Module 32: Diffraction

Module 32: Outline

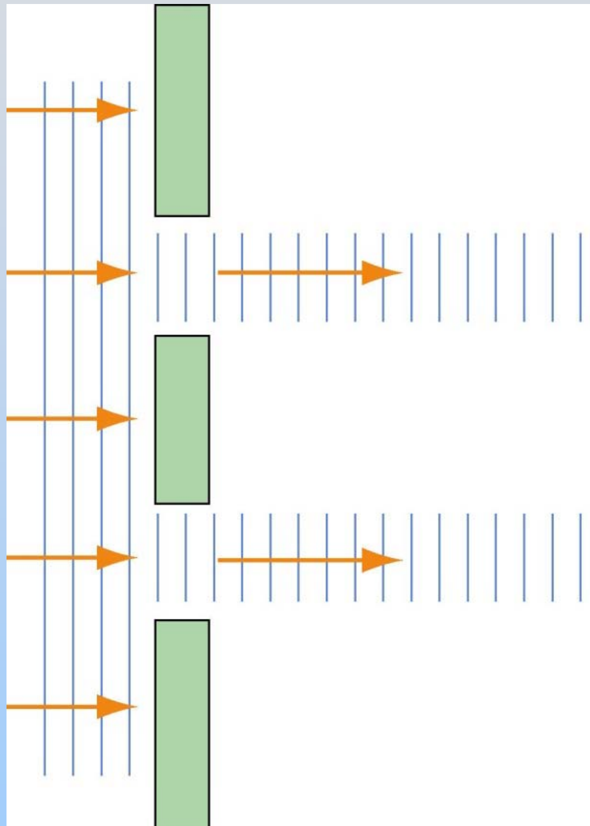
Diffraction

Experiment 11: Interference and Diffraction

Diffraction

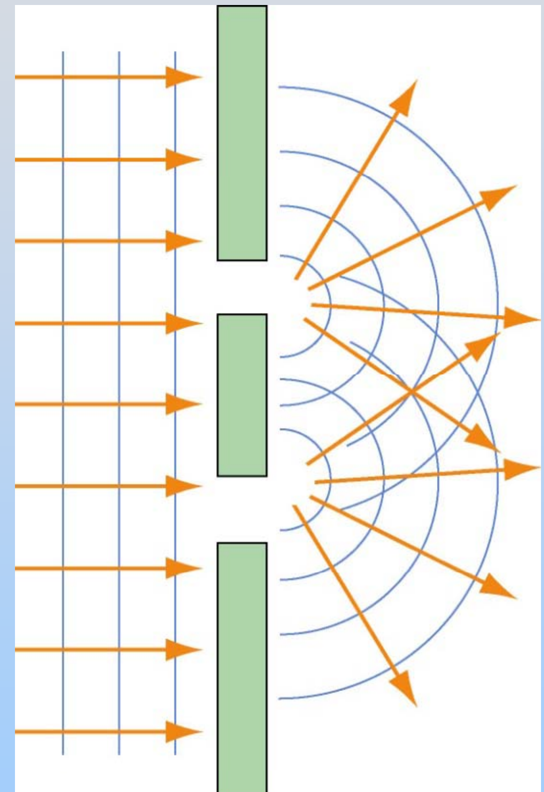
Diffraction

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



No Diffraction

No spreading after passing though slits

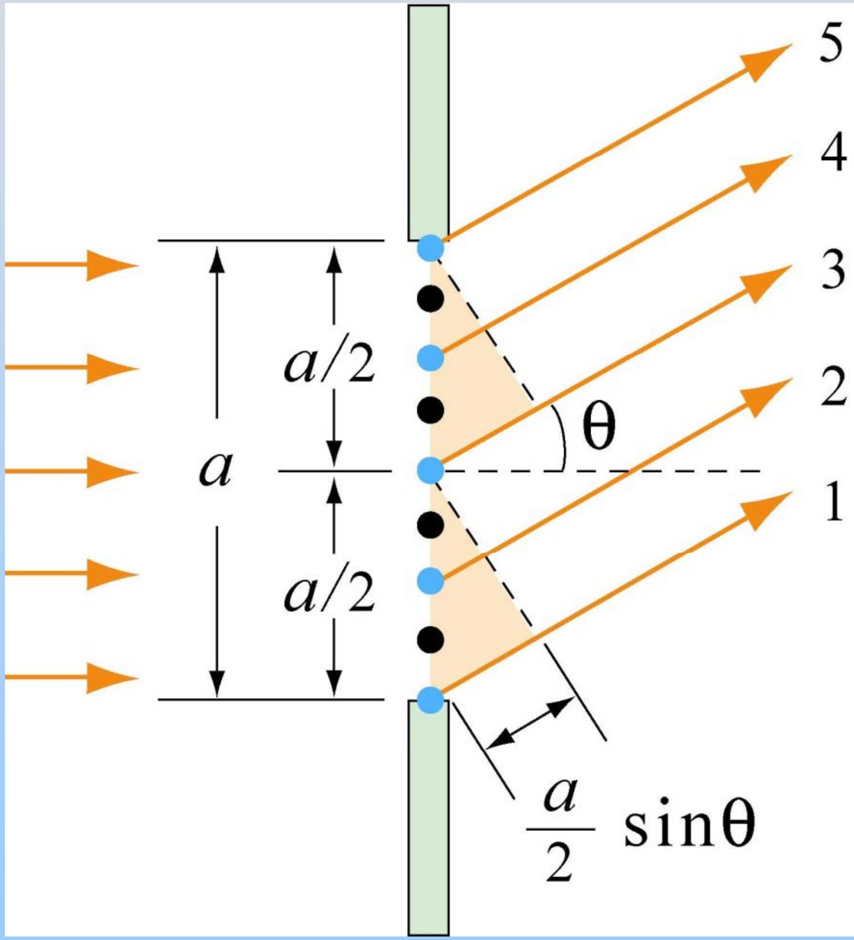


Diffraction

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:

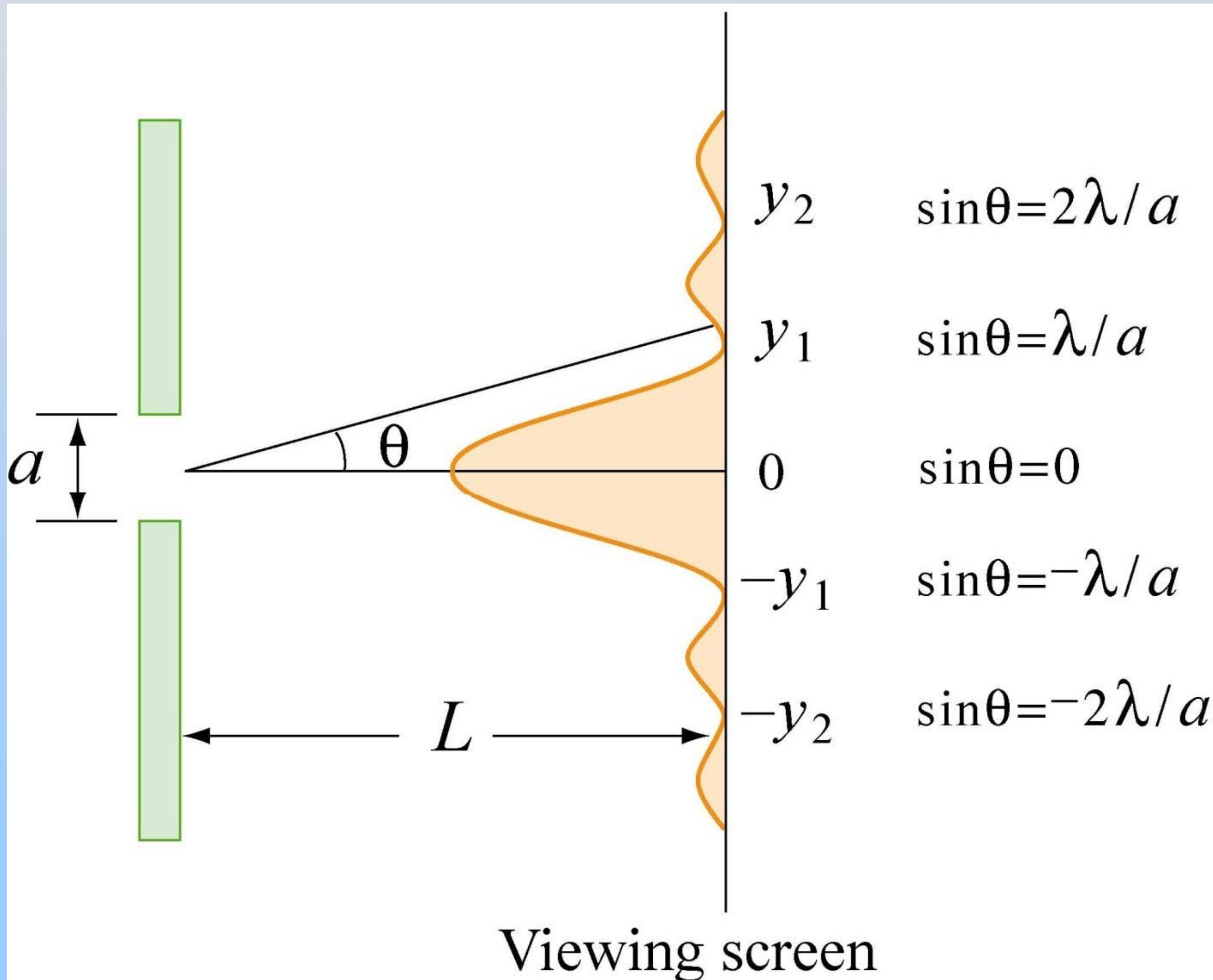
$$\delta = \frac{a}{2}\sin\theta = \left(m + \tfrac{1}{2}\right)\lambda$$

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

Don't get confused – this is DESTRUCTIVE!

Intensity Distribution

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



Diffraction in Everyday Life

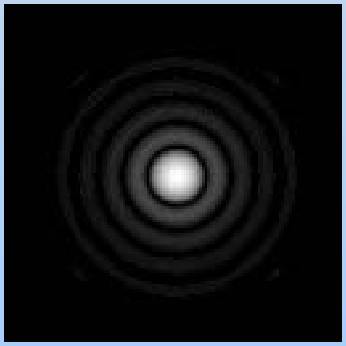
(Image by Bill Liao on Flickr)

Diffraction in Everyday Life: Rayleigh Criterion

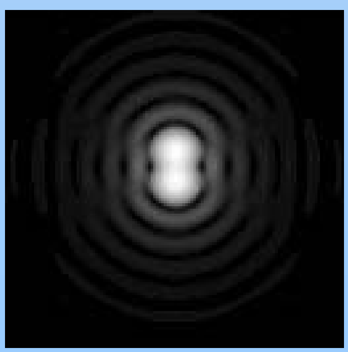
For circular apertures of diameter *D* (like pupils, optics…)

$$\sin\theta_{\min} = 1.22\,\lambda/D$$

Point-like light sources become “airy disks” after diffraction:



The apparent size of the object depends on the size *D* of the aperture (lens, pupil)



To resolve two objects, they need to be separated by more than the critical angle:

$$\alpha_{critical} = 1.22\,\lambda/D$$

Problem: Headlights

(Image by Roger May on Wikimedia Commons)

- Headlight separation:
  - $d \sim 1.5$ m
- Pupil Diameter:
  - $D \sim 4$ mm
- Wavelength:
  $\lambda \sim 550$ nm

About how close must a car be before you can distinguish the two headlights?

Concept Q.: Headlight Resolution

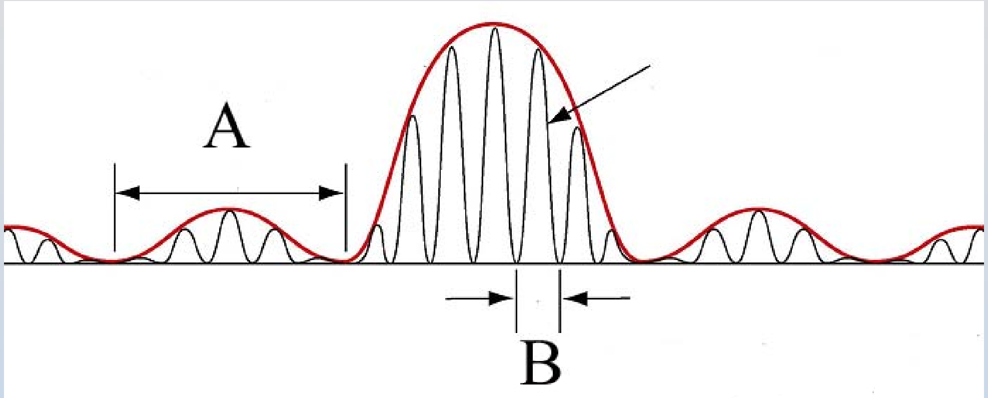
Is it easier to resolve two headlights at night or during the day?

1. At night
2. During the day
3. It doesn't matter
4. I don't know

Interference & Diffraction Together

Con. Q.: Interference & Diffraction

Coherent monochromatic plane waves impinge on two long narrow apertures (width a) that are separated by a distance d (d >> a).



The resulting pattern on a screen far away is shown above. Which structure in the pattern above is due to the finite width a of the apertures?

1. The distantly-spaced zeroes of the envelope, as indicated by the length A above.
2. The closely-spaced zeroes of the rapidly varying fringes with length B above.
3. I don't know

Two Slits With Finite width *a*

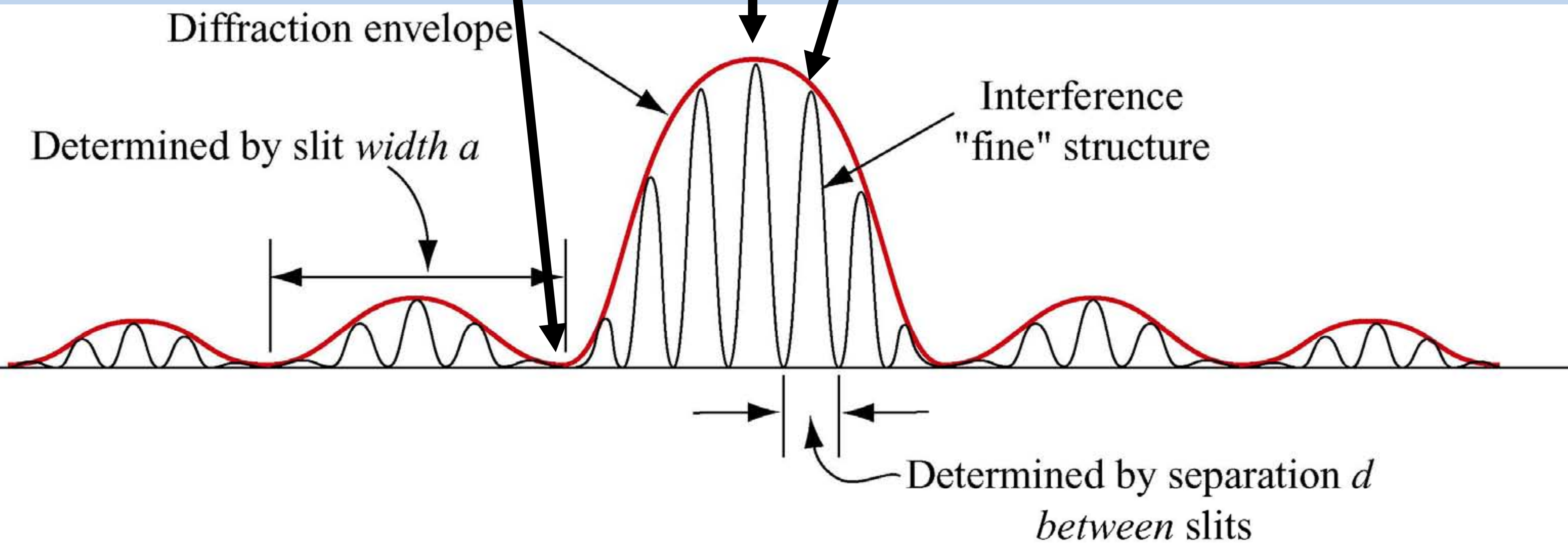
Zero Order Maximum

First Diff. Minimum

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

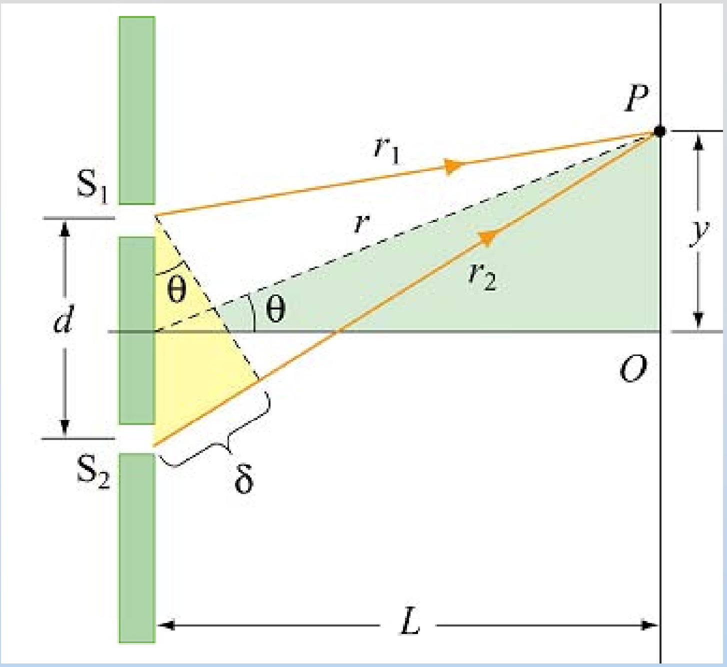
First Order Maximum

$$d\sin\theta - \lambda$$



Lecture Demonstration: Double Slits with Width

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**

Experiment 11, Part I: Measure Laser Wavelength

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

Experiment 10, Part I: Measure Laser Wavelength

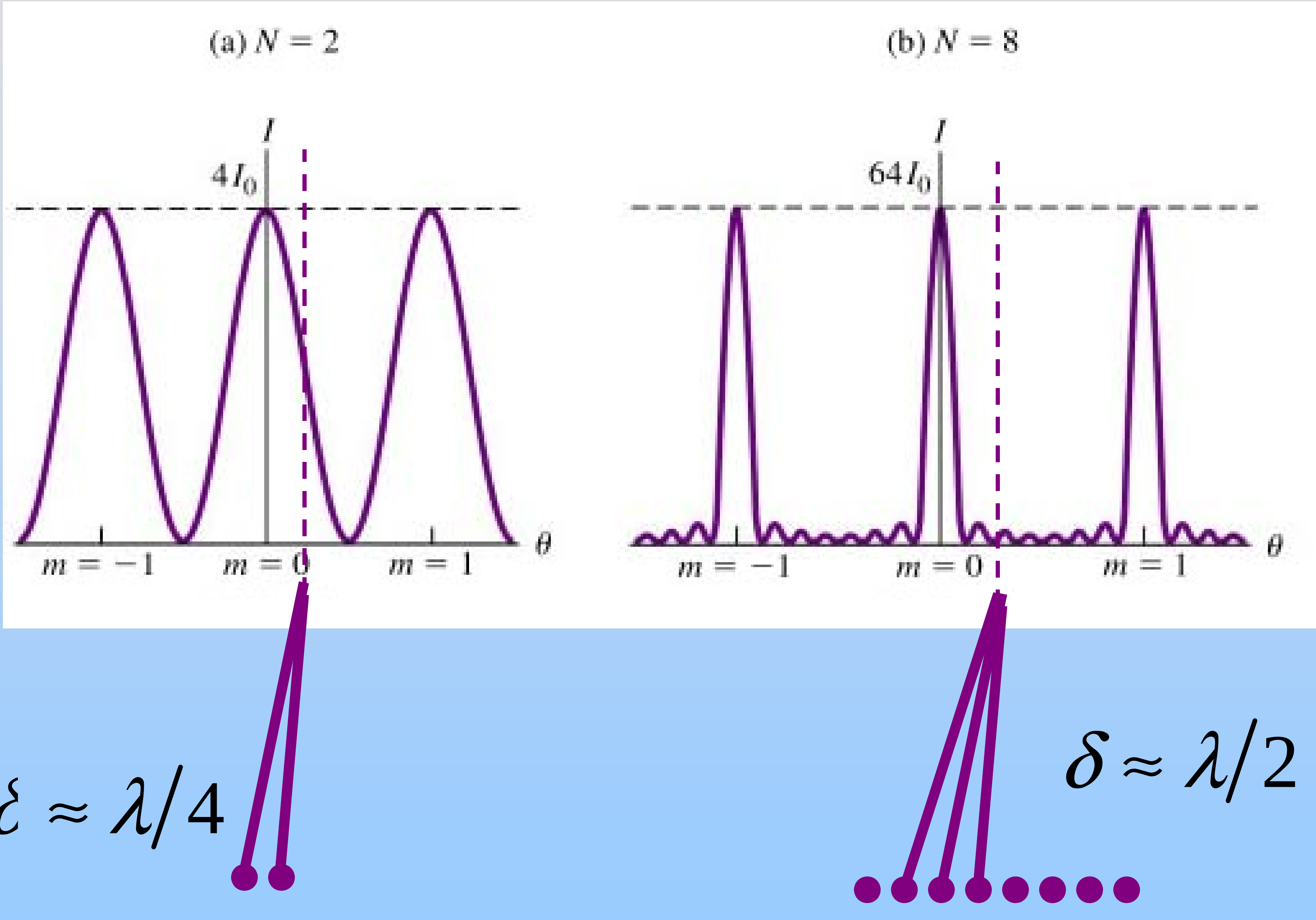
$$y_{constructive} = m\frac{\lambda L}{d} \quad m = 0, 1 \ldots$$

Concept Question: Changing Colors

You just observed an interference pattern using a red laser. What if instead you had used a blue laser? In that case the interference maxima you just saw would be

1. Closer Together
2. Further Apart
3. I Don’t Know.

From 2 to N Slits



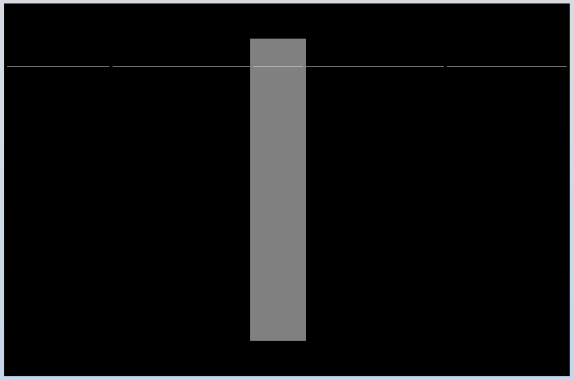
$\delta \approx \lambda/4$

$\delta \approx \lambda/2$

Experiment 11, Part II: Diffraction Grating: CD

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

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 opposites in order to cancel:

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

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

Experiment 11, Part III: Measure Hair Thickness

$$y_{destructive} = m\frac{\lambda L}{a} \quad m = 1, 2 \ldots$$

Concept Question: Lower Limit?

Using diffraction seems to be a useful technique for measuring the size of small objects. Is there a lower limit for the size of objects that can be measured this way?

1. Yes – but if we use blue light we can measure even smaller objects
2. Yes – and if we used blue light we couldn't even measure objects this small
3. Not really
.
4. I Don't Know