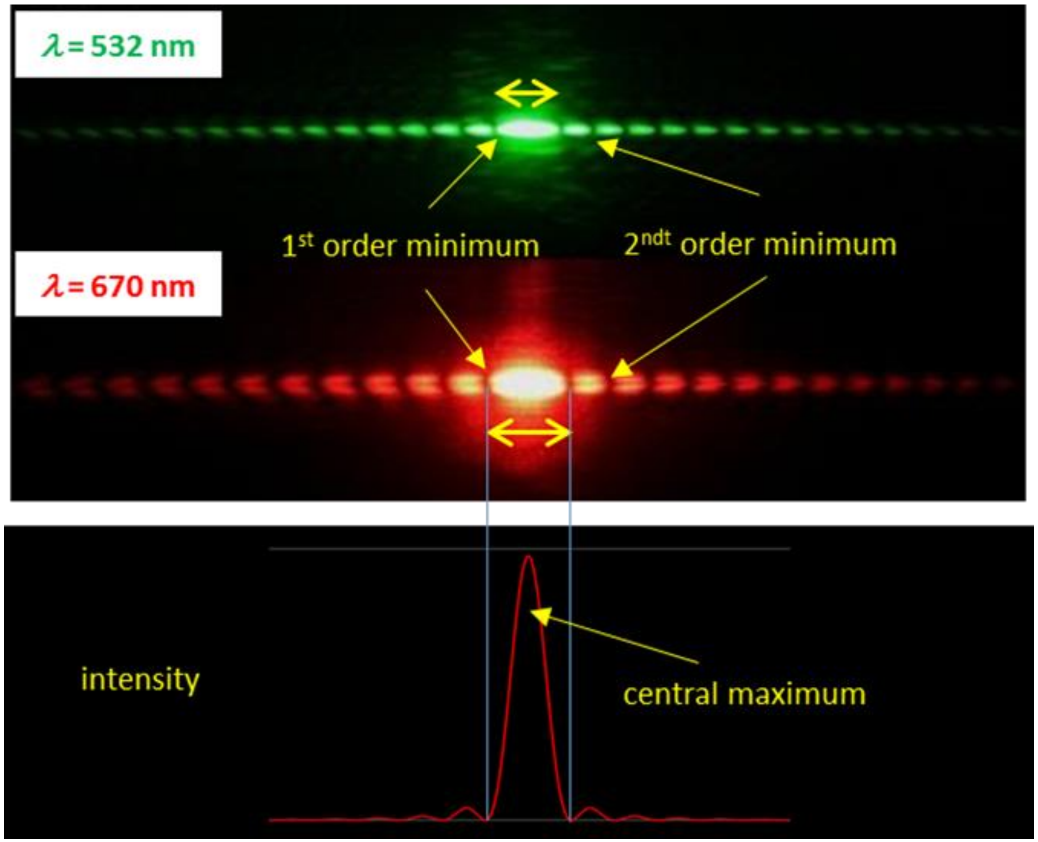
Studio Week 10
Combined Interference & Diffraction



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

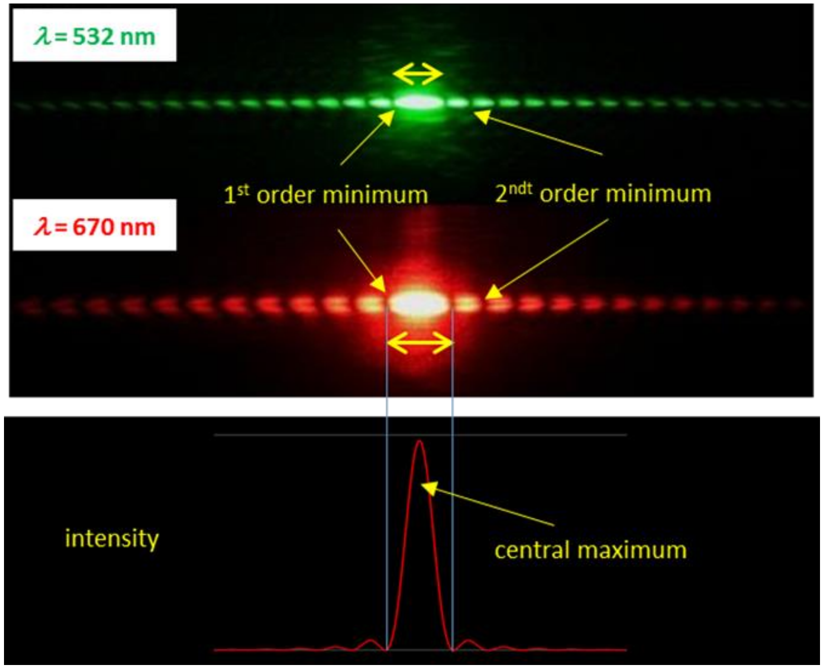
Principles for Success

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

Warm-up Activity

~5 min

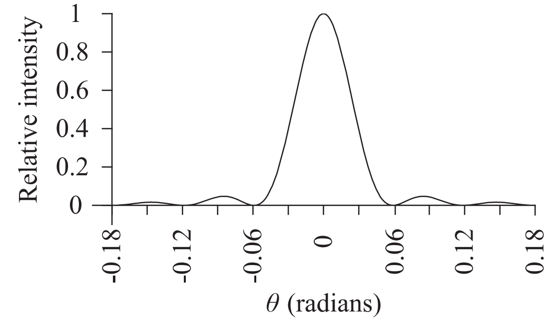
Picture credit:
http://www.physics.usyd.edu.au/teach_res/hsp/sp/mod31/m31_singleSlit.htm

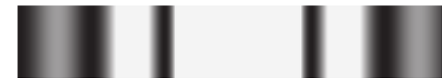


Note that
$a \sin\theta_p = p\lambda$
$p = 1, 2, 3, \ldots$
Thus $a \sin\theta_p \geq \lambda$.
Also, $\sin\theta_p \leq 1$, so
$a \geq a\sin\theta_p \geq \lambda$.
Student 2 is incorrect.

- Student 1: *"In lab, I determined that the width of one of the slits that we used to study single-slit diffraction was about 0.1 mm—that's definitely larger than λ."*
- Student 2: *"You must have made a mistake. A diffraction pattern has minima only when the slit width is less than λ."*

Activity 10-1




Pattern on screen due to *single* slit

- A slit with width bigger than λ produces the interference pattern shown at right.
- A second slit with the same width is added. The distance between the centers of the slits is 50λ.

A. What would you see on the screen if the original slit were covered and the second slit were uncovered?

Both slits are now uncovered.

B. For what angles will the light from each point on one slit be 180° out of phase with the light from the corresponding point on the other slit?

C. On the relative intensity graph above, clearly label these angles.

D. When the second slit is uncovered, will the intensity at the locations of the diffraction minima increase, decrease, or stay the same? Explain.

E. When the second slit is uncovered, how will the pattern on the screen change?

10-1 Two Slits with Width

Wrap 2:25 10:25

Uncovering One

Each slit of the same width creates the same single-slit pattern, centered directly in front of the slit.

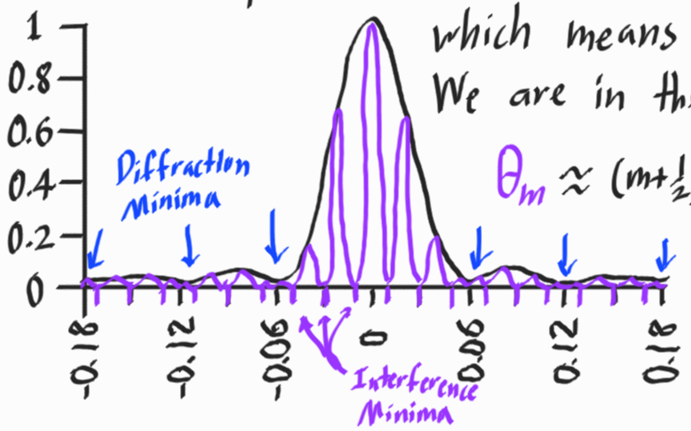
Since our slits are only 50λ apart, and light wavelengths are quite small (for example, 600 nm), the difference in where the pattern is centered is practically insignificant (only $50 \times 600\text{nm} = 30\mu\text{m}$, in our example), so the pattern is basically unchanged.

Uncovering Both

Out of phase: $\Delta\phi = 180°$ means destructive interference, which means we want to use $d\sin\theta_m = (m+\frac{1}{2})\lambda$.

We are in the realm of small angles, so

$$\theta_m \approx (m+\tfrac{1}{2})\frac{\lambda}{d} = (m+\tfrac{1}{2})\frac{1}{50} = \frac{2m+1}{100} = \pm 0.01, \pm 0.03, \pm 0.05, \ldots$$

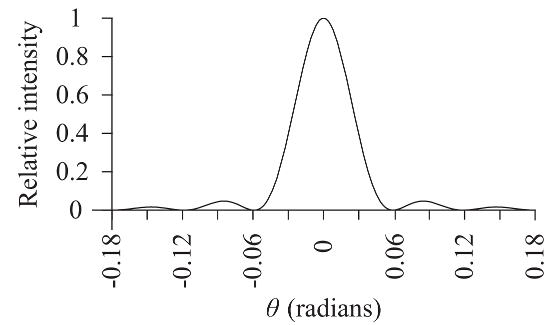


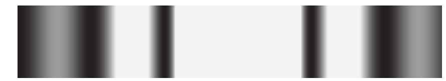
Diffraction Minima: Each slit is illuminating the diffraction minima with zero intensity, so the combined effect of both slits will remain zero at these locations.

Pattern: The diffraction pattern remains the same, except that new minima will be added for destructive interference. The remaining bright spots will get brighter than they were before due to constructive interference.

Activity 10-2

- Suppose that the width of both slits, *a*, were gradually decreased at the same rate (while keeping the distance between the centers of the slits the same).
  A. Which minima would move as *a* is decreased?
  B. Find a pair of relative intensity graphs from the handout that illustrate such a change.
- Suppose instead that the distance between the centers of the slits, *d*, were gradually decreased (while keeping the widths of the slits the same).
  A. Which minima would move as *d* is decreased?
  B. Find a pair of relative intensity graphs from the handout that illustrate such a change.
- For each graph in the handout, label (1) the interference minima that are closest to the center of the pattern and (2) the diffraction minima that are closest to the center of the pattern.





Pattern on screen due to *single* slit

10-2 Changing Width & Separation

Start 2:35 10:35 Wrap 2:50 10:50

Credits

a decreases (d constant)

$a\sin\theta_p = p\lambda$

decreases, must increase, constant (for fixed p)

$a \geq p\lambda \Rightarrow$ max p may decrease

The diffraction minima spread out (and may become fewer in number) as slit width decreases.

d decreases (a constant)

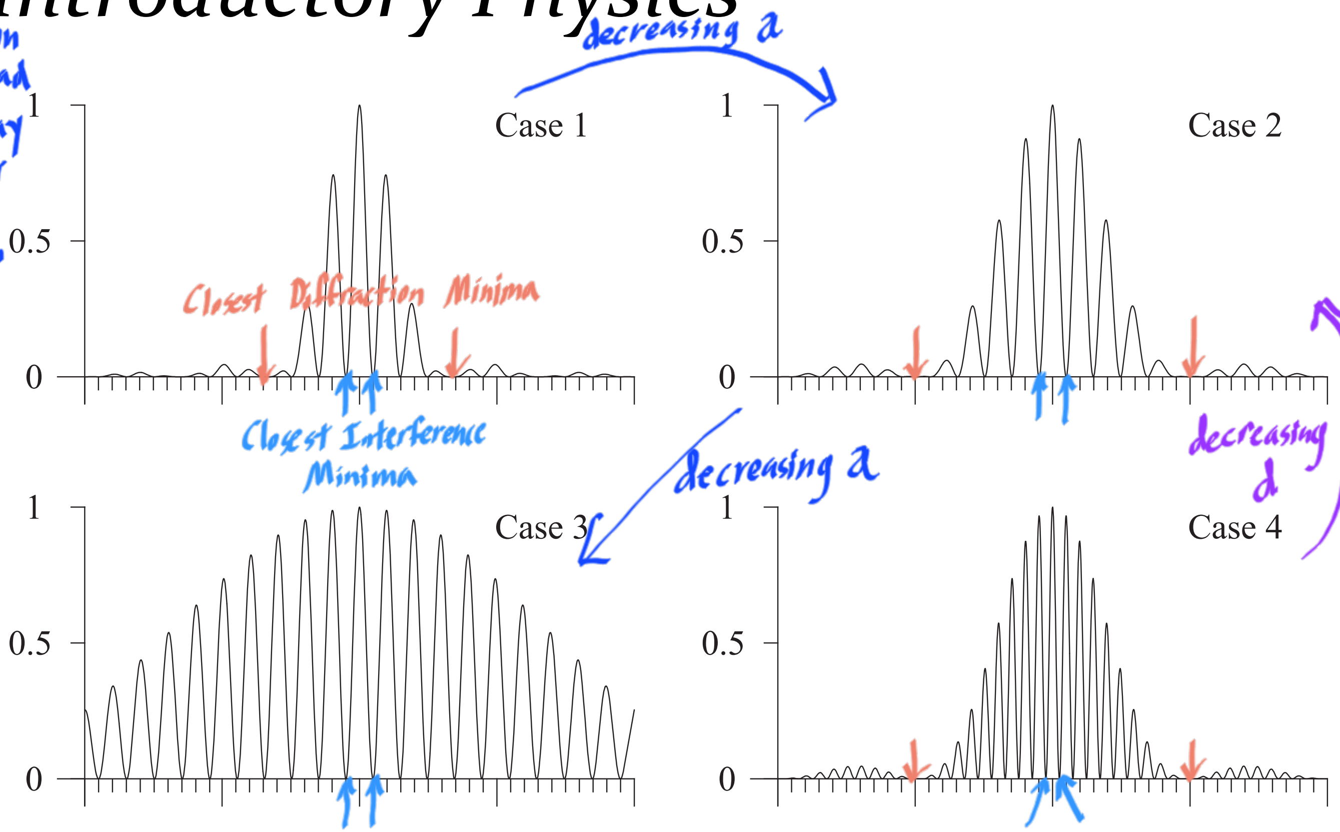
$d\sin\theta_m = (m+\frac{1}{2})\lambda$

decreases, must increase, constant (for fixed m)

$d \geq (m+\frac{1}{2})\lambda \Rightarrow$ max m may decrease

The interference minima spread out (and may become fewer in number) as slit separation decreases.

- Activities adapted from *Tutorials in Introductory Physics*



Normalized intensity version position graphs

Activity 10-3

- Consider the following relative intensity graph for a double-slit experiment. The wavelength of the light used was 633 nm.
  A. Determine the width of the slits and the distance between the slits. Clearly indicate which features of the graph you are using.

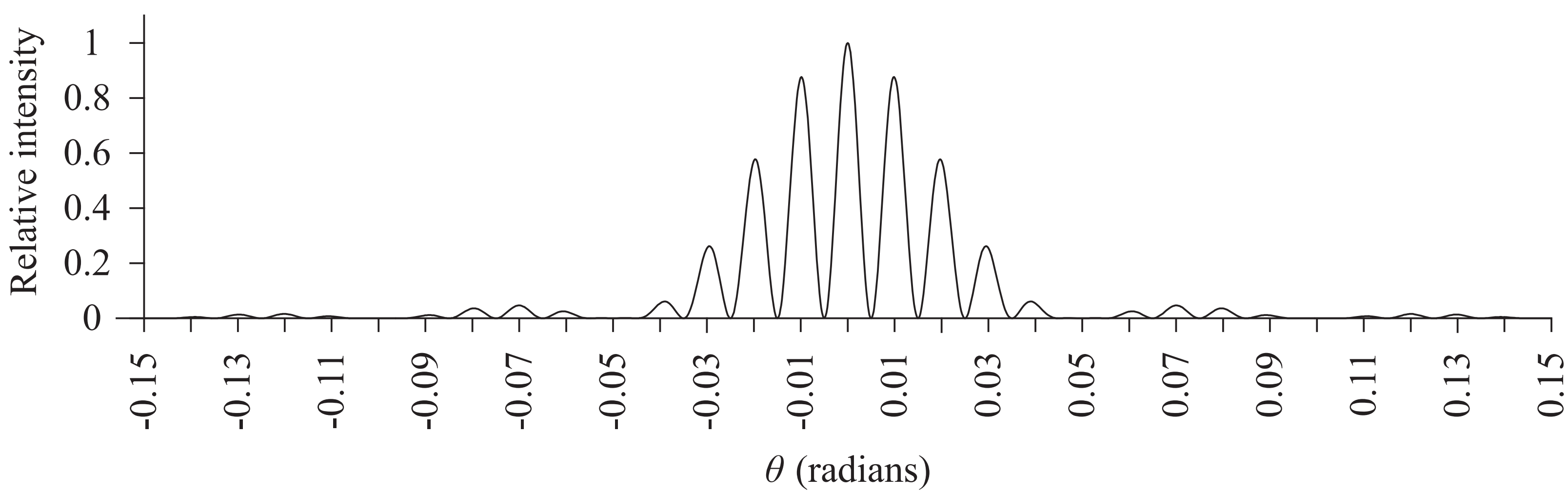
  B. Consider the following comment made by a student:

  should use 1st diff min @ 0.05 rad

  "To determine slit width, I used the first minimum, at 0.005 radians, and to determine the distance between the slits, I used the first maximum, at 0.01 radians."

  What is the flaw in the reasoning used by this student? Explain your reasoning.

  C. You may have already noticed that the maxima are (approximately) 0.01 radians apart, except that there are no maxima at 0.05 radians or 0.10 radians. How can you account for these "missing" maxima? (*Hint:* Consider how the relative intensity graph would be different if the width of the slits were decreased.)



10-3 Finding Width & Separation

Start 3:10
11:10
Wrap 3:25
11:25

Small Angles: $\sin\theta \approx \theta$

Slit Separation

The first order (m=1) interference maximum is at $\theta_{m=1} = 0.01$ rad.

$$d\theta_m = m\lambda \Rightarrow d = \lambda/\theta_{m=1} = 633\text{nm}/0.01 = 63300\text{nm} = 63.3\,\mu\text{m}$$

Slit Width

The First order (p=1) diffraction minimum is at $\theta_{p=1} = 0.05$ rad.

$$a\theta_p = p\lambda \Rightarrow a = \lambda/\theta_{p=1} = 633\text{nm}/0.05 = 12660\text{nm} = 12.66\,\mu\text{m}$$

The student is mistakenly using the first interference minimum at 0.005 rad.

Missing Maxima

Since $d = 5a$, we are getting perfect alignment of the 5th and 10th order interference maxima with the 1st and 2nd order diffraction minima. The individual slits provide no light to these spots, so their combined effect at these spots is a minimum, no matter what our interference equation says.