Class 33: Outline

Hour 1:

Interference

Hour 2:

Experiment 13: Interference

Last time: Microwaves (mw)

$$f_{mw} = 2\times10^{9}\ Hz \quad \lambda_{mw} = \frac{c}{f} = 15\,cm$$

This time: Visible (red) light:

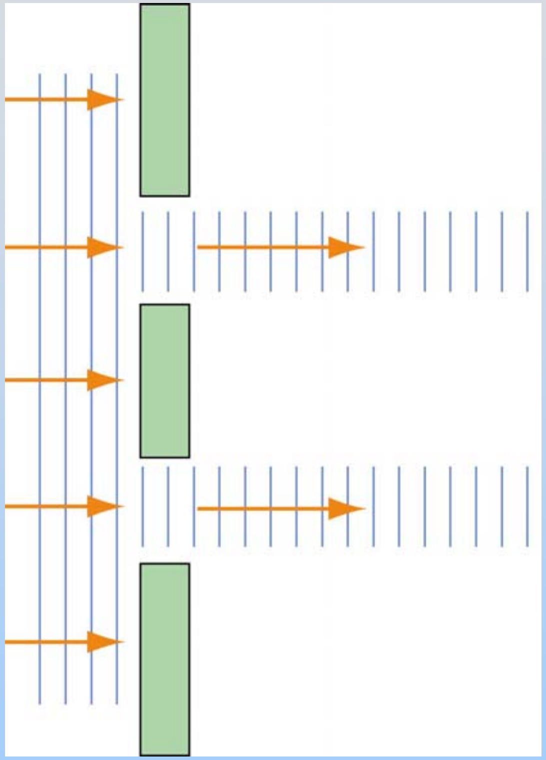
$$f_{red} = 4.6\times10^{14}\ Hz \quad \lambda_{red} = \frac{c}{f} = 6.54\times10^{-5}\,cm$$

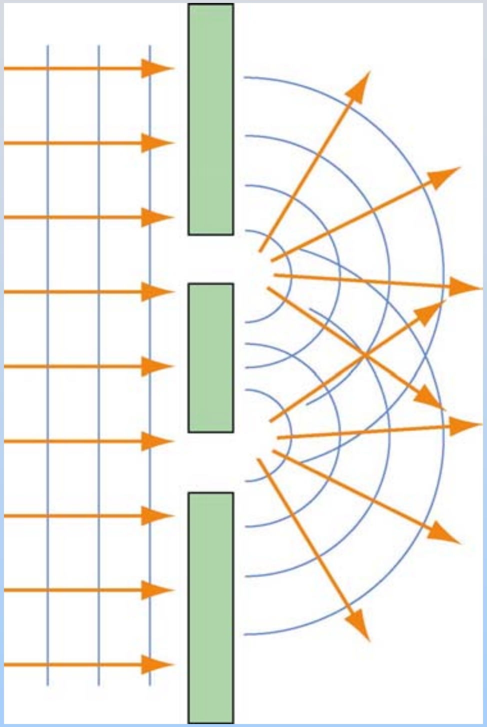
How in the world do we measure 1/10,000 of a cm?

We Use Interference

This is also how we know that light is a wave phenomena

Interference: The difference between waves and bullets



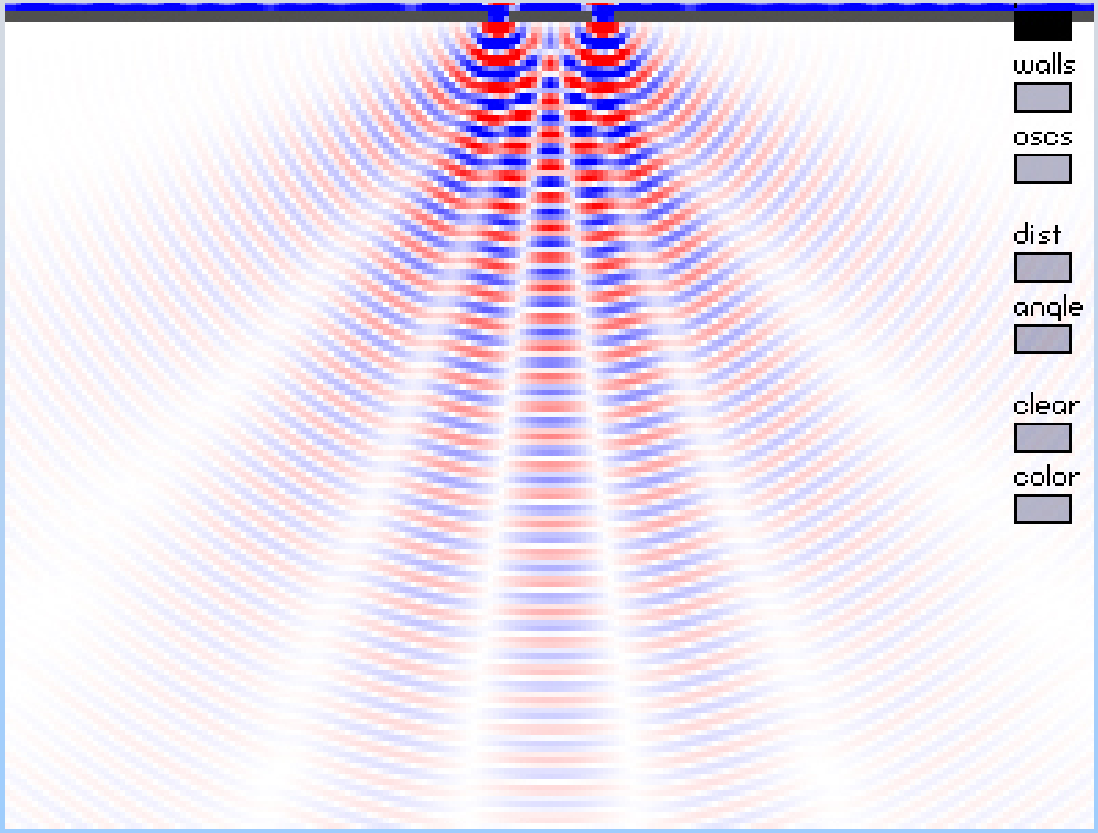


No Interference:

if light were made up of bullets

Interference: If light is a wave we see spreading and addition and subtraction

Interference: The difference between waves and bullets

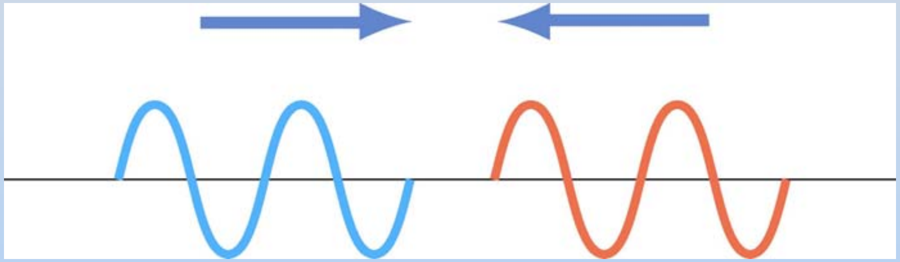


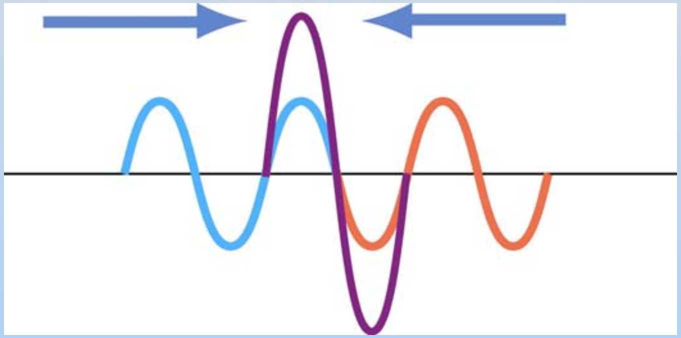
http://ocw.mit.edu/ans7870/8/8.02T/f04/visualizations/light/08-waves2d/08-waves320.html

Interference

Interference: Combination of two or more waves to form composite wave – use superposition principle.

Waves can add *constructively* or *destructively*





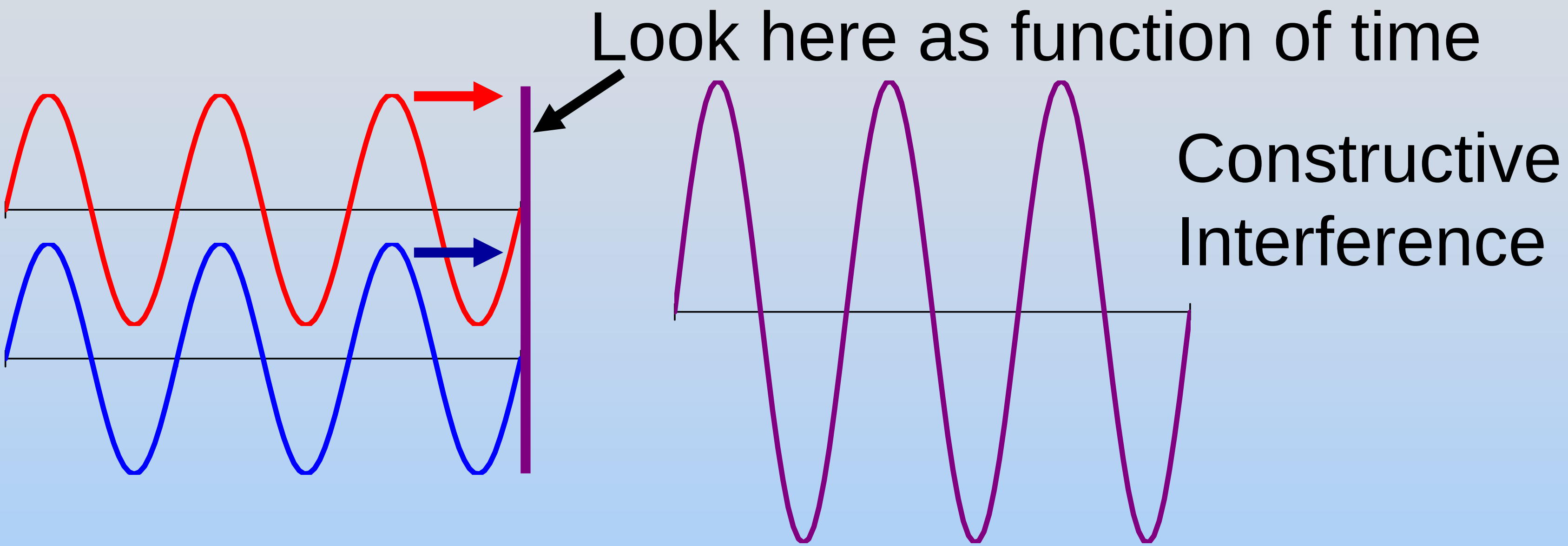
Conditions for interference:

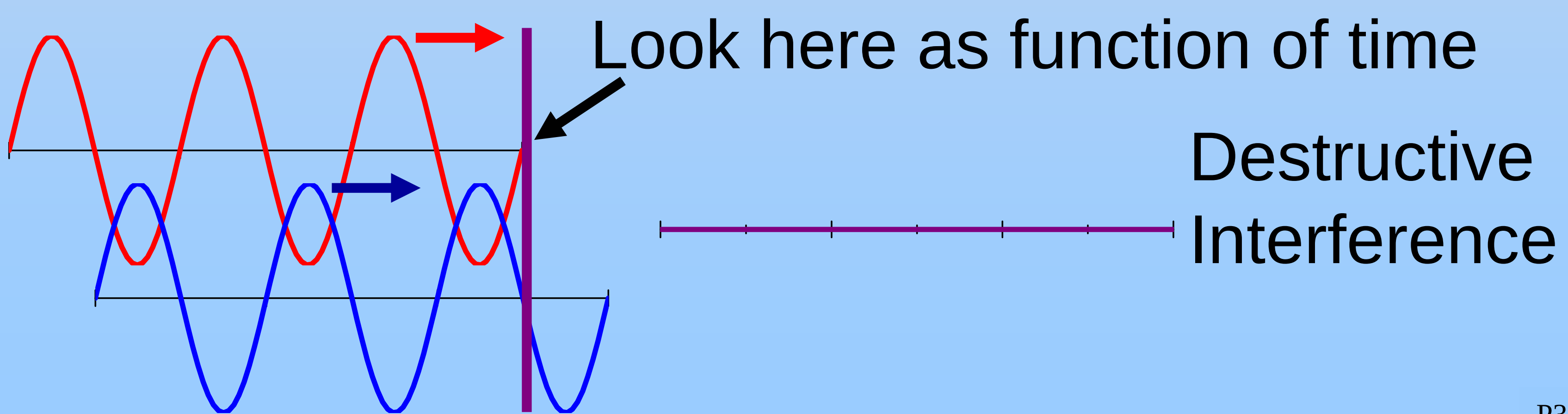
1. **Coherence**: the sources must maintain a constant phase with respect to each other
2. **Monochromaticity**: the sources consist of waves of a single wavelength

Demonstration:
Microwave Interference

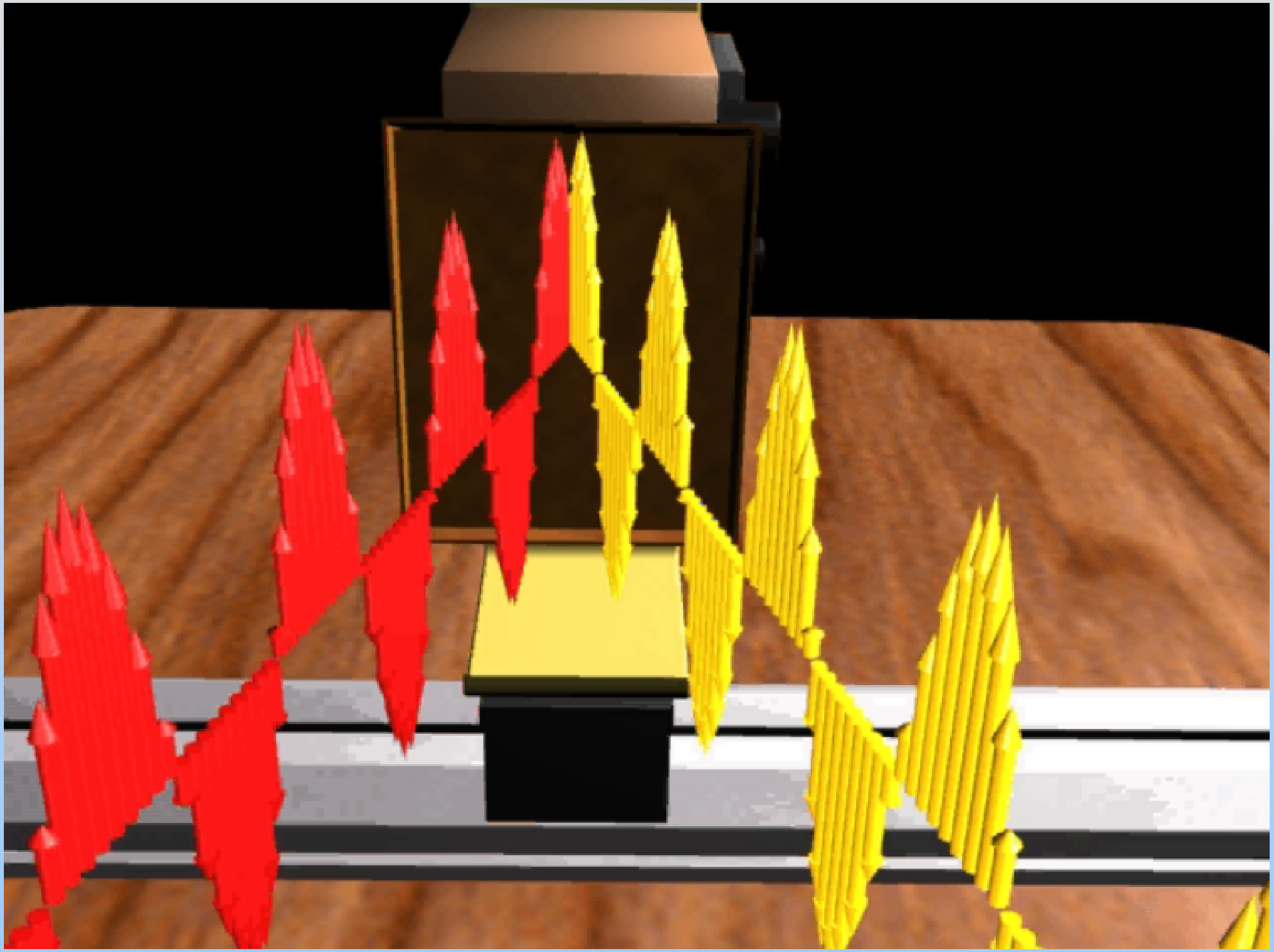
Interference – Phase Shift

Consider two traveling waves, moving through space:





Microwave Interference



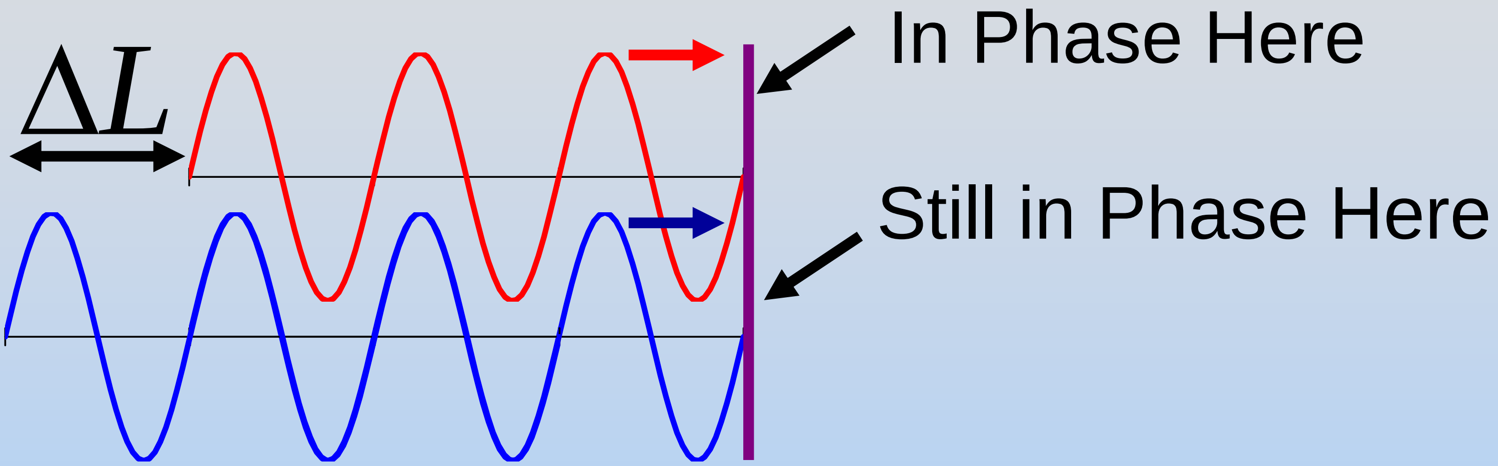
Interference – Phase Shift

What can introduce a phase shift?

1. From different, out of phase sources
2. Sources in phase, but travel different distances
    1. Thin films
    2. Microwave Demonstration
    3. Double-slit or Diffraction grating

PRS Question: Interference

Extra Path Length

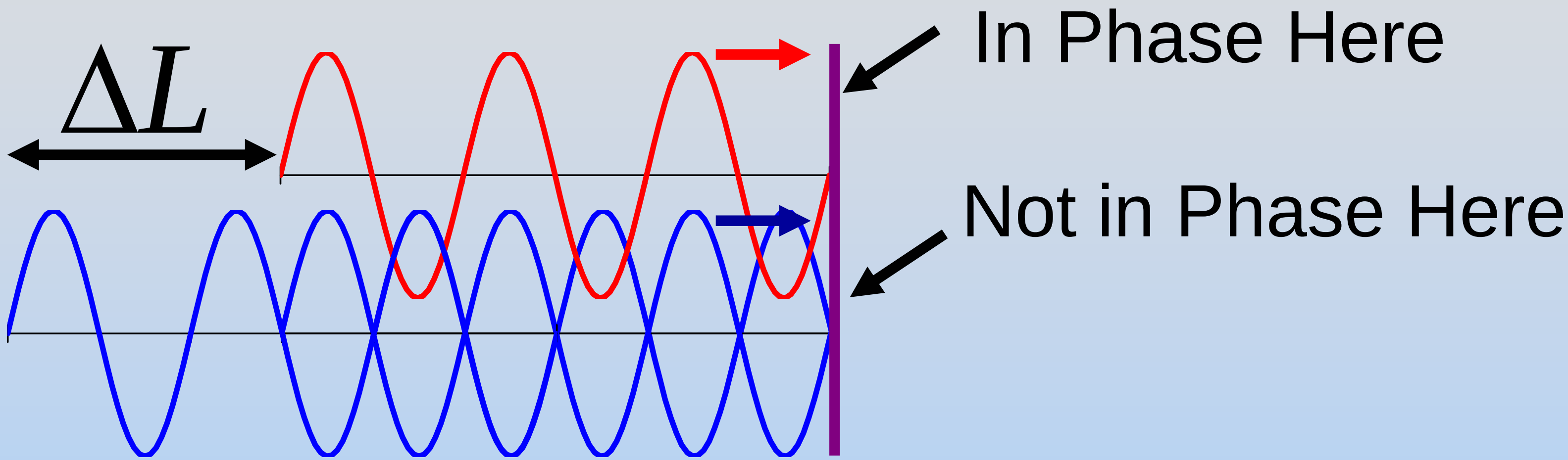


$$\Delta L = m\lambda \quad (m=0, \pm 1, \pm 2\ldots)$$

⇓

Constructive Interference

Extra Path Length



$$\Delta L = \left(m + \tfrac{1}{2}\right)\lambda$$

(m=0, ±1, ±2…)

$\Downarrow$

Destructive Interference

Thin Film Interference - Iridescence

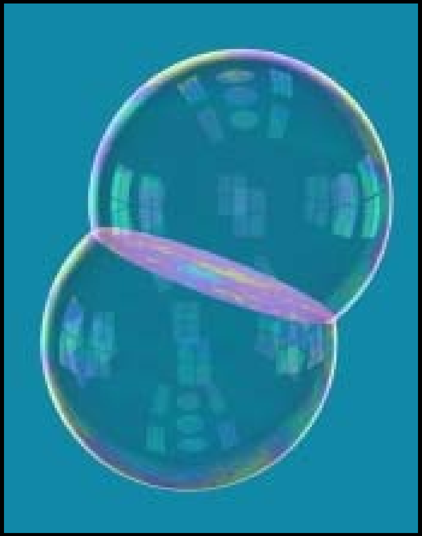
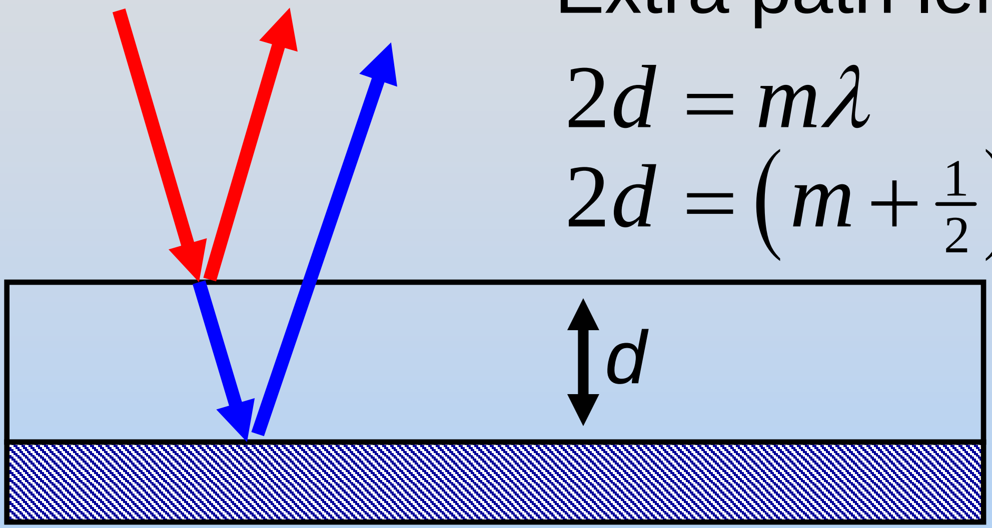


Image courtesy of John M. Sullivan, University of Illinois and Technical University of Berlin.

Thin Film Interference - Iridescence

- Bubbles
- Butterfly Wings
- Oil on Puddles

Thin Film: Extra Path



Extra path length ~ 2*d*

$$2d = m\lambda \qquad \Rightarrow \text{Constructive}$$

$$2d = \left(m + \tfrac{1}{2}\right)\lambda \Rightarrow \text{Destructive}$$

Oil on concrete, non-reflective coating on glass, etc.

Phase Shift = Extra Path?

What is exact relationship between ΔL & ϕ?

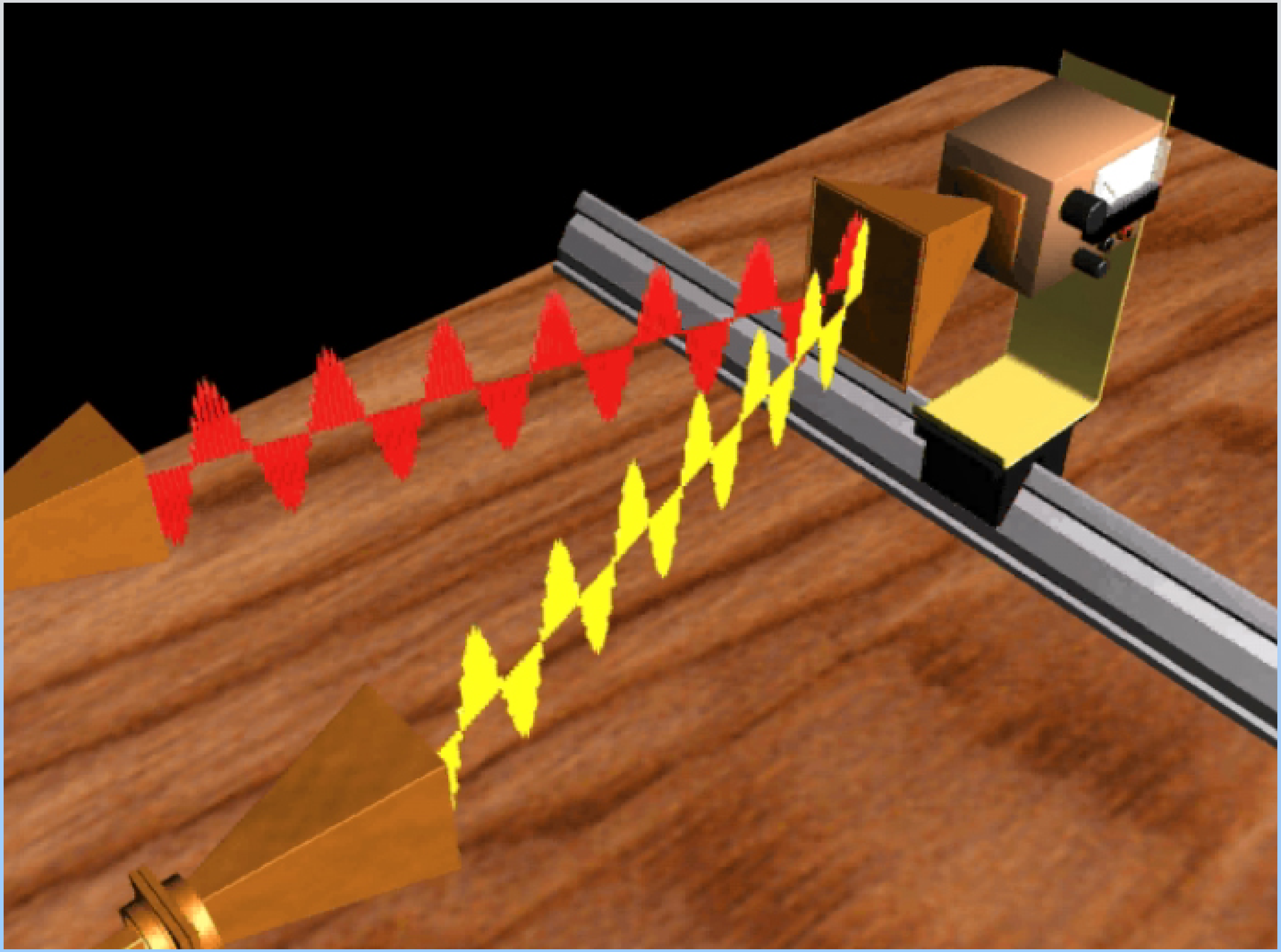
$$\sin(k\left(x+\Delta L\right)) = \sin(kx + k\Delta L)$$

$$= \sin(kx + \frac{2\pi}{\lambda}\Delta L) \equiv \sin(kx + \varphi)$$

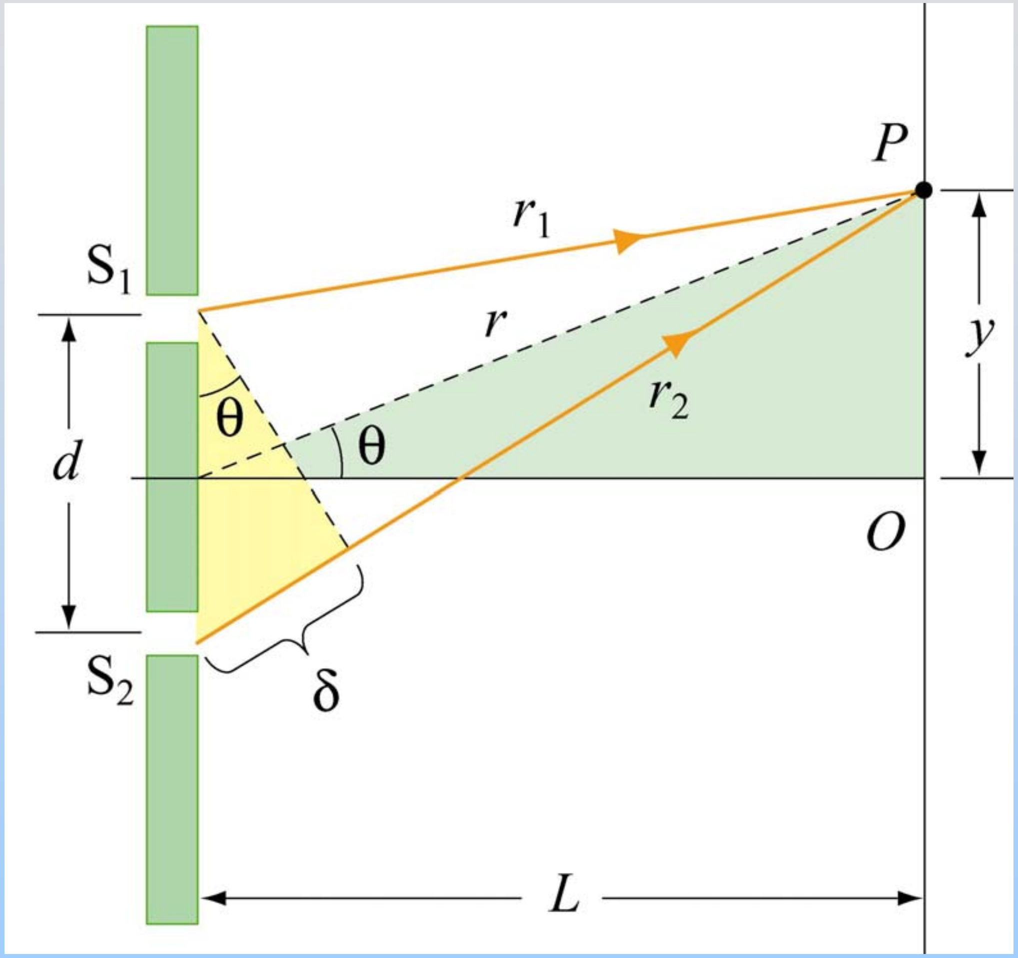
$$\boxed{\frac{\Delta L}{\lambda} = \frac{\phi}{2\pi}} = \begin{cases} m & \text{constructive} \\ m + \frac{1}{2} & \text{destructive} \end{cases}$$

Two Transmitters

Microwave Interference



Two In-Phase Sources: Geometry



Assuming $L \gg d$:

Extra path length

$$\delta = d\sin(\theta)$$

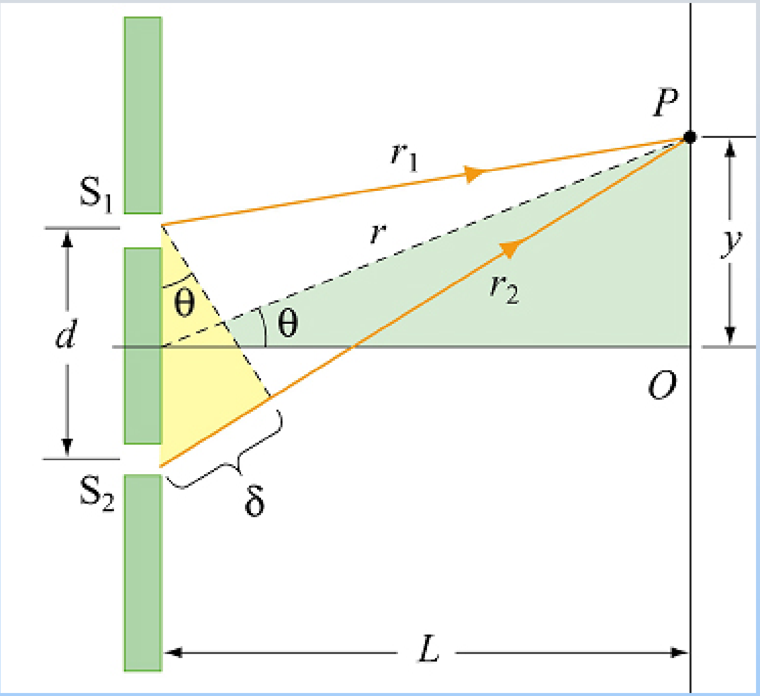
Assume $L \gg d \gg \lambda$

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

$\delta = d\sin(\theta) = m\lambda \quad \Rightarrow$ Constructive

$\delta = d\sin(\theta) = \left(m + \frac{1}{2}\right)\lambda \quad \Rightarrow$ Destructive

Interference for Two Sources in Phase



(1) Constructive: $\delta = m\lambda$

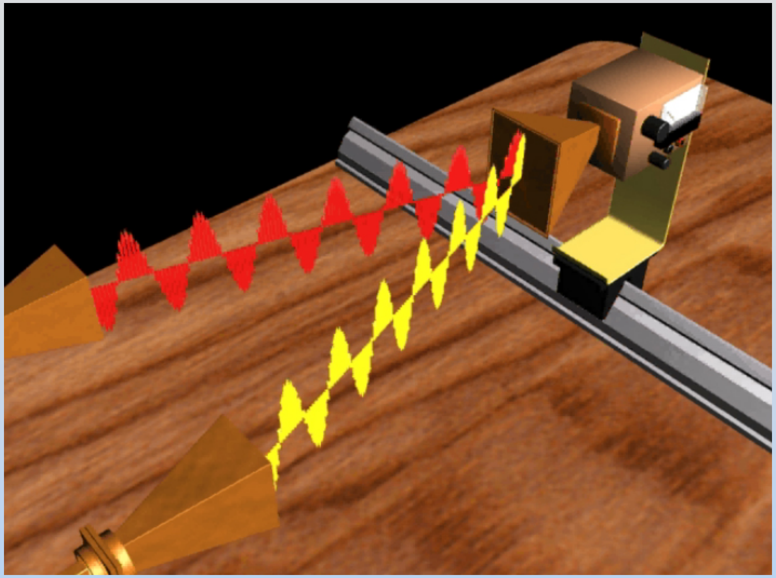
$$\sin\theta = \frac{\delta}{d} = \frac{m\lambda}{d} = \frac{y_{constructive}}{L}$$

$$y_{constructive} = m\frac{\lambda L}{d} \quad m = 0,1\ldots$$

(2) Destructive: $\delta = (m + 1/2)\lambda$

$$y_{destructive} = \left(m + \frac{1}{2}\right)\frac{\lambda L}{d} \quad m = 0,1,\ldots$$

In-Class: Lecture Demo



Just Found:

$$y_{destructive} = \left(m + \frac{1}{2}\right)\frac{\lambda L}{d} \quad m = 0, 1, \ldots$$

For m = 0 (the first minimum):

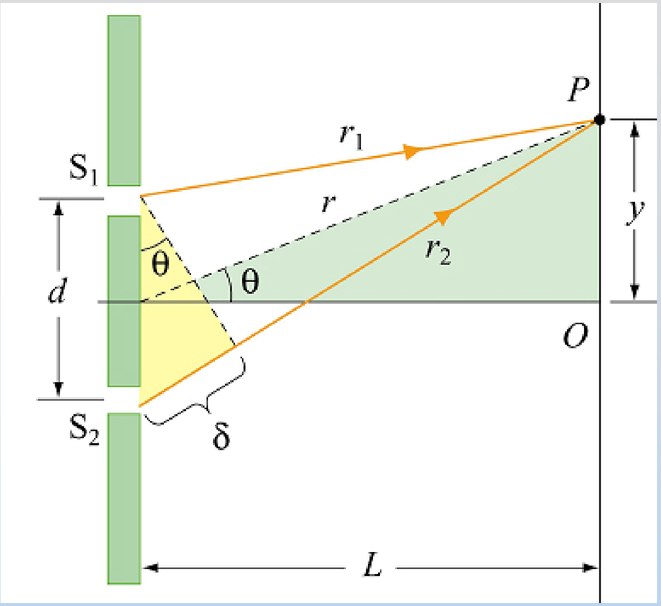
$$y_{destructive} = \lambda L / 2d$$

From our lecture demo, we measure:

L ~ 1.16 m; d ~ 0.24 m; $y_{destructive}$ ~ ? m

Estimate the wavelength & frequency of our microwaves

How we measure 1/10,000 of a cm



Question: How do you measure the wavelength of light?

Answer: Do the same experiment we just did (with light)

First $y_{destructive} = \lambda L / 2d$

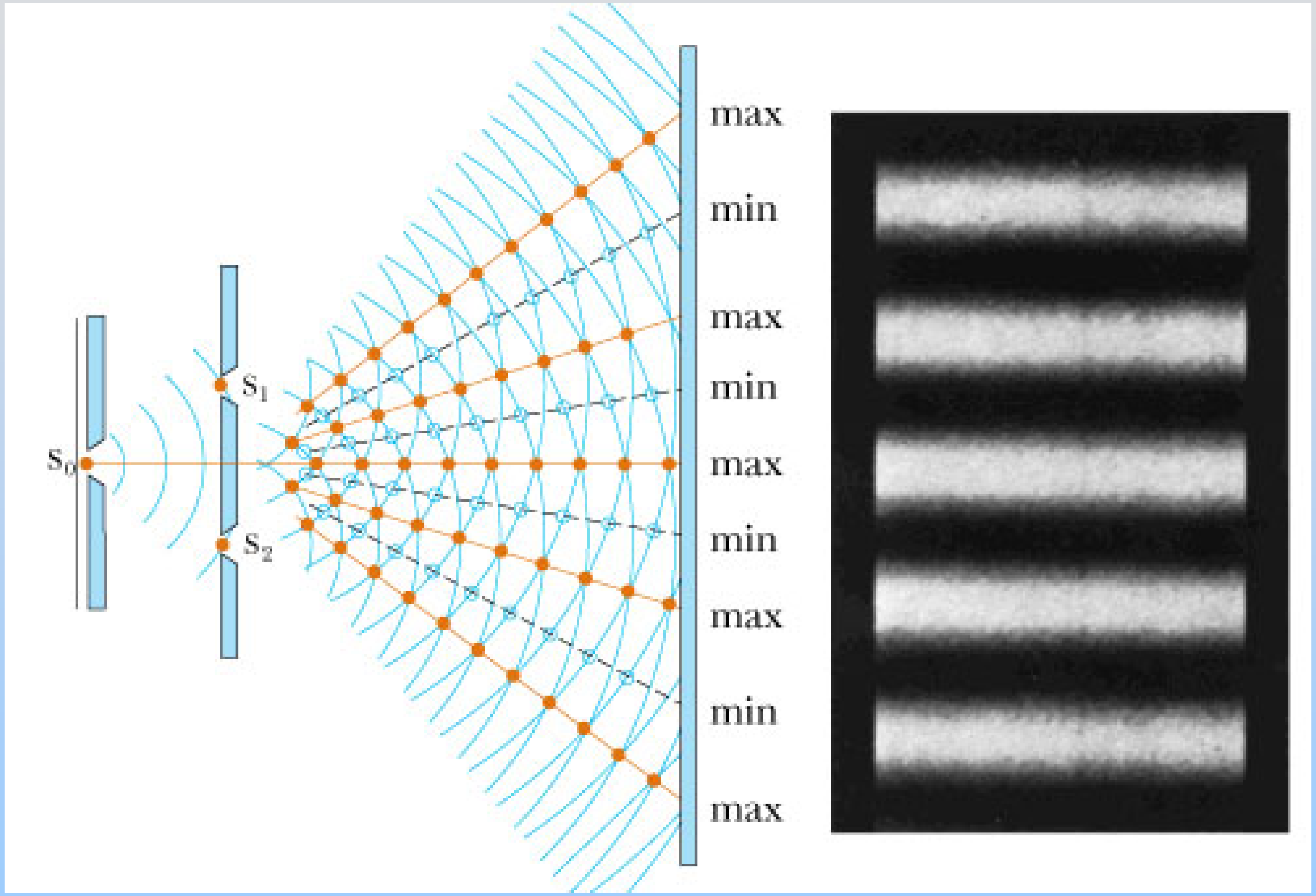
λ is smaller by 10,000 times.

But d can be smaller (0.1 mm instead of 0.24 m)

So y will only be 10 times smaller – **<u>still measurable</u>**

The Light Equivalent:
Two Slits

Young's Double-Slit Experiment



Bright Fringes: Constructive interference

Dark Fringes: Destructive interference

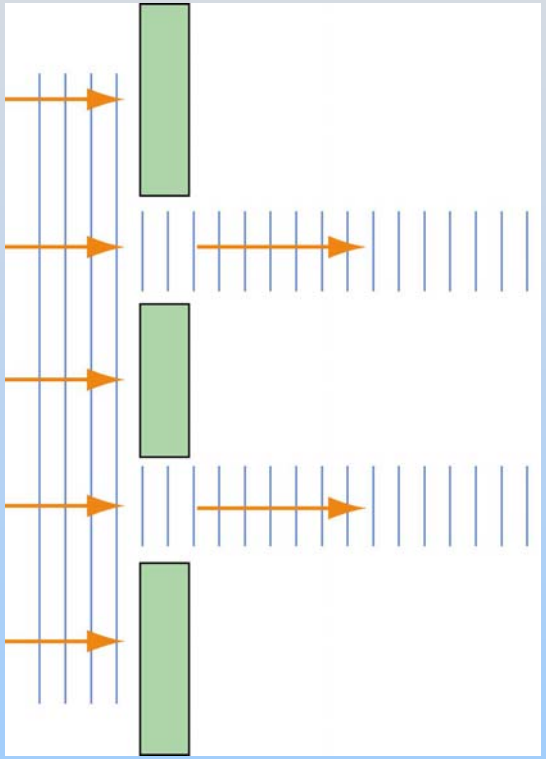
PRS Question
Double Slit Path Difference

Lecture Demonstration: Double Slit

Diffraction

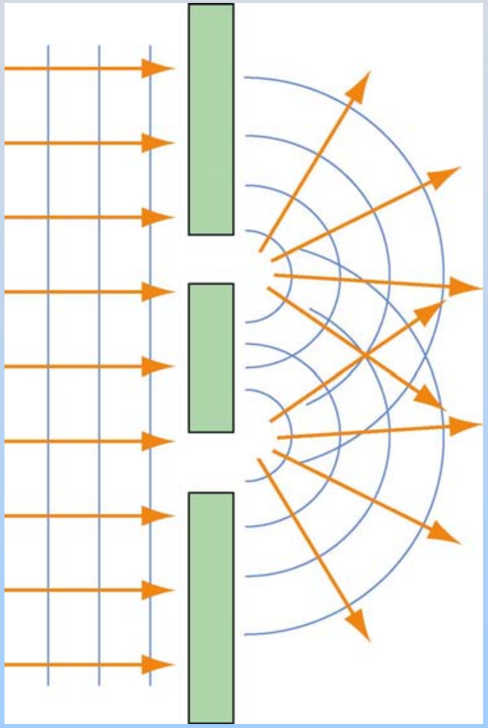
Diffraction

Diffraction: The bending of waves as they pass by certain obstacles



No Diffraction

No spreading after passing though slits

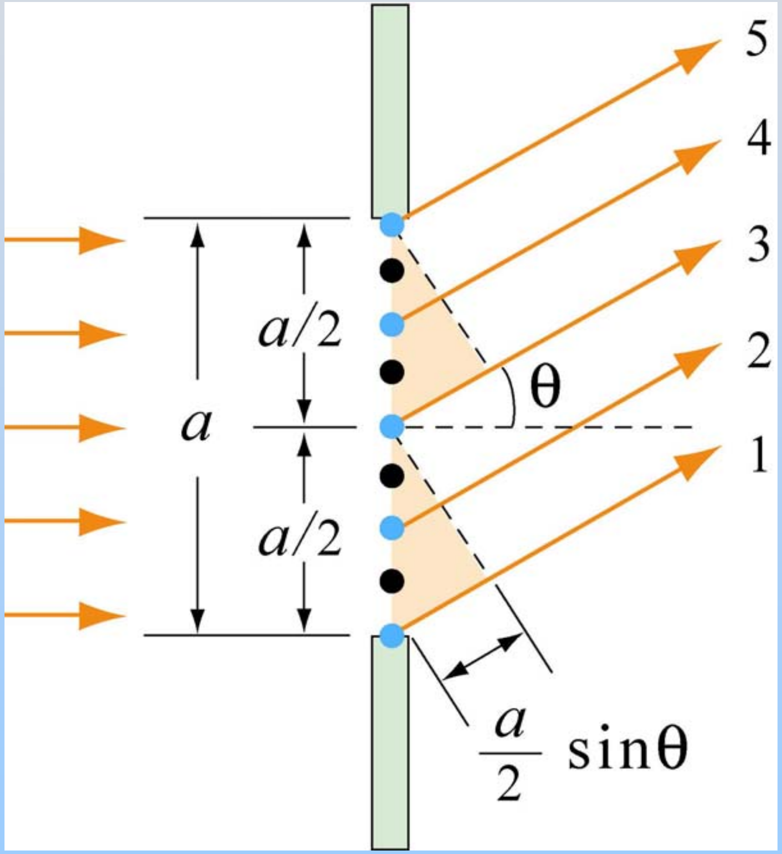


Diffraction

Spreading after passing though slits

Single-Slit Diffraction

"Derivation" (Motivation) by Division:



Divide slit into two portions:

$$\delta = r_1 - r_3 = r_2 - r_4 = \frac{a}{2}\sin\theta$$

Destructive interference:

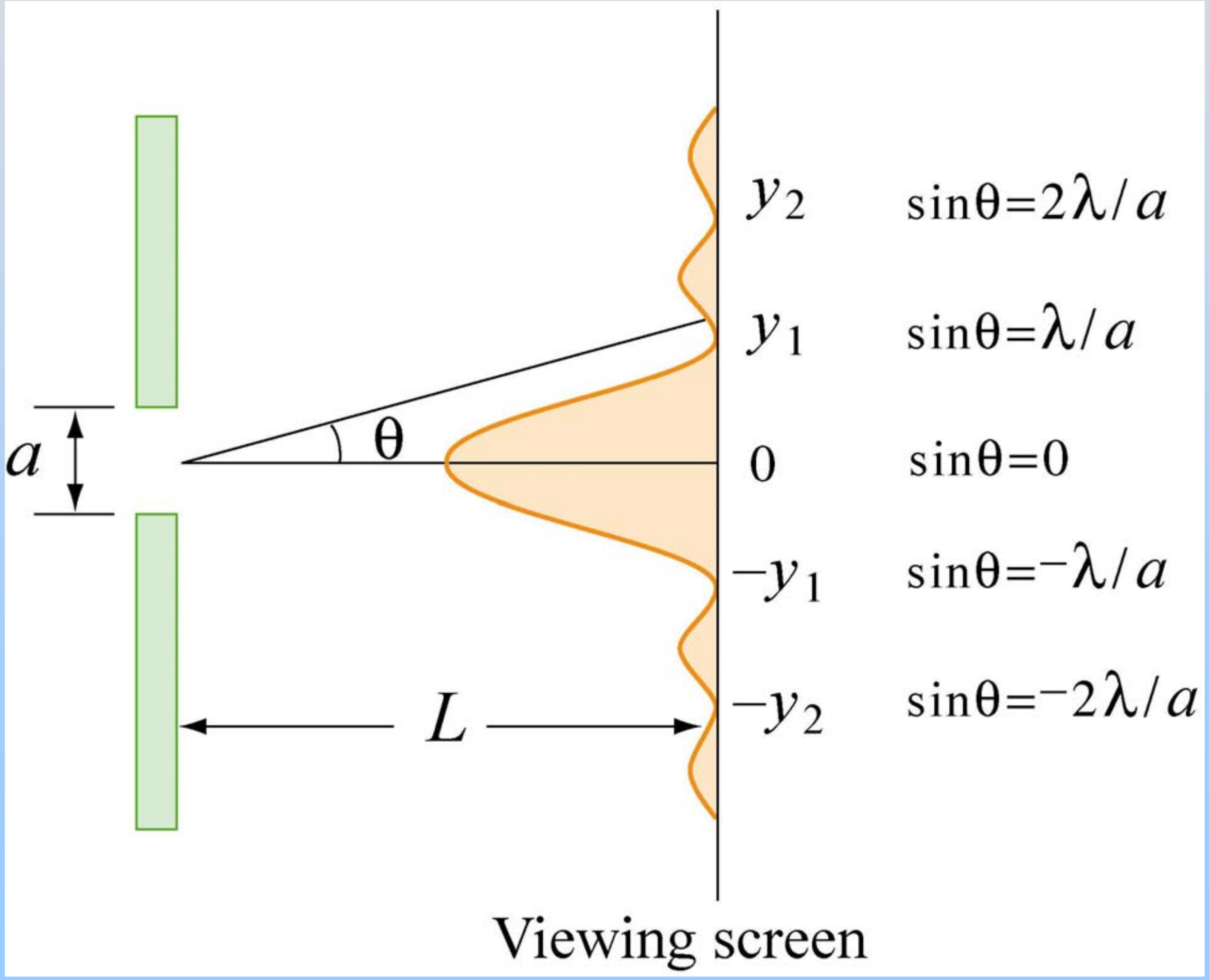
$$\delta = \frac{a}{2}\sin\theta = \left(m + \tfrac{1}{2}\right)\lambda$$

$$a\sin\theta = m\lambda \qquad m = \pm 1, \pm 2, \ldots$$

Don't get confused – this is DESTRUCTIVE!

Intensity Distribution

Destructive Interference: $a\sin\theta = m\lambda \qquad m = \pm 1, \pm 2, \ldots$



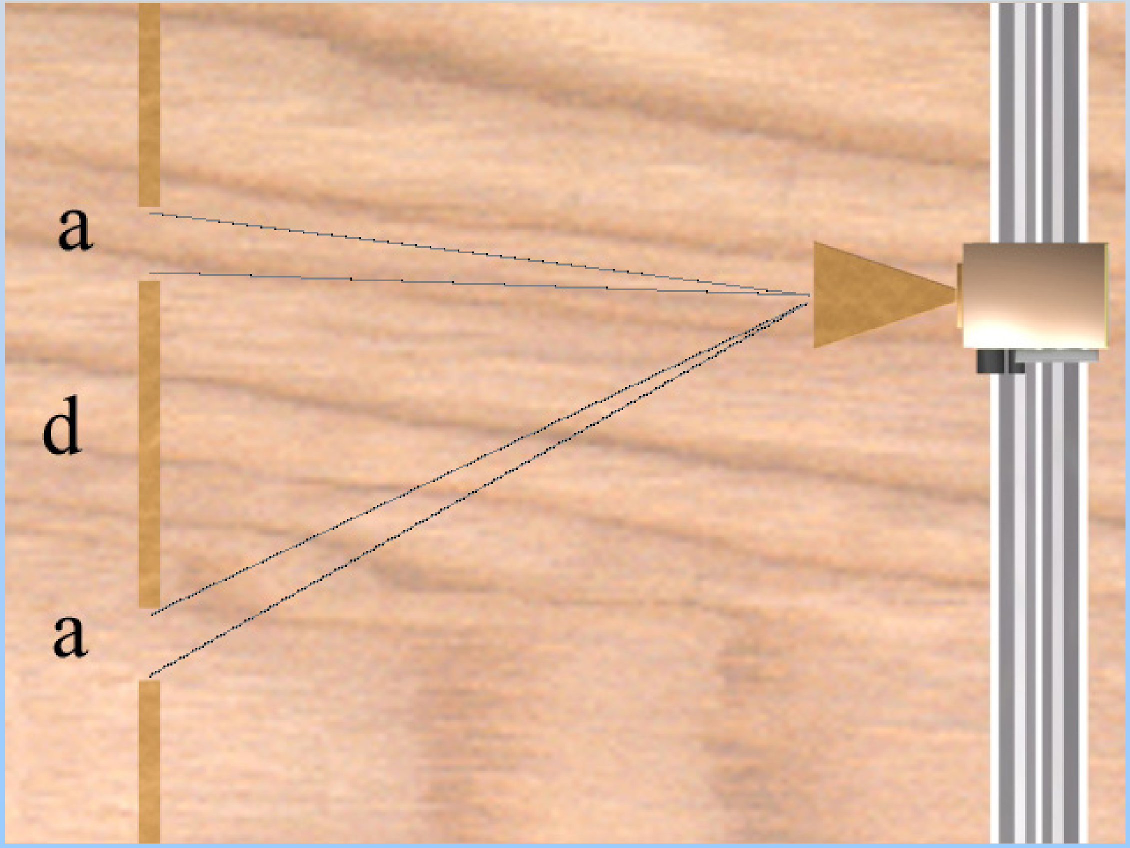
Putting it Together

PRS Question:
Two Slits with Width

Two Slits With Finite Width *a*

With more than one slit having finite width *a*, we must consider

1. Diffraction due to the individual slit
2. Interference of waves from different slits



Two Slits With Finite width *a*

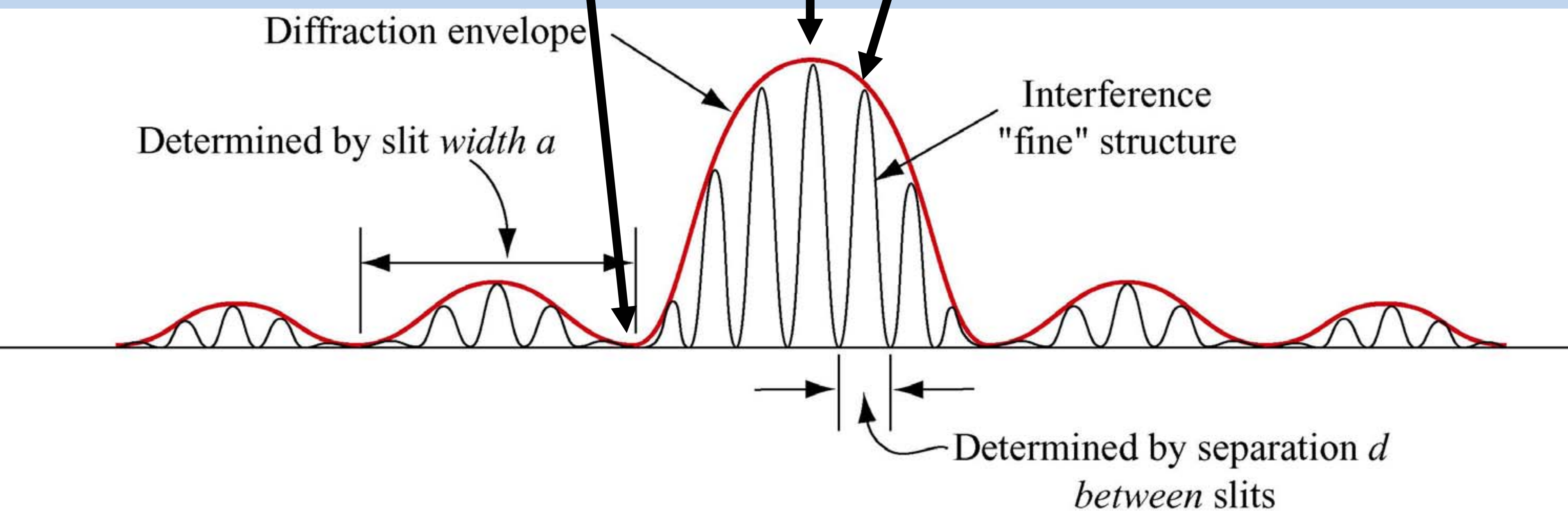
Zero Order Maximum

First Diff. Minimum

$$a \sin\theta = \lambda$$

First Order Maximum

$$d \sin\theta = \lambda$$



Lecture Demonstration: Double Slits with Width

Babinet's Principle

Case I: Put in a slit, get diffraction

Case II: Fill up slit, get nothing

Case III: Remove slit, get diffraction

By superposition, the E field with the slit and the E field with just the filling must be exact opposites in order to cancel:

$$E_{\text{filling}} = -E_{\text{slit}}$$

So the intensities are identical: $I_{\text{filling}} = I_{\text{slit}}$

Experiment 13: To Do

Download Excel File!

1. **Single Slit** – 4 different slits.
   Use known width *a* and zeroes $y_{destructive}$ to
   <u>Estimate wavelength of red light</u>
2. **Human Hair** (Babinet says just single slit).
   Use λ_{red} (from 1) and zeroes $y_{destructive}$ to
   <u>Estimate thickness of hair</u>
3. **Double Slit** – 4 different slits.
   Use known spacing *d* and zeroes to
   <u>Estimate wavelength of red light</u>
4. **CD Track Spacing** (Diffraction Grating)
   <u>Estimate track spacing</u>