- **<u>Theme Music:</u> Duke Ellington**
  Take the A Train
- **<u>Cartoon:</u> Lynn Johnston**
  For Better of For Worse

Previous Exam Results

	#1	#2	#3	#4	#5
Exam 1	52%	52%	74%	70%	60%
Exam 1 (MU)	47%	38%	58%	65%	60%
Exam 2	55%	72%	54%	72%	54%
Exam 2 (MU)	51%	33%	20%	65%	64%

Final exam

- The final exam will be 200 points and will be cumulative throughout the course,
  - with about half of the emphasis on material covered in the first and second exam and
  - With about half of the emphasis on material covered since the second exam.
- Review slides for the new material follows.
  - For reviews slides for earlier material see the slides posted for the dates of the first and second hour exams.

Foothold principles: Mechanical waves 2

- *Superposition*: when one or more disturbances overlap, the result is that each point displaces by the sum of the displacements it would have from the individual pulses. (signs matter)
- *Beats*: When sinusoidal waves of <u>different frequencies</u> travel <u>in the same direction</u>, you get variations in amplitude (when you fix either space or time) that happen at a rate that depends on the difference of the frequencies.
- *Standing waves*: When sinusoidal waves of the <u>same frequency</u> travel in <u>opposite directions</u>, you get a stationary oscillating pattern with fixed nodes.

Light: Three models

- Newton's particle model (rays)
  - Models light as bits of energy traveling very fast in straight lines like tiny particles. Each has a color. Intensity is the number of particles you get per second.
- Huygens's/Maxwell wave model
  - Models light at waves (transverse EM waves). Color is determined by frequency, intensity by square of a total oscillating amplitude. (Allows for cancellation – interference.)
- Einstein's photon model
  - Models light as "wavicles" or "quantons", quantum particles whose energy is determined by frequency and that can interferer with themselves.

Foothold Ideas: The Photon Model

- When it interacts with matter, light behaves as if it consisted of packets (photons) that carry both energy and momentum according to:

$$E = \hbar\omega \qquad p = \hbar k \qquad \hbar = \frac{h}{2\pi}$$

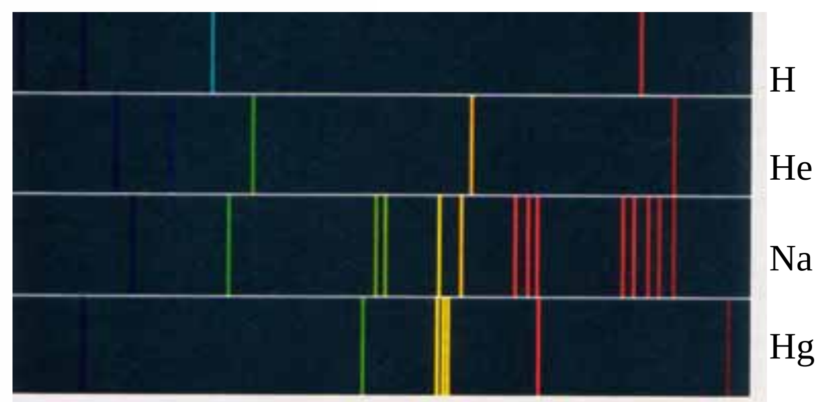
$$E = hf \qquad p = \frac{E}{c} = \frac{h}{\lambda}$$

with $hc \sim 1234$ eV-nm.

  – These equations are somewhat peculiar. The left side of the equations look like particle properties and the right side like wave properties.

Foothold ideas: Line Spectra

- When energy is added to gases of pure atoms or molecules by a spark, they give off light, but not a continuous spectrum.
- They emit light of a number of specific colors — *line spectra.*
- The positions of the lines are characteristic of the particular atoms or molecules.



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.

Foothold Ideas 1: Ray Model -- The Physics

- Certain objects (the sun, bulbs,…) give off light.
- Light can travel through a vacuum.
- In a vacuum light travels in straight lines (rays).
- Each point on a rough object scatters light, spraying it off in all directions.
- A polished surface reflects rays back again according to the rule: *The angle of incidence equals the angle of reflection*.
- When entering a transparent medium, a light ray changes its direction according to the rule $n_1 \sin\theta_1 = n_2 \sin\theta_2$
- "n" is a property of the medium and $n_{vac}=1$.

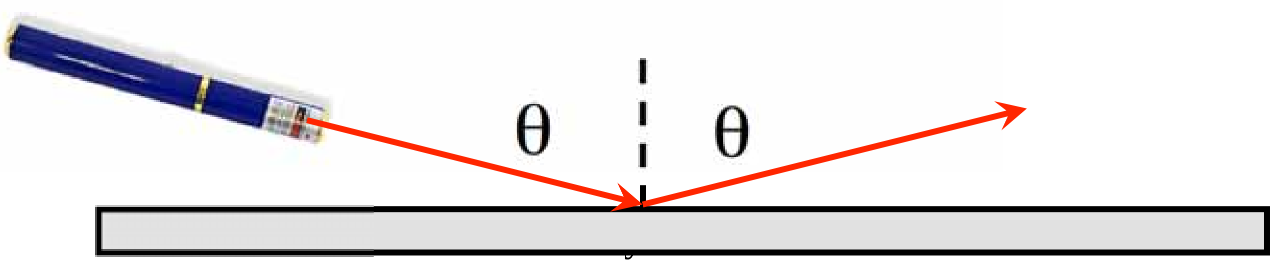
Foothold Ideas 2: Ray Model-- The Psycho-physiology

- We only see something when light coming from it enters our eyes.
- Our eyes identify a point as being on an object when rays traced back converge at that point.
  - (We use other clues as well – and some people's brains do not merge binocular vision.)

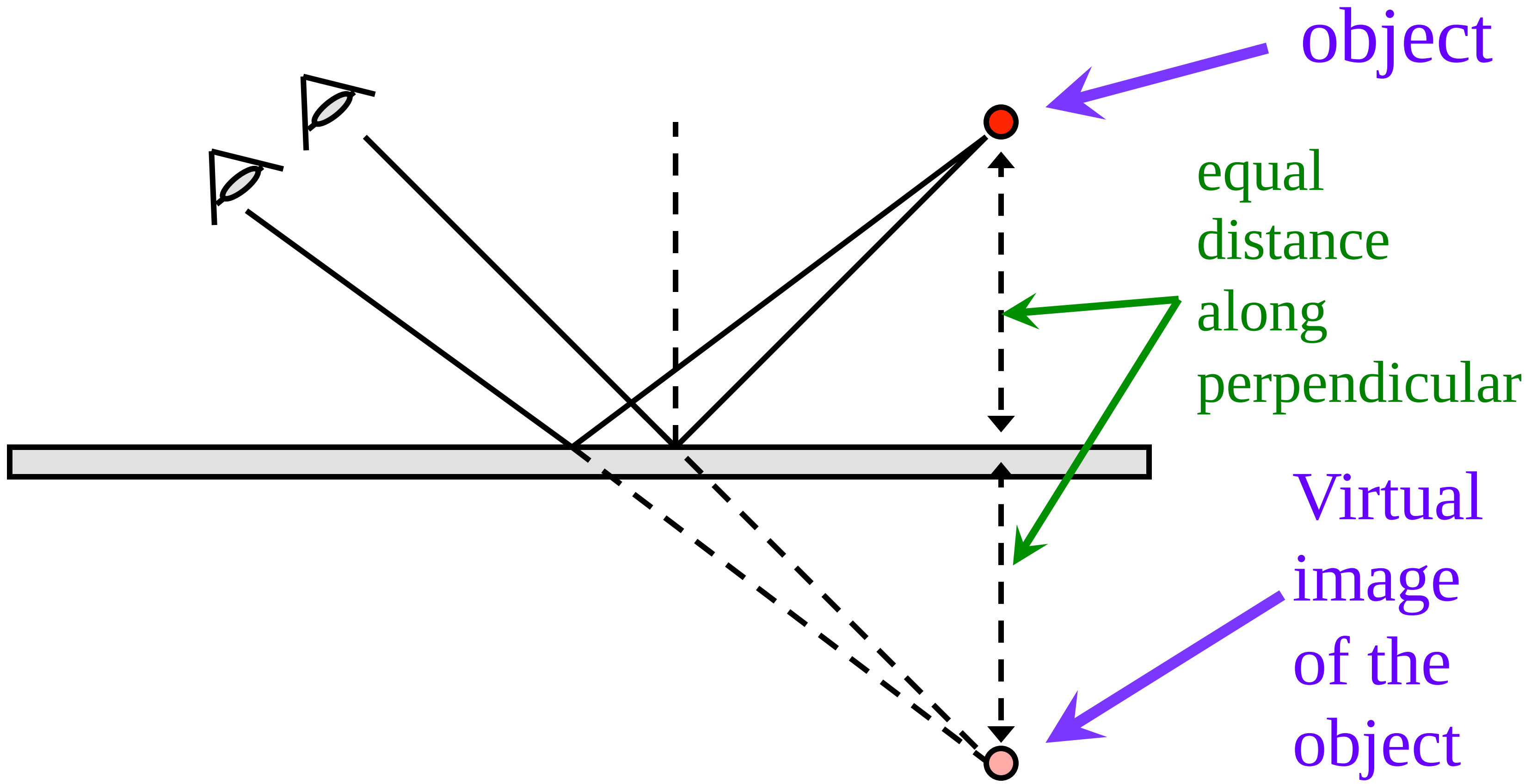
Foothold Ideas 3: Mirrors

- For most objects, light scatters in all directions. For some objects (mirrors) light scatters from them in controlled directions.

- A polished surface reflects rays back again according to the rule: *The angle of incidence equals the angle of reflection*.



Where does an object seen in a mirror appear to be?



Kinds of Images: Virtual

- In the case of the previous slide, the rays seen by the eye do <u>not</u> actually meet at a point – but the brain, only knowing the direction of the ray, assumes it came directly form an object.
- When the rays seen by the eye do not meet, but the brain assumes they do, the image is called *virtual*.
- If a screen is put at the position of the virtual image, there are no rays there so nothing will be seen on the screen.

Kinds of Images: Real

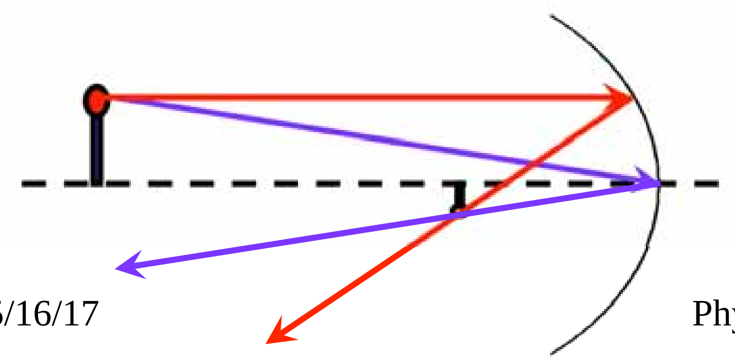
- In the case of the previous slide, the rays seen by the eye do in fact converge at a point.
- When the rays seen by the eye do meet, the image is called *real*.
- If a screen is put at the real image, the rays will scatter in all directions and an image can be seen on the screen, just as if it were a real object.

Unifying Equation for Mirrors

- If we treat our mirror quantities as "signed" and let the signs carry directional information, we can unify all the situations in a single set of equations.

$$\frac{1}{f}=\frac{1}{i}+\frac{1}{o} \qquad \frac{h'}{h}=\frac{i}{o} \qquad f = R/2$$

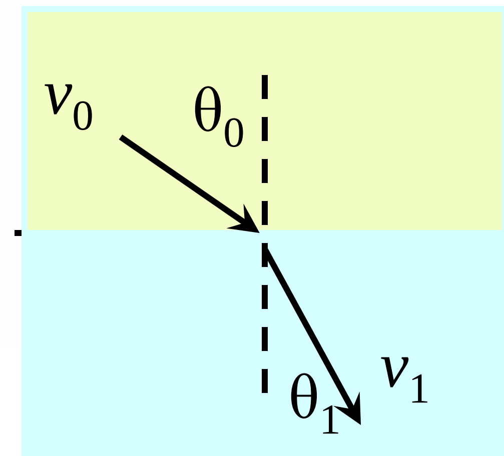
h > 0	h′ < 0	i > 0 o > 0	i < 0 o < 0
h < 0	h′ > 0		



"standard" arrangement

Snell's Law in Newton's Model

- Assume that there is a lower (negative compared to vacuum) PE for light particles in a denser medium. Then light would go faster since $(KE + PE)_{\text{in vac}} = (KE + PE)_{\text{in medium.}}$
- Assume no friction as it passes through the boundary.
- Since it goes faster but the parallel component of the speed stays the same (N2!) the perpendicular component must be bigger, tipping the direction toward the normal.



$$v_0 \sin\theta_0 = v_1 \sin\theta_1$$

Compare to speed in vacuum = c

$$\frac{v_0}{c}\sin\theta_0 = \frac{v_1}{c}\sin\theta_1$$

$$n_0 \sin\theta_0 = n_1 \sin\theta_1$$

Unifying Equation for Lenses

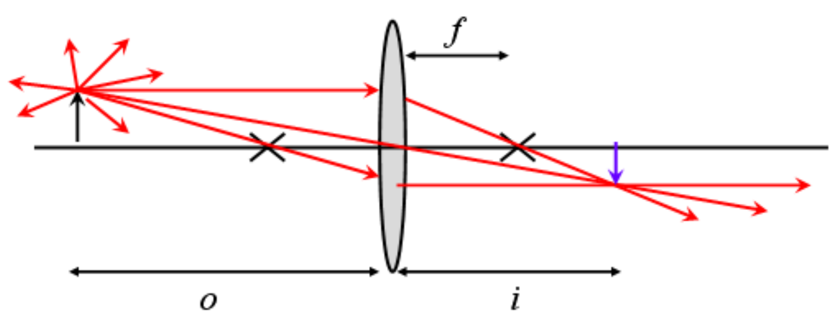
- If we treat our lens quantities as "signed" and let the signs carry directional information, we can unify all the situations in a single set of equations.

$$\frac{1}{f} = \frac{1}{i} + \frac{1}{o} \qquad \frac{h'}{h} = \frac{i}{o}$$

$h > 0$	$i < 0$, $o > 0$	$i > 0$, $o < 0$	$h' < 0$
$h < 0$			$h' > 0$

$f > 0$

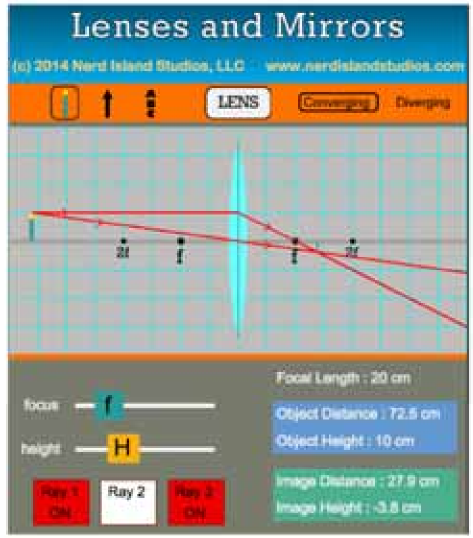
$f < 0$



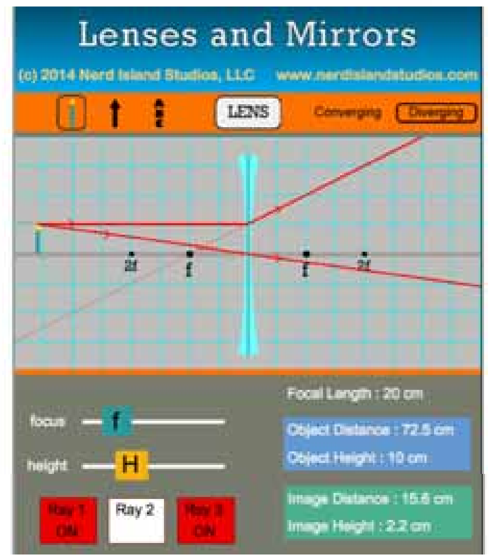
"standard" arrangement

Exploring Lenses

- Converging



- Diverging

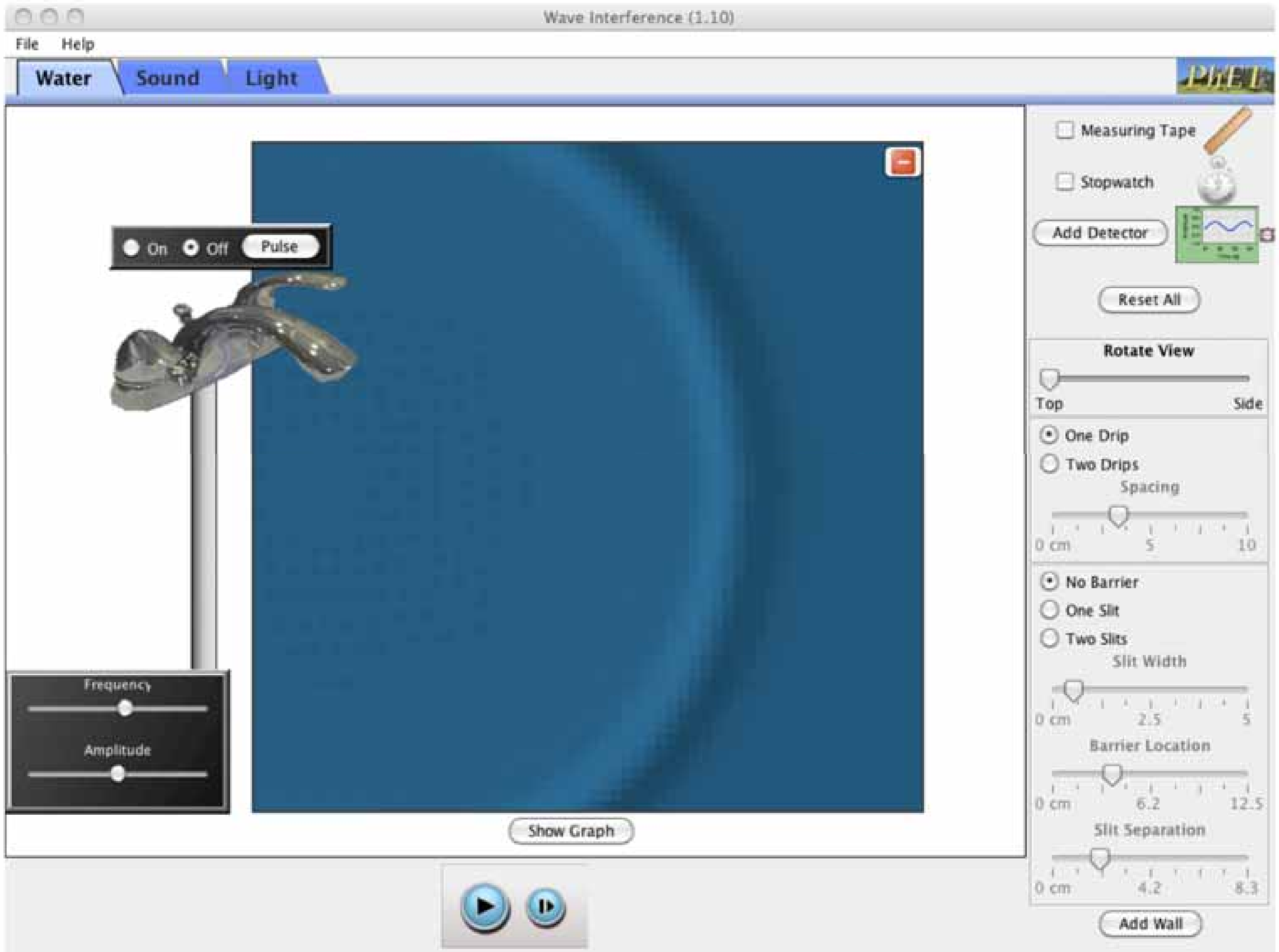


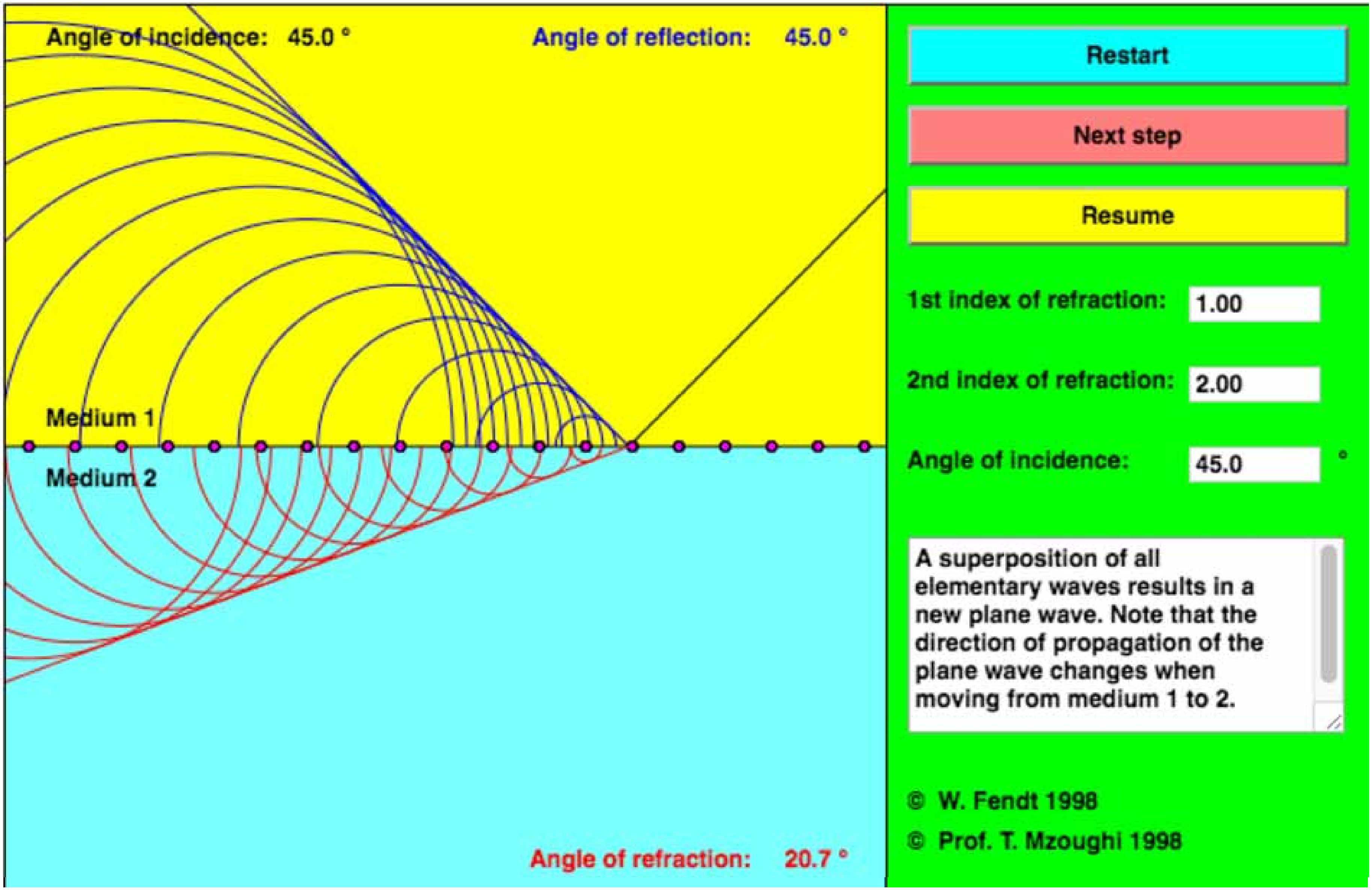
http://www.physicsclassroom.com/Physics-Interactives/Refraction-and-Lenses/Optics-Bench/Optics-Bench-Refraction-Interactive

Foothold wave ideas: Huygens' Model

- The critical structure for waves are the lines or surfaces of equal phase: <u>wavefronts</u>.
- Each point on the surface of a wavefront acts as a point source for outgoing spherical waves (wavelets).
- The sum of the wavelets produces a new wavefront.
- The waves are <u>slower</u> in a denser medium.
- The reflection principle and Snell's law follow from the assumptions of the wave model.
- We can even make rays – sort of.

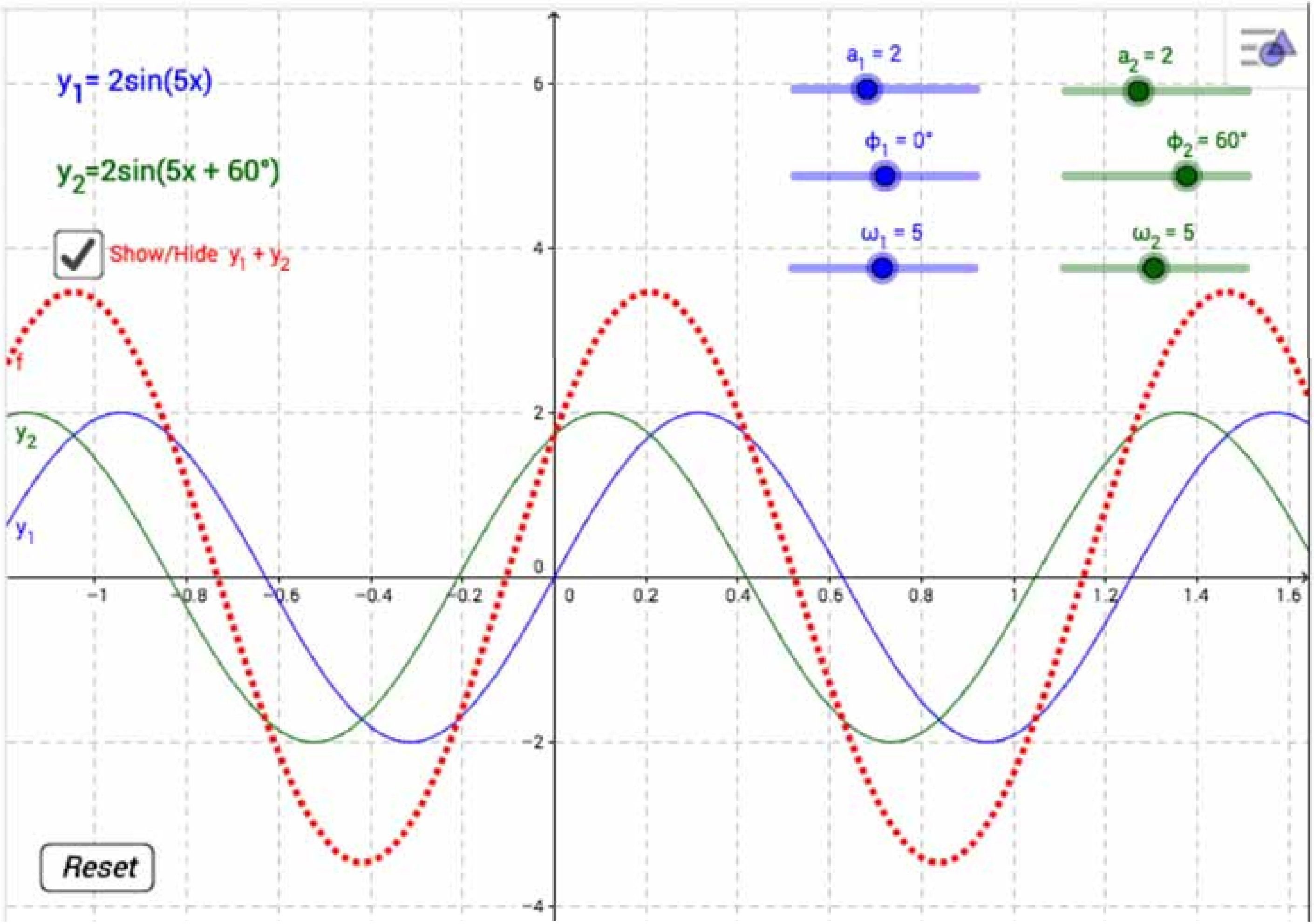
Explore the PhET sim





http://www.walter-fendt.de/html5/phen/refractionhuygens_en.htm

Adding two sine waves
(Think: at a point in space from two sources)



 https://www.geogebra.org/m/BOMfKCIK

Foothold ideas 2: Wave Model -- EM waves

- Point source:
  - An oscillating charge sends out a sphere of oscillating EM wave.
- Wavelets:
  - Any point in space with an oscillating EM wave sends out a sphere of oscillating EM wave.
- Superposition:
  - The resulting pattern at any point is the sum of the waves received.

Phase difference and path difference

- Our two waves from different sources have a phase difference, $\phi_1 - \phi_2$ because we are different distances from the two sources.

$$y = A\sin(kr_1 - \omega t) + A\sin(kr_2 - \omega t)$$

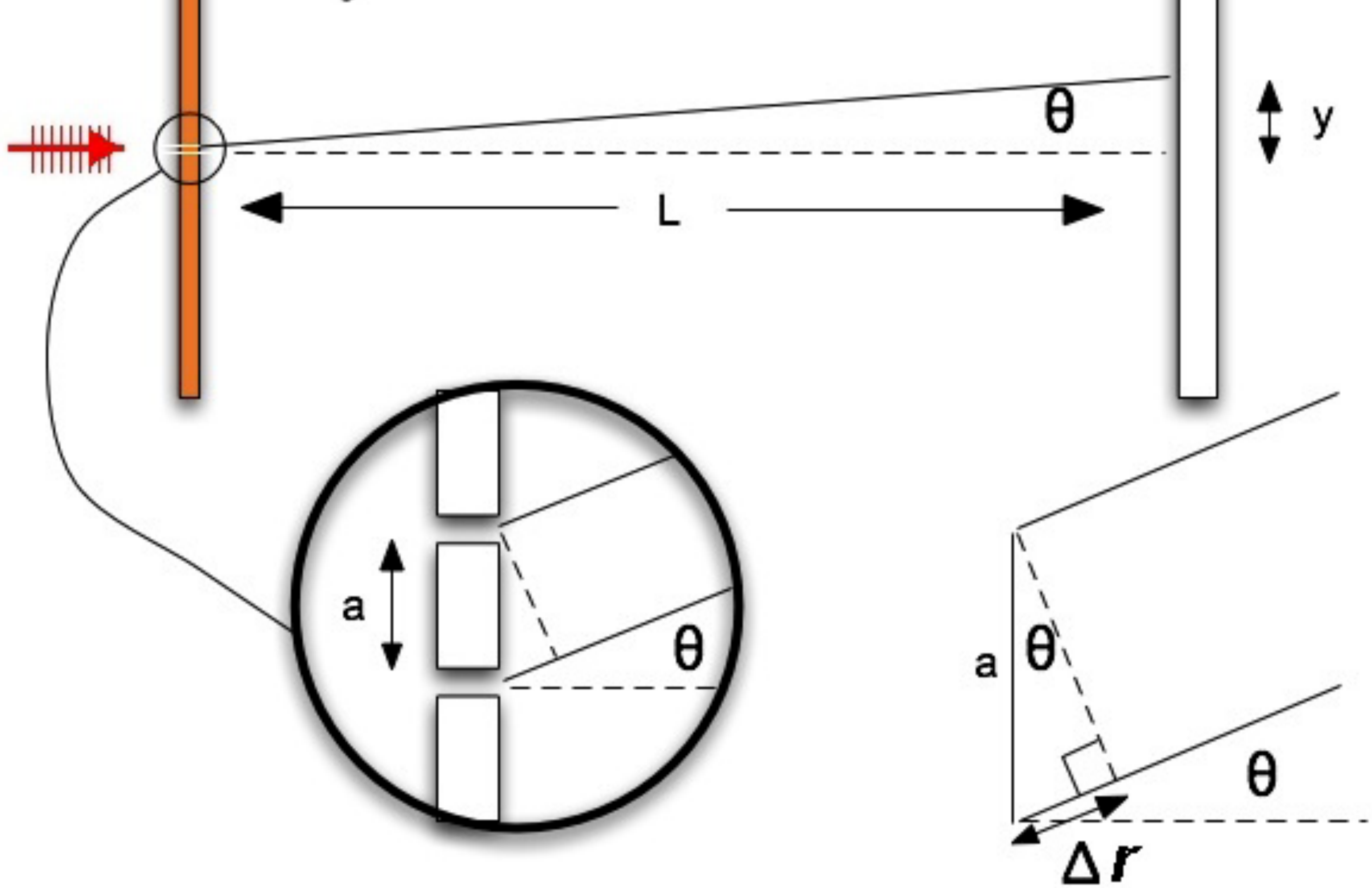
$$y = A\sin(\phi_1 - \omega t) + A\sin(\phi_2 - \omega t)$$

- The phase difference depends on the path difference:

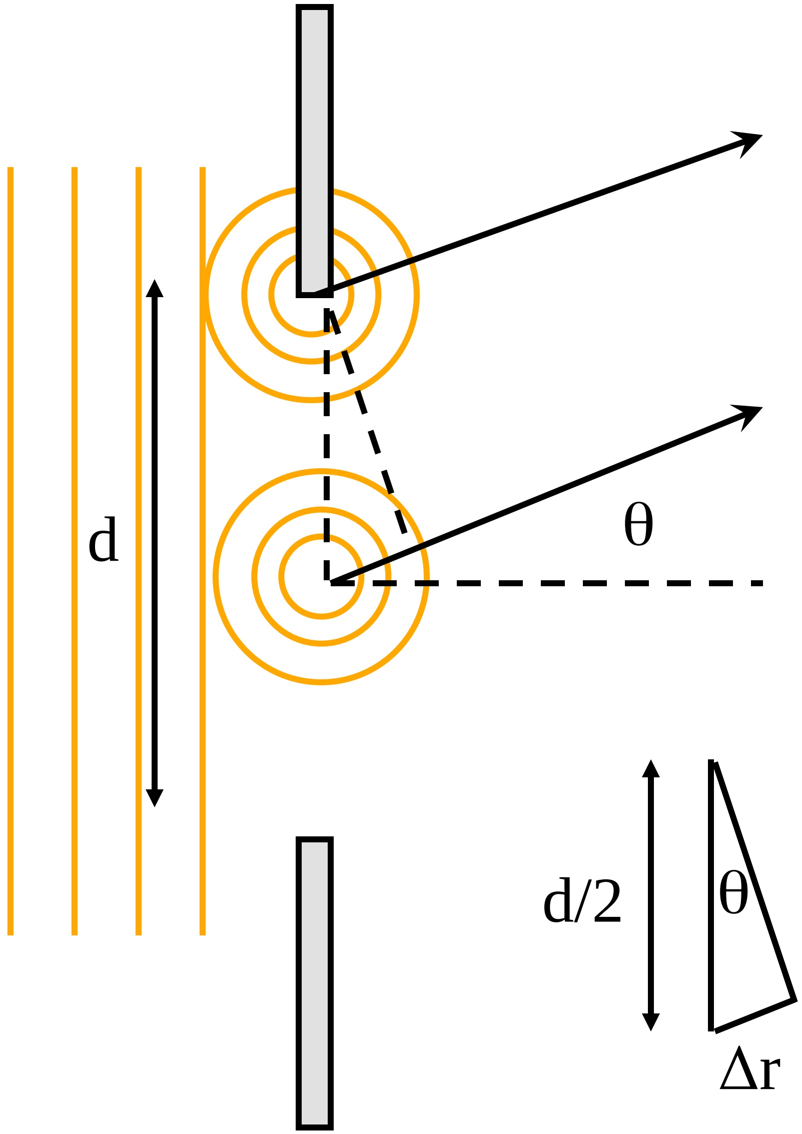
$$\phi_1 - \phi_2 = kr_1 - kr_2 = k(r_1 - r_2) = k\Delta r = 2\pi\left(\frac{\Delta r}{\lambda}\right)$$

How many wave lengths fit into Δr ?

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



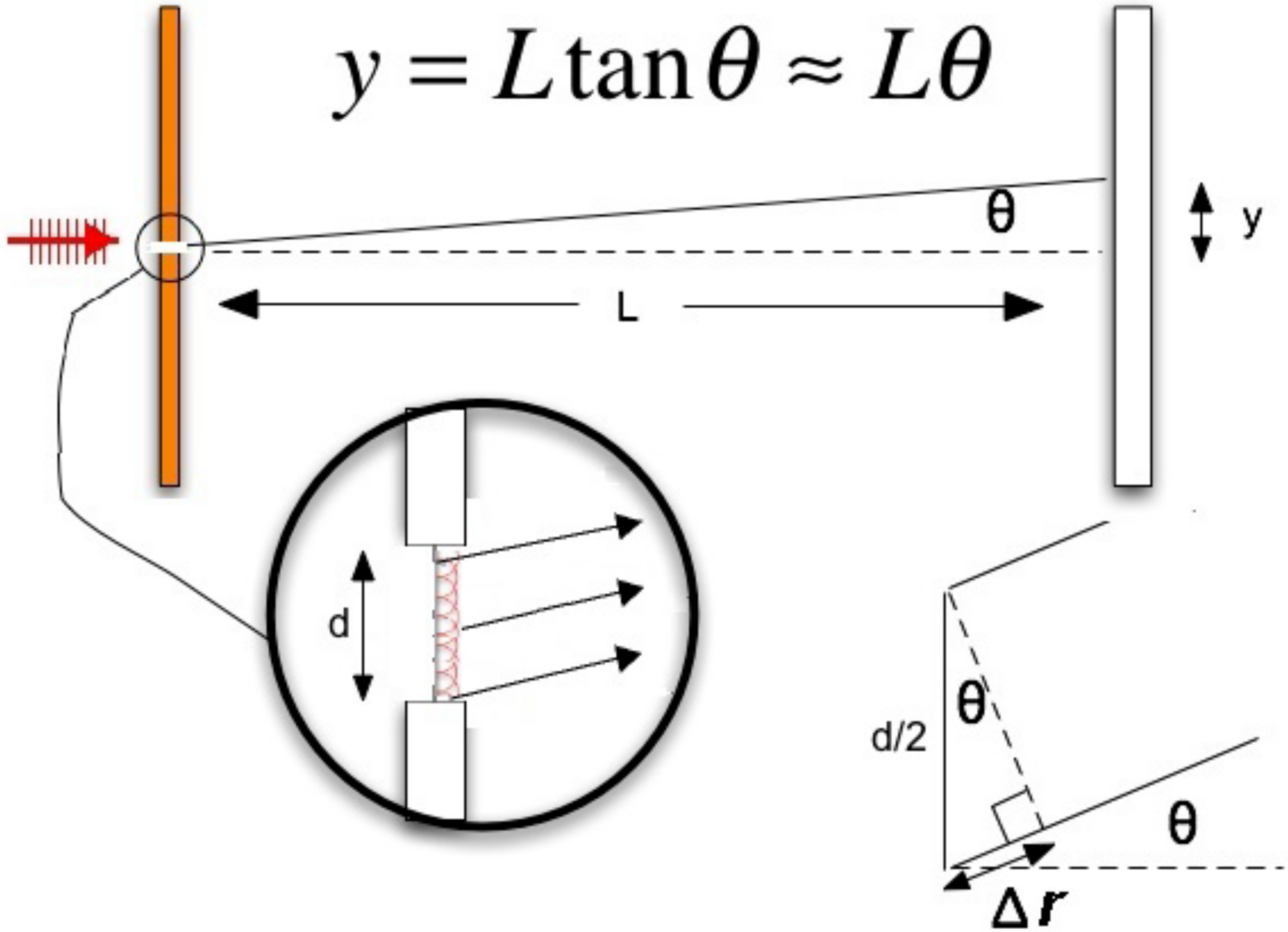
$$\Delta r = a\sin\theta \approx a\theta$$



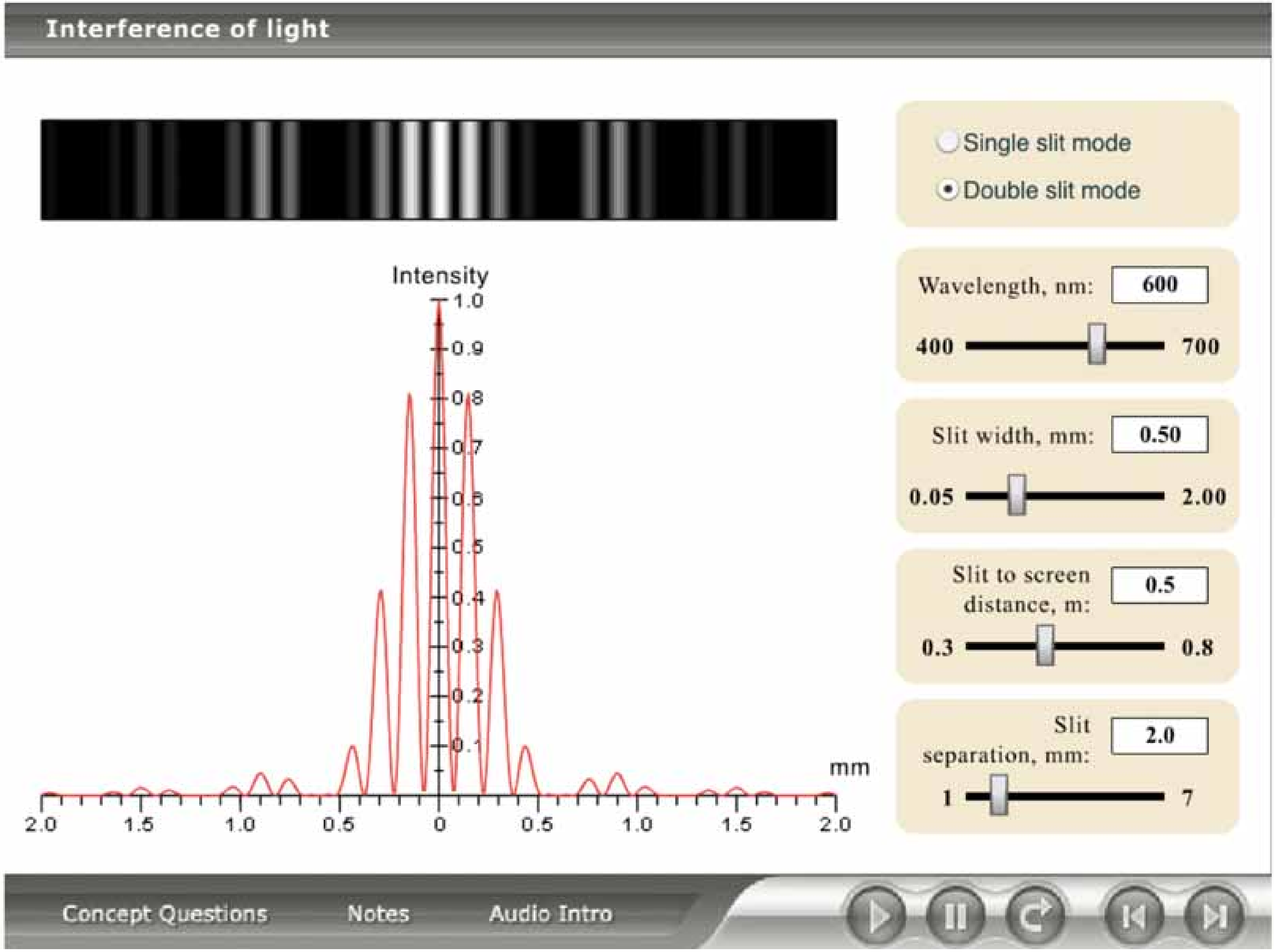
When the distance traveled by the wavelet from the middle of the slit is half a wavelength greater than the distance traveled by the wavelet from the top of the slit <u>every wavelet from the top half of the slit has a canceling wavelet from the bottom half of the slit</u>.

The result is no intensity at that angle.

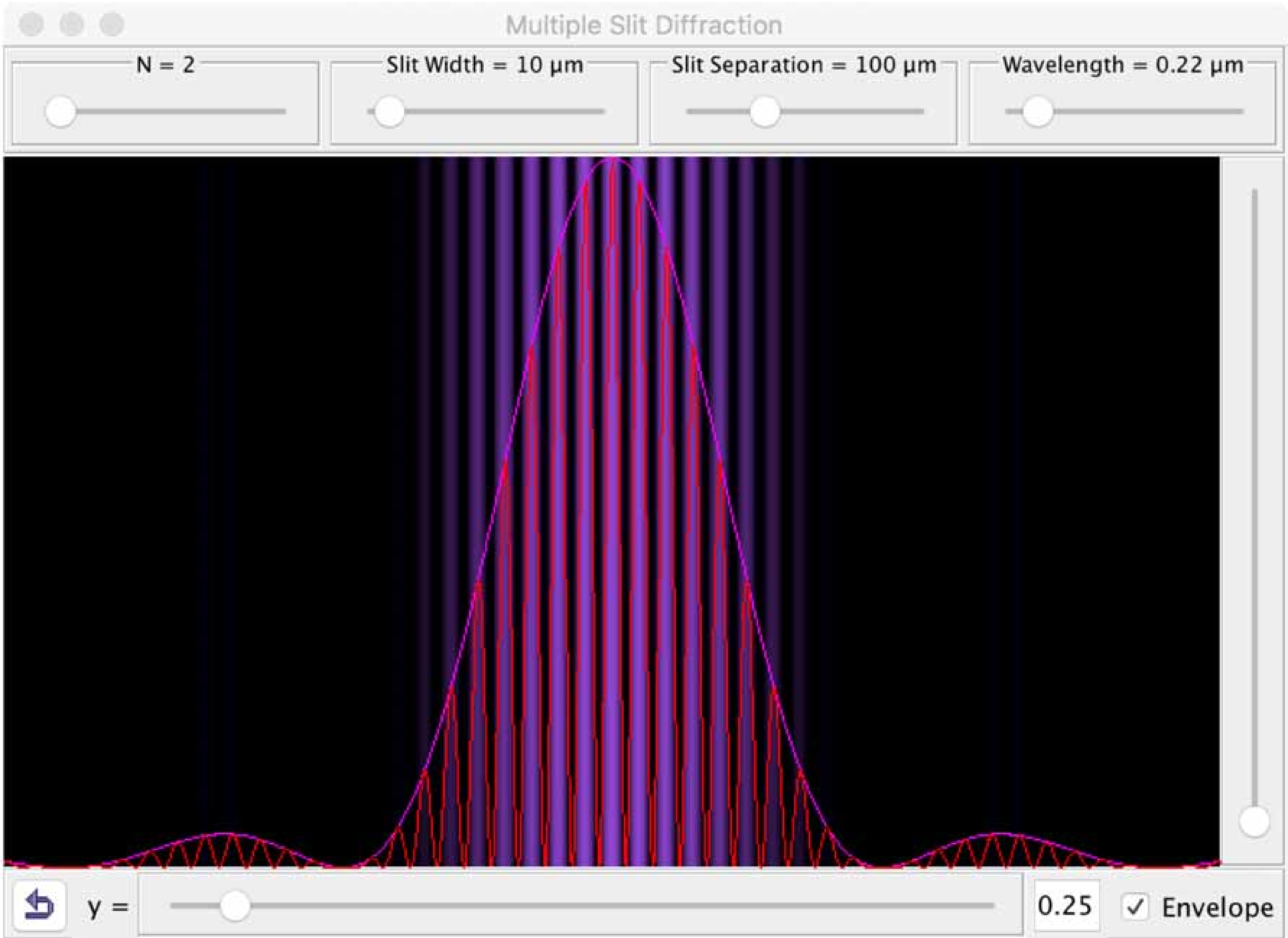
$$y = L\tan\theta \approx L\theta$$



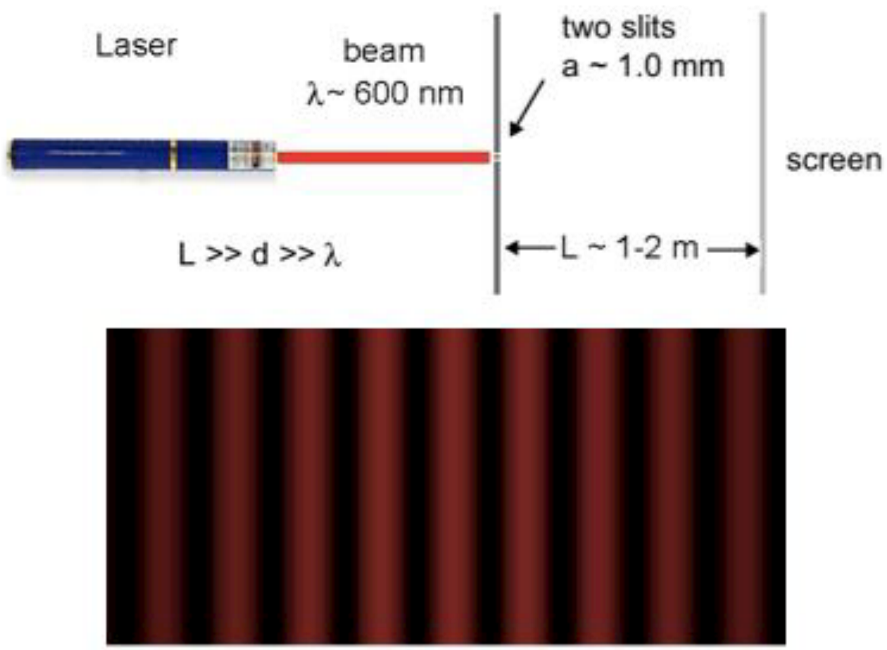
$$\Delta r = \frac{d}{2}\sin\theta \approx \frac{d}{2}\theta$$



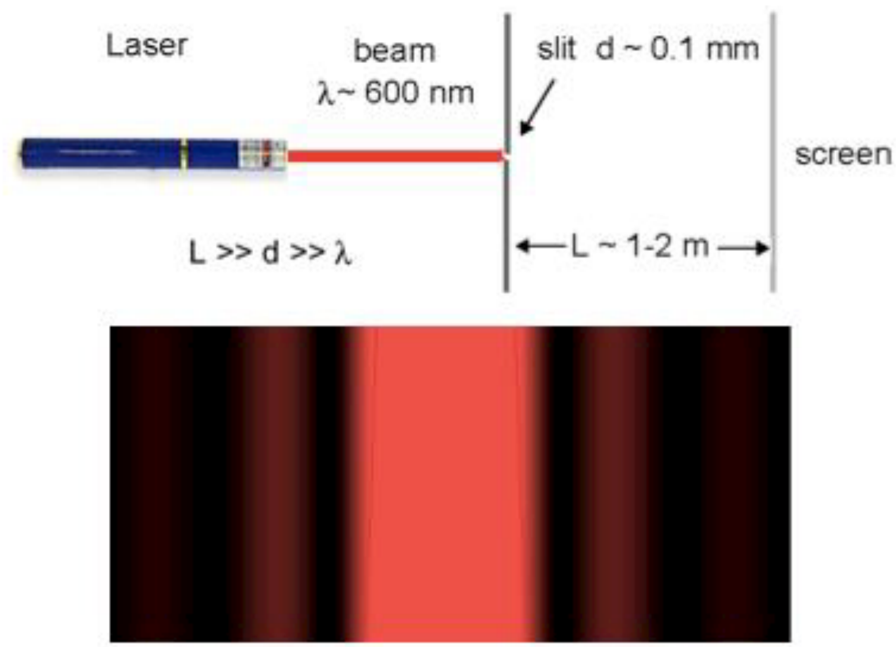
http://www.wiley.com/college/halliday/0470469080/simulations/sim48/sim48.html



http://www.cabrillo.edu/~jmccullough/Applets/OSP/Optics/MultipleSlitDiffraction.jar



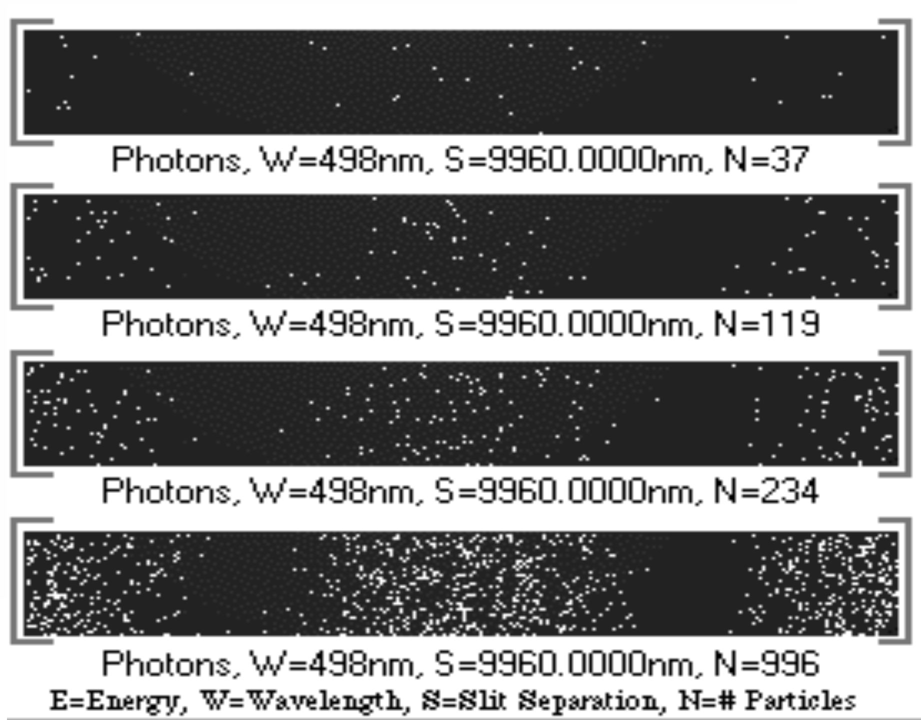
Interference from two narrow slits



Diffraction from one (wider) slit

Foothold Ideas: The Probability Framework for Light

- Both the wave model and the photon have an element of truth.
  - *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.*



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 <u>difference</u> of the energies of states.
- DeBroglie suggested that the discreteness property of atomic state might be explained if electrons had wave properties like photons.

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 yield 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.*