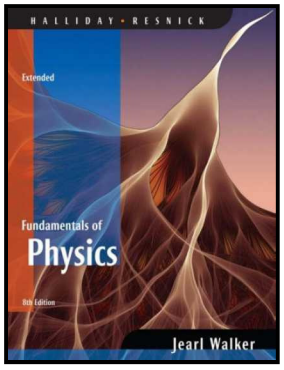
University Physics II



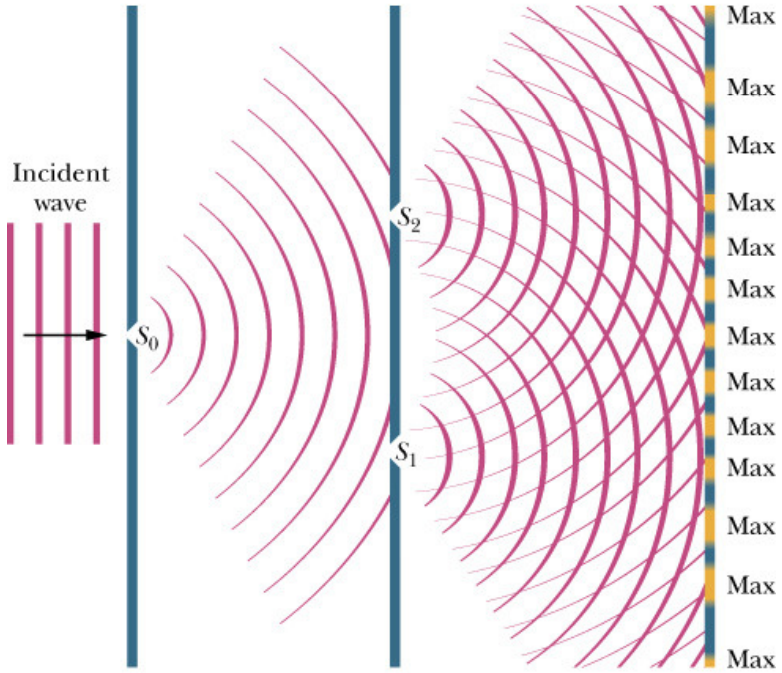
Week 9 : Day 3

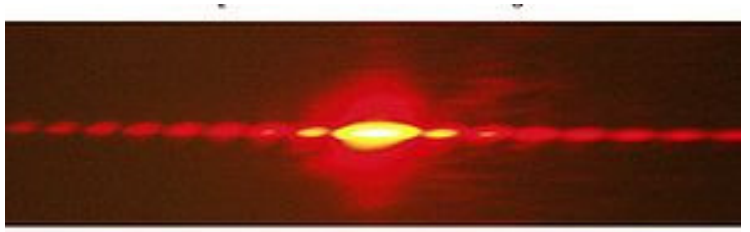
Outline

- **Double-slit Interference**
  - Young's experiment
  - Locating diffraction min/max
- **Diffraction gratings**
  - Defining dispersion
- **Activity – Laboratory #3**
  - Measuring with Interference and Diffraction

Young's Experiment

For waves entering two slits, the emerging waves interfere and form an interference (diffraction) pattern:

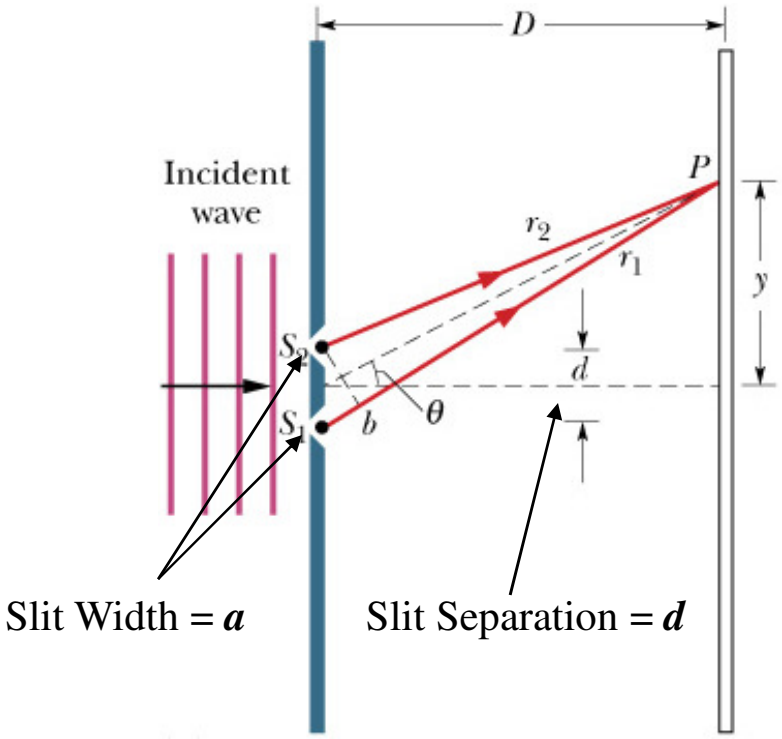


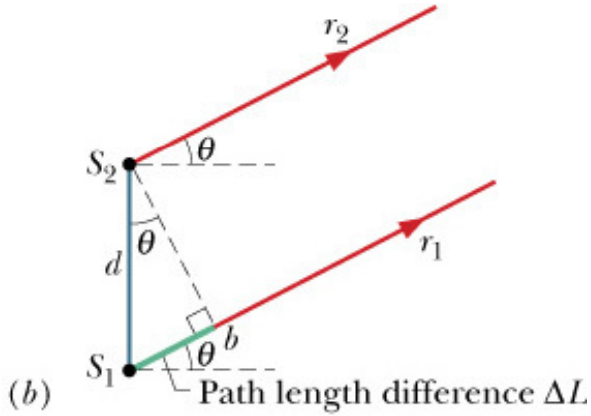


Pattern produced from a double slit.

Double-Slit Diffraction Fringes

What appears at each point on the screen is determined by the path length difference ΔL of the rays reaching that point.





Path Length Difference:

$$\Delta L = d \sin\theta$$

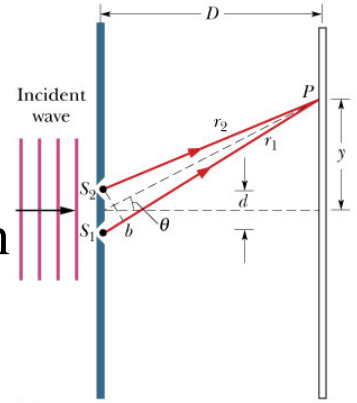
Intensity in Double-Slit Interference

Minima when: $\frac{1}{2}\phi = \left(m + \frac{1}{2}\right)\pi$

$\rightarrow d \sin\theta = \left(m + \frac{1}{2}\right)\lambda$ for $m = 0, 1, 2, \ldots$ (minima)

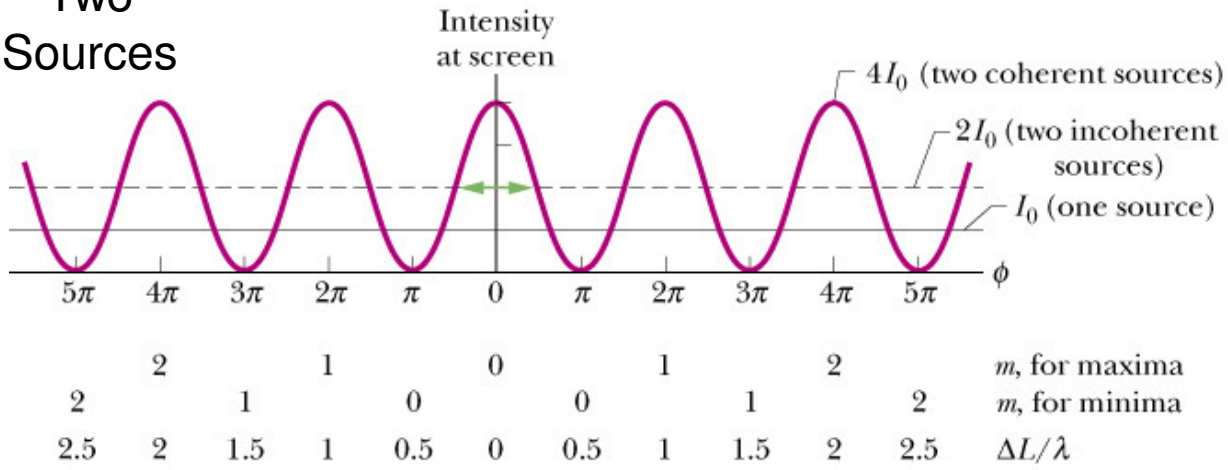
Maxima when: $\frac{1}{2}\phi = m\pi$ for $m = 0, 1, 2, \ldots \rightarrow \phi = 2m\pi = \frac{2\pi d}{\lambda}\sin$

$\rightarrow d \sin\theta = m\lambda$ for $m = 0, 1, 2, \ldots$ (maxima)



Two Sources

$$E_1 = E_0 \sin\omega t \quad \text{and} \quad E_2 = E_0 \sin(\omega t + \phi)$$



Phase Difference $\phi = \frac{2\pi d}{\lambda}\sin\theta$

$\Rightarrow I_{\text{avg}} = 2I_0$

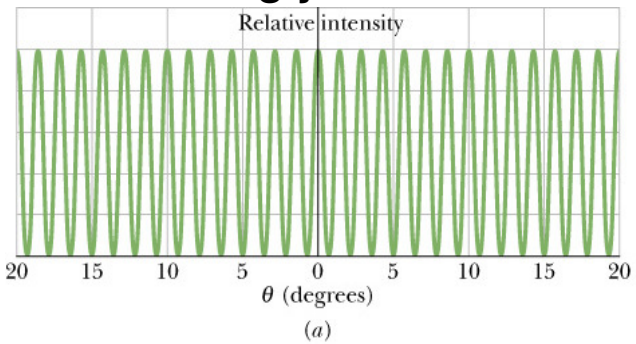
$\Downarrow$

$$I = 4I_0 \cos^2 \tfrac{1}{2}\phi$$

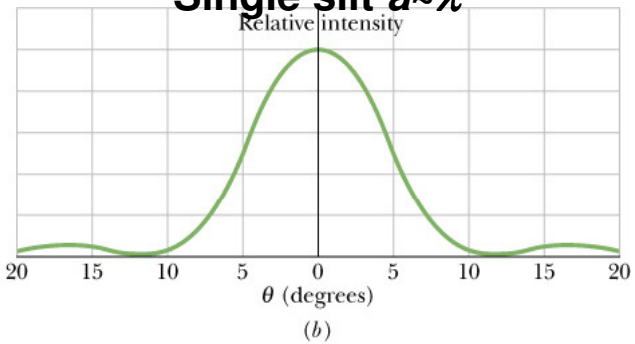
Diffraction by a Double Slit

In the double-slit experiment we assume that the slit width $a \ll \lambda$.
If this is not the case then the observed pattern changes:

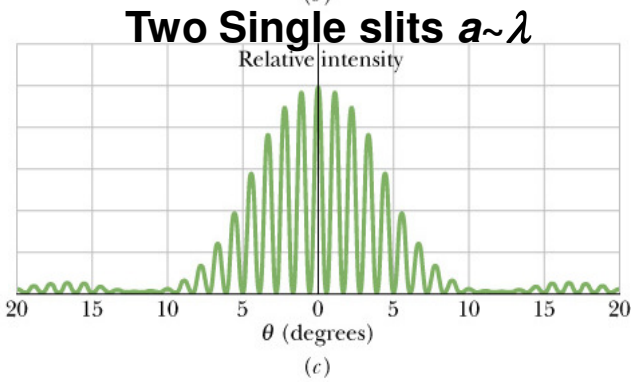
Two vanishingly narrow slits $a \ll \lambda$



Single slit $a \sim \lambda$



We observe diffraction from both!

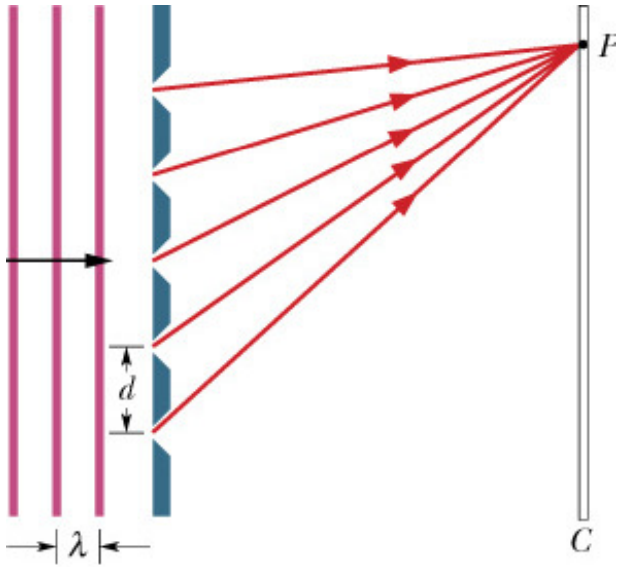


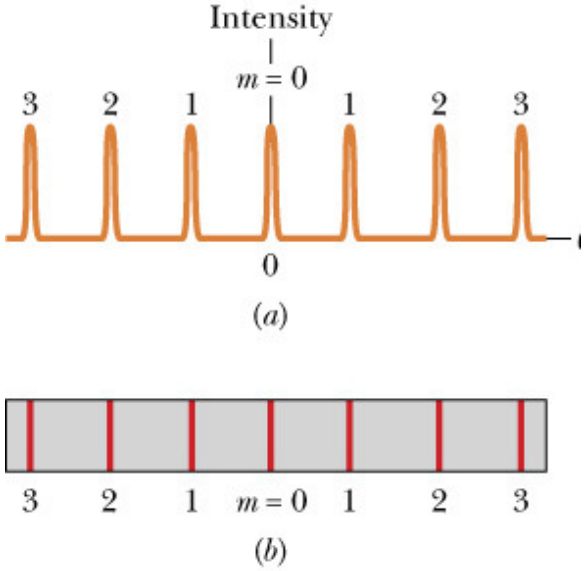
$$I(\theta) = I_m \left(\cos^2 \beta\right)\left(\frac{\sin\alpha}{\alpha}\right)^2 \quad \text{(double slit)}$$

$$\beta = \frac{\pi d}{\lambda}\sin\theta \qquad \alpha = \frac{\pi a}{\lambda}\sin\theta$$

Diffraction Gratings

A device with *N* slits (rulings) can be used to manipulate light, such as separate different wavelengths of light that are contained in a single beam. How does a diffraction grating affect monochromatic light?

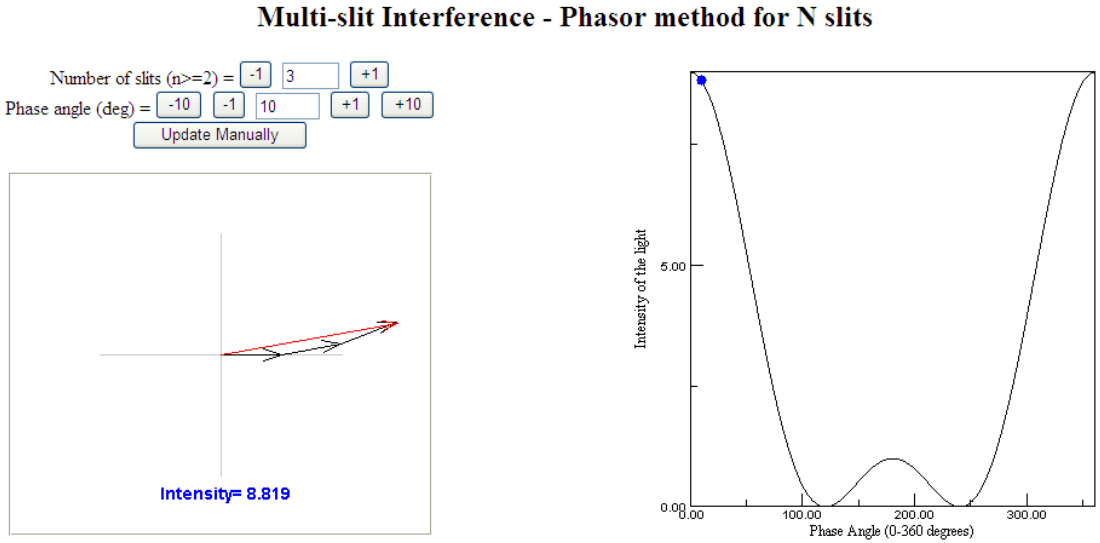




$$d \sin\theta = m\lambda \quad \text{for } m = 0, 1, 2\ldots \quad \text{(maxima-lines)}$$

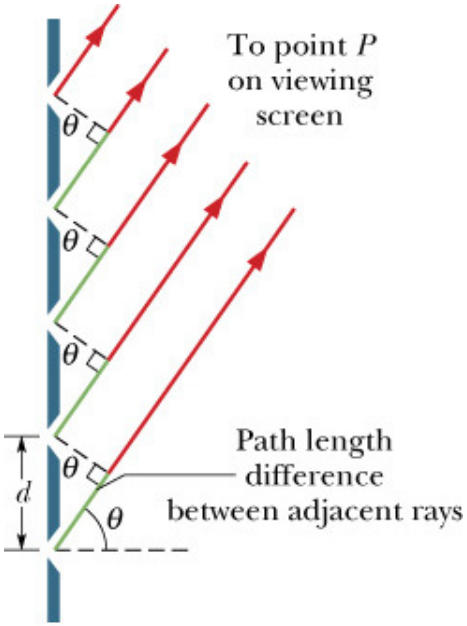
From One to Many Slits

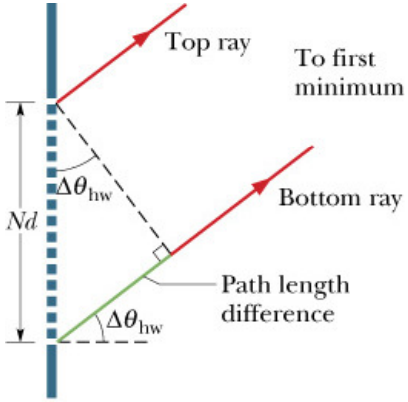
- **Intensity Pattern for N-Slits**
  - as the number of slits rises the peak intensities grow
  - the peaks themselves get more narrow
- **Online Applet**
  - http://qbx6.ltu.edu/s_schneider/physlets/main/phasorslits.shtml

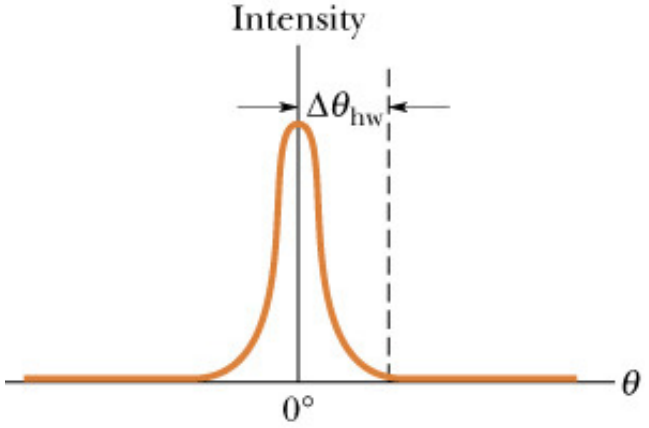


Width of Lines & Intensity

The ability of the diffraction grating to resolve (separate) different wavelengths depends on the width of the lines (maxima).







$$Nd \sin \Delta\theta_{\text{hw}} = \lambda, \quad \sin \Delta\theta_{hw} \approx \Delta\theta_{hw}$$

$$\Delta\theta_{\text{hw}} = \frac{\lambda}{Nd \cos\theta} \text{ (half width of line at } \theta)$$

Activity – *Measuring with Interference and Diffraction*

- **Measuring with Interference and Diffraction**
  - *Laboratory Write-Up*
    - Calibration
      - *Methods I – Double Slit*
      - *Method II* – Single-Slit *(OMIT)*
      - *Method III – Grating*
        - » *Note that small angle approximation does not work*
    - Width of Human Hair
      - Use Babinet's pricniple to measure the width of a human hair
        - » Pattern should resemble Single-Slit
        - » Width of hair ~

Your Name (**Print**): _____ Date: _____
Group Members: _____
_____ Group: _____

Measuring with Interference and Diffraction

Purpose: In this activity you will accurately measure the width of a human hair using the interference and diffraction properties of light.

Method: By shining laser light onto a hair, a diffraction pattern can be observed beyond the hair on a screen. According to **Babinet's Principle**, the diffraction pattern of an object is **identical** to the diffraction pattern of the negative of the object. Thus a single thin barrier such as a hair should have the same pattern as a single slit. By knowing the wavelength of the laser and making measurements on the setup, you can find the width of the hair using the single-slit formula. Recall, we do not know the wavelength of individual laser diodes in the lab. The wavelength depends on minute variations in the manufacturing process, etc. Typical values range from about 630 to 680 nm. To check the wavelength of the laser, you will use three different techniques to measure the wavelength: Double Slit, Single Slit and Diffraction Grating. These have been done previously, and serves as a nice review at this point, but be careful to measure accurately.

Safety Precautions:

Again, avoid looking directly into the laser or reflections off glass or mirror-like surfaces. Detach hair from head **before** mounting onto holder.

Setup Procedure: Mount the laser at one end, the slit holder near the laser, and the screen at the far end of the optical track.

Note: You can make the patterns easier to measure if you put the screen on the wall instead of the optical track. You can tape a sheet of paper to the wall on which to record positions.