Module 31: Interference

Module 31: Outline

Interference

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

Visible (red) light:

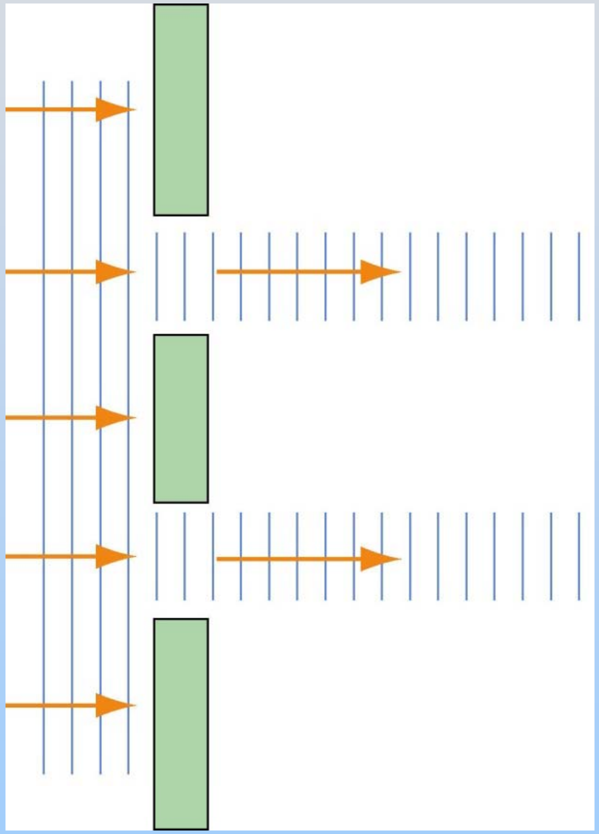
$$f_{red} = 4.6 \times 10^{14}\ \text{Hz} \quad \lambda_{red} = \frac{c}{f} = 6.54 \times 10^{-5}\text{cm}$$

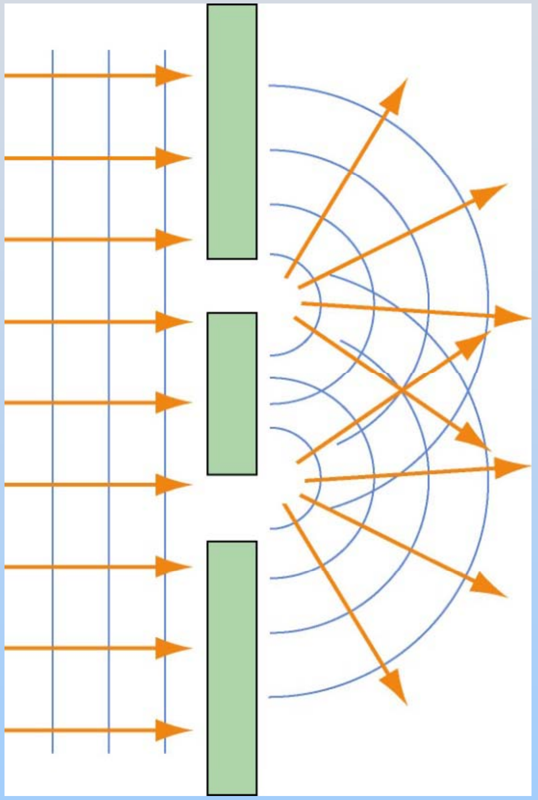
We Use Interference

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

Brief Comment: What is light?

Interference: The difference between waves and bullets





No Interference:

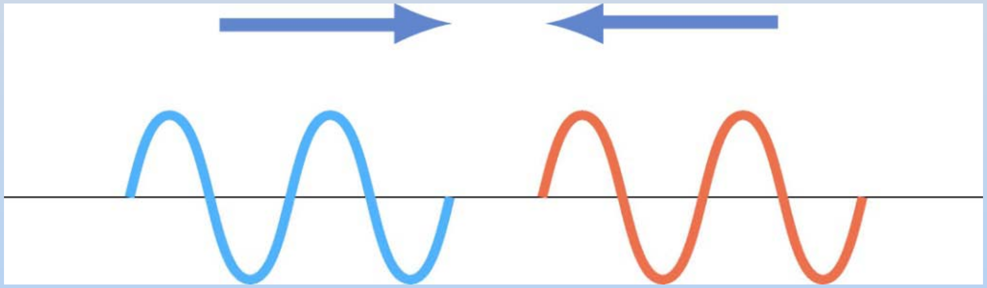
if light were made up of bullets

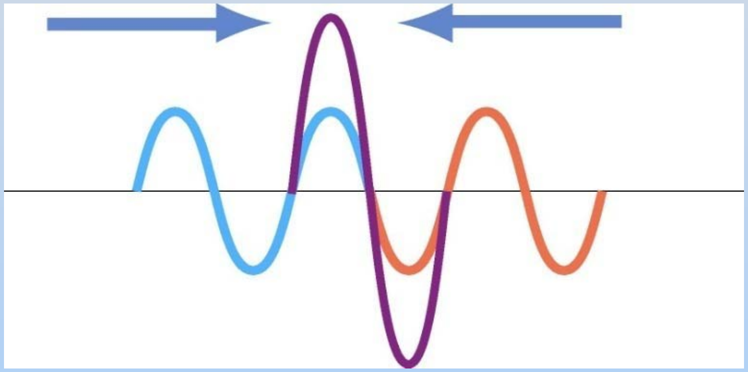
Interference: If light is a wave we see spreading and addition and subtraction

Interference

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

Waves can add *constructively* or *destructively*





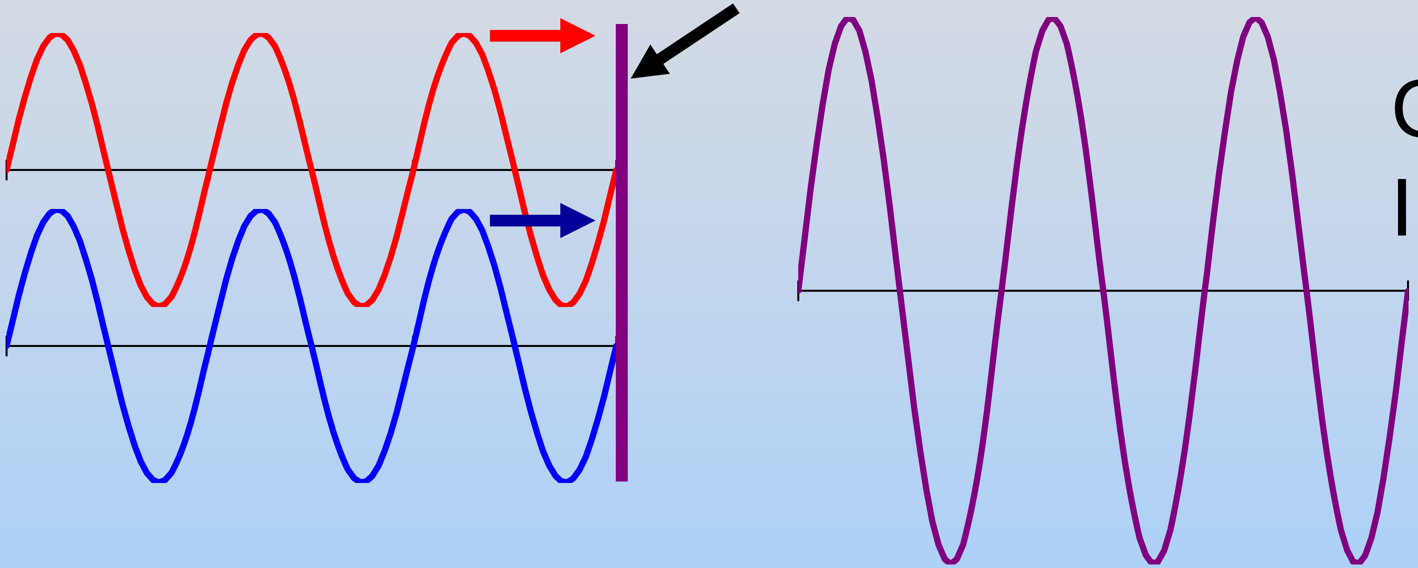
Conditions for interference:

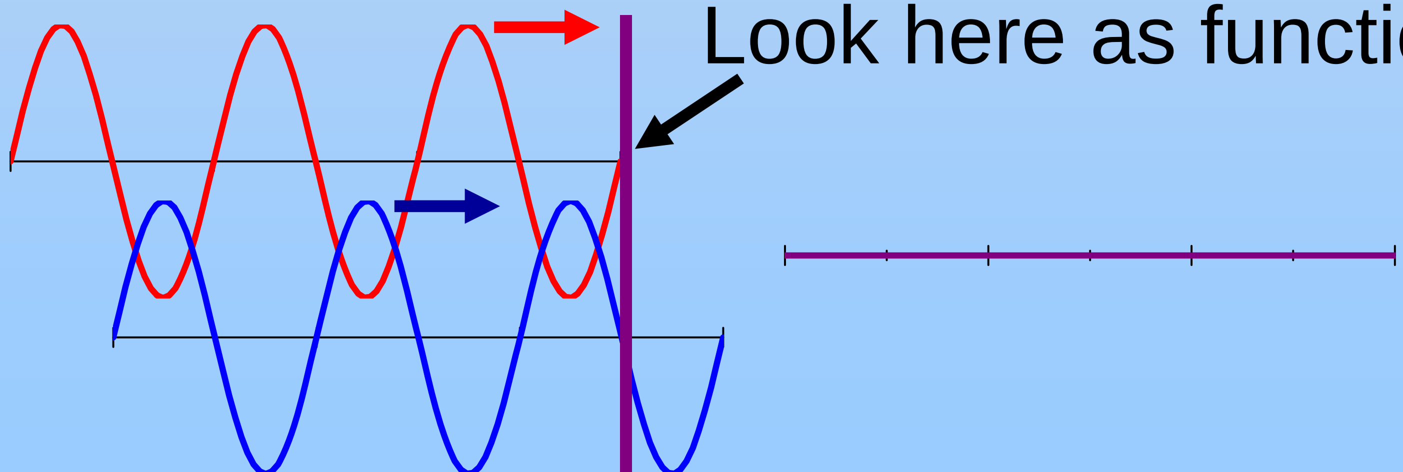
1. **Coherence**: the sources must maintain a constant phase with respect to each other
2. **Monochromaticity**: the sources consist of waves of a single wavelength

Demonstration:
Microwave Interference

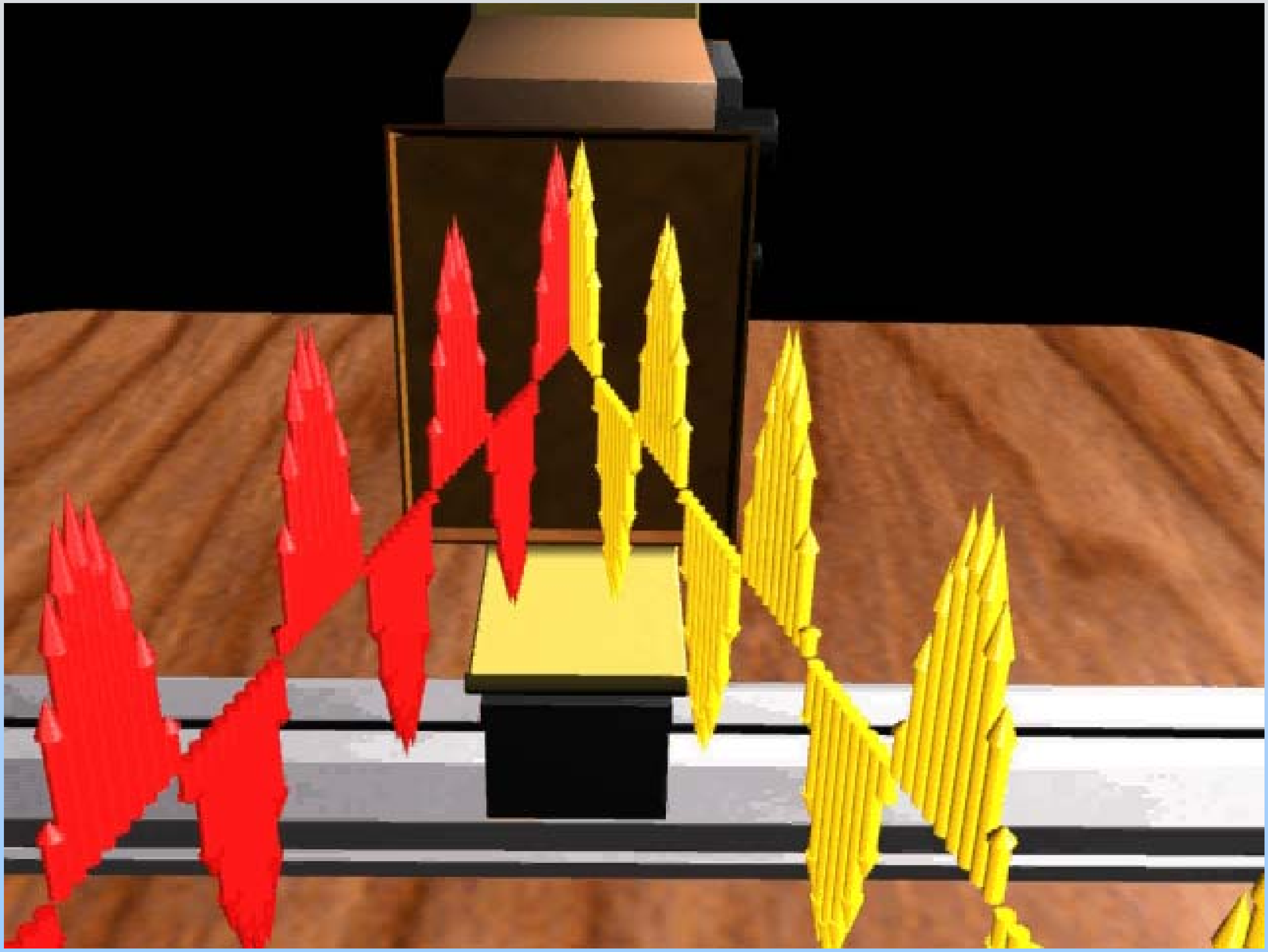
Interference – Phase Shift

Consider two traveling waves, moving through space:





Microwave Interference

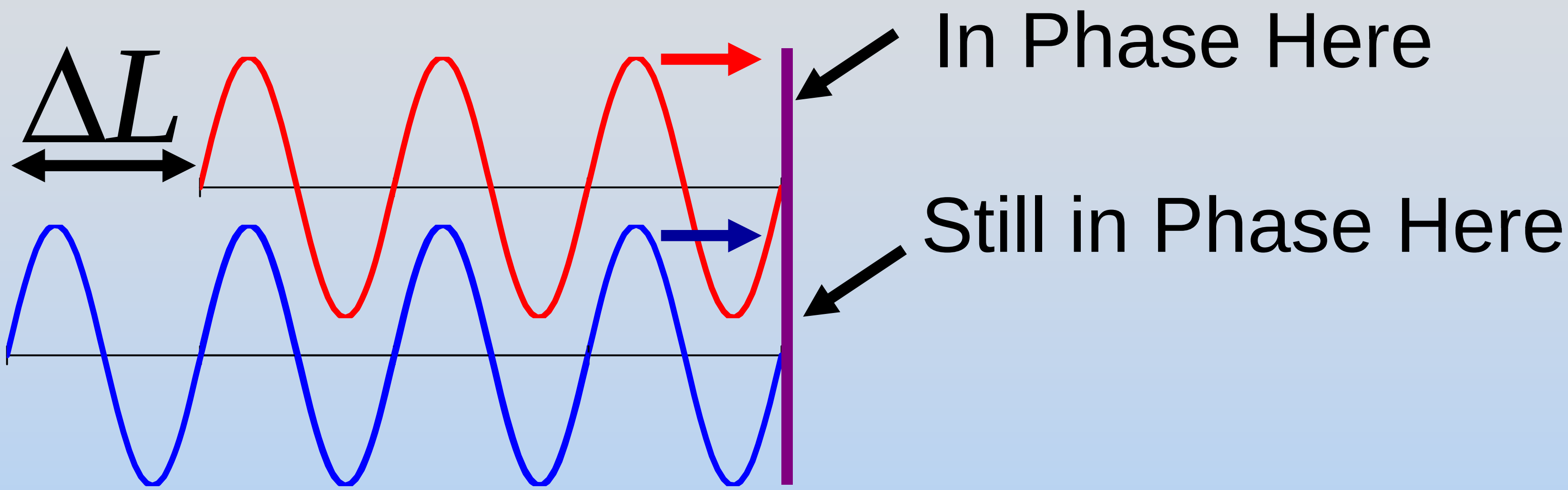


Interference – Phase Shift

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. Coming from different locations

Extra Path Length

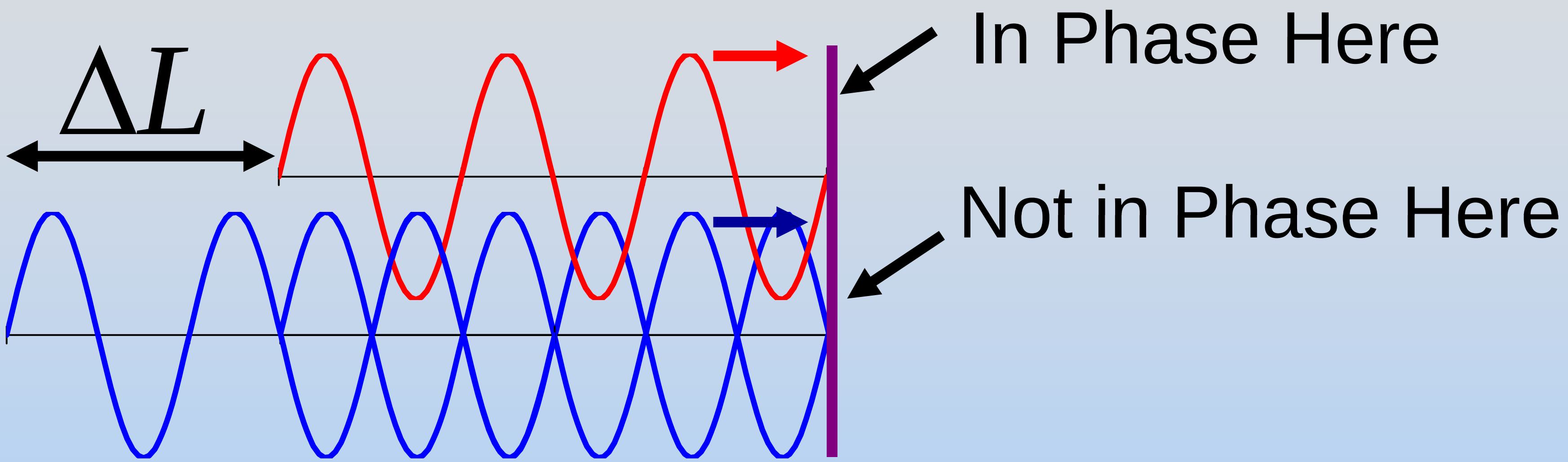


$$\Delta L = m\lambda \qquad (m=0, \pm 1, \pm 2\ldots)$$

$$\Downarrow$$

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

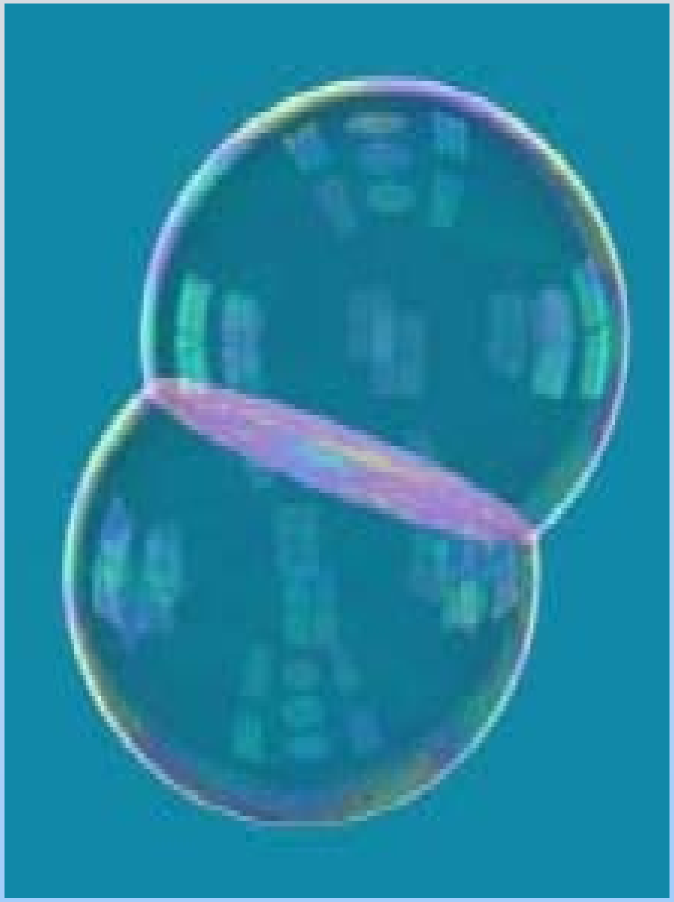
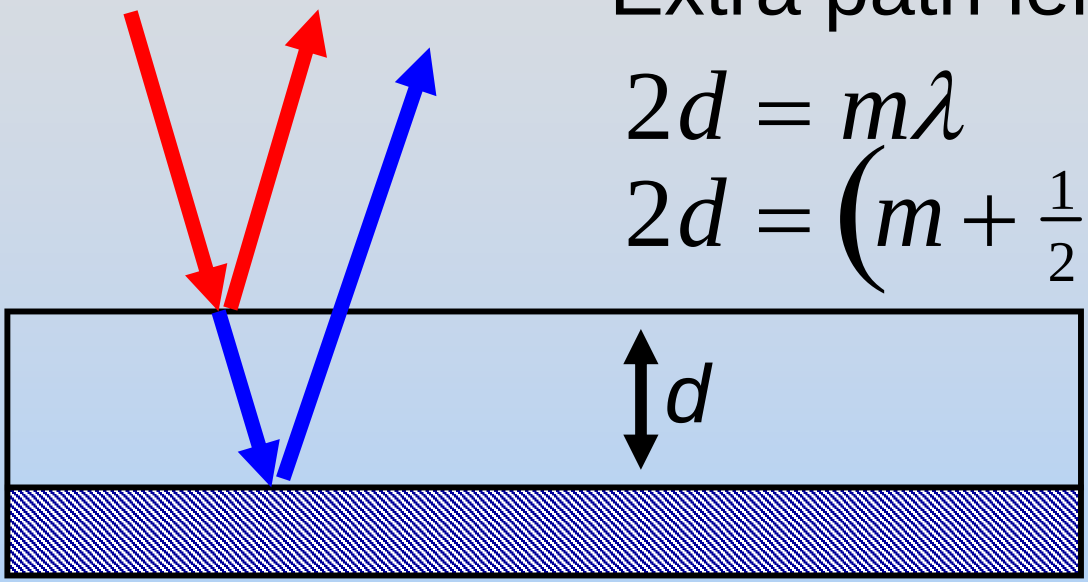


Image courtesy of John M. Sullivan, University of Illinois and Technical University of Berlin.

Thin Film Interference - Iridescence

- Bubbles
- Butterfly Wings
- Oil on Puddles

Thin Film: Extra Path

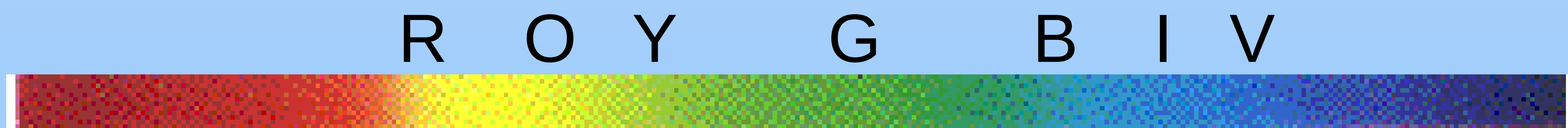


Extra path length ~ 2*d*

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

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

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



Red
λ ~ 700 nm

Violet
λ ~ 400 nm

Phase Shift = Extra Path?

What is exact relationship between ΔL & ϕ?

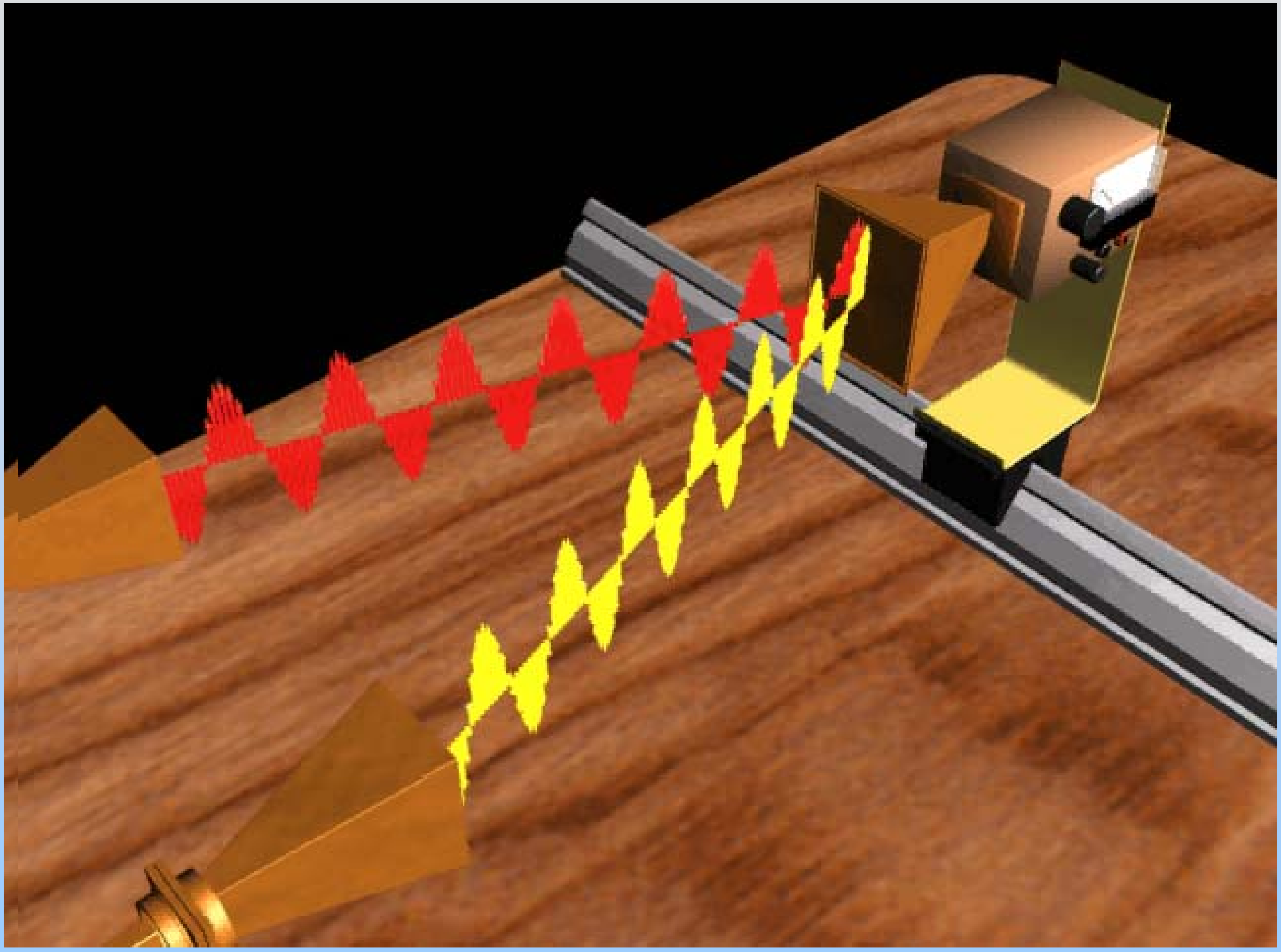
$$\sin(k(x+\Delta L)) = \sin(kx + k\Delta L)$$

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

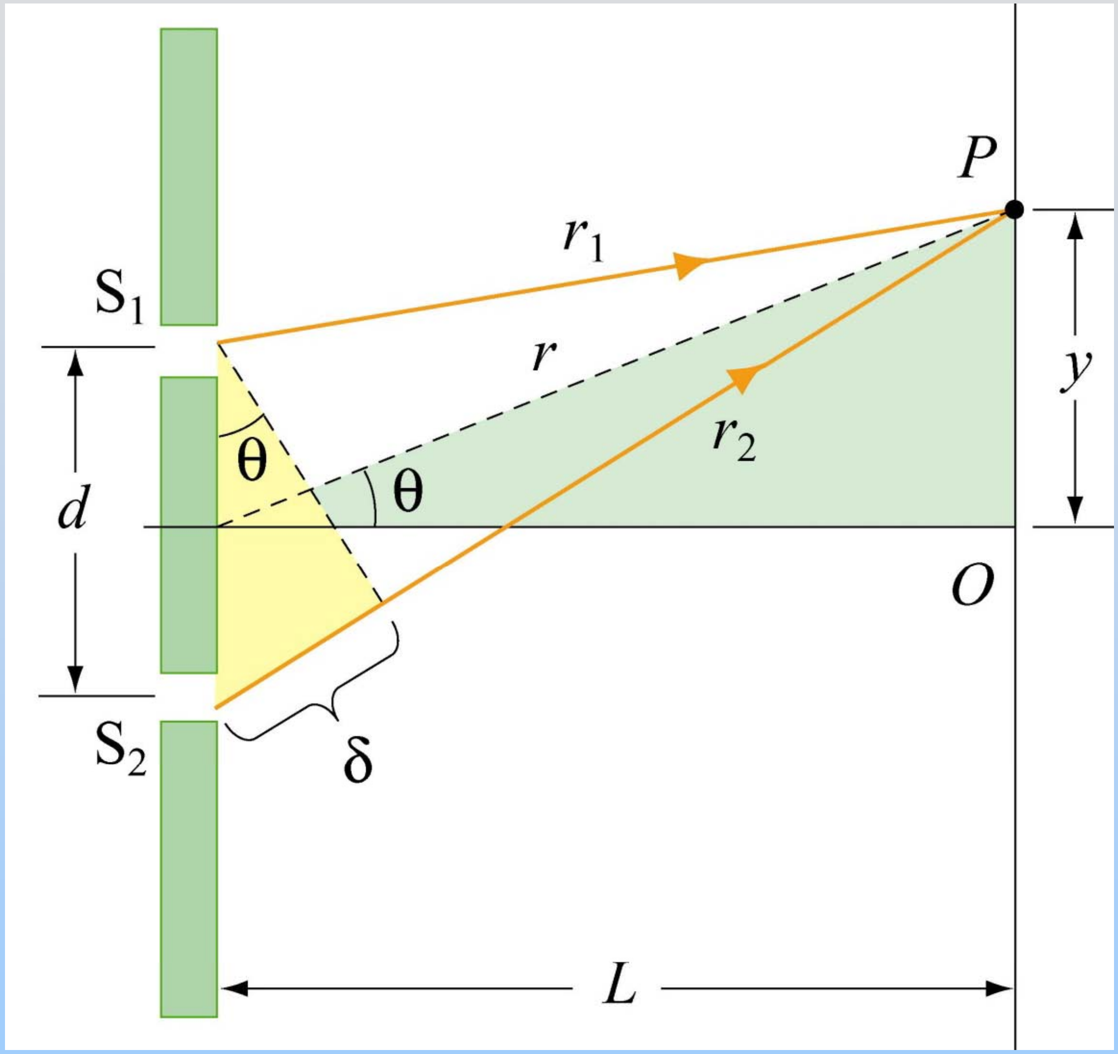
$$\boxed{\frac{\Delta L}{\lambda} = \frac{\phi}{2\pi}} = \begin{cases} m & \text{constructive} \\ m + \frac{1}{2} & \text{destructive} \end{cases}$$

Two Transmitters

Microwave Interference



Two In-Phase Sources: Geometry



Assuming $L >> d$:

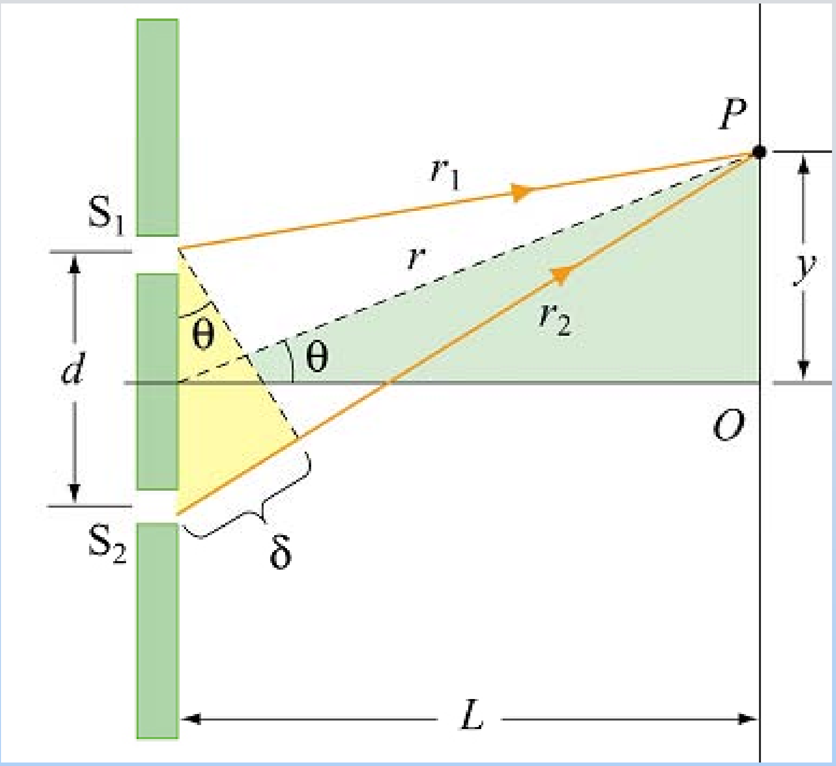
Extra path length

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

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

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

Two Sources in Phase



Assume $L >> d >> \lambda$

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

$$\Rightarrow \delta = d\sin\theta = dy/L$$

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

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

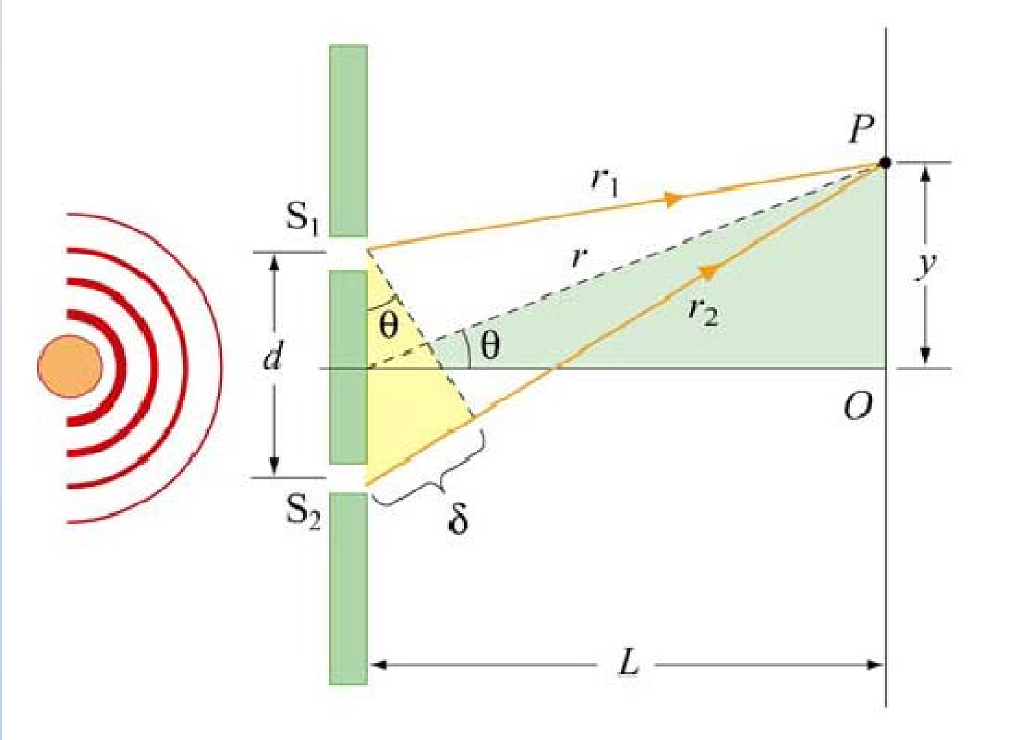
(2) Destructive: $\delta = (m + 1/2)\lambda$

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

Concept Question Question
Two Slits with Width

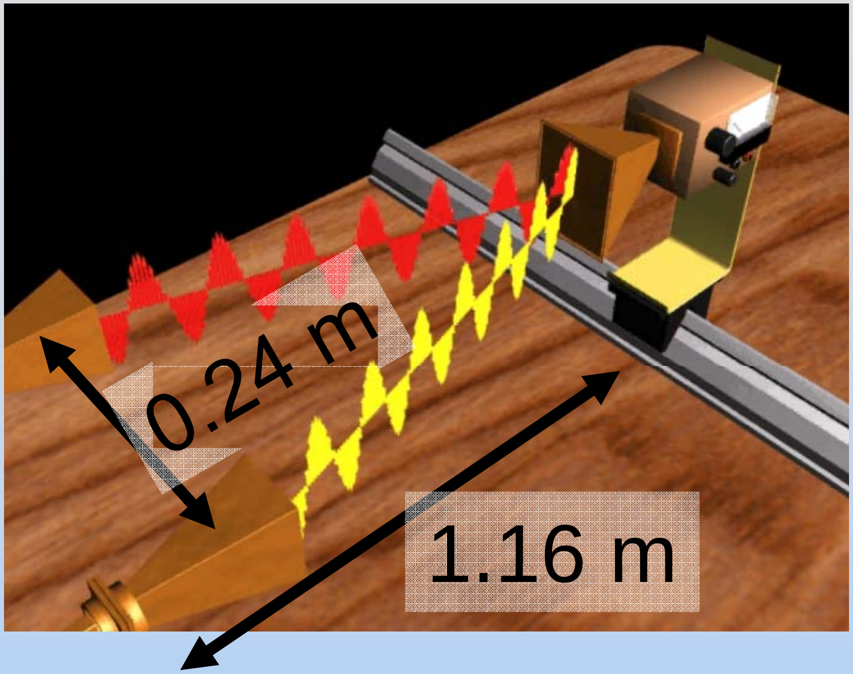
Concept Question: Double Slit

Coherent monochromatic plane waves impinge on two apertures separated by a distance d. An approximate formula for the path length difference between the two rays shown is



1. d sin θ
2. L sin θ
3. d cos θ
4. L cos θ
5. Don’t have a clue.

Problem: Lecture Demo



We just found that

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

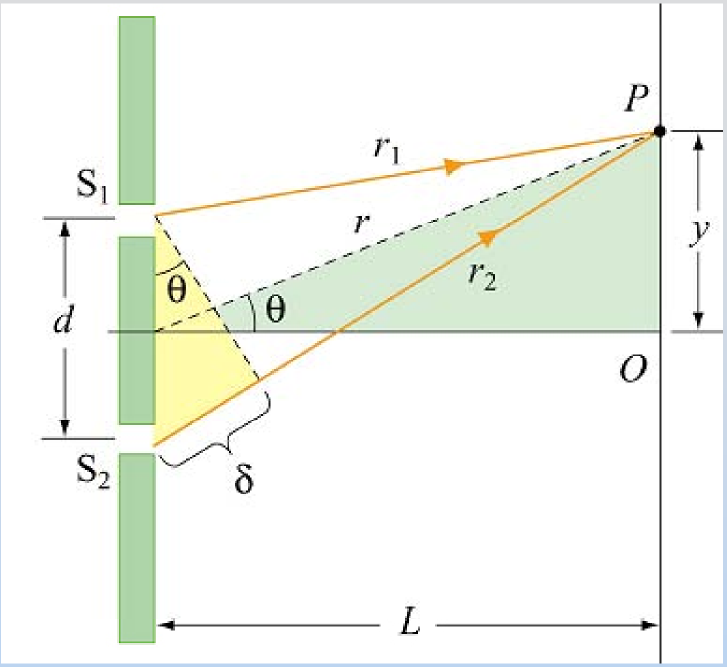
For m = 0 (the first minimum):

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

From our lecture demo, estimate the wavelength & frequency of our microwaves.

The Light Equivalent: Two Slits

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)

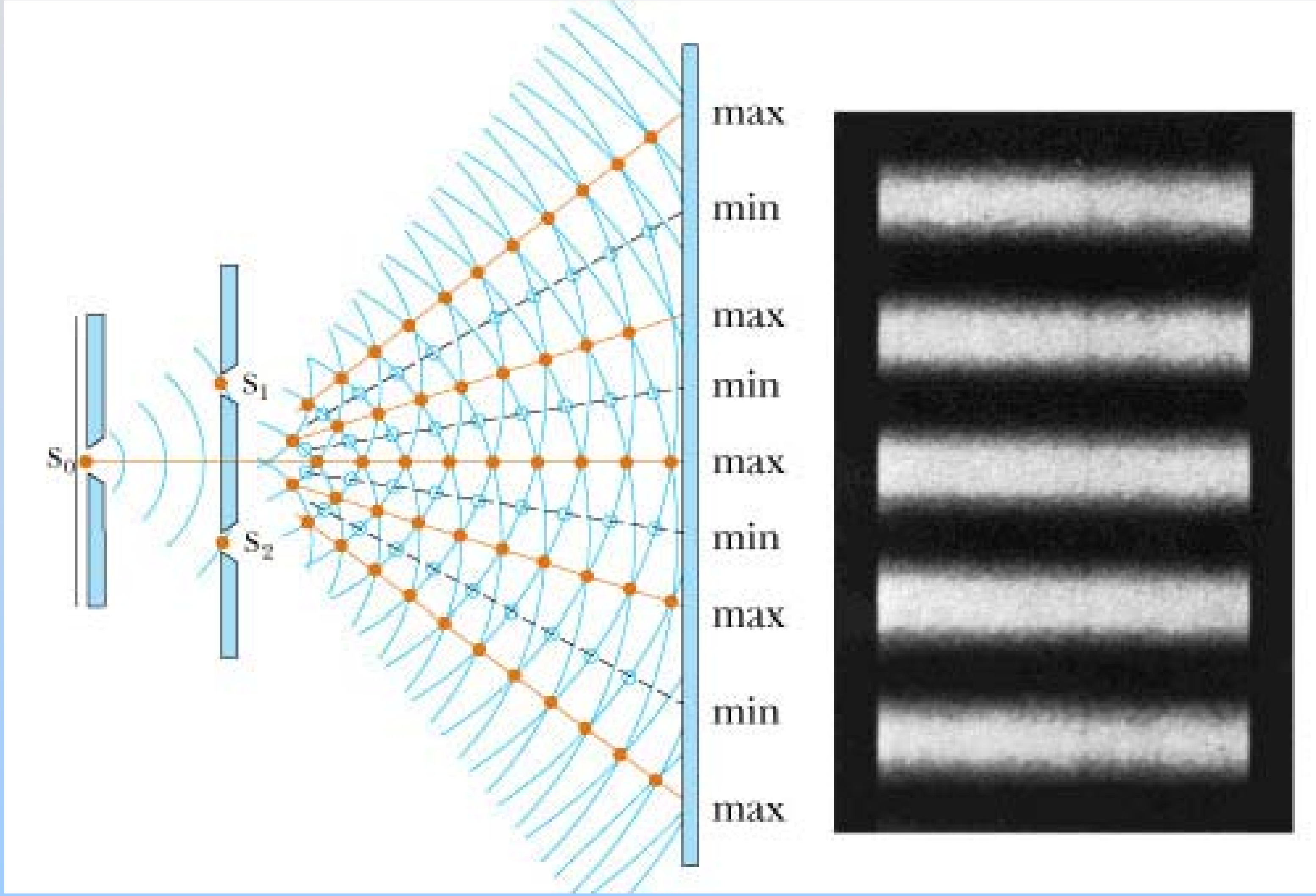
First $y_{destructive} = \lambda L / 2d$

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 – **still measurable**

Young's Double-Slit Experiment



Bright Fringes: Constructive interference

Dark Fringes: Destructive interference

Lecture Demonstration: Double Slit