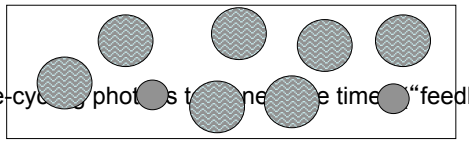
Three process, all play important roles:



Basic requirements for laser:

1) Need more atoms in an upper level than a lower one ("Population Inversion") *(hard part of making laser)*

2) Need method of re-cycling photons to clone time ("feedback") *(mirrors)*

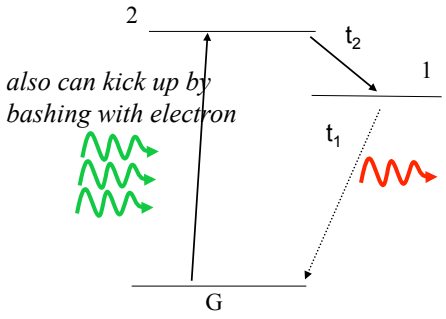


Getting a population inversion

need at least one more energy level involved.

Trick: use a second color of light

(why two levels (one color) won't work as HW problem (maybe))



also can kick up by bashing with electron

"pumping" process to produce population inversion

To create population inversion between G and level 1 would need:

a. time spent in level 2 (t_2) before spontaneously jumping to 1 is long and time spent in level 1 (t_1) before jumping to G is short.

b. $t_1=t_2$

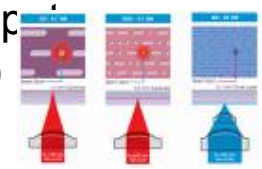
c. t_2 short, t_1 long

d. does not matter

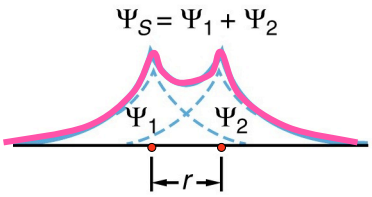
ans. c. show on sim

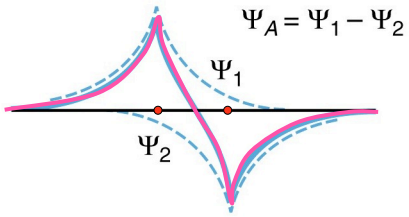
Many applications of lasers

- High energy small area:
  - Cutting: surgery, laser welding
  - "communication" (and weapons)
- Focus light into extremely small sp
  - (diffraction limit, because in phase!)
  - CDs, DVDs, …
- Collimated beam
  - Tracking, leveling,
- Pure color
  - LIDAR….



Look at what happens to these wave functions as bring protons closer…





Visualize how electron cloud is distributed… for which wave function would this cloud distribution tend to keep protons together? (bind atoms?) … what is your reasoning?

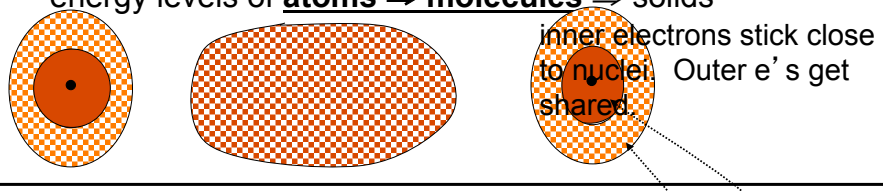
a. Ψ_S or Ψ_+

b. Ψ_A or Ψ_-

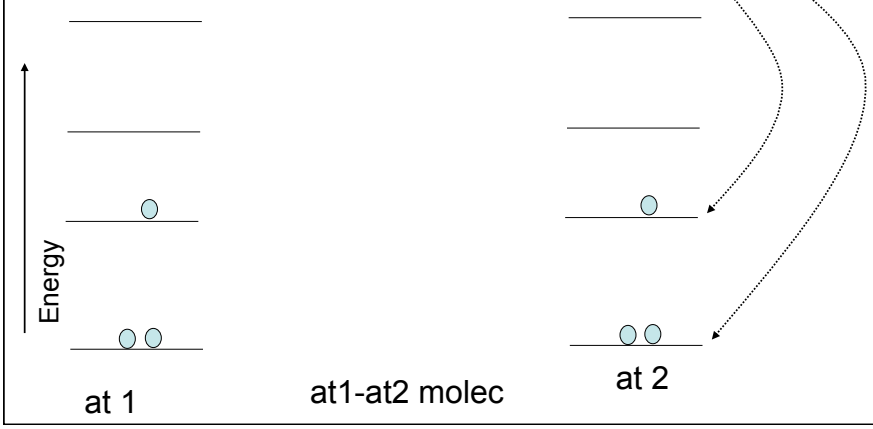
QM of electrical conduction

multielectron atoms

energy levels of **atoms ⇒ molecules** ⇒ solids



inner electrons stick close to nuclei. Outer e's get shared.



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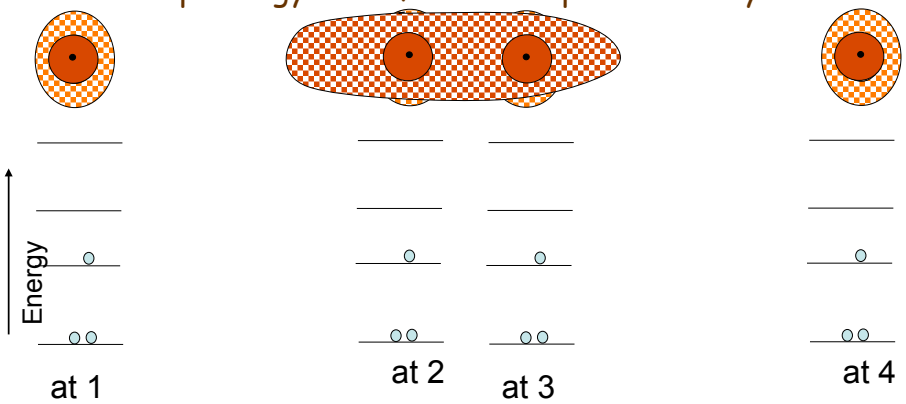
QM of electrical conduction

energy levels of **atoms ⇒ molecules** ⇒ solids

top energy wave functions spread waaaay out



many levels!

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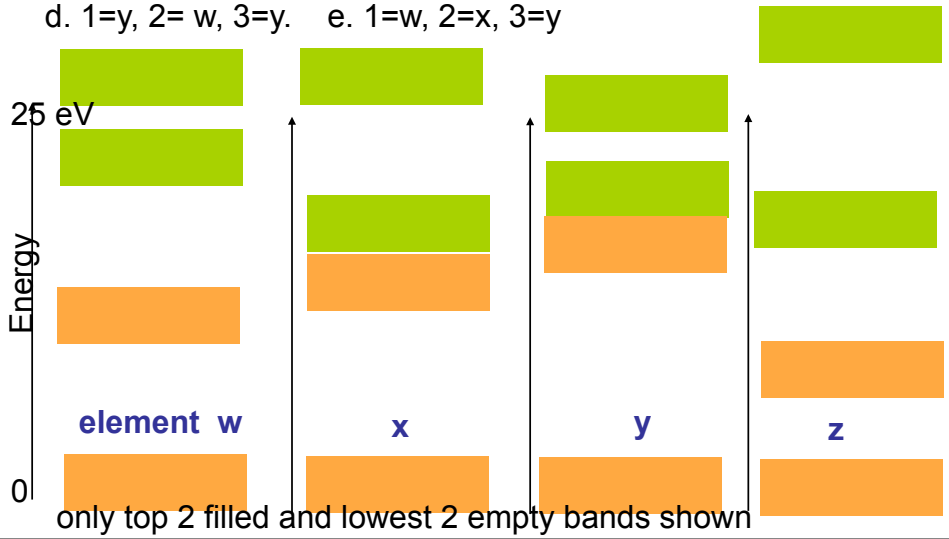
Which band structure goes with which material?
(be ready to give reasoning)

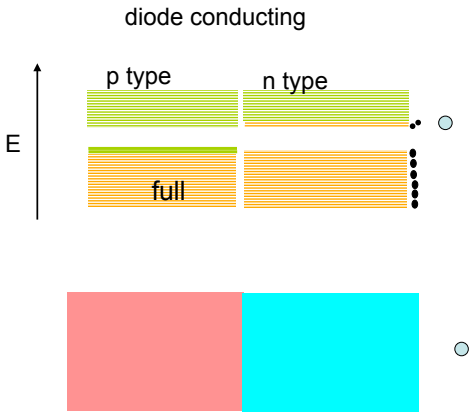
empty
full

1. Diamond **2. copper** **3. germanium (poor conductor)**

a. 1=w, 2=x, 3=y b. 1=z, 2=w, 3=y c. 1=z, 2=y, 3=x
d. 1=y, 2= w, 3=y. e. 1=w, 2=x, 3=y



only top 2 filled and lowest 2 empty bands shown



As electron moves across junction going from N type on right to P type on left

a. it stays at the same energy
b. it gains potential energy (if so from where?)
c. it loses potential energy (if so to where?)

c. loses potential energy- goes into 1) heat (vibrating atoms) or 2) if proper materials, light (light emitting diode)

Classical Ignorance vs. Quantum Uncertai

- Classical Experiment:
  - Take a blue sock and a red sock
  - Seal them up in identical boxes
  - Mix up boxes
  - Take them to opposite ends of galaxy
  - Open just one box, and you know what color sock is in the other box.
- The math we use to describe this is that

Expectation = 0.5 blue + 0.5 red

$$|\Psi_{12}\rangle = |\uparrow_1\rangle|\downarrow_2\rangle + |\downarrow_1\rangle|\uparrow_2\rangle$$

Same math as spin up / down … is the PHYSICS the same?

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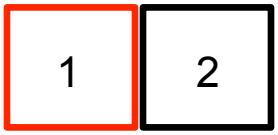
Completeness

Locality

EPR make one other ***assumption***, but is it really an assumptio



Suppose we have two physical systems, **1** & **2**.

Local Realism

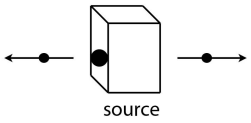
Realism refers to a perspective where the properties of physical systems are considered to be objectively real (observation independent), in the sense that they exist and have definite values independent of any observer, human or not. Physical systems exist in definite states, whether we can completely know what that state is or not.

HIDDEN VARIABLES

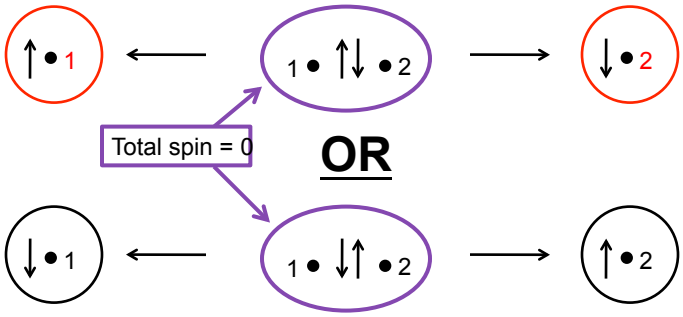
The term ***hidden variable*** refers to any of these physical quantities not described by an incomplete theory. Some examples might be the position or momentum of a particle (things to do with its trajectory), the orientation of an atom's magnetic moment, the polarization state of a photon, etc…

Hidden variable theories assume quantum mechanics is incomplete, in this case that it does not describe all relevant properties of the spin ½ particles. A hidden variable is an additional physical quantity not described by quantum theory and thus unknown to the observer. You can consider the entangled particles from decay of a an atom / molecule.. if they head off in opposite directions with entangle spins, hidden variable would say that their spins are known. These hidden variables are local, as they are assumed to originate at the point of production of the particles at the source. Thus, the measurement performed by observer A has no influence on the outcome of the measurement for observer B.

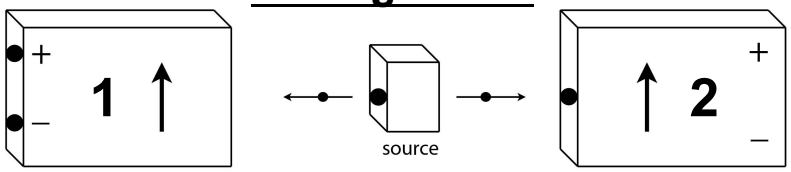
Entanglement



Suppose we have a source that produces ***pairs of atoms*** traveling in ***opposite directions***, and having ***opposite spins***:



Entanglement

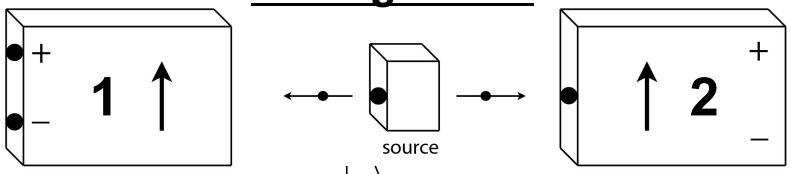


Place two Stern-Gerlach analyzers to the left and right of the source, and oriented at the same angle.

Let $|\Psi_{12}\rangle$ represent the quantum state of ***both*** atoms **1** & **2**.

How would we represent this?

Entanglement



We measure at analyzer 1 $|\downarrow_1\rangle$

What is the wave function (state):

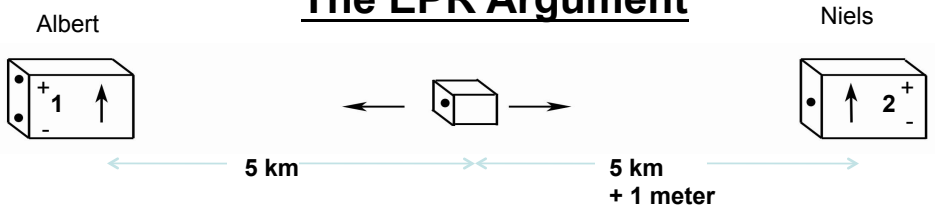
a) $|\Psi_{12}\rangle = |\uparrow_1\rangle|\downarrow_2\rangle$

b) $|\Psi_{12}\rangle = |\downarrow_1\rangle|\uparrow_2\rangle$

c) $|\Psi_{12}\rangle = |\uparrow_1\rangle|\downarrow_2\rangle + |\downarrow_1\rangle|\uparrow_2\rangle$

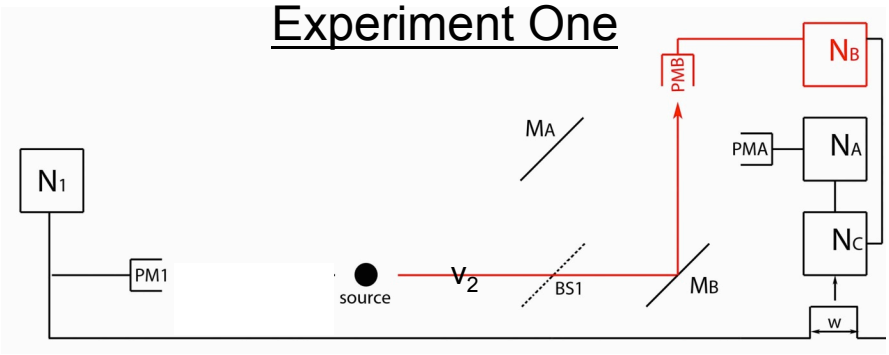
d) We can tell anythign

The EPR Argument



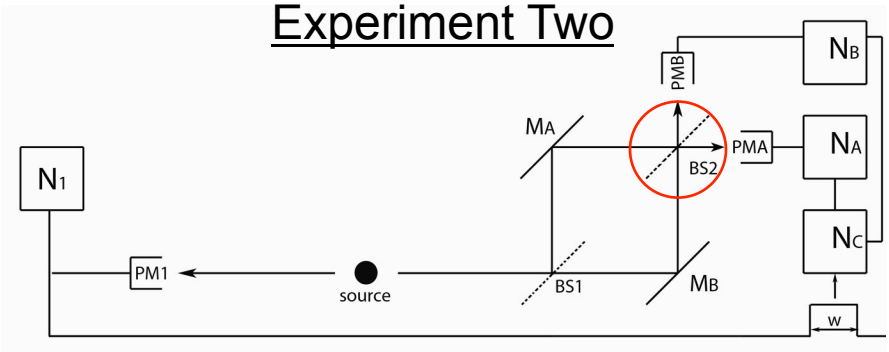
Single-Photon Experiments/ Wave-Particle Duality

Experiment One



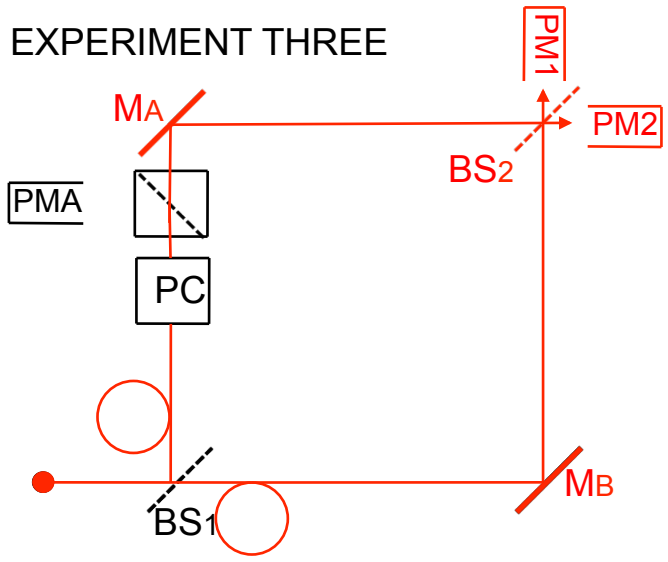
- If the second photon (v_2) is detected by PMA, then the photon must have traveled along Path A.
- If the second photon (v_2) is detected by PMB, then the photon must have traveled along Path B.
- The photon must decide at BS1 whether to take Path A or Path B.

Experiment Two



- Whether the photon is detected in PMA or PMB, **both** Path A **or** Path B are possible.
- When we compare data from PMA & PMB, we observe interference – the photon must decide at BS1 to take **both paths**.

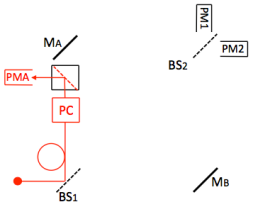
EXPERIMENT THREE



Both paths to BS2 possible with **no voltage** applied to PC

➔ $P_1 = 1 - P_2 \quad (0 \le P_2 \le 1$ ➔ interference)

EXPERIMENT THRE



NO VOLTAGE applied to PC

- Two paths to BS2 = Interference

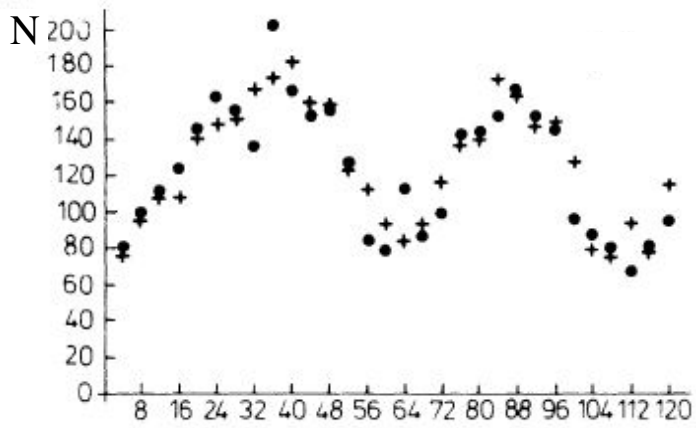
VOLTAGE APPLIED to PC

- One path to BS2 = No interference

"DELAYED-CHOICE" MODE

- Photon encounters BS1 with **VOLTAGE APPLIED** (Experiment One)
- Photon *should* choose either one path (to PMA) **or** the other path (to BS2)
- *after* photon encounters BS1 **VOLTAGE TURNED OFF** (switch to Experiment Two)

EXPERIMENT THREE

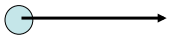


Dots: apparatus operating in "normal mode" – no voltage applied to PC

Crosses: apparatus operating in "delayed-choice mode"

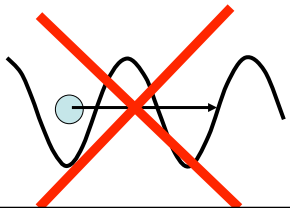
Three Experiments with Photons

Experiment One says photons behave like ***particles***.



Experiment Two says photons behave like ***waves***.

Delayed Choice says photons ***do not*** behave like particle ***and*** wave at the same time.



Thanks very much

- We are quite proud of how hard you worked
- And your achievements
- This class has been one of best parts of our semester…
- we've enjoyed the teamwork
  - Thanks Prof. Becker!!
  - Thanks Omkar, Aidan and Marcus
  - Thanks Jessica
  - Thanks to you the mighty mighty 2130 students