Purdue University Department of Physics

Physics 21900

General Physics II

Electricity, Magnetism and Optics

Lecture 20 – Chapter 23.1-2

Wave Optics

Fall 2015 Semester

Prof. Matthew Jones

Announcement

Exam #2 will be on Thursday, November 5th (tomorrow) in Phys 112 at 8:00 pm

Electric current, DC circuits, Kirchhoff's Rules
Magnetic Fields, Lorentz Force, Forces on Currents
Ampere's Law, Magnetic Induction, Lenz's Law
Induced EMF, AC Voltage, Transformers

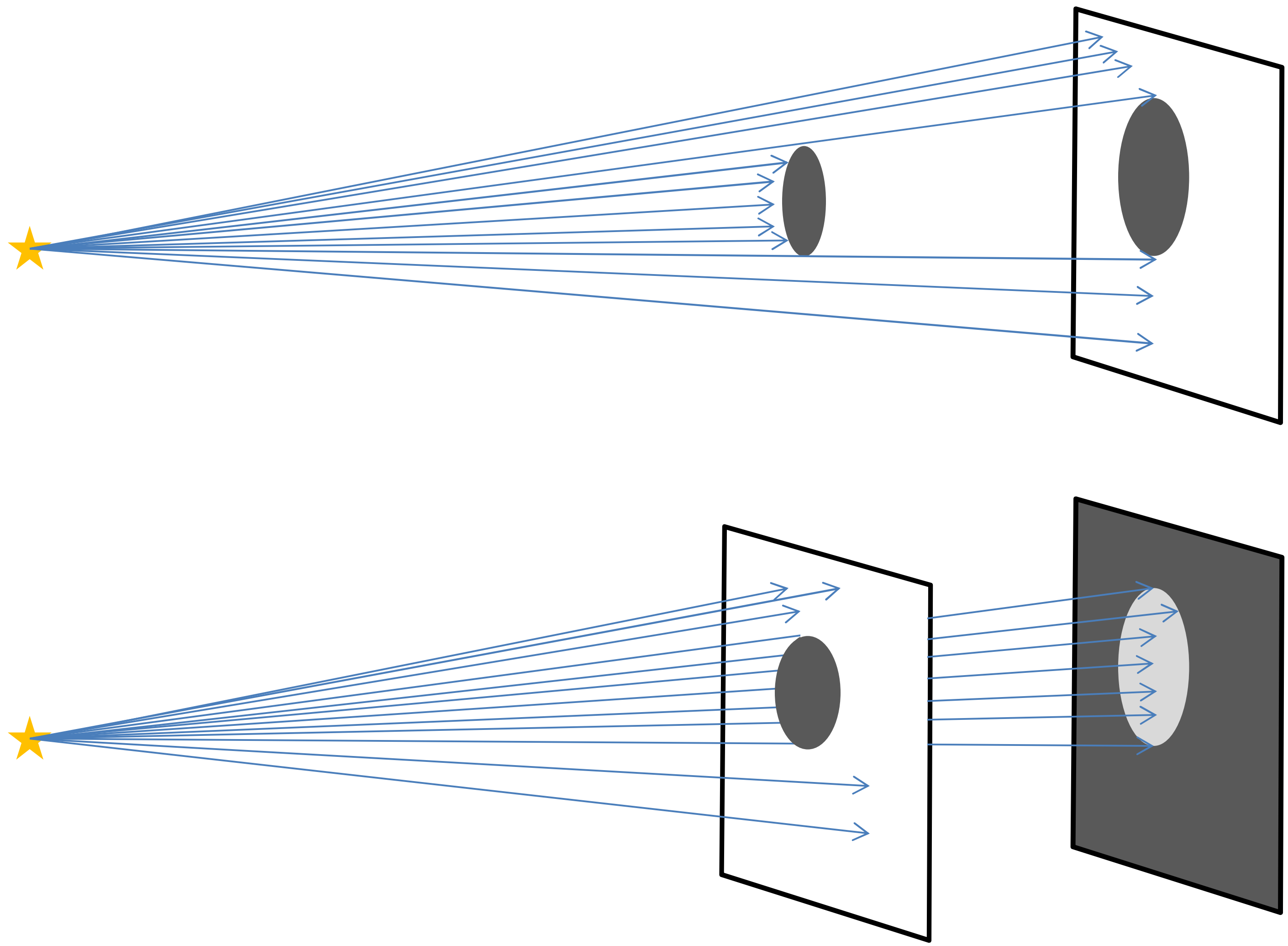
To keep the number of questions reasonable, some will require that you combine knowledge from multiple areas. For example, you might need to know Kirchhoff's rules and how to analyze series and parallel resistors in the same problem.

Optics

Three ways to describe the properties of light:

- Geometric optics
  - Light travels in straight lines (rays)
- Wave optics
  - Light is described by waves
- Quantum optics
  - Light is described by particles (photons) that satisfy the laws of quantum mechanics

Geometric Optics *vs* Wave Optics

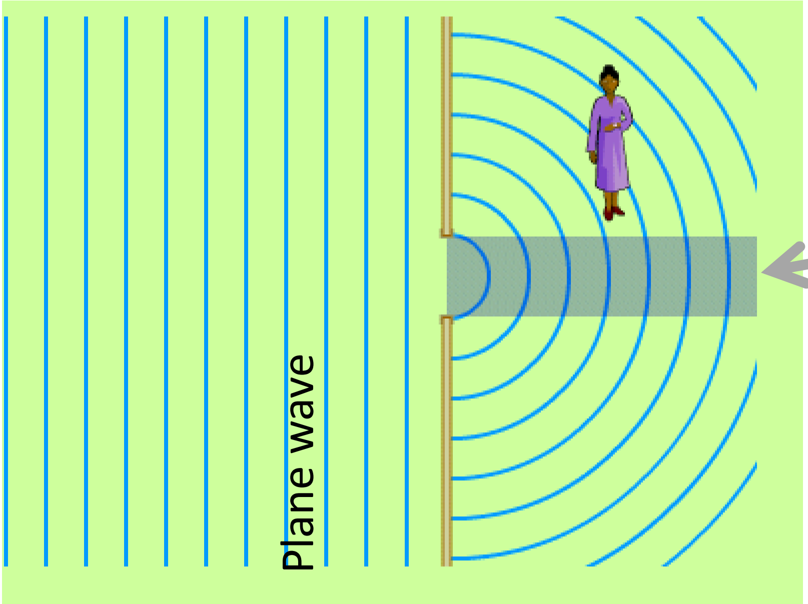


Geometric Optics *vs* Wave Optics

Water waves passing through a narrow opening

In both cases, the opening has a dimension comparable to the wavelength of the waves.

Sound waves passing through an opening



Expectation based on ray propagation

In both cases, the wave “bends” around the edges of the opening.

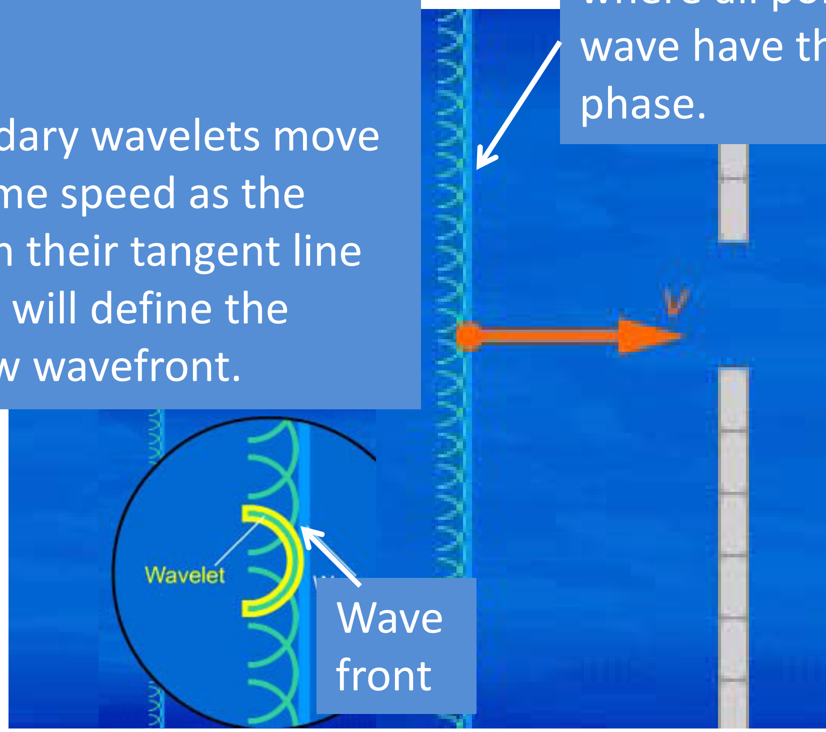
Huygens Principle (1678)

How to predict how a wave will propagate? Huygens claimed that each point on a wave contains a future version of the wave itself.

At some time, every point on a wave can be considered as a source of a secondary wave.

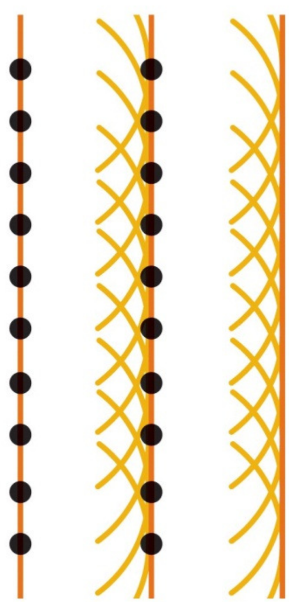
If ALL these secondary wavelets move outward at the same speed as the original wave, then their tangent line at some later time will define the location of the new wavefront.

The wavefront is an imaginary line in space where all points on the wave have the same phase.



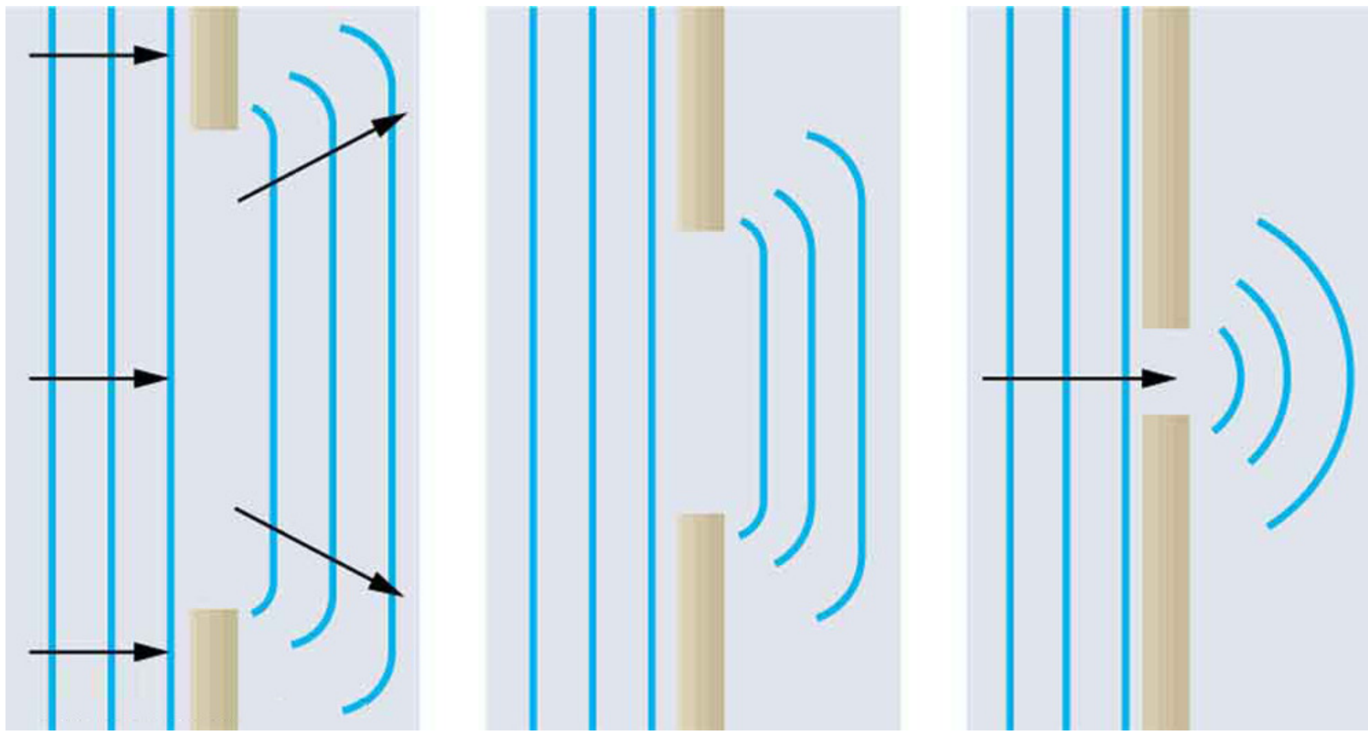
Propagation in Transparent Media

- Huygen's Principle: Light is continuously re-emitted in all directions from all points on a wave front
  - Further developed by Fresnel and Kirchhoff
  - Destructive interference except in the forward direction



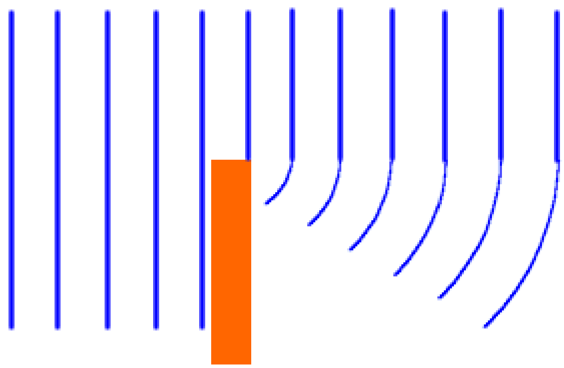
Propagation in Transparent Media

- Can you observe Huygen's wavelets?

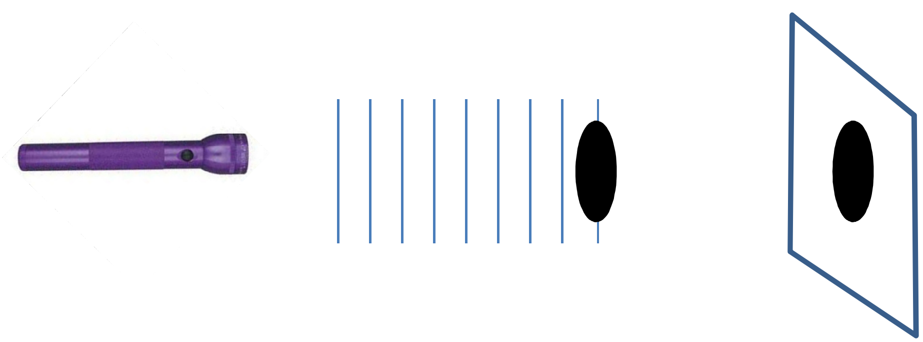


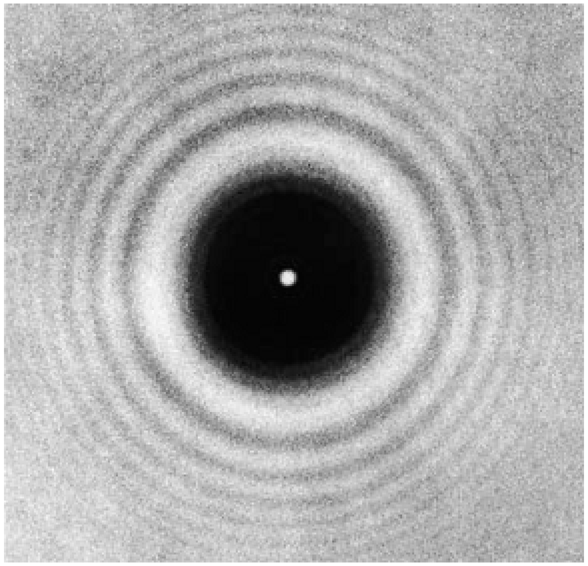
Propagation in Transparent Media

- Light will “bend” around obstacles:



Easier to observe with coherent light (like from a laser)





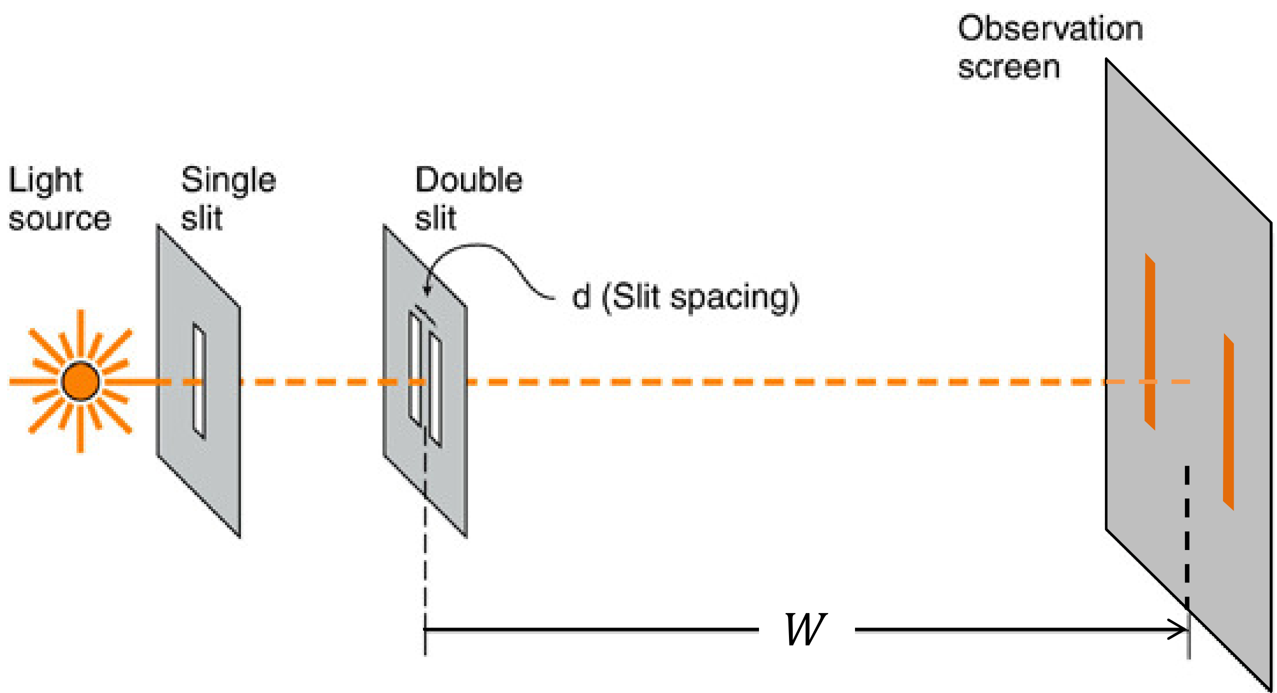
Wave Optics

Vocabulary for wave optics:

- Wavelength
- Wavelet
- Wavefront
- Coherence
- Phase difference
- Interference – constructive and destructive
- Diffraction

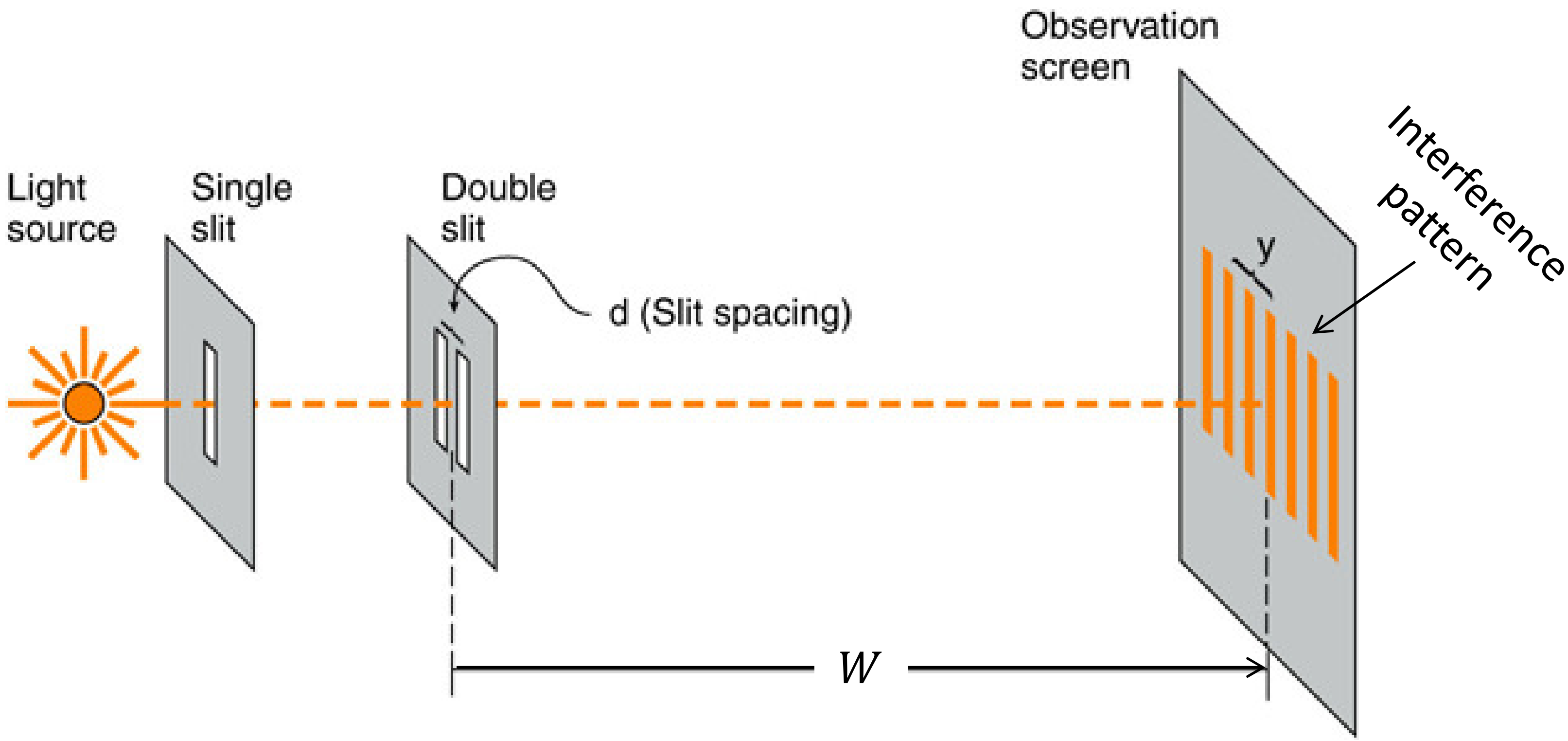
Young's Double Slit Experiment - 1803

Is this what happens?



Prediction based on the ray nature of light.
(not to scale)

Experiment: many fringes of bright and dark bands are seen on the observing screen.

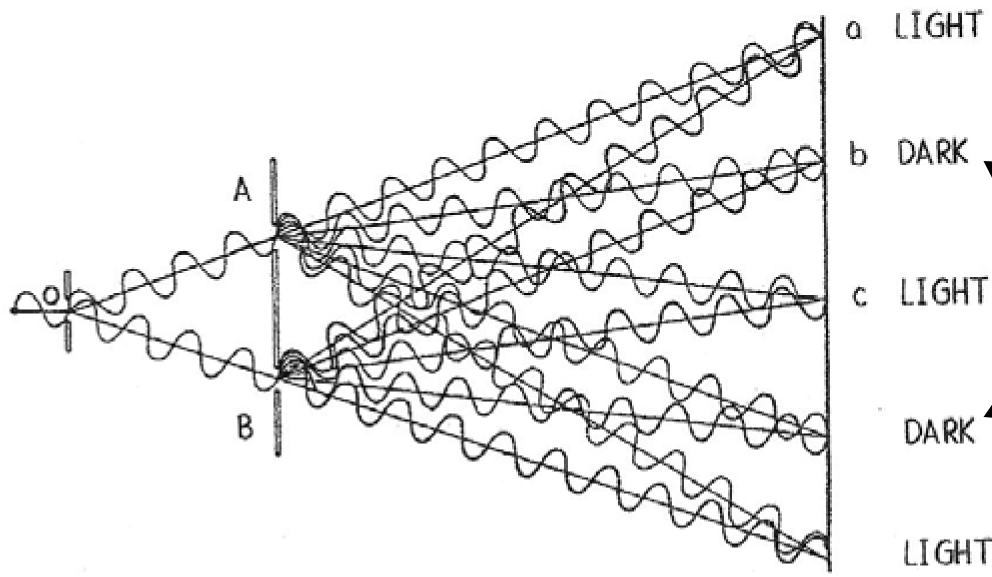


Conditions that must be satisfied:

- **Monochromatic light**: only one wavelength (color)
- **Coherent light**: the phase difference between any two light waves arriving at a given location remains the same over time.

Model to explain Young's double slit

Key idea: Two coherent light beams interfere after following different paths



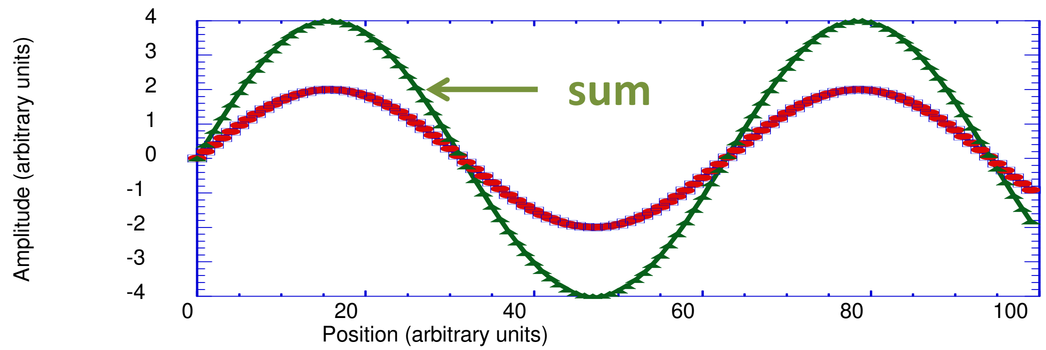
Out of phase by 180°

Important historically because it provided an easy way to determine the wavelength of light.

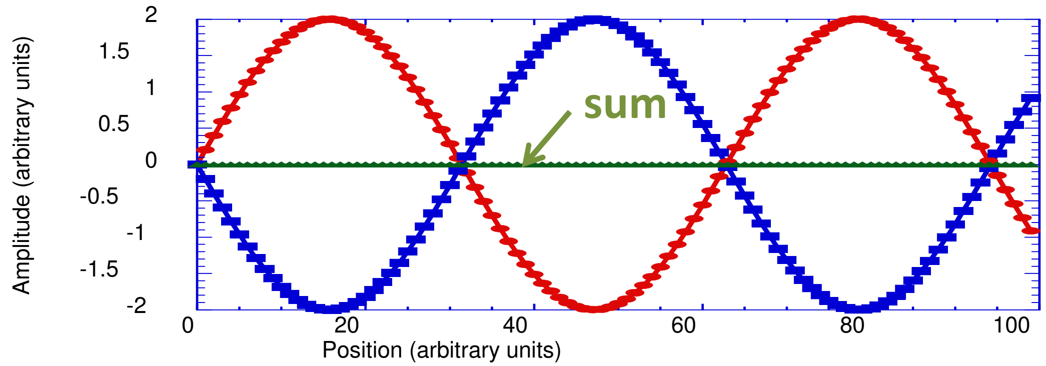
Adding in-phase and out-of-phase waves

$$f_1(t) = A\sin(\omega t)$$
$$f_2(t) = A\sin(\omega t + \Delta\theta)$$

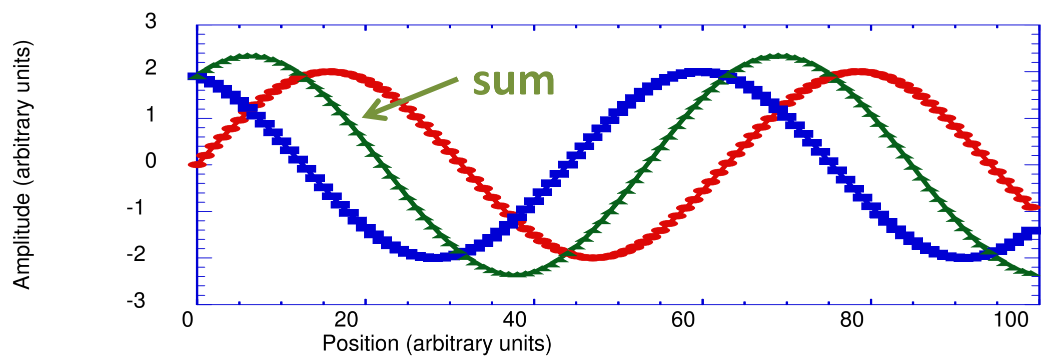
$\Delta\theta = 0$:
Constructive interference



$\Delta\theta = \pi$:
Destructive interference



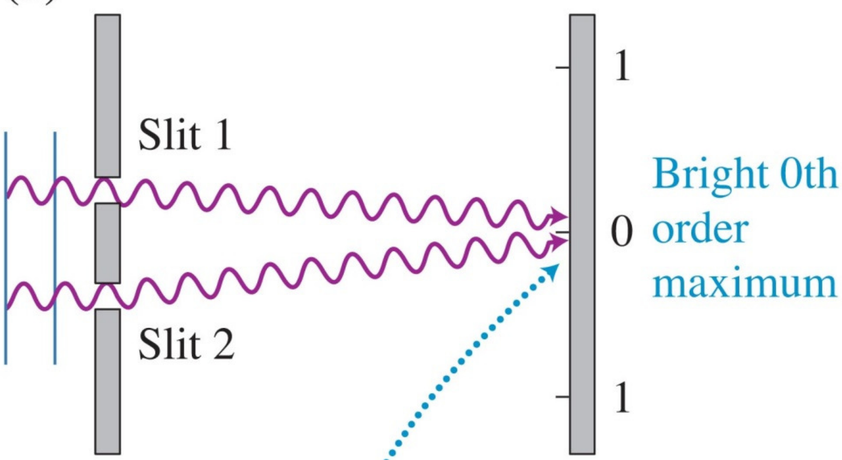
Some other value of $\Delta\theta$



Constructive/Destructive Interference for two slits

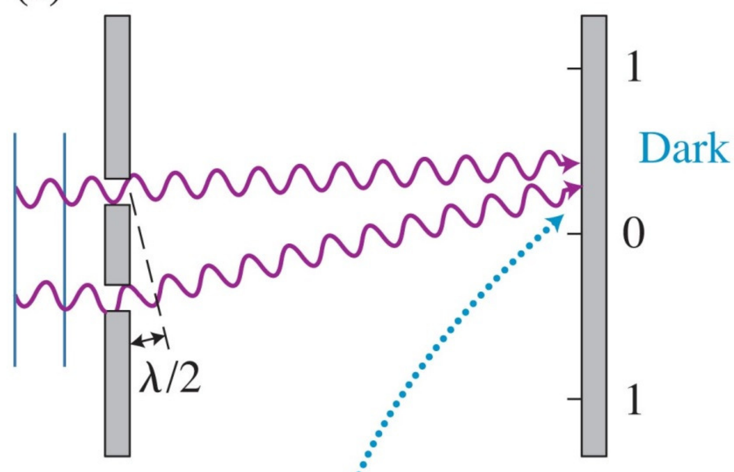
- Waves that are in-phase give constructive interference
- Waves completely out-of-phase give destructive interference.

(b)



The waves travel equal distances and are in phase when they reach the screen.

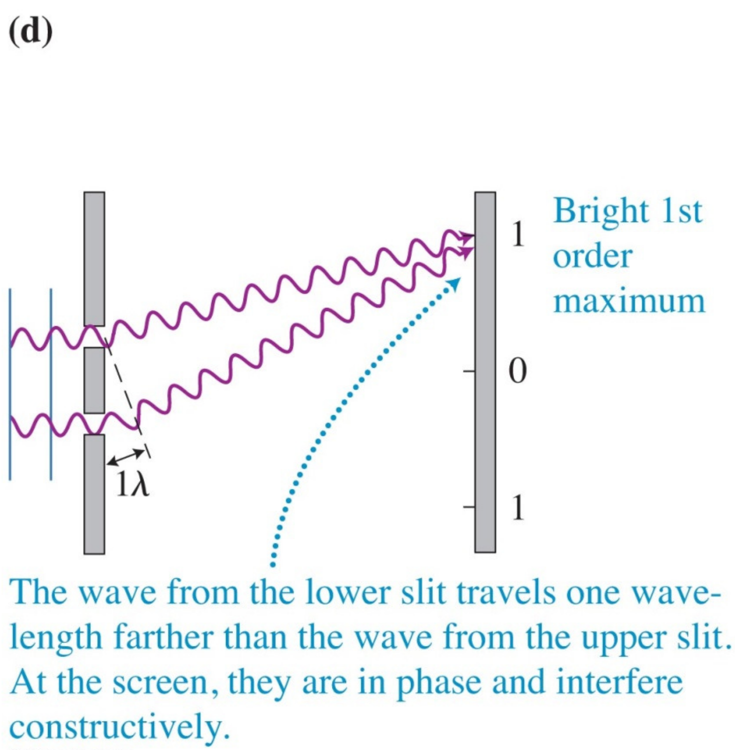
(c)

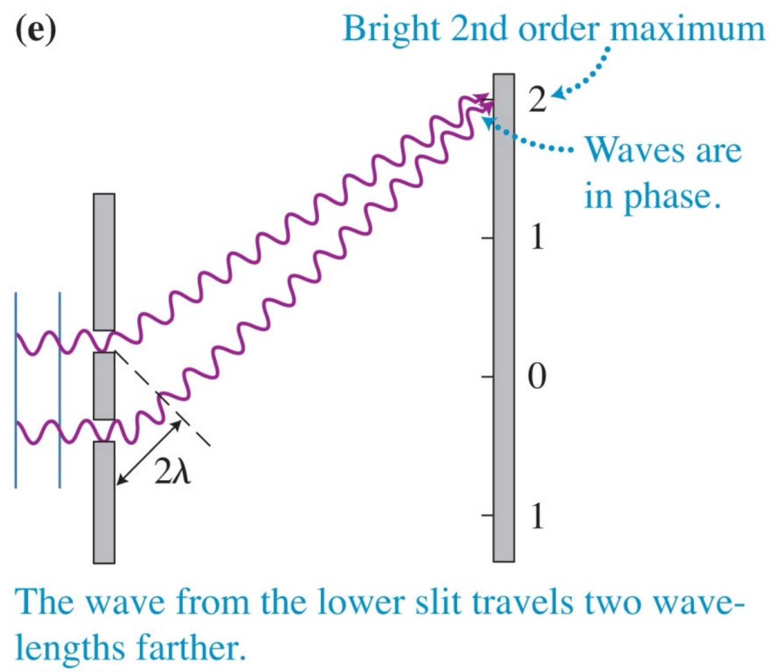


The lower wave travels $\lambda/2$ farther than the upper wave. They are out of phase when they reach the screen.

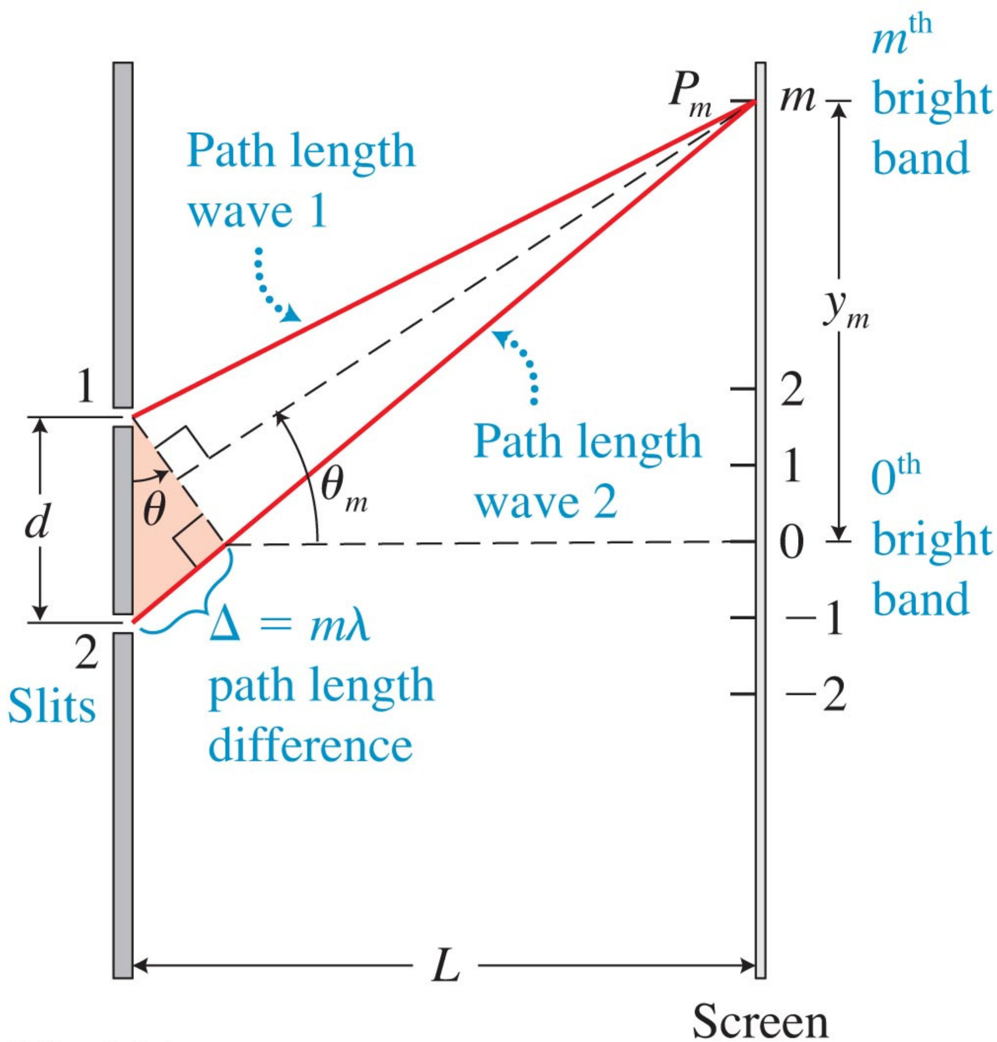
Constructive/Destructive Interference for two slits

- Waves that are in-phase give constructive interference
- Waves completely out-of-phase give destructive interference.





How to calculate the phase difference



$$\sin\theta_m = \frac{m\lambda}{d}$$

But when the angle is small,

$$\sin\theta_m = \frac{y_m}{L}$$

So the bright fringes occur at

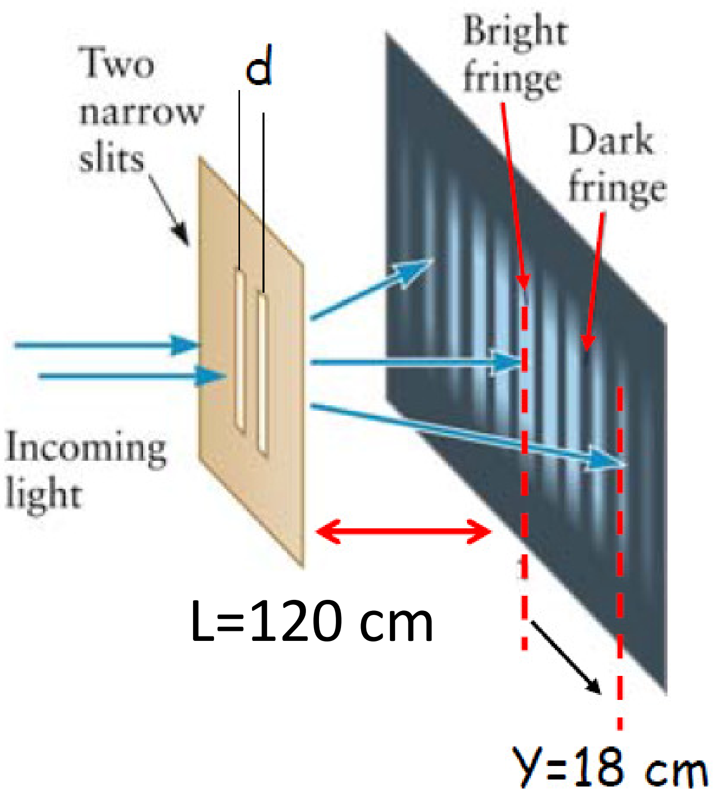
$$y_m = \frac{m\lambda L}{d}$$

Dark fringes occur at

$$y_m = \frac{(m + ½)\lambda L}{d}$$

Example

Monochromatic light of **unknown wavelength** passes through two narrow slits that are separated by 15 μm. A viewing screen is placed 1.2 m behind the double slits. The 4th bright fringe observed on the screen is located 18.0 cm from the central bright fringe. What is the wavelength of the light?



$$y_m = \frac{m\lambda L}{d} \rightarrow \lambda = \frac{y_m d}{mL}$$

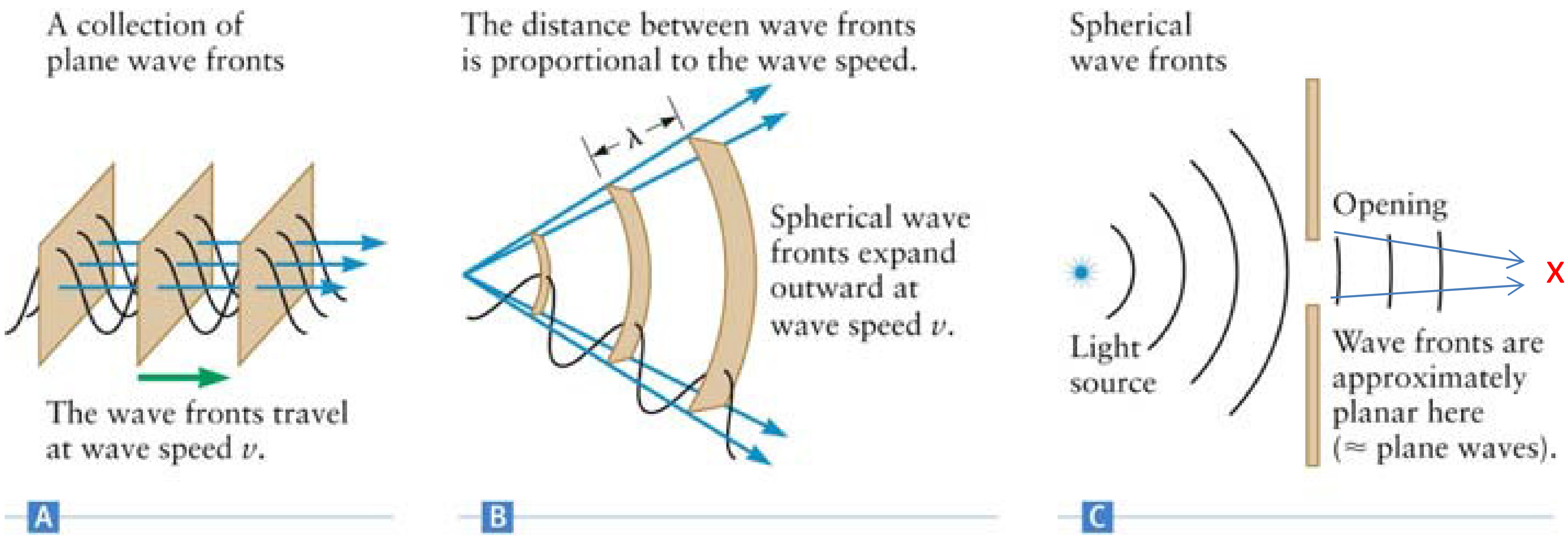
$$15 \times 10^{-6}\,\text{m} \cdot \left(\frac{18\text{ cm}}{120\text{ cm}}\right) = 4\lambda$$

$$\lambda = \frac{15 \times 10^{-6}\,\text{m}}{4} \cdot \left(\frac{18\text{ cm}}{120\text{ cm}}\right)$$

$$= \left(3.75 \times 10^{-6}\right)\left(0.150\right)$$

$$= 5.625 \times 10^{-7}\,\text{m} = 562.5\,\text{nm}$$

Interference – Underlying assumptions



Coherence requirement is readily achieved by a laser.

Waves spread out after passing through a narrow slit.

Phase difference between different paths determines intensity at point x.