December 1st

Diffraction
Chapter 37

"I'm the invention. The inventor should be along any moment now."
Schedule for rest of term

- Dec. 1-2 (Mon-Tues) – cover Chpt. 37
- Dec. 3-5 (Wed-Fri) – Review for final
- Dec. 3 (Wed) – HW set #12 due
- Dec. 8 (Mon) – Corrections #3 due
- Dec. 8 (Mon) – Final Exam 5:45-7:45pm
  - N130 BCC (Business College) for section 1
  - 158 NR (Natural Resources) for section 2
Review

- When 2 waves interact get interference
  - If phase difference is 0 or integer \# of wavelengths (1\(\lambda\), 2\(\lambda\), ...) waves are in-phase and constructively interfere giving a bright spot or maxima
  - If phase difference is half a wavelength (0.5\(\lambda\), 1.5\(\lambda\), ...) waves are out-of-phase and destructively interfere giving a dark spot or minima
Review

- 3 ways for phase difference between 2 light waves to change
  - Waves travel through media of different indexes of refraction, $n$
  - Waves travel along paths of different lengths
  - Waves are reflected
Review

- Materials of different $n$
  - Different #’s of wavelengths occur in different $n$’s
    \[ N_1 = \frac{L}{\lambda_{n_1}} = \frac{Ln_1}{\lambda} \]
  - Phase shift given by
    \[ N_2 - N_1 = \frac{L}{\lambda}(n_2 - n_1) \]
  - Effective phase difference is decimal fraction
  - $1 \lambda = 2\pi$ radians $= 360^\circ$
Review

- **Different path lengths**
  - Ray 1 travels distance $\Delta L$ farther than ray 2
  - Waves interfere fully constructively when $m \lambda = \Delta L$, $m = 0, 1, 2, ...$

- Central maximum at $m=0$, first order maxima $m=1$, second order maxima $m=2$

- Waves interfere fully destructively when $\Delta L = (m + 1/2) \lambda$, $m = 0, 1, 2, ...$

- First order minima $m=0$, second order minima $m=1$, third order minima $m=2$
Review

- Different path lengths
- Relate path length difference $\Delta L$ to angle with central axis $\theta$ and distance between slits $d$

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

- Maxima, bright spots at

$$d \sin \theta = m\lambda, \ m = 0,1,2,...$$

- Minima, dark spots at

$$d \sin \theta = (m + 1/2)\lambda, \ m = 0,1,2,...$$
**Review**

- **Different path lengths**

- **Use small angle relation**
  \[ \tan \theta \approx \sin \theta \approx \theta \]

- **Distance** \( y \) **on screen from central maxima to maxima of order** \( m \) **is**
  - \( D \) **is distance between screen and slits**, \( d \) **is distance between slits**
  \[ y = \frac{mD\lambda}{d} \]
Review

- **Reflection**
- If incident light reflected by surface with higher $n$ phase shifted by $\frac{1}{2}\lambda$
  - $n_1 < n_2$, phase shift = $0.5\lambda$
- If incident light reflected by surface with lower $n$ no phase shift
  - $n_1 > n_2$, phase shift = 0
- **Refracted light is not phase shifted**

Example: soap bubble in air
Review

- Phase shift from thin films
- Combine reflection and path length difference
- First find phase shift (if any) between 2 rays from reflection at top and bottom of film
- Which path length equation to use depends on the reflection phase shift and what type of interference you want, maxima or minima

\[ 2L = (m + \frac{1}{2}) \frac{\lambda}{n_2}, \quad m = 0,1,2,... \]

\[ 2L = m \frac{\lambda}{n_2}, \quad m = 0,1,2,... \]
Diffraction

- Waves **diffract** (bend) if pass through an opening whose size is comparable to its wavelength
- The narrower the slit, the greater the diffraction
- Example of **double-slit interference** assumed slit width $a$ much smaller than $\lambda$ of incident light and we talked about 2 light rays
Two slit interference (Fig. 36-9)

- Intensity of 2 coherent sources
  \[ I = 4I_0 \cos^2 \left( \frac{1}{2} \phi \right) \]

- Maxima when
  \[ \phi = 2\pi m \]

- Minima when
  \[ \phi = 2\pi (m + 1/2) \]

- \( m \) is called the “order”

\[ y = \frac{m \lambda D}{d}, \quad m = 0, 1, 2 \ldots \]
3-slit interference

- The distance between each is $d$.
- The most intense maxima are still given by

$$y = \frac{m \lambda D}{d}$$

- But now there are also secondary maxima related to the larger spacing $2d$

$$y = \frac{m \lambda D}{2d}$$
4-slit interference

- The distance between each is $d$.
- The most intense maxima are still given by $y = \frac{m \lambda D}{d}$.
- But now there are also secondary maxima related to the larger spacing $3d$.
- The primary maxima gets narrower as the number of slits increases.
Diffraction Gratings (Figs. 37-16, 17)

- Increase # of slits from 2 to a large number
- Bright fringes in intensity plot are now very narrow (called lines) and separated by wide dark regions
- A mask that contains a large number of slits at equal separation distances, \( d \), is called a diffraction grating
Diffraction Gratings (Figs. 37-16, 17)

- The equation for the positions of the maxima are the same as those for two slits at distance $d$

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

- Grating spacing is

$$d = \frac{\text{Total Width}}{\text{Num. Rulings}} = \frac{w}{N}$$
Diffraction Gratings (Fig. 37-22)

- Angle $\theta$ from central axis to any line depends on wavelength of light $\lambda$
  - Larger $\lambda$, bigger $\theta$

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

- Light from a given source can be split into its emission lines (below are lines for hydrogen)
  - Use this to determine types of gases in stars

Violet=430 nm  Red=690 nm
Diffraction

- Do we still get an interference pattern if we have only one slit?

- Yes, see a bright central maximum and then other less bright spots on the sides (side maxima) separated by dark minima
  - Caused by interference of wavelets from same wavefront going through slit
Diffraction

- **Interference** –
  - Combining waves from small number of coherent sources – double-slit experiment with slit width much smaller than wavelength of the light

- **Diffraction** –
  - Combining of large number of wavelets from single wavefront – as in single slit experiment

- **Diffraction and interference are both**
  - the result of combining waves with different phases at a given point
  - Usually present simultaneously

- Example see photo 37-14 p.902