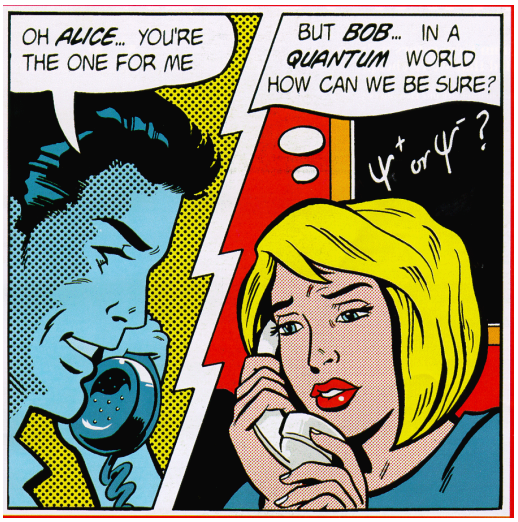
May 6, 2013 Physics 132 Prof. E. F. Redish

- **Theme Music:**
  Blondie
  Atomic

- **Cartoon:**



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Rest of term

- Remember to do evalUM (campus survey)!
- MPEX on line
- Surveys in recitation/lab tomorrow
- One page to read for Wed. (Fluorescence)
- When do you want help/review sessions?
- Anyone have a problem with extra final exam time?
- Practice problems and review slides will be posted by Wednesday.

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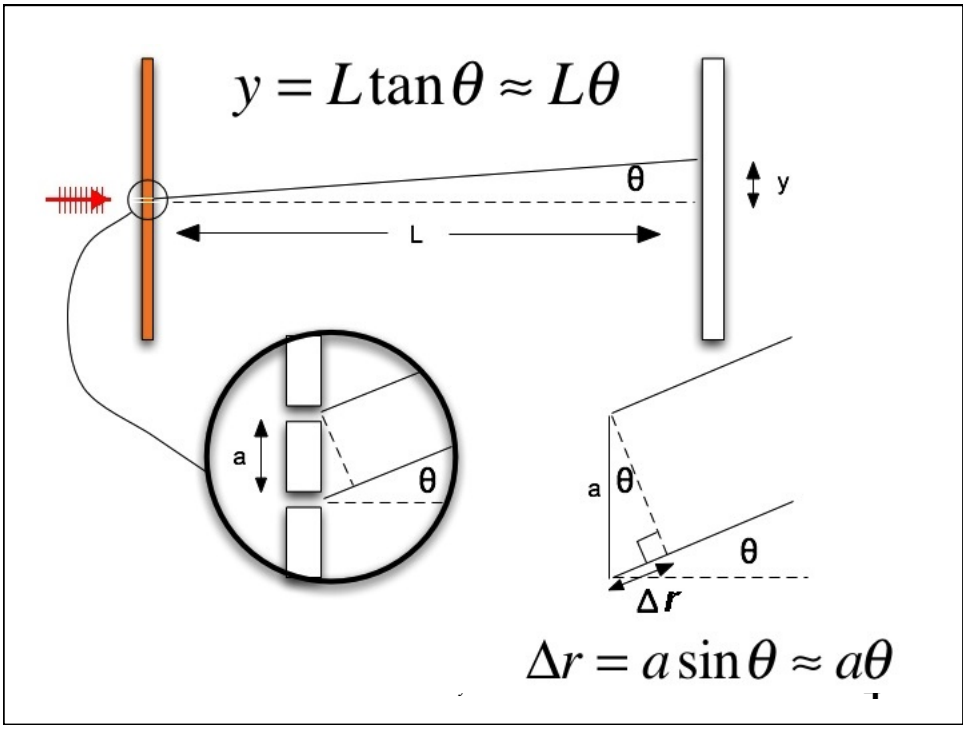
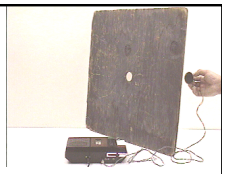
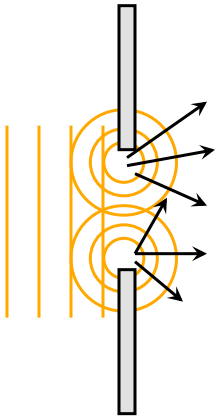
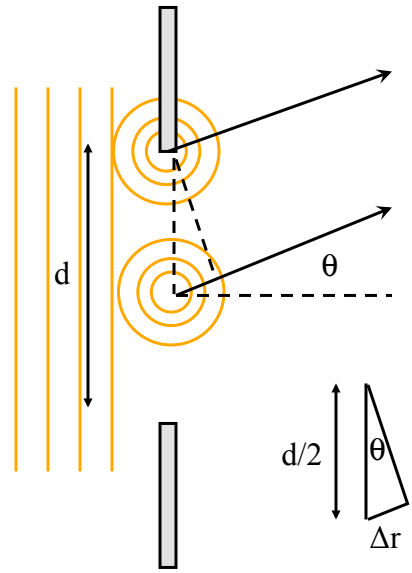


Diffraction





- Every bit of the interior of the slit acts as a source of outgoing spherical Huygens' wavelets.
- The outgoing wavelets from one part of the slit can interferer with the wavelets from another part of the slit.



When the distance traveled by the wavelet from the middle of the slit is half a wavelength greater than the distance traveled by the wavelet from the top of the slit every wavelet from the top half of the slit has a canceling wavelet from the bottom half of the slit.

The result is no intensity at that angle.

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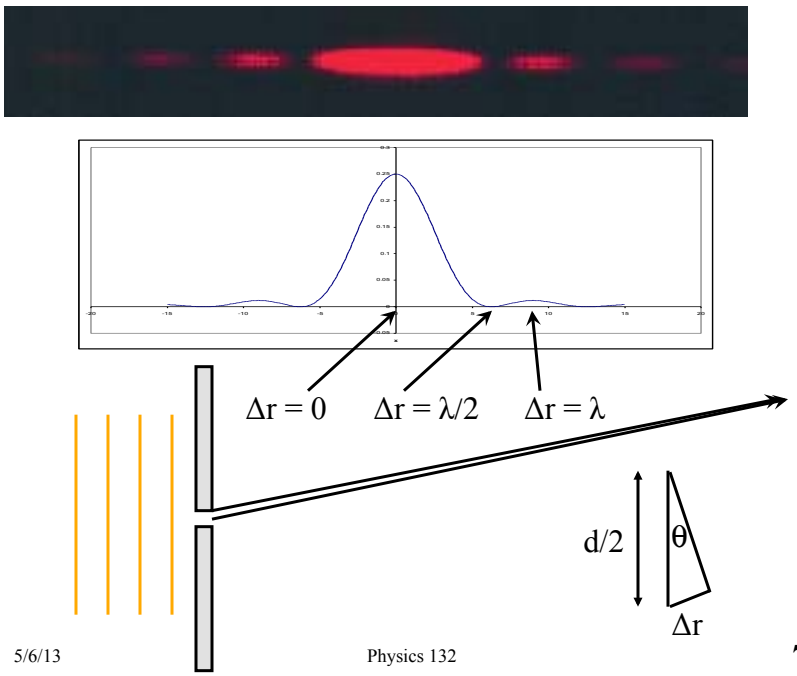

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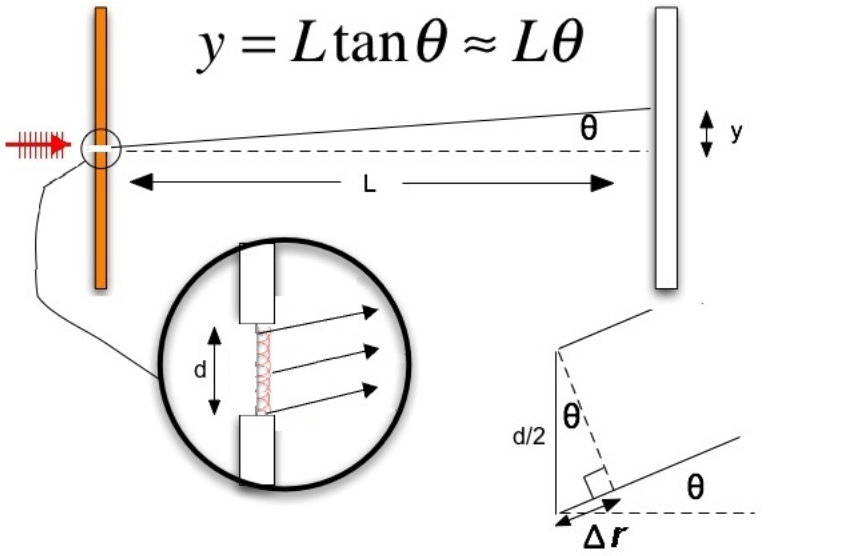
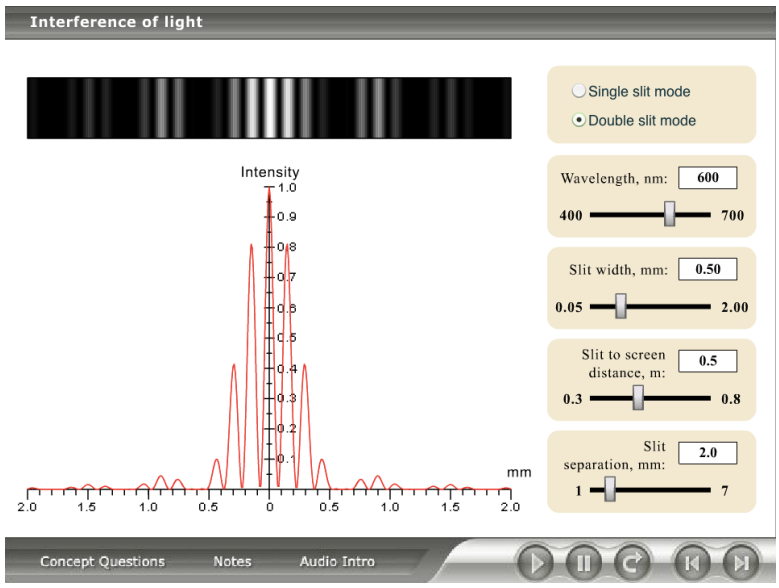


$$y = L\tan\theta \approx L\theta$$

$$\Delta r = \frac{d}{2}\sin\theta \approx \frac{d}{2}\theta$$



http://www.wiley.com/college/halliday/0470469080/simulations/sim48/sim48.html

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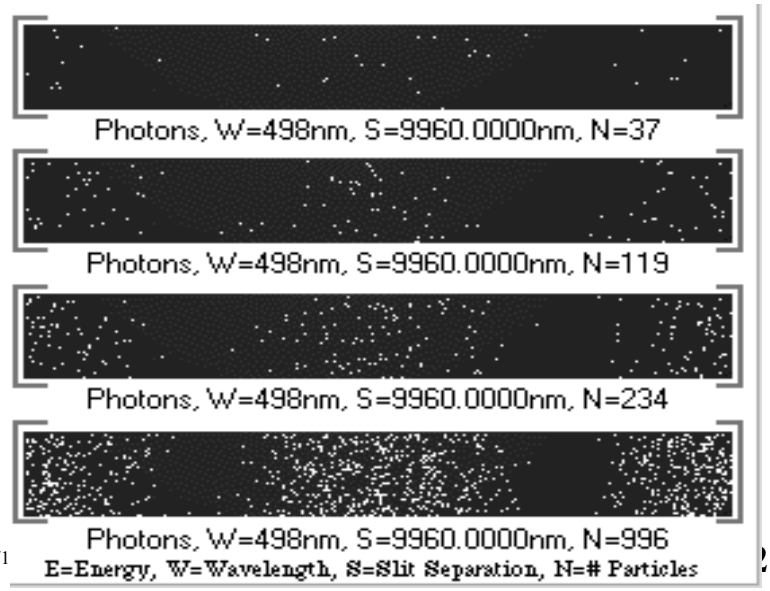
Reconciling Photons and the Wave Model: Starting Quantum Physics

- The photoelectric effect and the photon picture seem to contradict the wave model -- but relies on it.
- What if we pass photons through a double-slit but with a low enough energy density that we expect only one photon in the system at a time.
- What would the pattern look like?

http://phys.educ.ksu.edu/vqm/html/doubleslit/

Results



Both Particle and Wave Properties are Displayed

- Individual photons strike the target individually and are detected as tiny spots.
- Individual photons still follow an interference pattern – but at random.
- The intensity of an EM wave only tells us the *probability* of finding a photon at a particular place.

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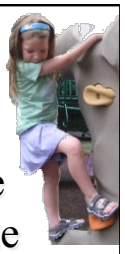
Foothold Ideas: The Probability Framework



- It's clear that both the wave model and the photon have an element of truth. Here's the way we reconcile it:
  - *Maxwell's equations and the wave theory of light yield a function – the electric field – whose square (the intensity of the light) is proportional to the probability of finding a photon.*
  - *No theory of the exact propagation of individual photons exist. This is the best we can do: a theory of the probability function for photons.*

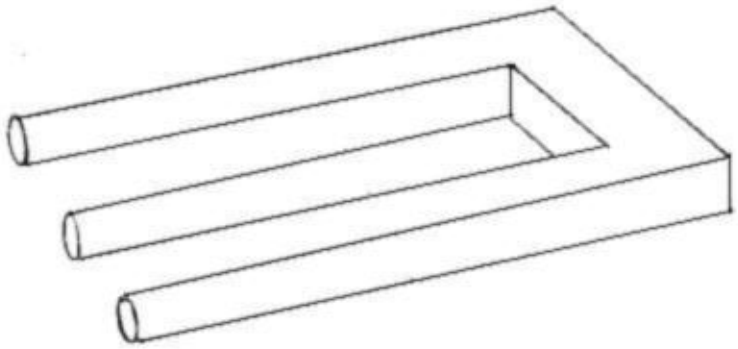
Reading questions

- I don't understand how photons are able to "interfere with themselves". What property of the photon allows it to even have an interference pattern?
- Is there a way to explain how it is that photons interfere with themselves even though it should technically be impossible?
- I thought that the intensity of light was a quantitative measure of the magnitude of almost the brightness of light at a particular point? How can we relate this to the position of a photon? Lastly, for any single wave, wouldn't the probability that you can find a photon anywhere along that wave or oscillation be the same?
- I am confused on what it means by the photons interfere with themselves to create the interference pattern. How can one photon compete with itself for a position on the screen?
- How does a photon interfere with itself?

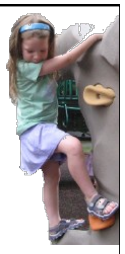
So are they waves? Or particles?

- Alice laughed. "There's no use trying," she said: "one *can't* believe impossible things."
- "I daresay you haven't had much practice," said the Queen. "When I was your age, I always did it for half-an-hour a day. Why, sometimes I've believed as many as six impossible things before breakfast."
  - *Through the Looking Glass*
    Lewis Carroll

A Quantum Model of Light



Foothold Ideas: The Nature of Matter



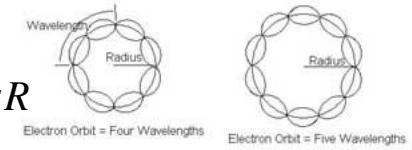
- Atoms and molecules naturally exist in states having specified energies. EM radiation can be absorbed or emitted by these atoms and molecules.
- When light interacts with matter, both energy and momentum are conserved.
- The energy of radiation either emitted or absorbed therefore corresponds to the difference of the energies of states.
- DeBroglie suggested that the discreteness property of atomic state might be explained if electrons had wave properties like photons.

DeBroglie's matter waves

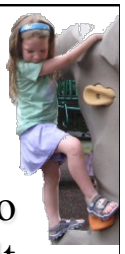
- Assume that Einstein's photon equations hold for free electrons:

$$E = hf \qquad p = h/\lambda$$
$$E = \tfrac{1}{2}mv^2 \qquad p = mv$$
$$E = p^2/2m = h^2/2m\lambda^2$$

- This would suggest that you would only be allowed to have discrete electron orbits (standing waves) when the wavelengths fit into the orbit. $n\lambda = 2\pi R$



Foothold Ideas: The Probability Framework



- DeBroglie's waves have to be generalized to 3D and potential energy included. The result is the Schrödinger equation.
  - *Schrödinger's equation is the wave theory of matter. It's solution yields the wave function whose square is proportional to the probability of finding an electron.*
  - *No theory of the exact propagation of individual electrons exist. This is the best we can do: a theory of the probability function for electrons.*