- **Theme Music:** **Duke Ellington**
  Take the A Train
- **Cartoon:** **Chic Young**
  Blondie

Blondie

Previous Exam Results

	#1	#2	#3	#4	#5
Exam 1	49%	65%	38%	81%	46%
Exam 1 (MU)	90%	34%	59%	68%	84%
Exam 2	80%	66%	54%	42%	71%
Exam 2 (MU)	*	*	*	*	*

* Ex2MU was taken by too few students to be meaningful; but note that performance was poorest on problem 3.

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.

Foothold principles: Standing Waves

- Some points in the pattern

$$y(x,t) = 2A\sin(kx)\cos(\omega t)$$

(values of *x* for which $kx = n\pi$) are always 0 (*nodes*)

- We can tie the string down at these points and still let it wiggle in this shape. (*normal modes* or *harmonics*)
- To wiggle like this (all parts oscillating together) we need

$$kL = n\pi \qquad \text{or} \qquad L = n\frac{\lambda}{2}$$

- We still have

$$v_0 = \omega/k \quad \text{that is} \quad v_0 = \lambda f$$

Light: Three models

- Newton's particle model (rays)
  - Models light as bits of energy traveling very fast in straight lines. Each bit has a color. Intensity is the number of bits you get.
- Huygens's/Maxwell wave model
  - Models light at waves (transverse EM waves). Color determined by frequency, intensity by square of a total oscillating amplitude. (Allows for cancellation – interference.)
- Einstein's photon model
  - Models light as "wavicles" == 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:

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

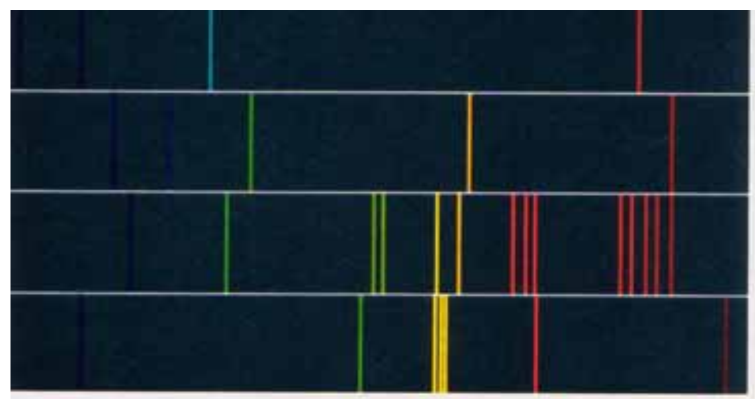
$$E = hf \qquad p = \frac{E}{c} = \frac{h}{\lambda}$$

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 <u>difference</u> of the energies of states.

Foothold Ideas 1: Ray Model -- The Physics

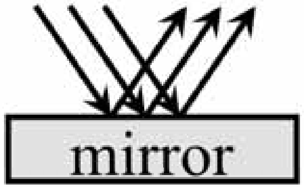
- Certain objects (the sun, bulbs,…) give off light.
- Light can travel through a vacuum.
- In a vacuum light travels in straight lines (rays).
- Each point on a rough object scatters light, spraying it off in all directions.
- A polished surface reflects rays back again according to the rule: *The angle 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

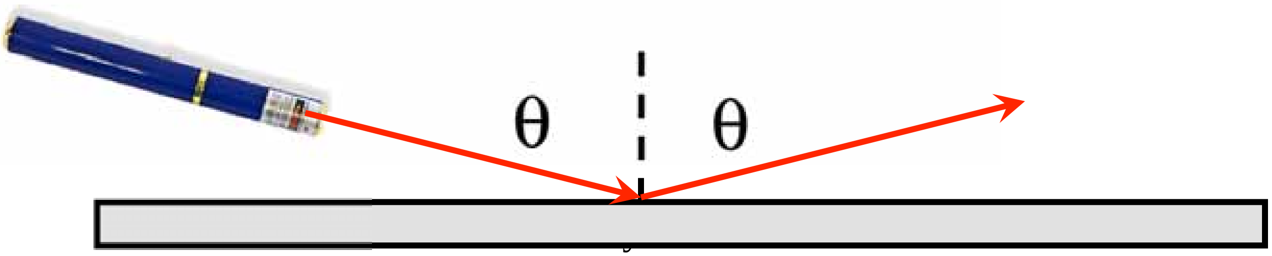
- We only see something when light coming from it enters our eyes.
- Our eyes identify a point as being on an object when rays traced back converge at that point.
  – (We use other clues as well – and some people's brains do not merge binocular vision.)

Foothold Ideas 3: Mirrors

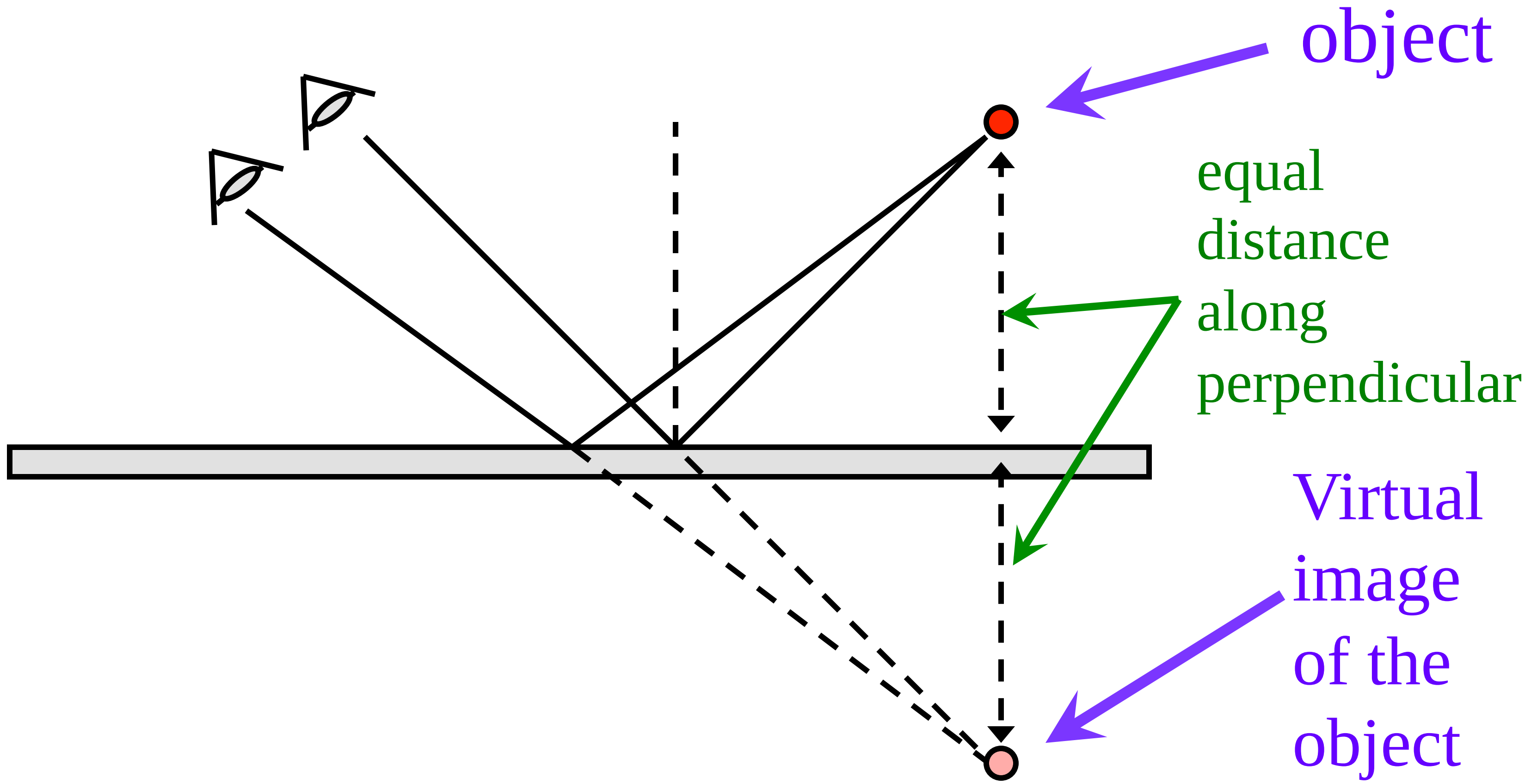
- For most objects, light scatters in all directions. For some objects (mirrors) light scatters from them in controlled directions.



- 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 not 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

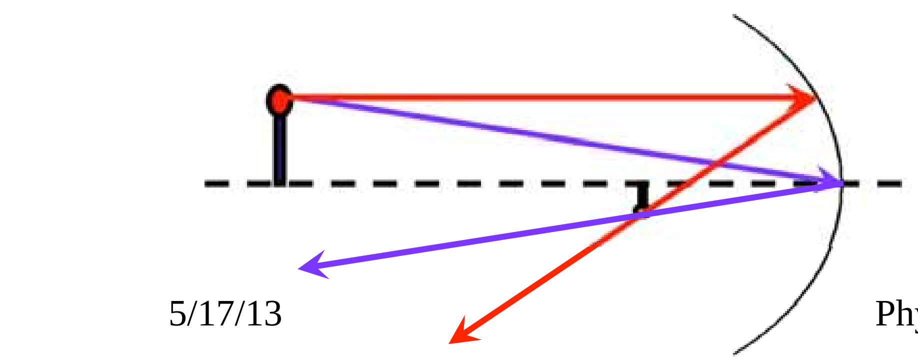
- If we treat our mirror quantities as “signed” and let the signs carry directional information, we can unify all the situations in a single set of equations.

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

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

$f < 0$

$f > 0$



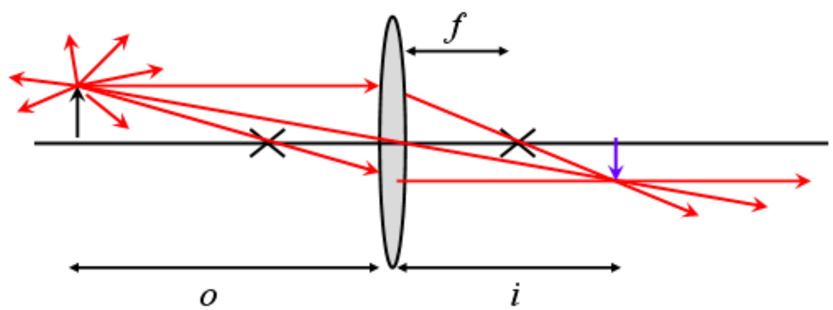
“standard” arrangement

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.

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

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



“standard” arrangement

$f > 0$

$f < 0$

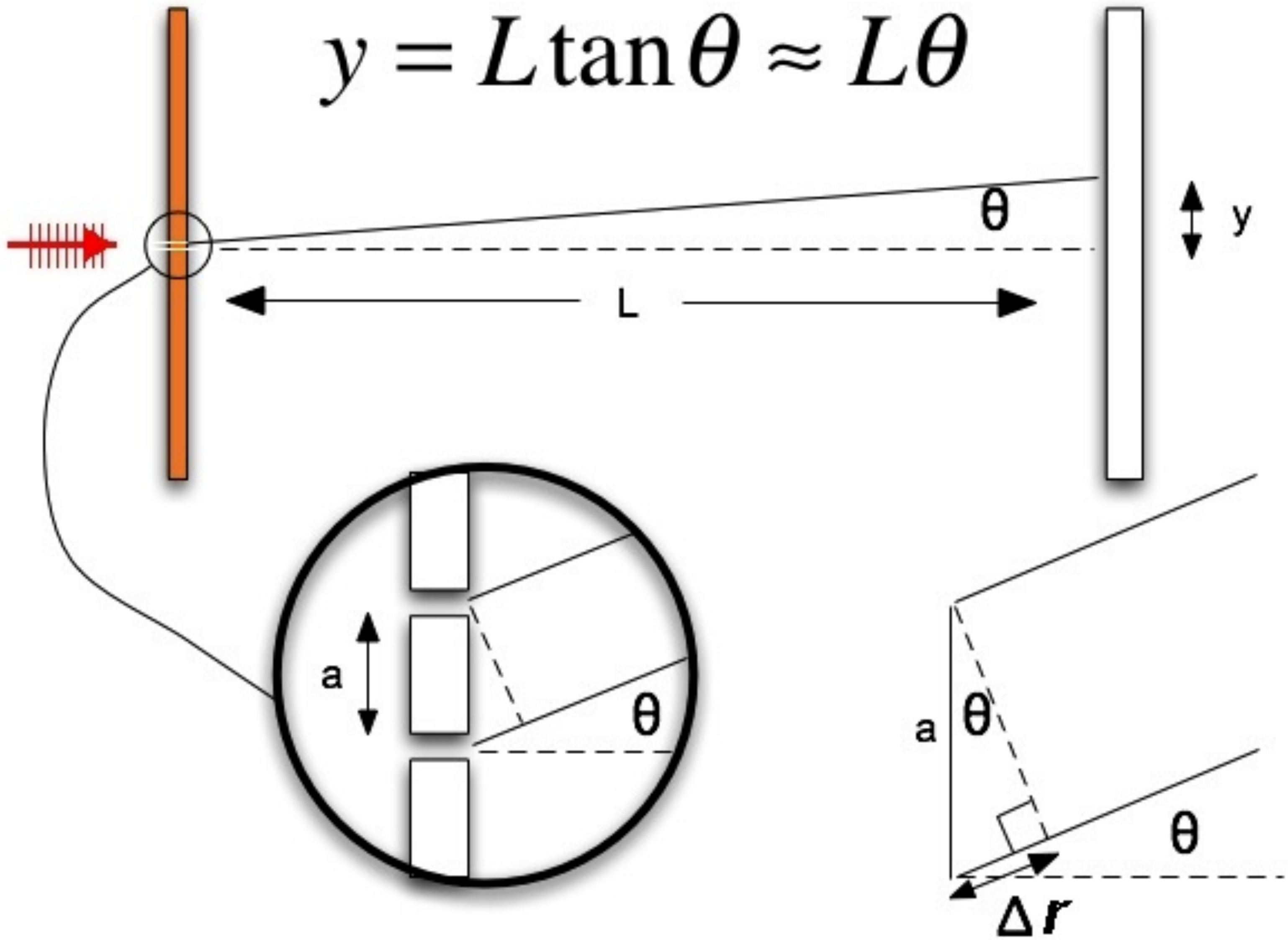
Foothold ideas 1: Wave Model -- Huygens' Principle

- The critical structure for waves are the lines or surfaces of equal phases: wavefronts.
- 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 slower in a denser medium.
- The reflection principle and Snell's law follow from the assumptions of the wave model.

Foothold ideas 2:
Wave Model -- EM waves

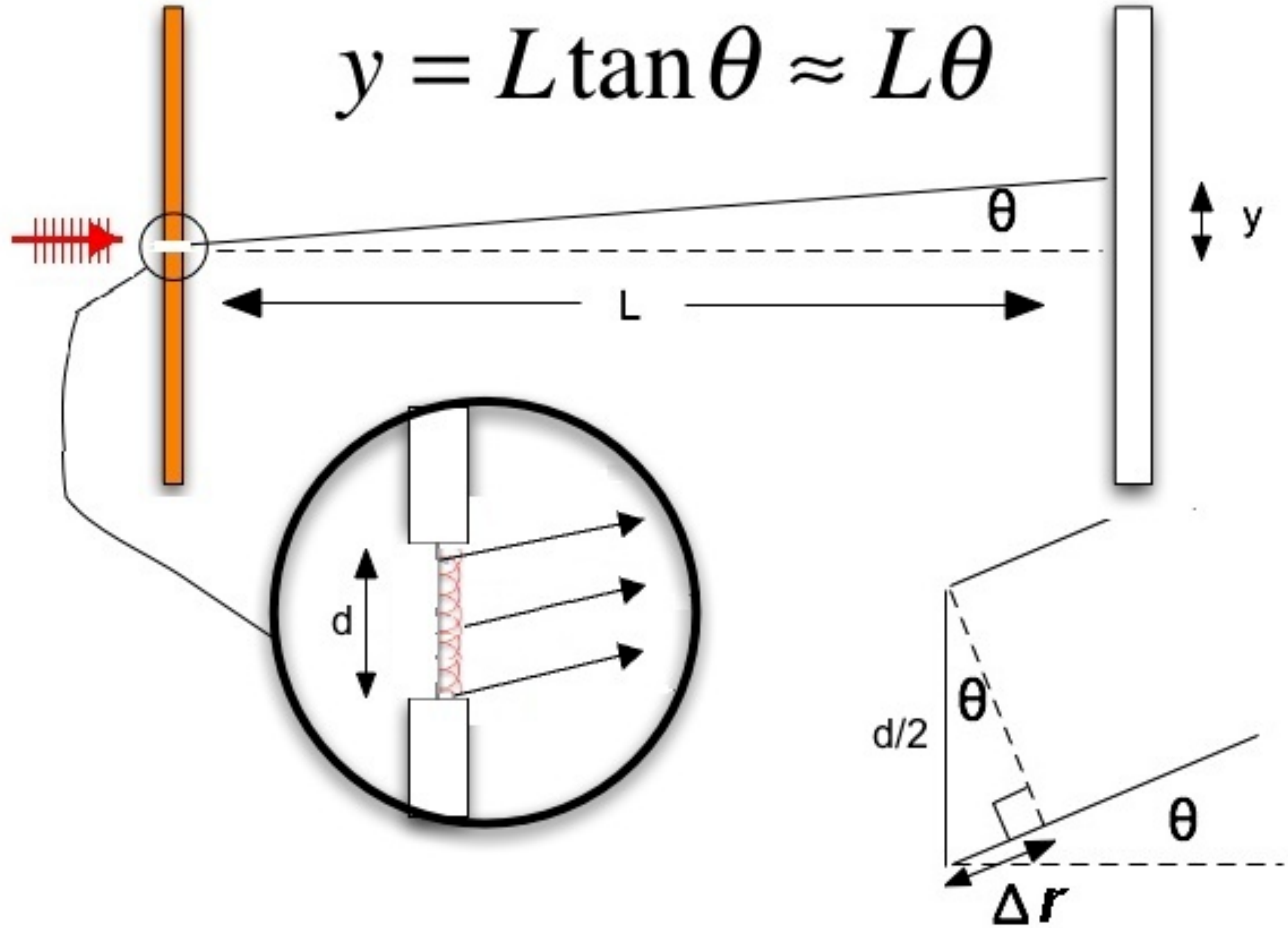
- Point source:
  - An oscillating charge sends out a sphere of oscillating EM wave.
- Wavelets:
  - Any point in space with an oscillating EM wave sends out a sphere of oscillating EM wave.
- Superposition:
  - The resulting pattern at any point is the sum of the waves received.

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

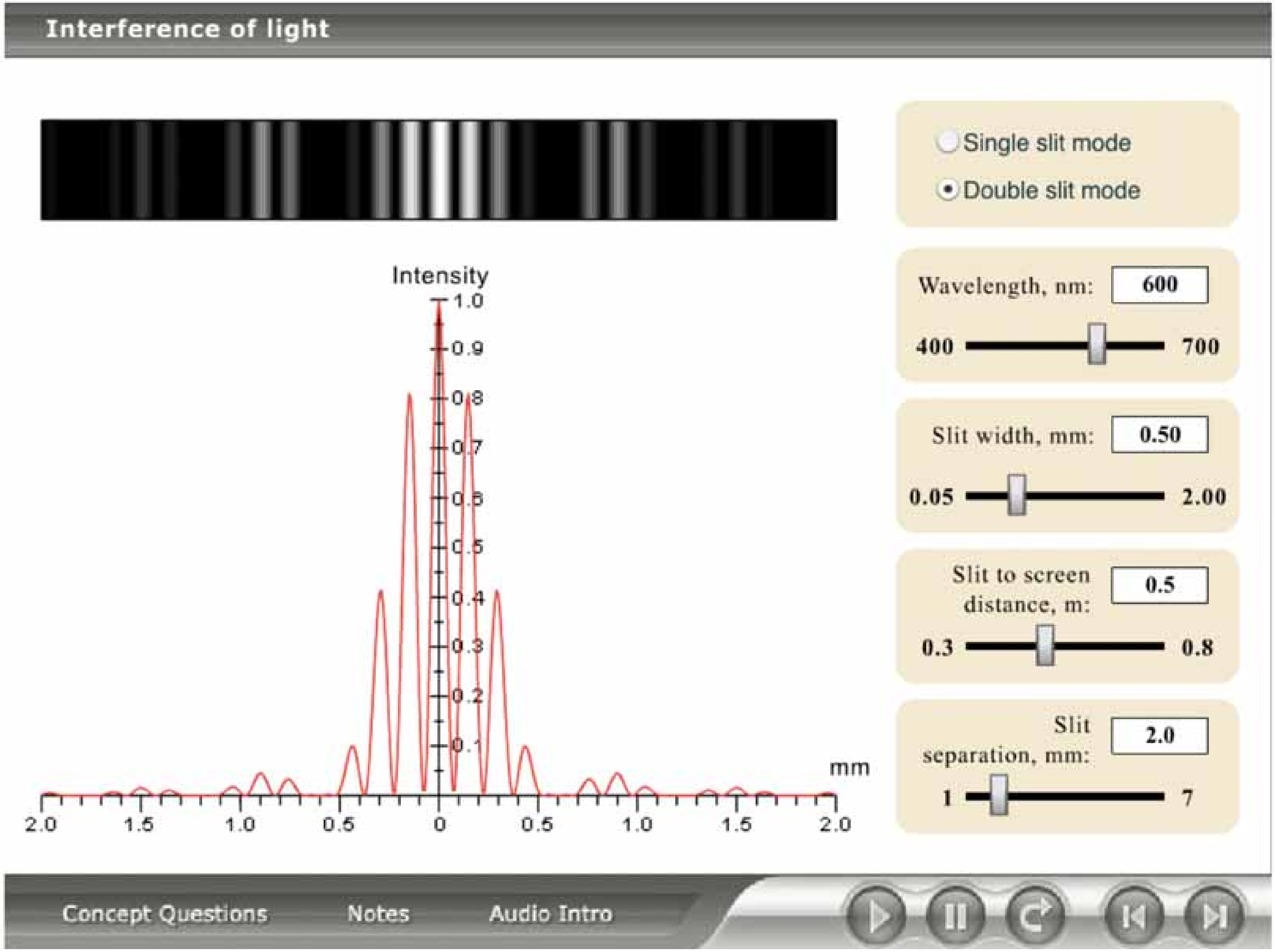


$$\Delta r = a\sin\theta \approx a\theta$$

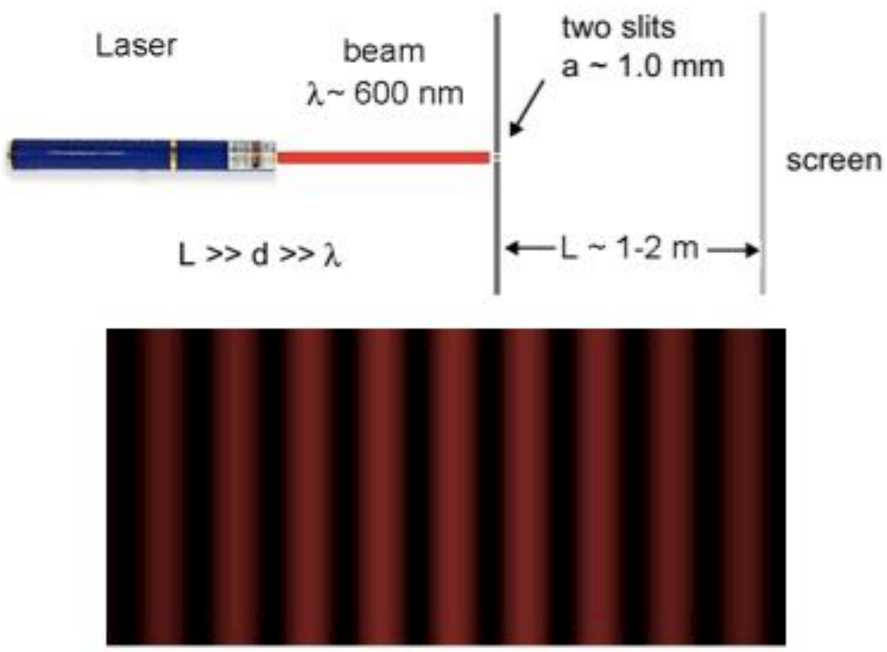
$$y = L\tan\theta \approx L\theta$$



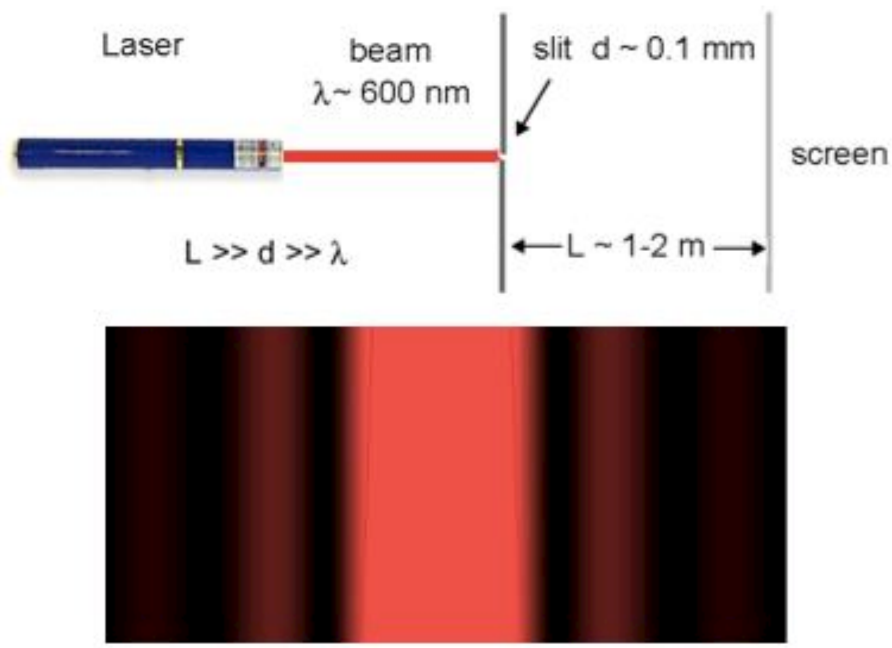
$$\Delta r = \frac{d}{2}\sin\theta \approx \frac{d}{2}\theta$$



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



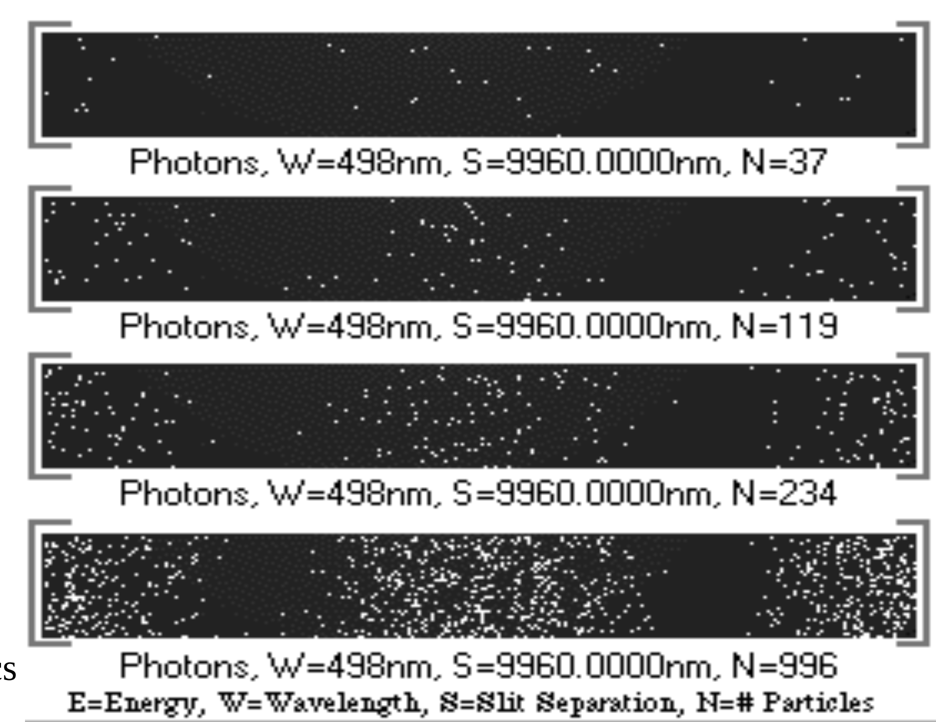
Interference from two narrow slits



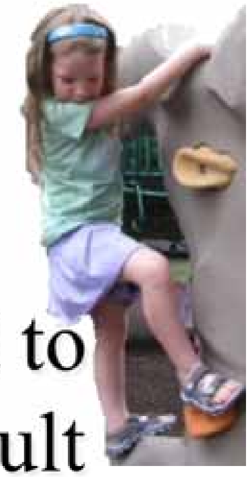
Diffraction from one (wider) slit

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 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.*