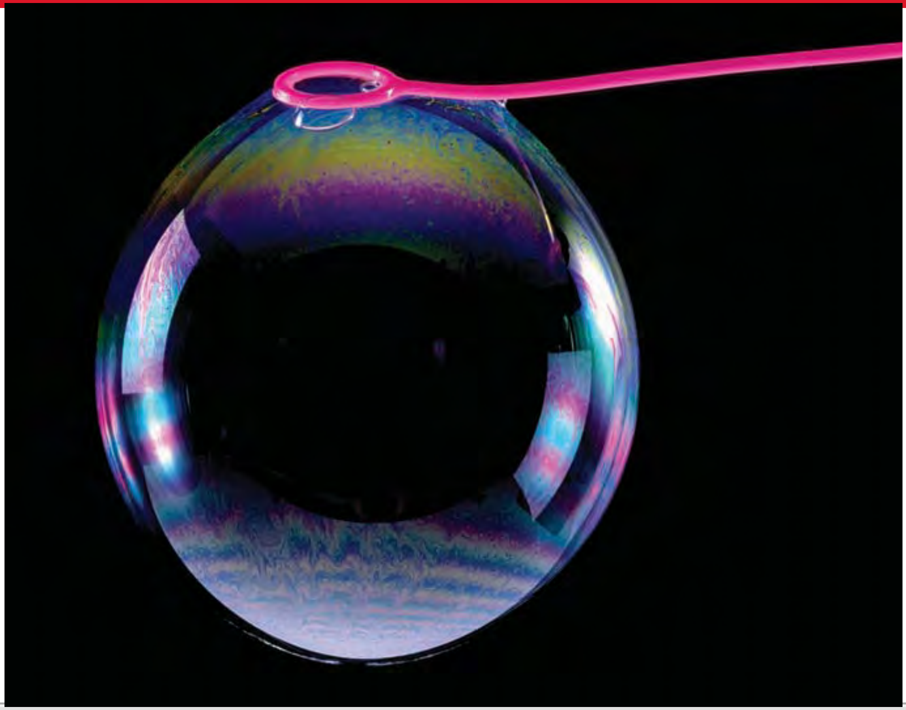
Electricity & Magnetism Lecture ?

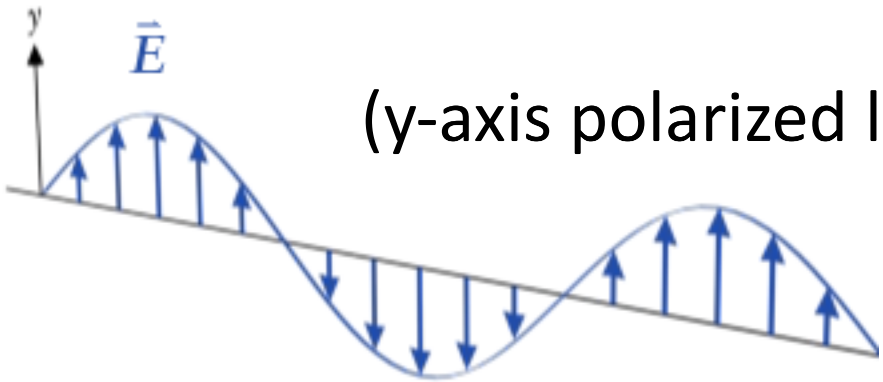
Today's Concepts:

- -Polarization
- -Interference
- -Diffraction

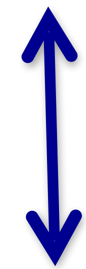


Polarization

The direction of the of the electric field of light gives the polarization angle of light.



(y-axis polarized light)



(unpolarized light)

Most light comes unpolarized

(a mix of all directions of polarization)

Linear Polarization

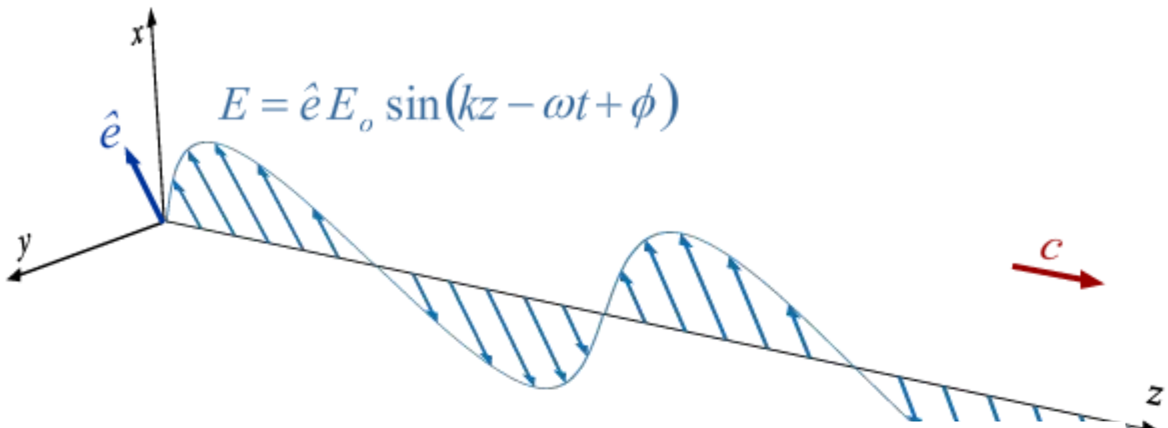
$\hat{e}$ is a unit vector. For example: if θ is 45° $\hat{e} = \dfrac{\hat{i} + \hat{j}}{\sqrt{2}}$

$$\omega = kc$$

$$E_o = cB_o$$

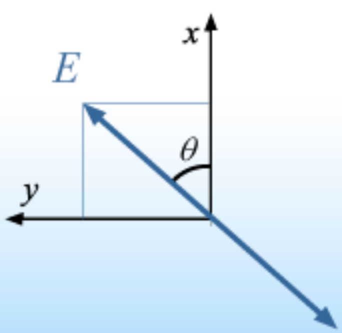
$$c = \frac{1}{\sqrt{\mu_o \varepsilon_o}}$$

$$E = \hat{e} E_o \sin(kz - \omega t + \phi)$$



$$E_x = E_o \cos\theta \sin(kz - \omega t + \phi)$$

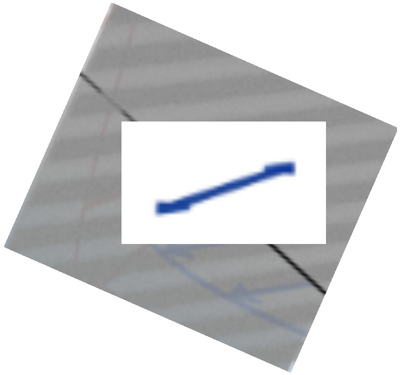
$$E_y = E_o \sin\theta \sin(kz - \omega t + \phi)$$



Wave Coming Out of the Screen

Polarizing Filter

Polarizing filters select only component of light that has **E** in the direction of the transmission axis of the filter



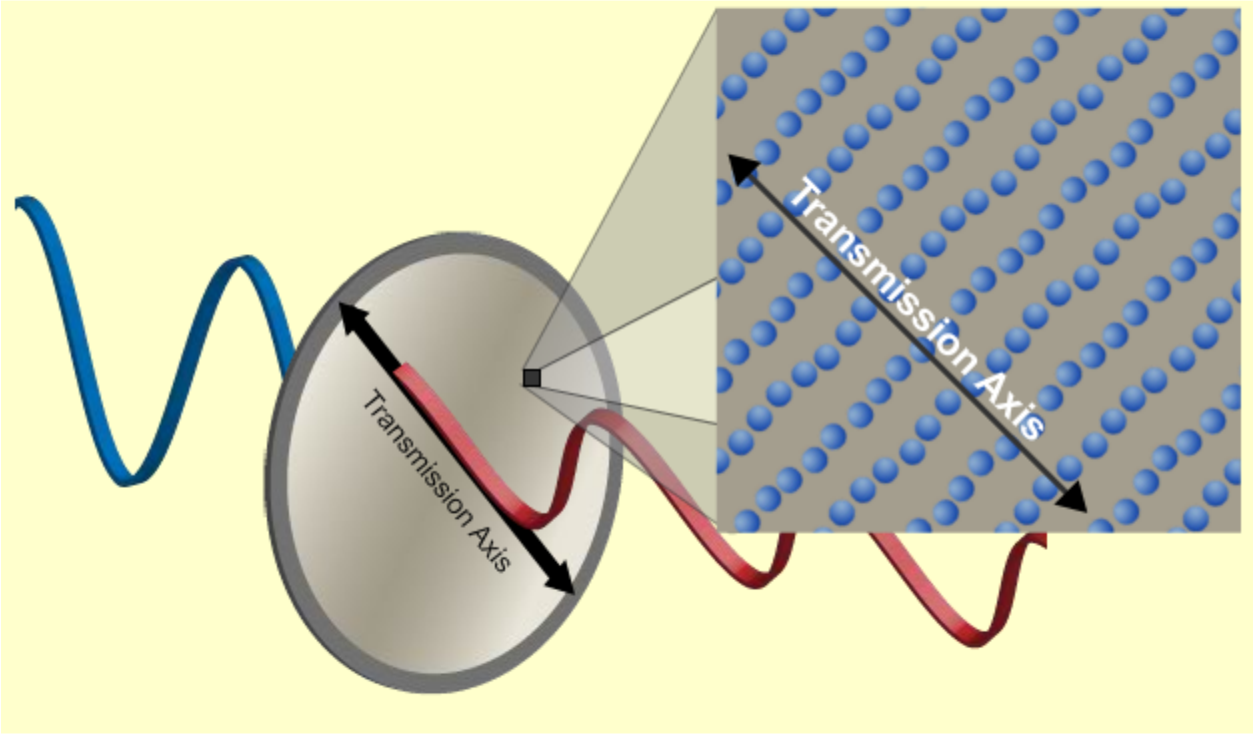
Also reduces the amplitude of the electric field…

$$E_f = E_0 \cos\theta$$

…and the intensity of light

$$I_f = I_0 \cos^2\theta$$

Polarizer



The molecular structure of a polarizer causes the component of the E field perpendicular to the Transmission Axis to be absorbed.

Bridge Question 1a

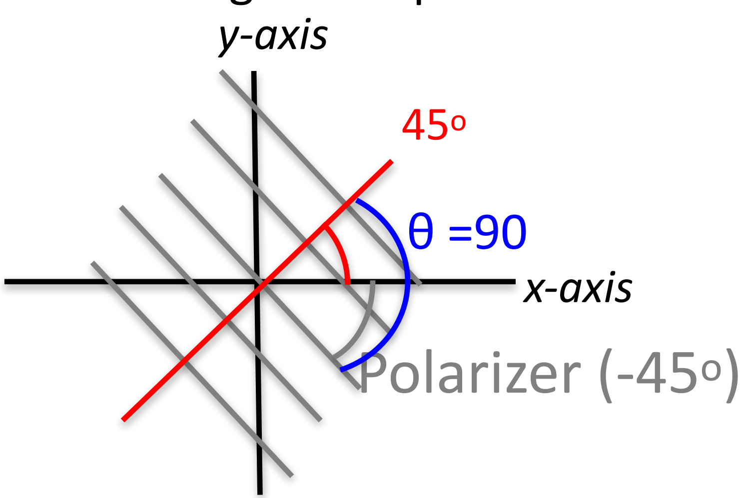
1. A beam of light is directed at a linear polarizing filter that has a transmission direction of 45° relative to the x-axis. In which case is the fraction of the original light intensity reduced to a minimum?
   - A. Case 1: Incident light is polarized parallel to the x-axis.
   - B. Case 2: Incident light is polarized at -45° relative to the x-axis.
   - C. Case 3: Incident light is unpolarized.

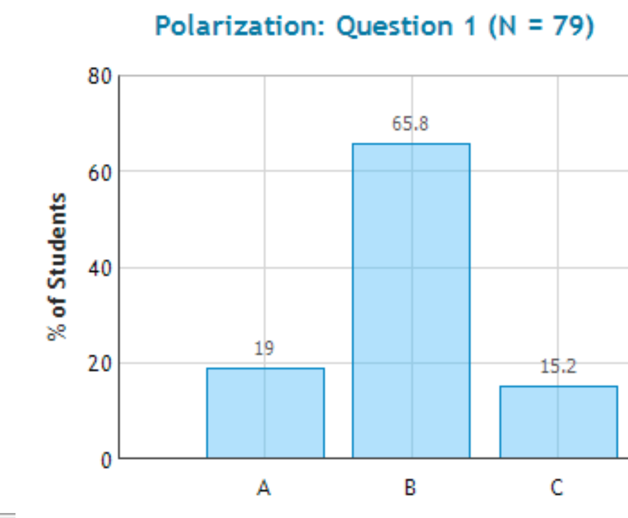
$$E_f = E_0 \cos(\theta)$$

$$E_f = E_0 \cos(90)$$

$$E_f = 0$$

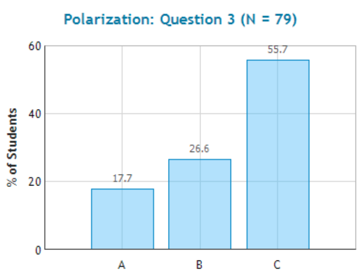
No light gets through!





Bridge Question 1b

1. Unpolarized light is directed at three pairs of linear polarizing filters. The intensity of light directed at each pair is the same. Which pair transmits the minimum intensity of light?



		First polarizing filter	Second polarizing filter
A)	Pair 1	Transmission axis parallel to the vertical direction	Transmission axis at 30° with respect to the vertical direction
B)	Pair 2	Transmission axis at 45° with respect to the vertical direction	Transmission axis at 45° with respect to the vertical direction
C)	Pair 3	Transmission axis at 30° with respect to the vertical direction	Transmission axis at -60° with respect to the vertical direction

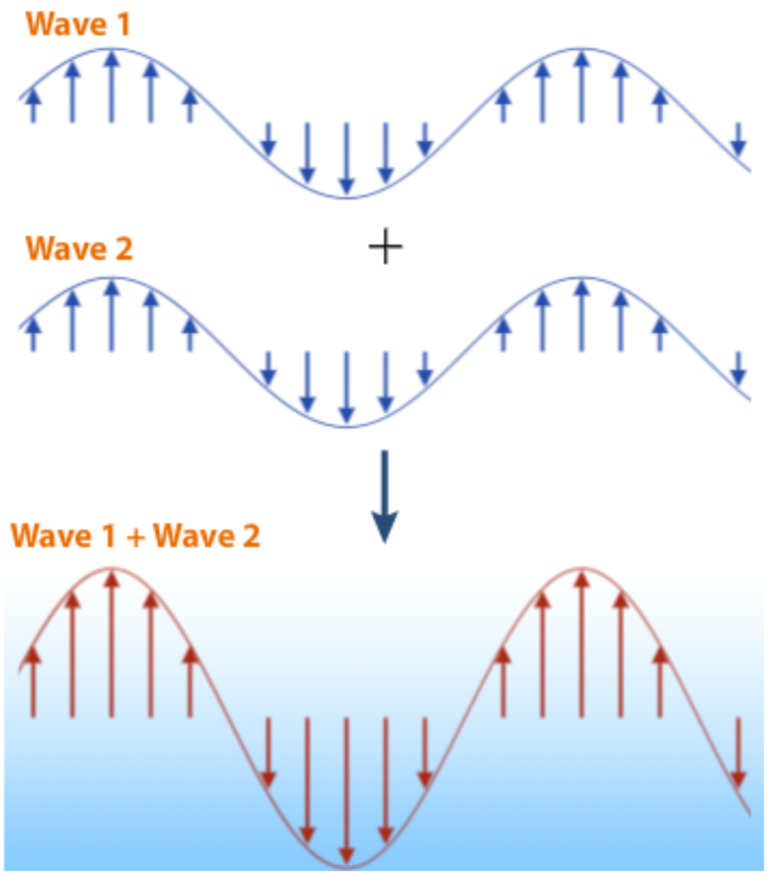
$E_f = E_0 \cos(\theta)$

Need the two filters to be at 90° from one another for minimum

Thin Film Interference

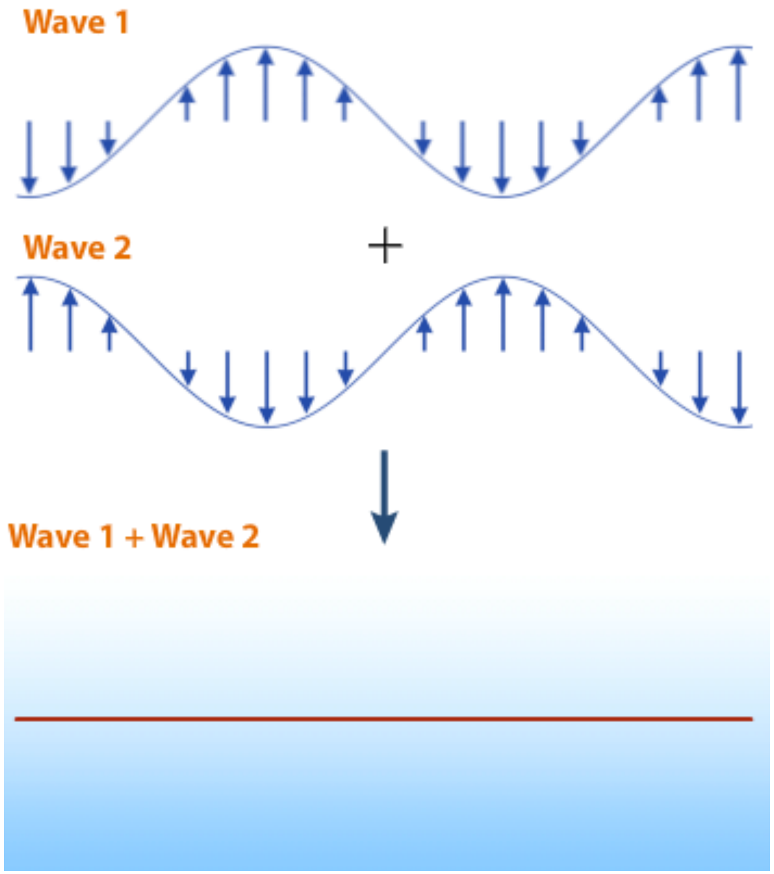
Interference

Constructive Interference



Two waves align, and the peaks add to make a larger amplitude wave

Destructive Interference



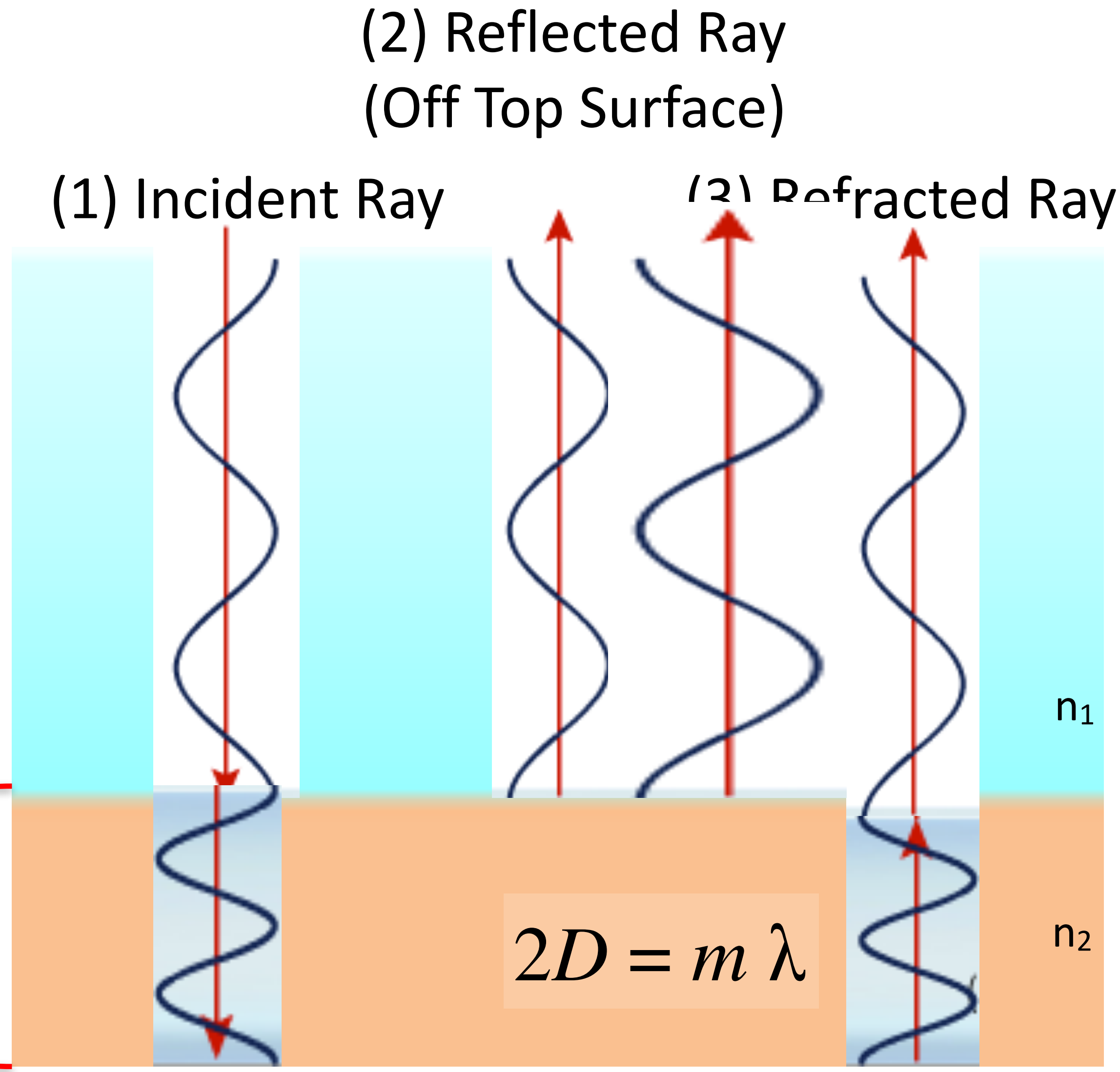
Two waves anti-align and add to zero amplitude

Thin Film Interference

(1) Beam Travels in

(2) Beam reflects off of top surface

(3) Beam reflects off of bottom surface



If the total film is the thickness of an integer number of wavelengths…

$$2D = m\,\lambda$$

…Constructive Interference!

$$m = 1, 2, 3\ldots$$

Thin Film Interference

(2) Reflected Ray
(Off Top Surface)

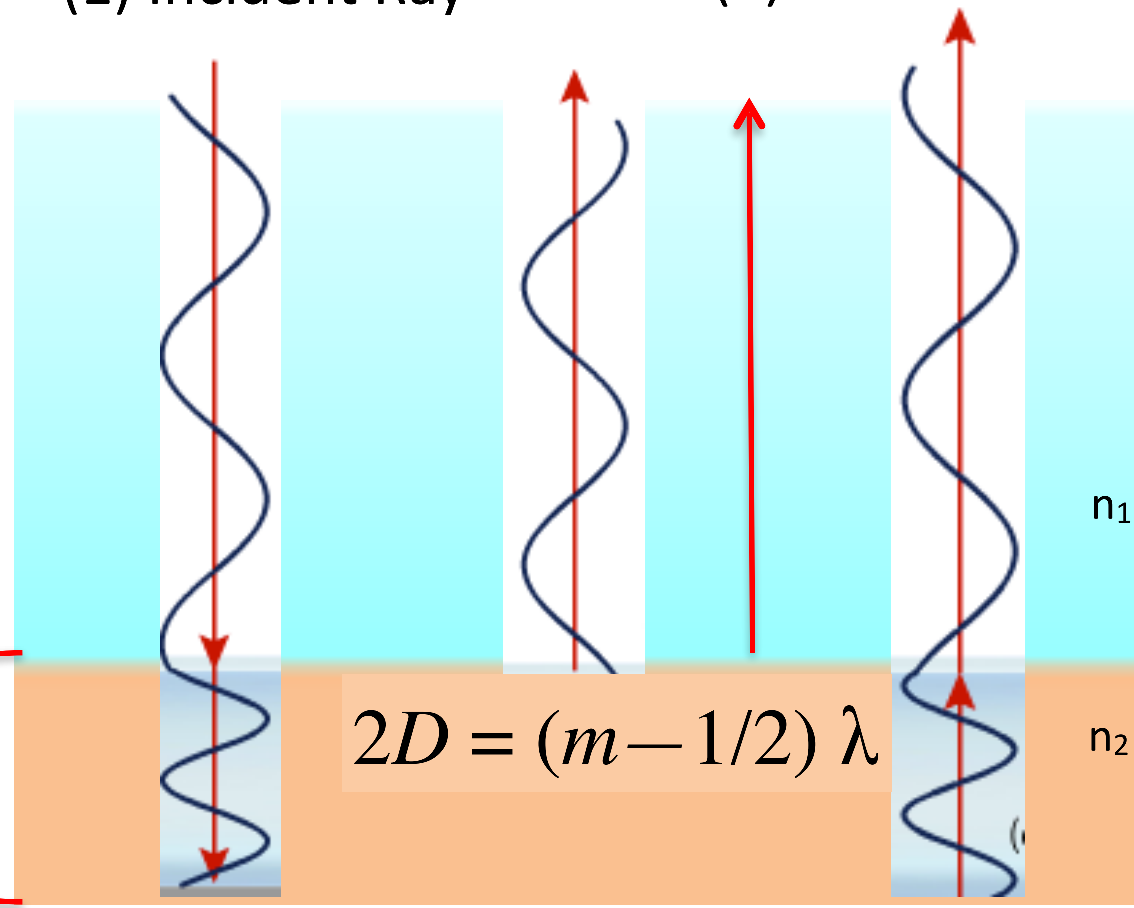
(1) Incident Ray

(3) Refracted Ray

(1) Beam Travels in

(2) Beam reflects off of top surface

(3) Beam reflects off of bottom surface



If the total film is the thickness of an integer number of wavelengths plus ½ wavelength…

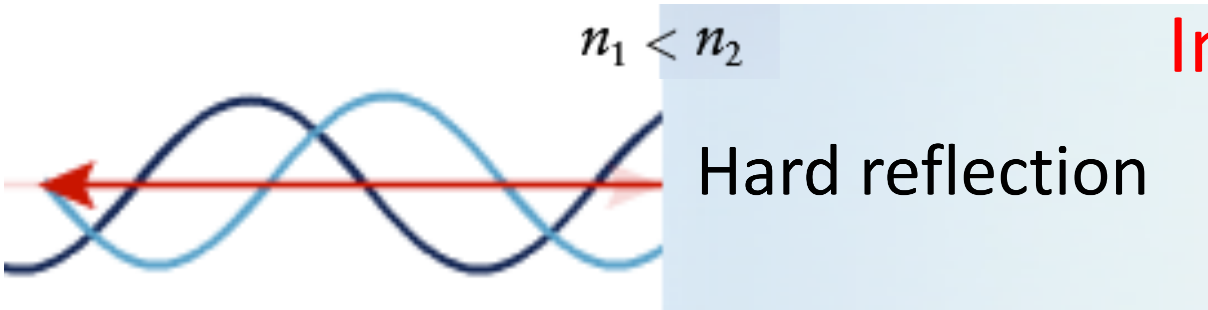
$$2D = (m - 1/2)\,\lambda$$

…Destructive Interference!

$$m = 1, 2, 3 \ldots$$

Different Reflections

If reflection hits a higher *n* surface:

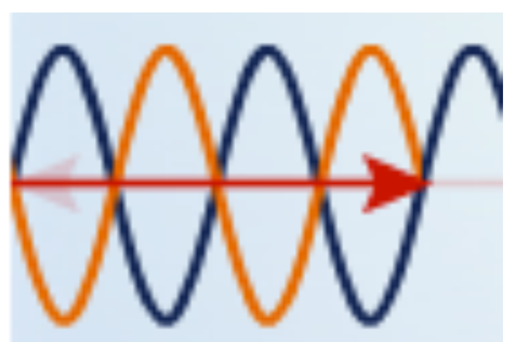


Inverts phase of the wave

If reflection hits a lower *n* surface:

$n_1 > n_2$

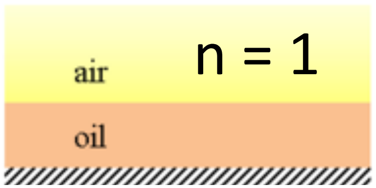
Soft Reflection



Does not invert the phase of the wave

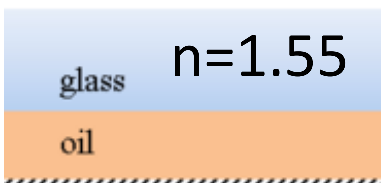
Bridge Question 2

A beam of green light illuminates a thin film of oil (n_{oil} = 1.47). The thin film is deposited on an opaque surface. In all cases, consider only the reflections at the boundaries with oil. In which case is green light strongly reflected off the thin film of oil?



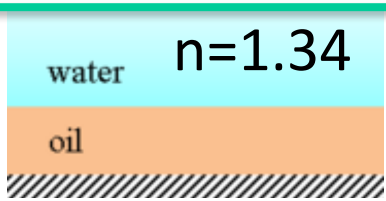
Case A

Thin film thickness = ¼ λ_{in_oil}



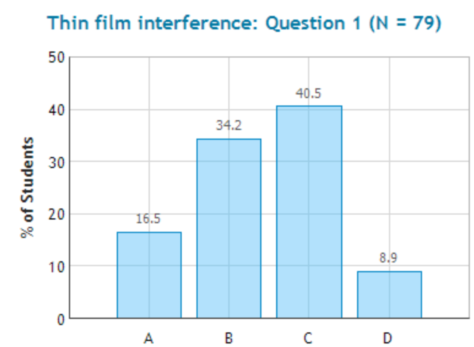
Case B

Thin film thickness = ½ λ_{in_oil}



Case C

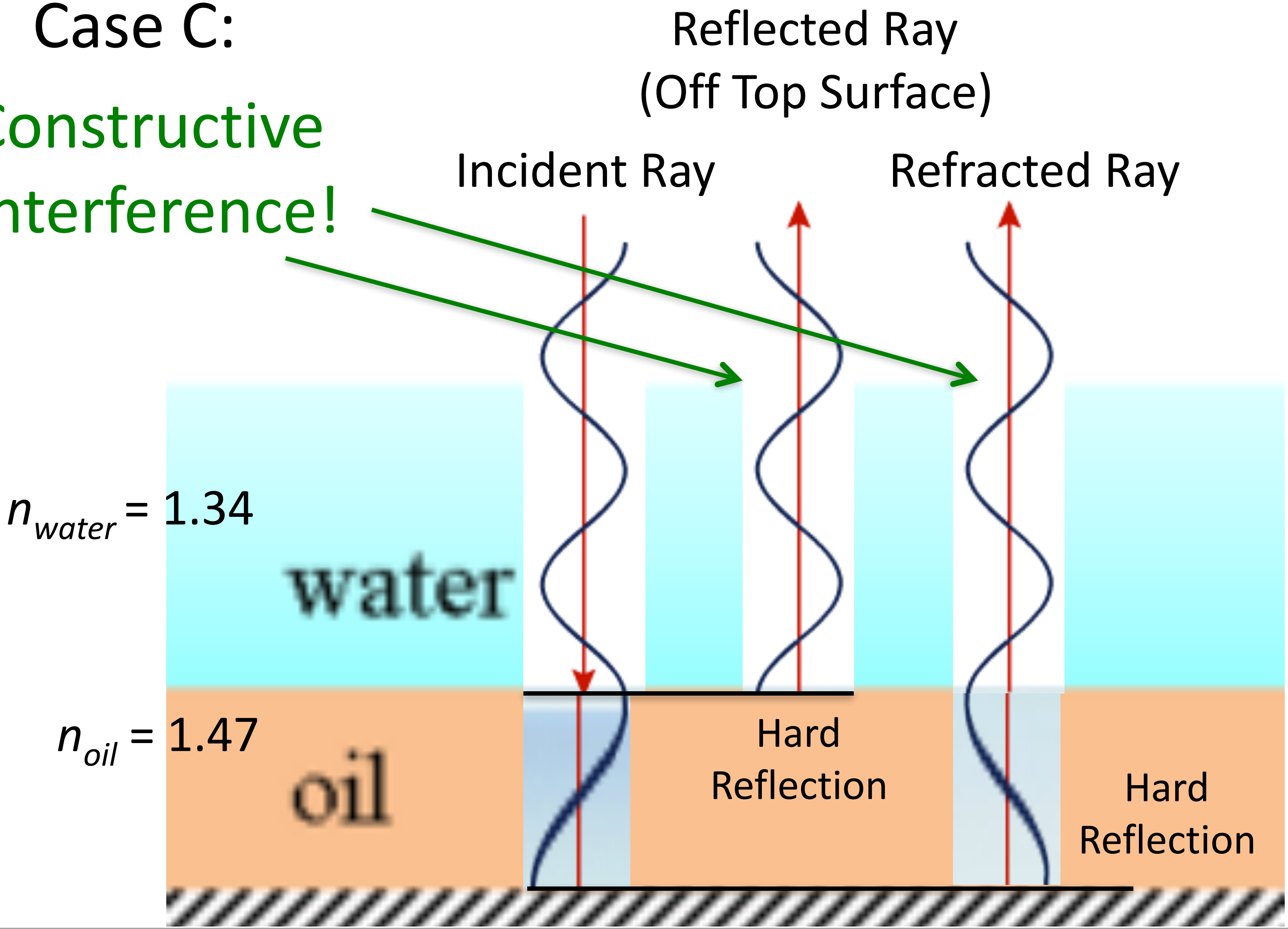
Thin film thickness = ½ λ_{in_oil}



Bridge Question 2 Explanation

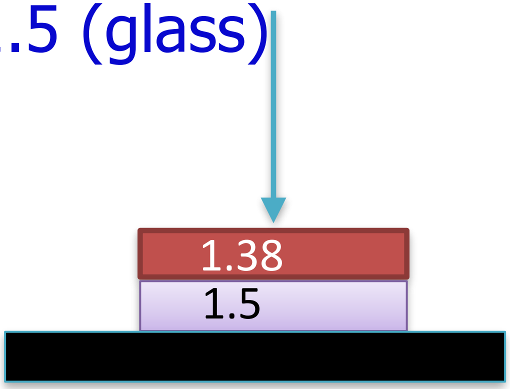
Case C:

Constructive Interference!



Example of Thin Film Interference

Let λ = 500 n_1 = 1.38 (MgF2) n_2 = 1.5 (glass)



$$\lambda_{1.38} = \frac{500}{1.38} = 362.3\,\text{nm}$$

Max intensity $d = \frac{1}{2} m \lambda_{1.38} = 181\,\text{nm}, 362\,\text{nm}, 543\,\text{nm}, \ldots$

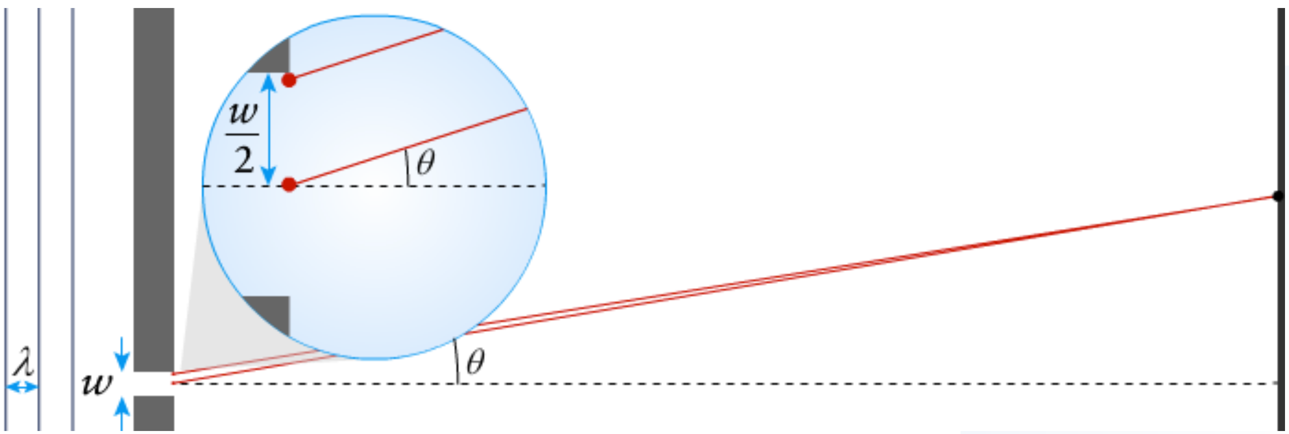
Min intensity $d = \frac{1}{2}\left(m + \frac{1}{2}\right)\lambda_{1.38} = 90.6\,\text{nm}, 272\,\text{nm}, 453\,\text{nm}, \ldots$

Must be careful about phase shift at boundary:

- Reflection for $n_{in} < n_{out}$ has ½ λ phase shift, 0 if $n_{in} > n_{out}$
- Since $n_0 < n_1$ and $n_1 < n_2$, the phase shift has no effect here
- But for other cases, there can be an extra ½ λ phase shift

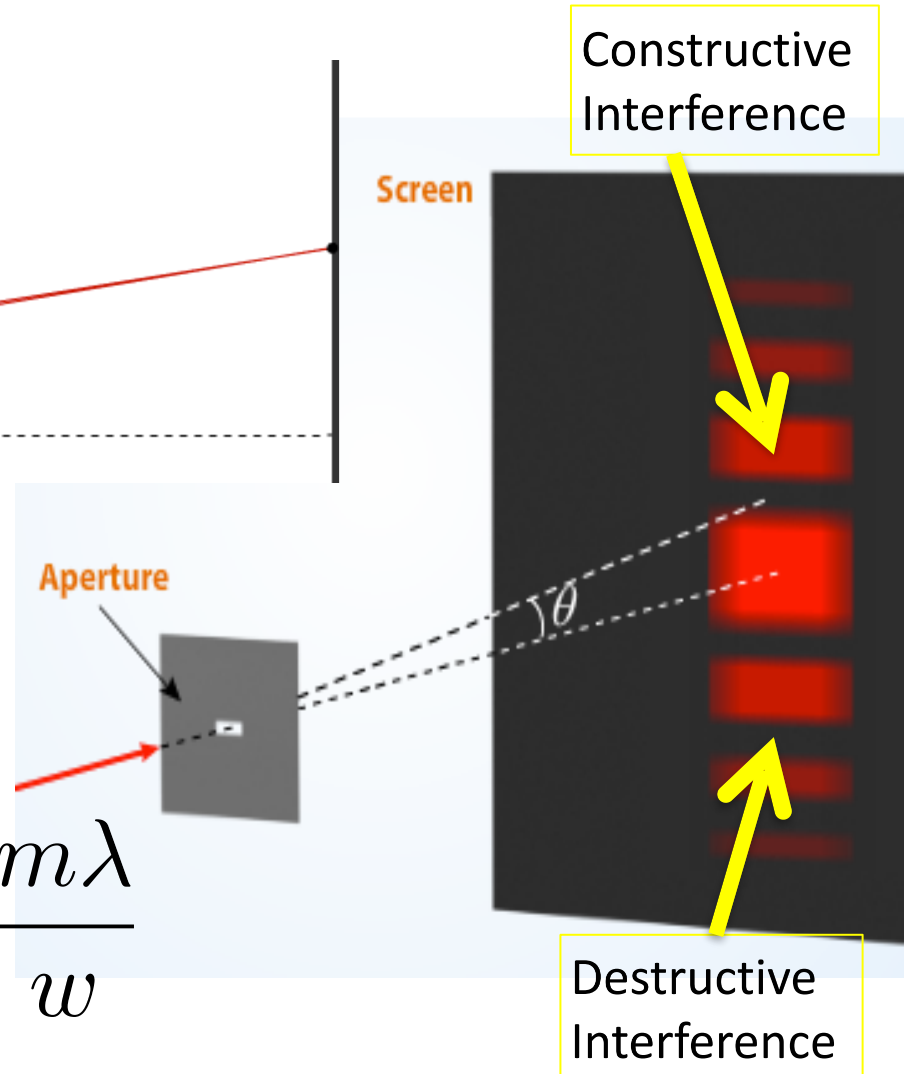
Diffraction

As light goes through a slit it spreads out like a wave



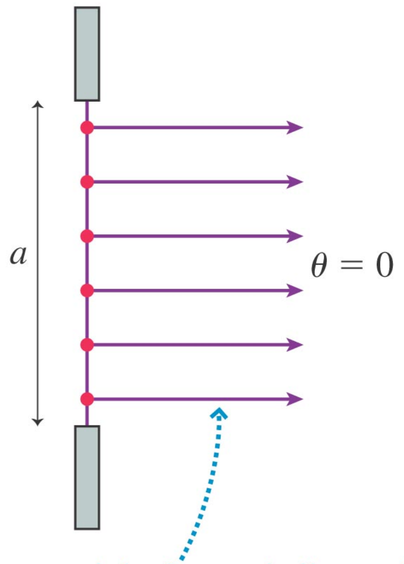
Light from different parts of the slit interfere to create interference patterns

Angle of dark fringes: $$\sin\theta = \frac{m\lambda}{w}$$



Single Slit

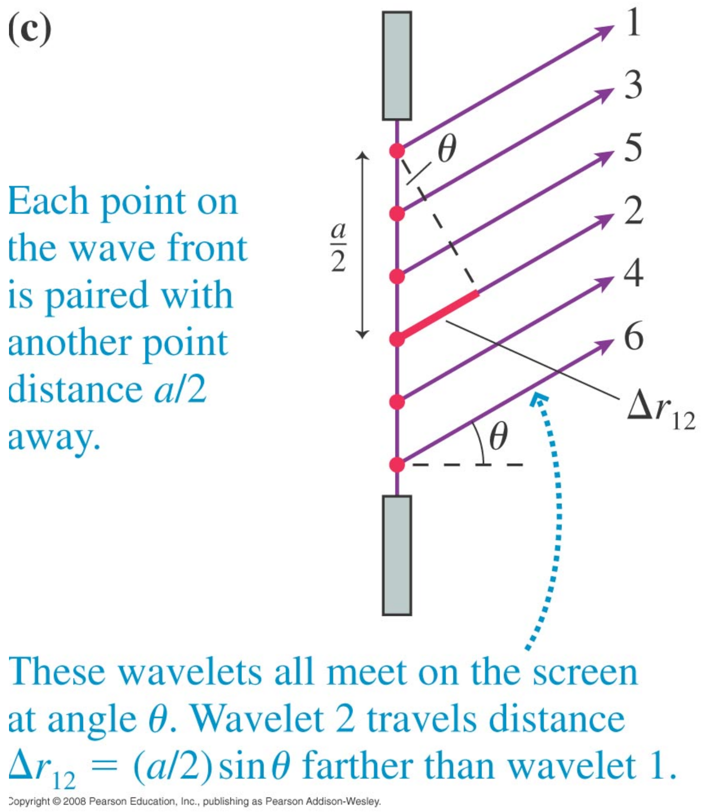
(b)



The wavelets going straight forward all travel the same distance to the screen. Thus they arrive in phase and interfere constructively to produce the central maximum.

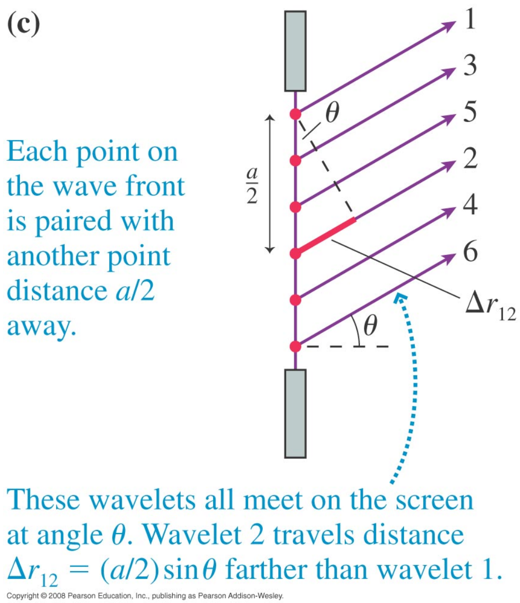
- Wavelets from any part of the slit have to travel approximately the same distance to reach the center of the screen.
- A set of in-phase wavelets therefore produce constructive interference at the center of the screen.

Single Slit



- Consider the path-lengths well away from the centre axis
- For any wavelet it is possible to find a partner which is $a/2$ away.
- If the path difference between partners happens to be $\lambda/2$ then this pair will create total destructive intereference. A dark band will be created.
- For any given wavelength there will be an angle for which this condition is true! There will always be dark bands, as long as a is greater than λ and the slit is narrow.

Single Slit



- The path difference between 1 and 2 is

$$\Delta r_{12} = \frac{a}{2}\sin\theta_1 = \frac{\lambda}{2}$$

- What about the other angles for destructive interference? The general formula becomes

$$a\sin\theta_p = p\lambda, p = 1, 2, 3, \ldots$$

The small angle approximation means we can write

$$\theta_p = p\frac{\lambda}{a}, p = 1, 2, 3, \ldots$$

- But if a is small then θ_p is large and the small angle approximation is not valid.

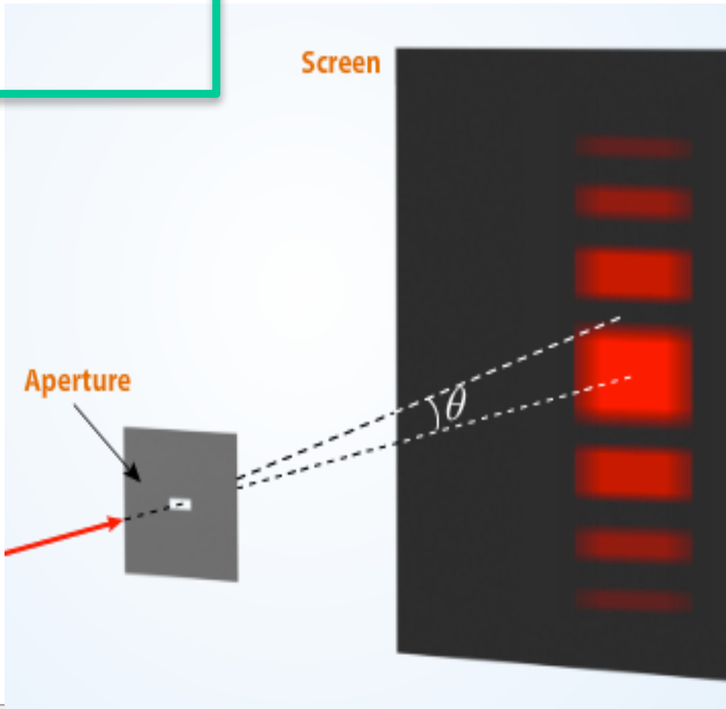
Question

A beam of monochromatic light is aimed at a slit of width *w* and forms a diffraction pattern. In which case is the width of the central band **smaller**?

A. When the slit is wider

B. When the slit is narrower

C. Same in both cases



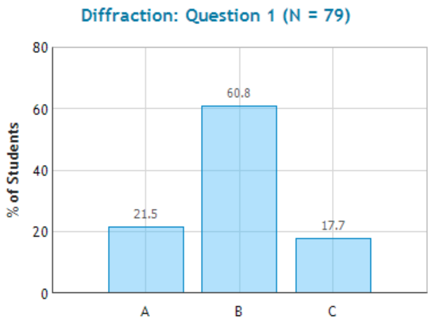
Bridge Question 3a

A beam of monochromatic light is aimed at a slit of width *w* and forms a diffraction pattern. In which case is the width of the central band **greater**?

A. When the incident light is blue

B. When the incident light is yellow

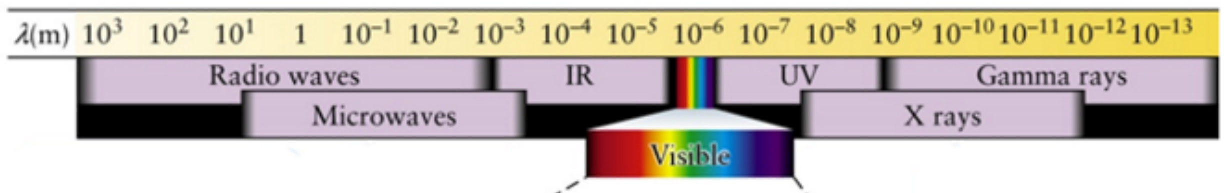
C. Same in both cases, blue and yellow



The larger width of the central band, the larger the angle

$$\uparrow \sin\theta = \frac{m\lambda}{w} \uparrow$$

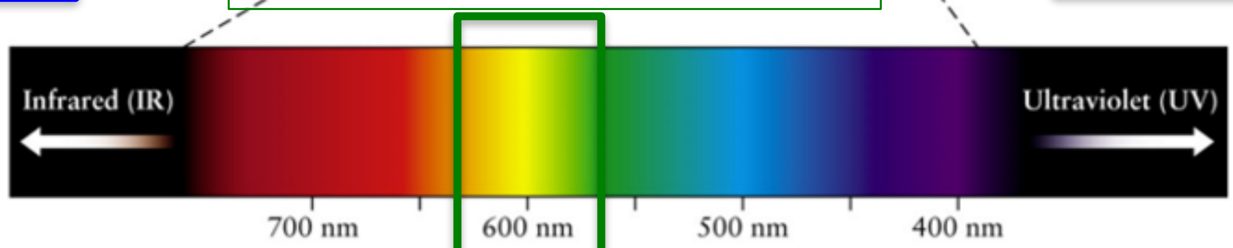
The larger the angle, the longer the wavelength!



Low Frequency
Long Wavelength

Answer B: Yellow Light, Longer Wavelength!

High Frequency
Short Wavelength



Bridge Question 3b

1. Beams of blue and yellow light are both aimed at the same slit of width *w* at the same time. Which of the following features of the diffraction pattern changes relative to the single monochromatic beam case?

   A. Color of the central bright fringe only

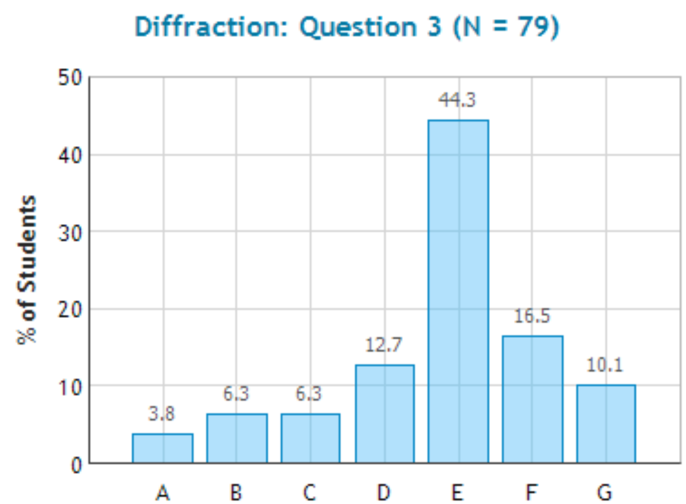
   B. Color of all bright fringes

   C. Location of dark fringes

   D. A, B and C

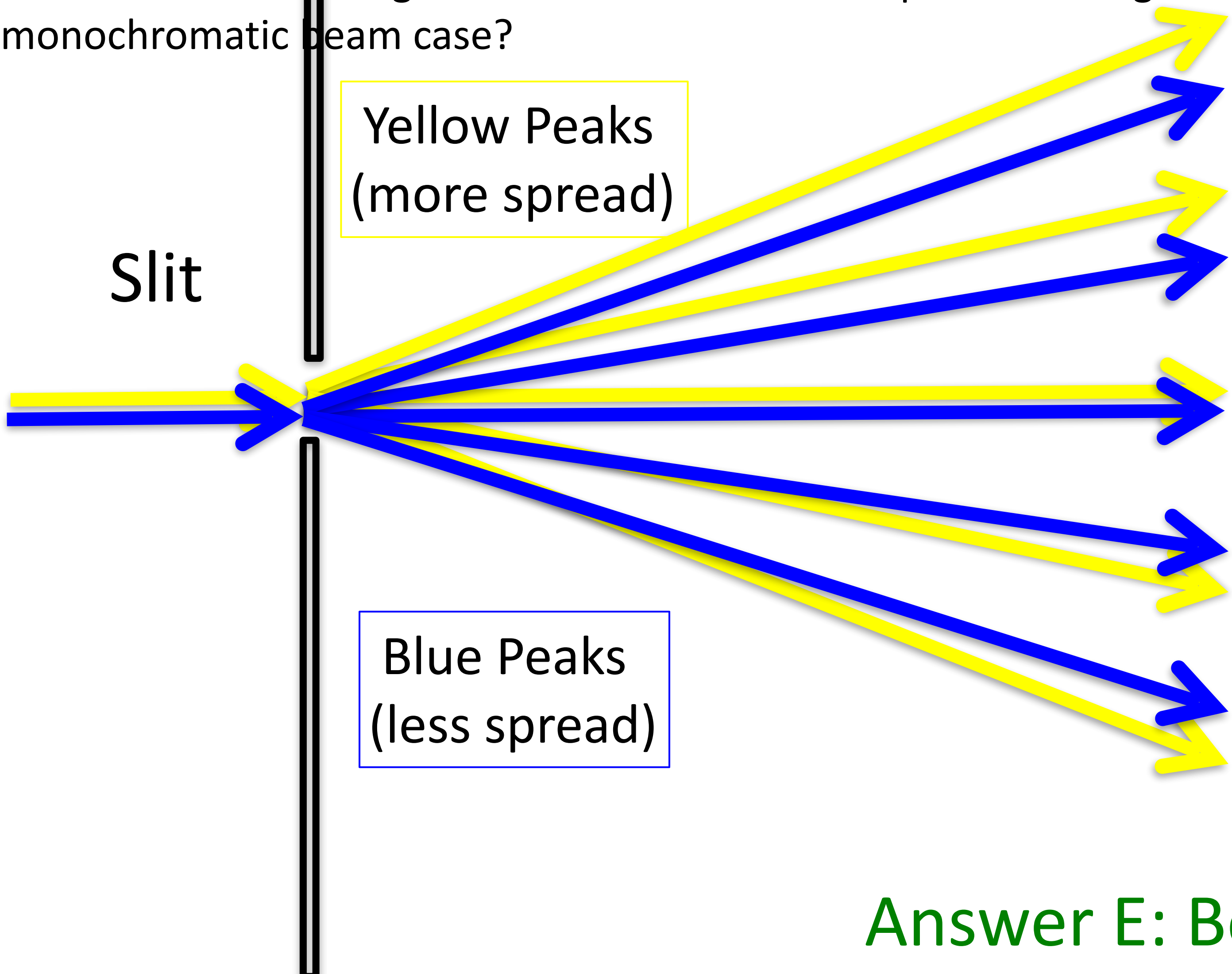
   E. Only A and C

"The color of the central bright fringe will change because the two colors of light will blend creating new colors. The location of the dark fringes will change because of the different wavelengths of light."



Bridge Question 3b Explained

Beams of blue and yellow light are both aimed at the same slit of width *w* at the same time. Which of the following features of the diffraction pattern changes relative to the single monochromatic beam case?



a. Color of the central bright fringe only

~~b. Color of all bright fringes~~

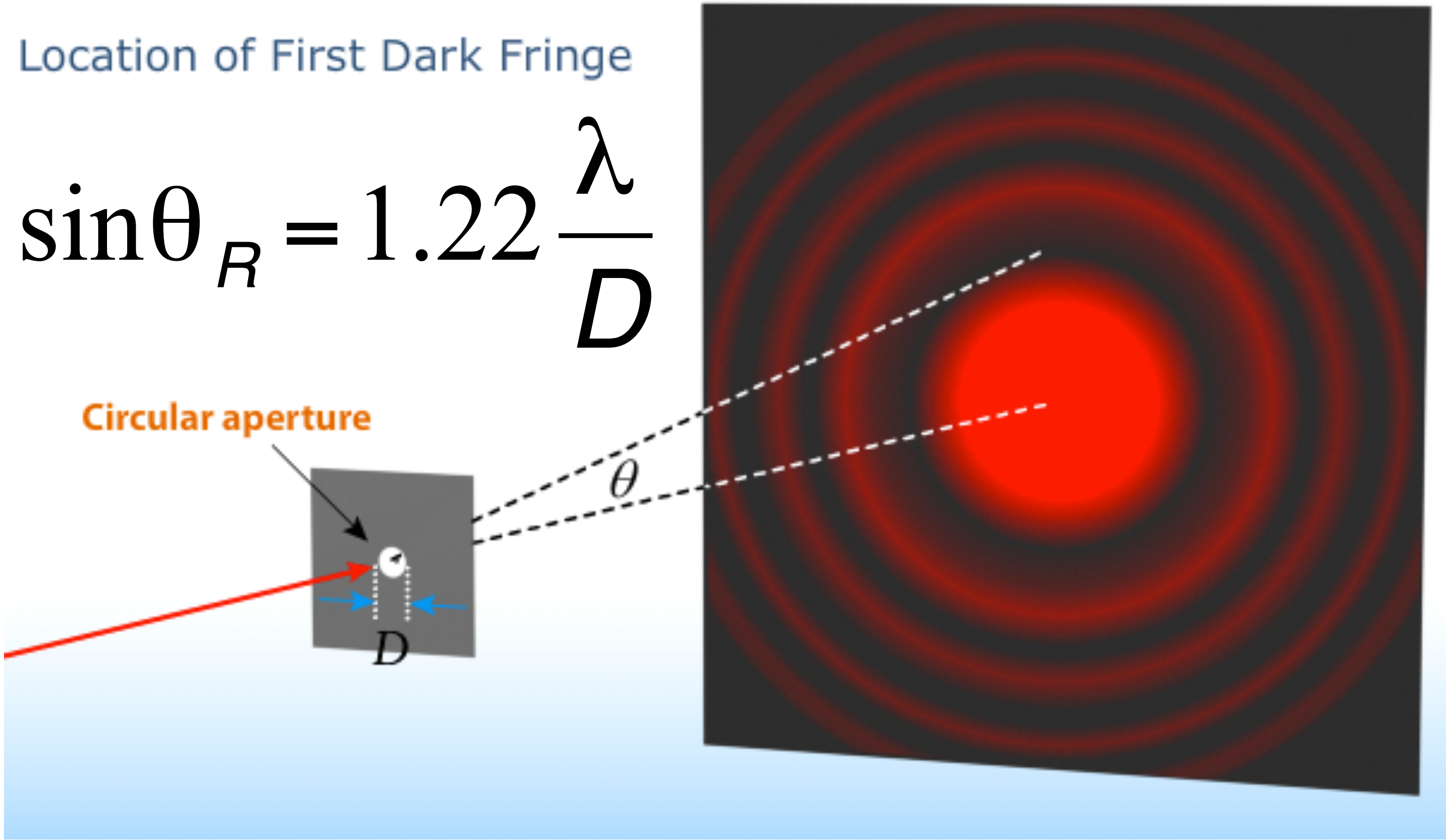
c. Location of dark fringes

Answer E: Both a and c

Imaging

Larger Diameter Aperture → Smaller Angle of Dark Spots

Higher Resolution!



$$\sin\theta_R = 1.22\frac{\lambda}{D}$$

Bridge Question 4

1. An experiment is set up to test the angular resolution of an optical device when red light (wavelength λ_r) shines on an aperture of diameter *D*. Which aperture diameter will give the best resolution?

   A. $D = 0.5\ \lambda_r$

   B. $D = \lambda_r$

   C. $D = 2\ \lambda_r$

Larger diameter, better resolution.