Lecture 11, 8/4/2017

- Double Slit Experiment
- Dispersion
- Diffraction
- Thin fil interference
- Limits to resolution
Example

Light comes in horizontally from air \((n_{\text{air}} = 1.0)\) into an object made of lucite \((n_{\text{lucite}} = 1.50)\). The object is in the shape of an equilateral triangle of side \(L\). At what angle from the horizontal will light come out on the other side?

\[
1 \sin 30^\circ = 1.5 \sin \theta_2 \quad \Rightarrow \quad \theta_2 = 20^\circ
\]

\[
1.5 \sin 40^\circ = 1 \sin \theta_3 \quad \Rightarrow \quad \theta_3 = 75^\circ
\]
If light is a wave, interference effects will be seen, where one part of wavefront can interact with another part.

One way to study this is to do a double-slit experiment:
Interference—Young’s Double-Slit Experiment

If light is a wave, there should be an interference pattern.
The interference occurs because each point on the screen is not the same distance from both slits. Depending on the path length difference, the wave can interfere constructively (bright spot) or destructively (dark spot).
Interference—Young’s Double-Slit Experiment

We can use geometry to find the conditions for constructive and destructive interference:

\[ d \sin \theta = m \lambda, \quad m = 0, 1, 2, \ldots \] [constructive interference (bright)]

\[ d \sin \theta = \left( m + \frac{1}{2} \right) \lambda, \quad m = 0, 1, 2, \ldots \] [destructive interference (dark)]
Interference—Young’s Double-Slit Experiment

Observation: Between the maxima and the minima, the amplitude varies smoothly.
The Visible Spectrum and Dispersion

Wavelengths of visible light: 400 nm to 750 nm

Shorter wavelengths are ultraviolet; longer are infrared
The index of refraction of a material varies somewhat with the wavelength of the light.
The Visible Spectrum and Dispersion

This variation in refractive index is why a prism will split visible light into a rainbow of colors.
The Visible Spectrum and Dispersion

Atmospheric rainbows are created by dispersion in tiny drops of water.
Diffraction by a Single Slit or Disk

Light will also diffract around a single slit or obstacle.
Diffraction by a Single Slit or Disk

The resulting pattern of light and dark stripes is called a diffraction pattern.

This pattern arises because different points along a slit create wavelets that interfere with each other just as a double slit would.
Diffraction by a Single Slit or Disk

The minima of the single-slit diffraction pattern occur when

\[ D \sin \theta = m\lambda, \quad m = \pm 1, \pm 2, \pm 3, \ldots, \]
A diffraction grating consists of a large number of equally spaced narrow slits or lines. A transmission grating has slits, while a reflection grating has lines that reflect light.

The more lines or slits there are, the narrower the peaks.
The maxima of the diffraction pattern are defined by

$$\sin \theta = \frac{m \lambda}{d}, \quad m = 0, 1, 2, \ldots$$

(a) 700 nm 400 nm 700 nm 400 nm Both \( \lambda \) 400 nm 700 nm 400 nm 700 nm

Rainbow (fainter) Rainbow White Rainbow Rainbow (fainter)
Interference in Thin Films

Another way path lengths can differ, and waves interfere, is if the travel through different media.

If there is a very thin film of material—a few wavelengths thick—light will reflect from both the bottom and the top of the layer, causing interference.

This can be seen in soap bubbles and oil slicks, for example.
Interference in Thin Films

The wavelength of the light will be different in the oil and the air.
Interference in Thin Films; Newton's Rings

A similar effect takes place when a shallowly curved piece of glass is placed on a flat one. When viewed from above, concentric circles appear that are called Newton’s rings.
Interference in Thin Films; Newton’s Rings

One can also create a thin film of air by creating a wedge-shaped gap between two pieces of glass.
Interference in Thin Films

Problem Solving: Interference

1. Interference occurs when two or more waves arrive simultaneously at the same point in space.

2. **Constructive** interference occurs when the waves are in phase.

3. **Destructive** interference occurs when the waves are out of phase.

4. An extra **half-wavelength shift** occurs when light reflects from a medium with higher refractive index.
The Michelson interferometer is centered around a beam splitter, which transmits about half the light hitting it and reflects the rest. It can be a very sensitive measure of length.
Polarization

We know that light is partially polarized after reflecting from a nonmetallic surface.

At a special angle, called the polarizing angle or Brewster’s angle, the polarization is 100%.

\[ \tan \theta_p = \frac{n_2}{n_1} \]
Telescopes

Parallel rays from object at \( \infty \)

Objective lens

Eyepiece
Resolution: The distance at which a lens can barely distinguish two separate objects.

Resolution is limited by aberrations and by diffraction.

Aberrations can be minimized, but diffraction is unavoidable; it is due to the size of the lens compared to the wavelength of the light.
Limits of Resolution; Circular Apertures

For a circular aperture of diameter $D$, the central maximum has an angular width:

$$\theta = \frac{1.22\lambda}{D}$$
The Rayleigh criterion states that two images are just resolvable when the center of one peak is over the first minimum of the other.
Resolution of Telescopes and Microscopes; the $\lambda$ Limit

Since the resolution is directly proportional to the wavelength ($\lambda$) and inversely proportional to the diameter (D), radio telescopes are built to be very large.
Resolution of Telescopes and Microscopes; the $\lambda$ Limit

For microscopes, assuming the object is at the focal point, the resolving power is given by:

$$\text{RP} = s = f\theta = \frac{1.22\lambda f}{D}$$

Typically, the focal length of a microscope lens is half its diameter, which shows that it is not possible to resolve details smaller than the wavelength being used.

$$\text{RP} \approx \frac{\lambda}{2}$$