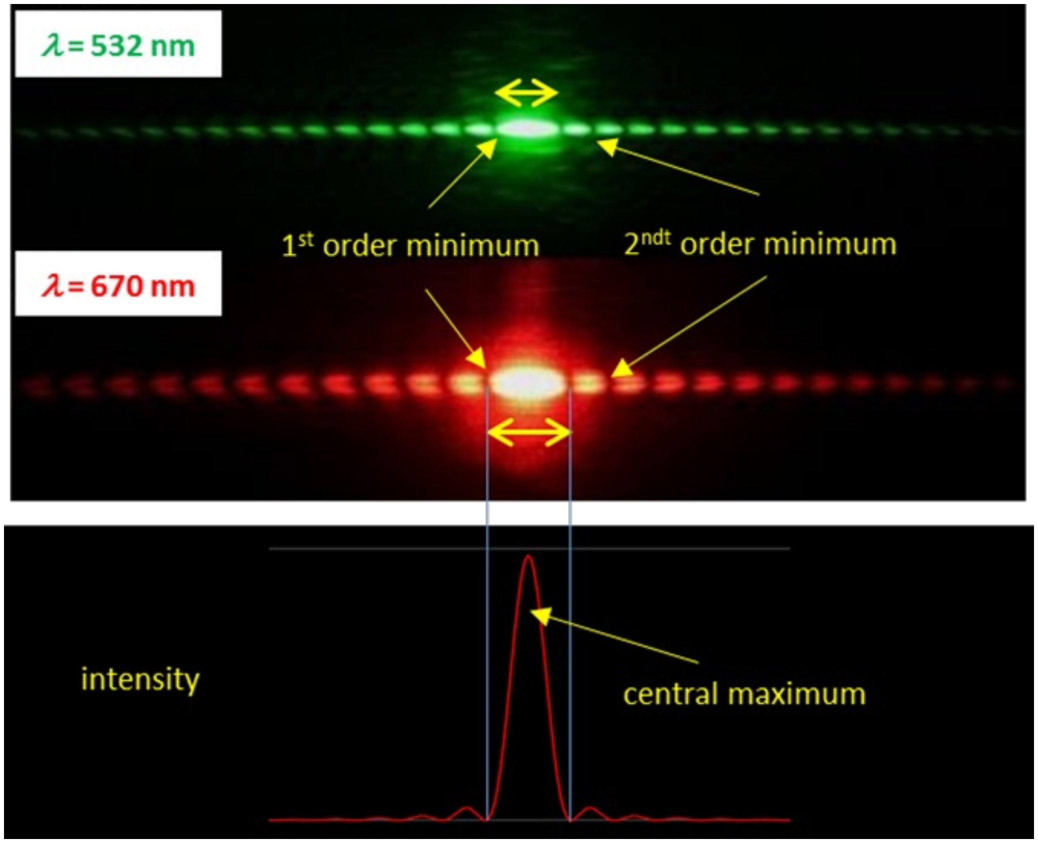
Studio Week 8
Interference of Light

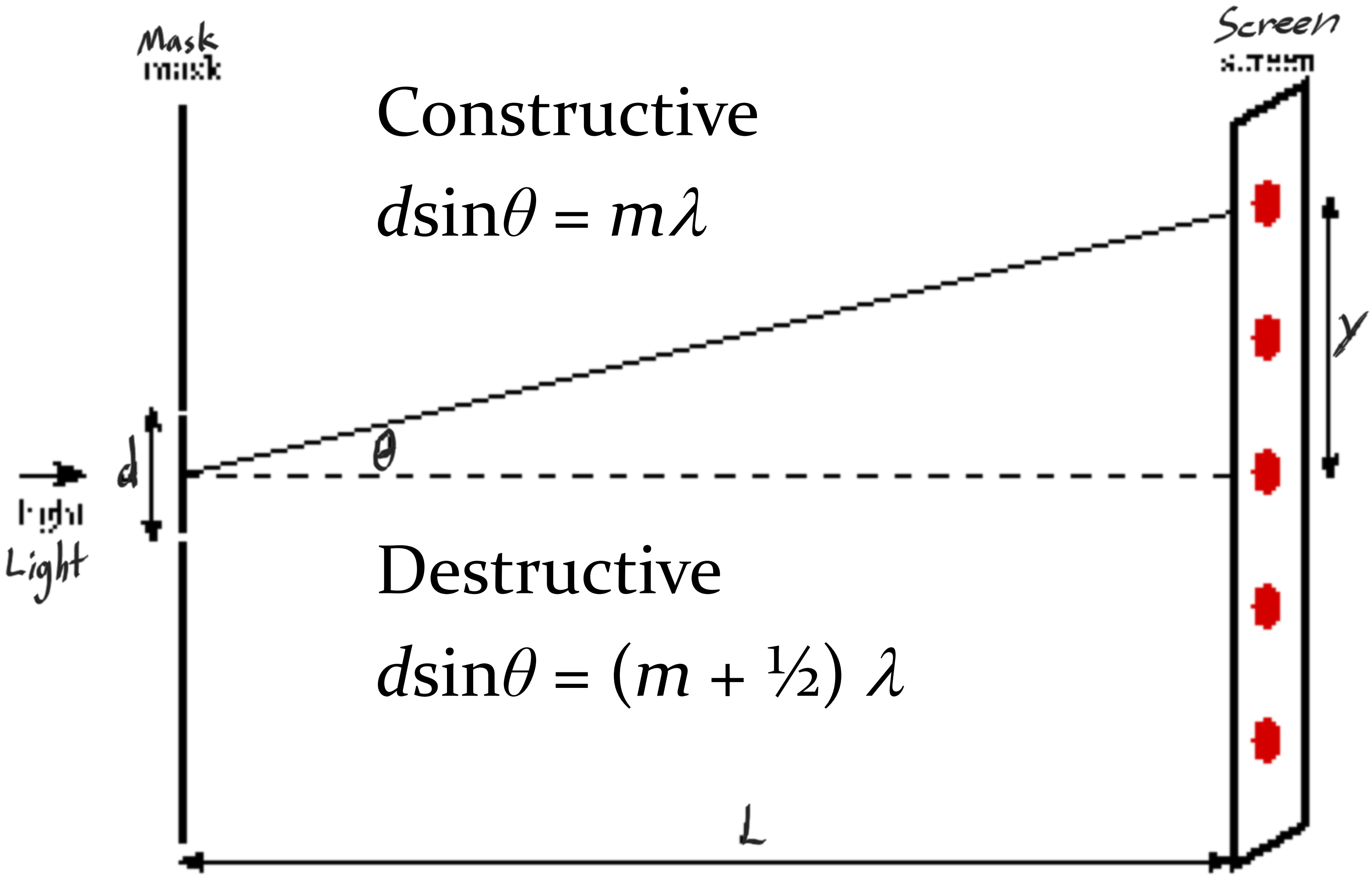


Picture credit:
http://www.physics.usyd.edu.au/teach_res/hsp/sp/mod31/m31_singleSlit.htm

Principles for Success

- **Treat everyone with respect.**
- **Learn by doing and questioning.**
- **Everything should make sense.**

Two-slit Interference



Constructive

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

Destructive

$$d\sin\theta = (m + ½)\, \lambda$$

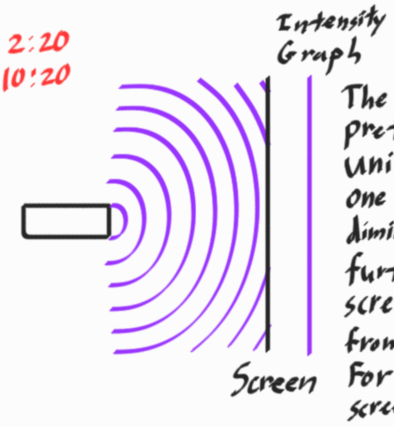
Activity 8-1

- Start the following simulation: https://phet.colorado.edu/en/simulation/wave-interference. Click on the Interference tab and then on the "laser" icon in the gray box. Turn on the light sources.
  A. Sketch a top-down diagram of what you see in the simulation.
  B. In your sketch, identify any lines of maximum constructive or destructive interference. How did you identify them?
  C. If you have not done so already, check the "screen" button. How does what you see on the screen compare to the lines of maximum constructive or destructive interference you identified?
  D. Try at least 5 different colors of light. If you measure the distance between the sources as a number of wavelengths, does this number of wavelengths *increase, decrease,* or *remain the same* when you increase the frequency. Explain your reasoning.
  E. Devise a qualitative rule for how the distance between bright spots on the screen depends on the *wavelength* of the light. (Recall that frequency and wavelength are related by the wave speed.)

8-1 Interference Simulation

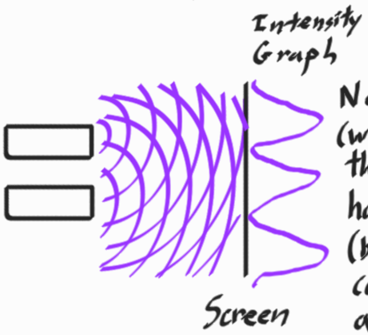
Wrap 2:20 10:20

An individual light creates waves like this:

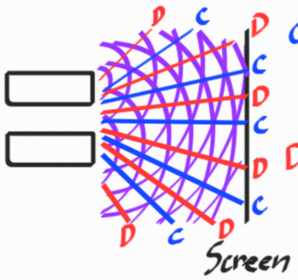


The intensity is pretty much uniform, though one might expect diminishing intensity further along the screen, farther from the laser. For this chunk of screen, however, the distance from the laser does not change much along its length.

Two lights create overlapping waves that interfere with each other:



Now, the intensity graph (which should be more symmetric than my drawing skills allowed) has areas of high intensity (bright fringes) where the waves constructively interfere, and areas of low intensity (dark fringes) where they destructively interfere.



Constructive Interference
— peaks align with peaks and troughs align with troughs
— aligns with bright fringes

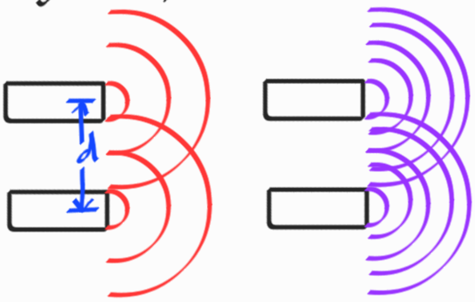
Destructive Interference
— peaks align with troughs
— aligns with dark fringes

Multiple Colors

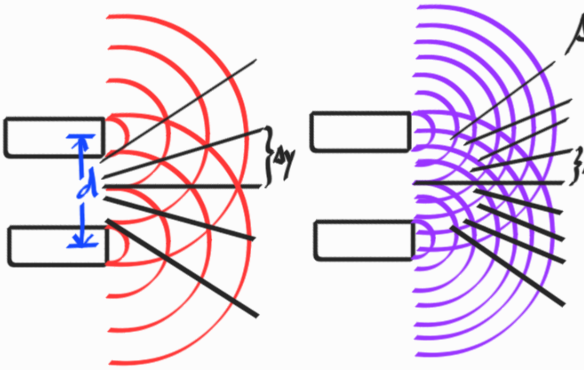
As frequency increases (going toward the purple end of the spectrum), wavelength decreases (as $v = \lambda f$, and v is a constant — the speed of light), so the number of wavelengths that can fit in the gap between the sources increases.

Example: The lowest frequency red light in the simulation has $\lambda \approx 770$ nm, and the highest frequency purple light has $\lambda \approx 390$ nm, nearly half as large. You can fit almost twice as many wavelengths between the sources using this purple light as you could with this red light.

Note: We ALWAYS measure the distance between sources (d) from center to center, no matter what poor choices I make when drawing.



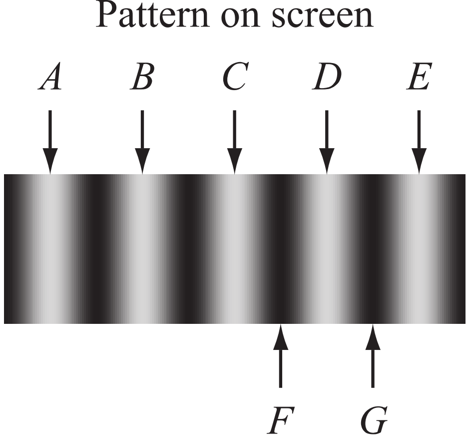
Distance Between Fringes

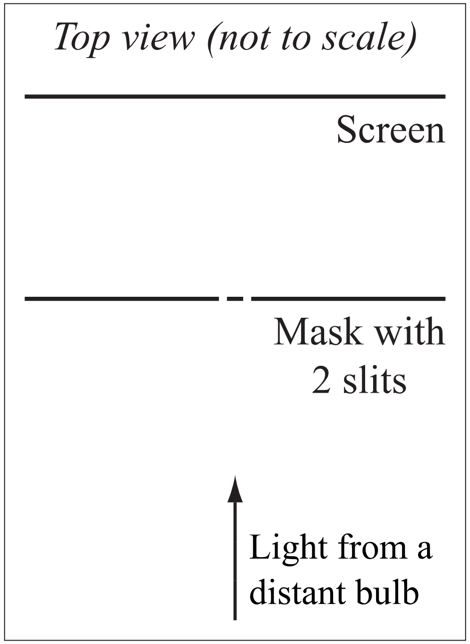


As λ decreases, there are more lines of constructive interference, and they are closer together, so the space between bright fringes decreases also.

Activity 8-2

- Red light from a distant point source is incident on a mask with two identical, very narrow vertical slits. The diagram illustrates the pattern that appears at the center of a distant screen.
- How is this pattern *different* from what you would predict using the ideas developed in ray optics (*e.g.*, light travels in straight lines through slits)?
- For each of the lettered points, determine ΔD (in terms of λ) and $\Delta\varphi$, the phase difference between the waves. *Note:* Point *C* is at the center of the screen.
- Suppose that one of the slits were covered. At which points would the brightness increase? At which points would it decrease?
- In each part below, suppose that a *single* change were made to the original apparatus. For each case, determine how, if at all, that change would affect the pattern on the screen. Sketch your predictions.
  - The distance between the slits is decreased (without changing the width of the slits).
  - The screen is moved closer to the mask containing the slits.
  - The wavelength of the incident light is decreased.
  - The width of each slit is decreased (without changing the distance between the slits).



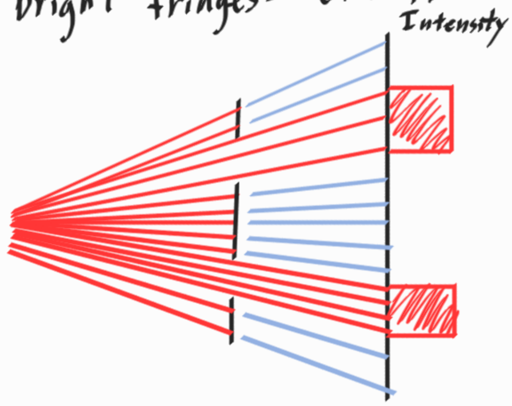


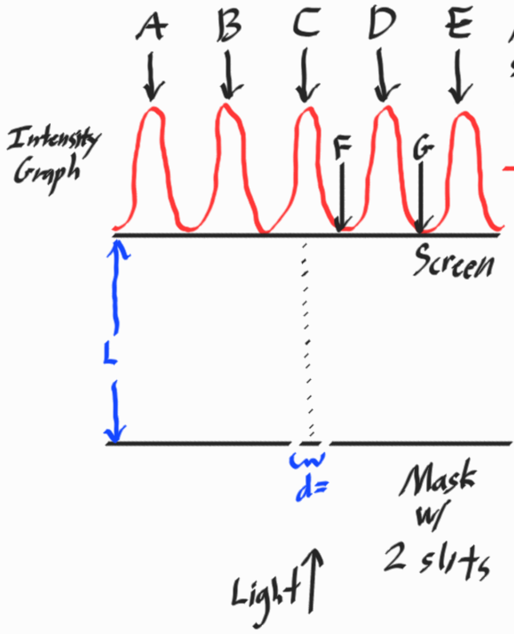
8-2 Double-Slit Interference

start 2:30 10:30
wrap 2:45 10:45

Difference from Ray Optics

A ray does not spread, and they do not interfere with each other, so we would expect to see two bright fringes—one from each slit.





Cover One Slit?

As we saw in the simulation, the intensity is about uniform for a single slit.

The bright spots would dim and the dark spots would brighten if you covered one slit. Not only has half of the transmitted light energy been blocked, but the remaining energy that had been concentrated in the bright spots must be spread over the entire area.

Path Length and Phase Difference

Constructive interference occurs when waves are in-phase, meaning the peaks line up (so ΔD must be an integer multiple of λ) and the phase difference is a multiple of 2π.

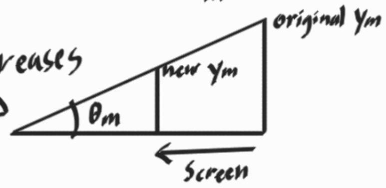
Destructive interference occurs when waves are out of phase, so peaks line up with troughs (so ΔD must be a half-integer multiple of λ) and the phase difference is an odd multiple of π.

Constructive	Destructive	ΔD	$\Delta \phi$
A		2λ	4π
B		λ	2π
C (center)		0	0
	F	$\lambda/2$	π
D		λ	2π
	G	$3\lambda/2$	3π
E		2λ	4π

$d \sin \theta_m = m\lambda$

d decreases $\Rightarrow$ θ_m increases ($m\lambda$ constant for each m) $\Rightarrow$ fringes spreads out

L decreases $\Rightarrow$

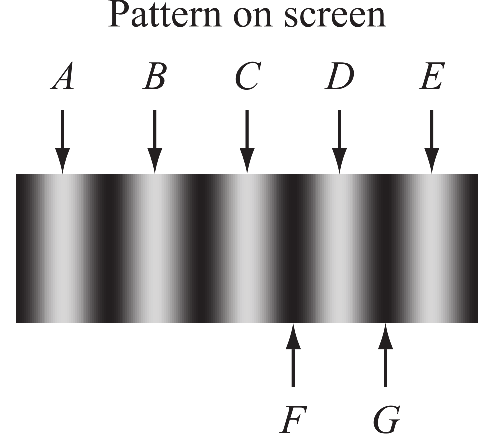


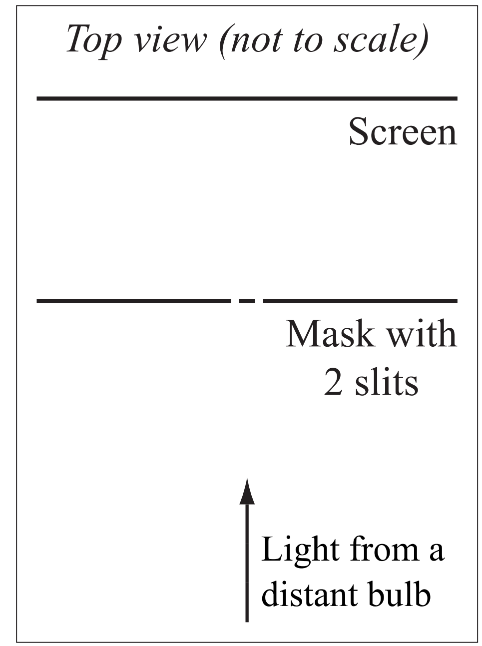
$\Rightarrow$ y_m decreases $\Rightarrow$ fringes get closer together (θ_m the same)

λ decreases $\Rightarrow$ θ_m decreases (d and m fixed) $\Rightarrow$ fringes get closer together

Slit width does not affect interference (note that it does not appear in the equation), though if it gets small enough, we will need to account for the effects of diffraction, an upcoming topic.

Activity 8-3



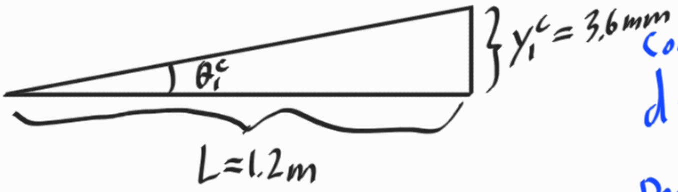


- Red light from a distant point source is incident on a mask with two identical, very narrow vertical slits. The diagram illustrates the pattern that appears at the center of a distant screen.
- Consider point *B*, the first maximum to the left of the center of the screen. Suppose that the two slits are separated by 0.2 mm, that the screen is 1.2 m away from the slits, and that the distance from the center of the pattern (point *C*) to point *B* is 3.6 mm. Use this information to determine the wavelength of the light.
- Determine the location of point *G*, the second minimum to the right of the center of the screen.

8-3 Behind the Mask of Shadow

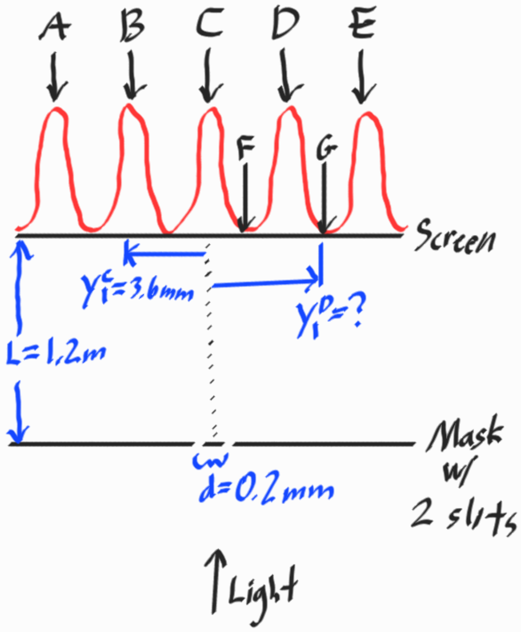
start 3:05 11:05
wrap 3:15 11:15

First, note that $3.6\text{ mm} \ll 1.2\text{ m}$.



Constructive:
$$d\sin\theta_m^C = m\lambda$$

Destructive:
$$d\sin\theta_m^D = (m+\tfrac{1}{2}\lambda)$$



Therefore, the small angle approximation is certainly appropriate:

$$\theta \simeq \sin\theta \simeq \tan\theta$$

Therefore, $d\sin\theta_m \simeq d\tan\theta_m = d\frac{y_m}{L}$

At point B, the first bright fringe $(m=1)$, we have

$$\lambda \approx d\frac{y_1^c}{L} = (0.2\text{ mm})\frac{0.0036\cancel{\text{m}}}{1.2\cancel{\text{m}}} = 0.0006\text{ mm} = 600\text{nm}$$

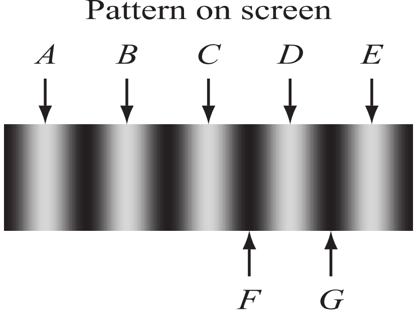
At point G, the second dark fringe (also $m=1$, since the first dark fringe was at $m=0$), we can go through this process in reverse:

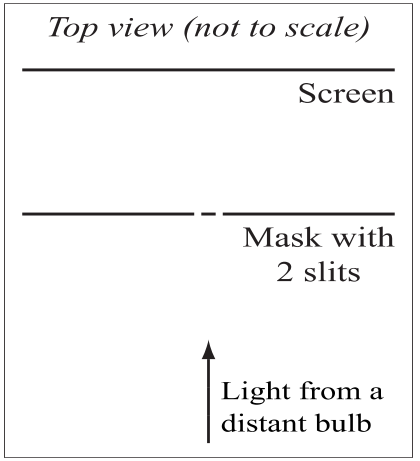
$$\frac{3}{2}\lambda = \underbrace{(1}_{m=1}+\tfrac{1}{2})\lambda \approx d\frac{y_1^D}{L} \Rightarrow y_1^D = \frac{3}{2}\frac{\lambda}{d}L = \frac{3}{2}\frac{0.0006\cancel{\text{mm}}}{0.2\cancel{\text{mm}}}1.2\text{m} = 0.0054\text{m}$$
$$= 5.4\text{ mm}$$

However, we don't really need to know λ to find this out:

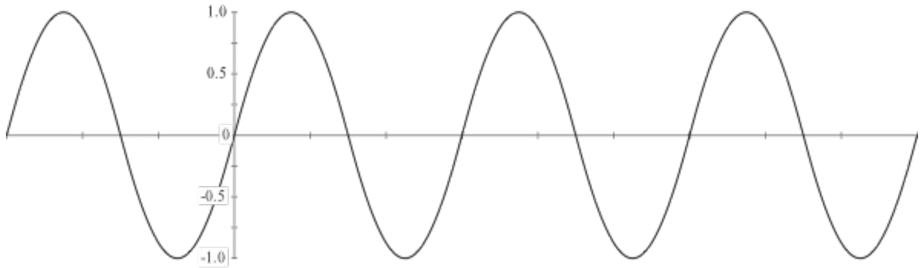
$$\left.\begin{array}{l} \lambda \approx d\frac{y_1^c}{L} \\ \frac{3}{2}\lambda \approx d\frac{y_1^D}{L} \end{array}\right\} \Rightarrow \frac{y_1^D}{y_1^c} \approx \frac{\frac{3}{2}\cancel{\lambda\frac{L}{d}}}{\cancel{\lambda\frac{L}{d}}} = \frac{3}{2} \Rightarrow y_1^D \approx \frac{3}{2}y_1^c = \frac{3}{2}(3.6\text{ mm}) = 5.4\text{mm}$$

Activity 8-4





- Below is a graph that represents the light from the left slit. Draw a second graph so the transverse displacements add in a way that represents the two light waves at point *B*.
  - Indicate the phase difference between these two waves.
- Now draw a second graph so that the transverse displacements of the two graphs add in a way that represents the two light waves at point *G*.
  - Indicate the phase difference between these two waves.
- Suppose you had a mask with *three* slits instead of two.
  - Find a way to draw *two* additional graphs so that the transverse displacements of the three graphs add in a way that results in maximum constructive interference for all three graphs.
  - Find a way to draw *two* additional graphs so that the transverse displacements of the three graphs add in a way that results in complete destructive interference for all three graphs.
- What do you think happens if you have more than three slits?



8-4 Multi-Slit Interference

Start 3:25 11:25

Wrap 3:40 11:40

Do NOT write on handouts!

Two Slits

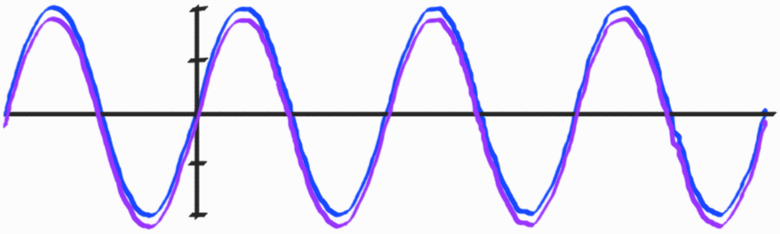
Left Right

B

Constructive

$\Delta\phi = 0$

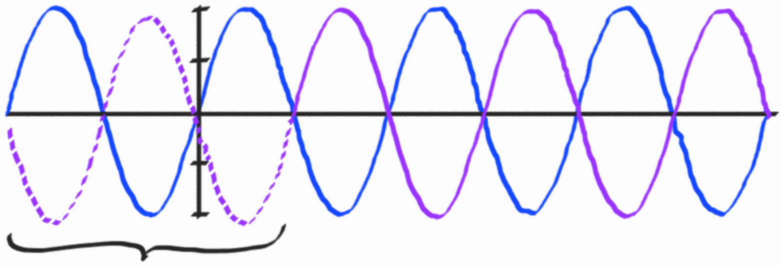
$\Delta D = 0$



G

Destructive

$\Delta\phi = 3\pi$



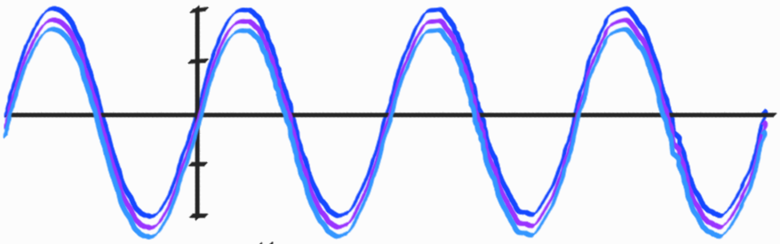
$\Delta D = \frac{3}{2}\lambda$

Three Slits

Left Middle Right

Constructive

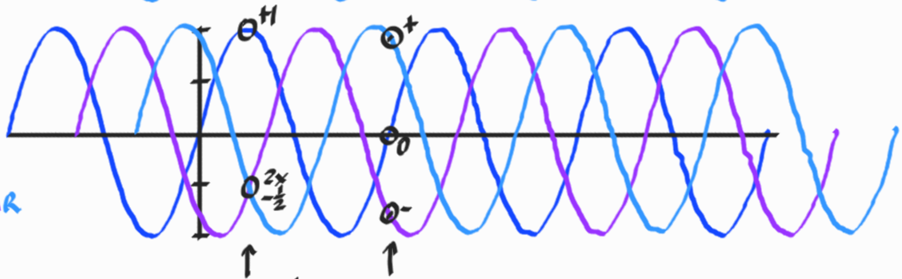
$\Delta\phi = 0$



Destructive

$\Delta\phi_{LM} = \frac{2}{3}\pi = \Delta\phi_{MR}$

$\Delta\phi_{LR} = \frac{4}{3}\pi$

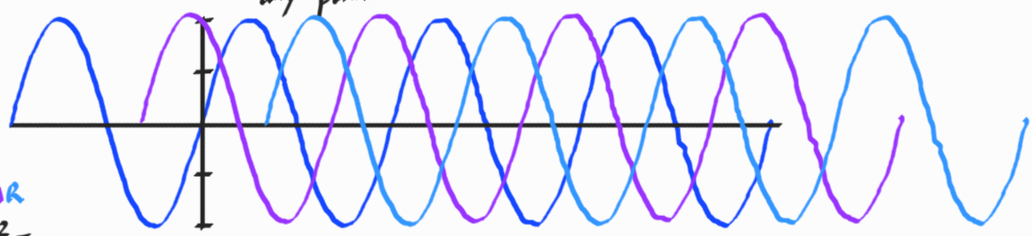


All three add to zero at any point.

Destructive

$\Delta\phi_{LM} = \frac{4}{3}\pi = \Delta\phi_{MR}$

$\Delta\phi_{LR} = \frac{8}{3}\pi = 2\pi + \frac{2}{3}\pi$



More (n) Slits

Pattern: Destructive interference can happen when each adjacent pair of slits has a phase difference equal to an integer multiple of $\frac{2\pi}{n}$ (except when the integer is n, because $n\frac{2\pi}{n} = 2\pi$ gives constructive interference.

In effect, more slits mean more places where perfect destructive interference can occur, so the bright spots get better defined and more isolated.