When a light wave travels from one medium to another, its frequency does not change, but its wavelength does:

\[ \frac{\lambda_2}{\lambda_1} = \frac{v_2}{v_1} = \frac{n_2}{n_1} \quad (v = c/n) \]

\[ \frac{n_1}{n_2} = \frac{\lambda_2}{\lambda_1} = \frac{\sin(r)}{\sin(i)} \]

The shorter \( \lambda \), the larger refraction angle.

Example: Monochromatic yellow light illuminates two narrow slits 1 mm apart. The screen is 1 m from the slits, and the distance from the central bright light to the next bright line is found to be 0.589 mm. Find the wave length of the light.

Solution: \( d \sin \theta = m \lambda \), where \( m = 1 \) or \( \lambda = d \sin \theta / 1 = (1 \times 10^{-3} \text{m}) \times (5.89 \times 10^{-4} \text{m}) / 1 \text{m} = 5.89 \times 10^{-7} \text{ m} = 589 \text{ nm} \)
There are two difficulties in using a double slit for measuring wavelengths.
1. The bright lines on the screen are actually extremely faint and an intense light source is therefore required;
2. The lines are relatively broad and it is hard to locate their center accurately.

A diffraction grating that consists of a large number of parallel slits overcomes both of these difficulties.

A diffraction grating uses interference to disperse light. It is often an important component in optical instrumentation for wavelength determinations.

$$dsin\Theta=ml\lambda$$

m=0,1,2,3, . . . Constructive inference
m=1/2,3/2,5/2, . . . Destructive inference

For a diffraction grating, the intensity falls away from these maxima much more rapidly than that for a double slit. Because there are so many slits to act as sources, any angle other than those for maxima will be dark or nearly dark.

Example: Visible light includes wavelengths from 4x10^-7 m to 7x10^-7 m. Find the angular width of the first-order spectrum produced by a grating ruled with 800 lines/cm.

Solution: The slit space d that corresponding to 800 line/cm is

d=(10^-2 m/cm)/(8x10^3 lines/cm)=1.25x10^-6 m

Since m=1,

$$sin\Theta_1=\lambda/d = 4x10^{-7}m/1.25x10^{-6}m = 0.32, \Theta_1=19^\circ$$

$$sin\Theta_2=\lambda/d = 7x10^{-7}m/1.25x10^{-6}m = 0.56, \Theta_2=34^\circ$$

The total width of the spectrum is therefore $34^\circ-19^\circ=15^\circ$

The angle can be measured to very high accuracy, so the wavelength of a line can be determined to high accuracy using

$$\lambda=d sin\Theta/m$$

Question: A characteristic property of the spectra produced by a diffraction grating is

(a) the sharpness of the bright lines
(b) diffuseness of the bright lines
(c) absence of bright lines
(d) absence of dark lines

Answer: a
**Question:** The greater the number of lines that are ruled on a grating of given width,
(a) The shorter the wavelengths that can be diffracted
(b) The longer the wavelengths that can be diffracted
(c) The narrower the spectrum that is produced
(d) The broader the spectrum that is produced

Answer: d

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**A prism also disperses light**

\[ \frac{n_1}{n_2} = \frac{\lambda_2}{\lambda_1} = \frac{\sin(r)}{\sin(i)} \]

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**Single-slit Diffraction**

Light from all parts of the slit travels the same distance and arrives "in phase" so there is a bright central maximum.

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**Spectrometer and Spectroscopy**

**using a grating or prism**

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**Question:** White light strikes (a) a diffraction grating, and (b) a prism. A rainbow appears on a screen just below the direction of horizontal incident beam in each case. What is the color of the top of the rainbow in each case?

Answer: (a) Violet for diffraction grating \((m\lambda = d\sin\Theta)\)

(b) Red for prism \((\frac{n_1}{n_2} = \frac{\lambda_2}{\lambda_1})\)
**Interference in Reflected Waves**

Phase changes due to Reflection

- No Phase change
- Half wavelength phase change

A wave on a string with no phase change

A wave on a string with a phase change

- There is no phase change when light reflects from a region with a lower $n$
- There is a half-wavelength phase change when light reflects from a region with a higher $n$

**Interference in Thin Films**

- Ray 1 undergoes a phase change of 180° with respect to the incident ray
- Ray 2, which is reflected from the lower surface, undergoes no phase change with respect to the incident wave

- Ray 2 also travels an additional distance of $2t$ before the waves recombine

For constructive interference

- $2nt = (m + \frac{1}{2})\lambda \quad m = 0, 1, 2 \ldots$
  - This takes into account both the difference in optical path length for the two rays and the 180° phase change

For destruction interference

- $2nt = m\lambda \quad m = 0, 1, 2 \ldots$

**Newton's Rings (Interference by thin films)**

- Dark spot: the beam light changes phase by $\frac{1}{2}$ cycle ($\frac{\lambda}{2}$) i.e., due to destructive interference
Monochromatic light of wavelength $\lambda$ is normally incident on a soap film in air. In terms of the wavelength, what is the thickness of the thinnest film for which the reflected light will be a maximum?

(a) $\lambda/4$  
(b) $3\lambda/4$  
(c) $3\lambda/2$  
(d) $\lambda/2$  
(e) $\lambda$

Question: If a lens looks greenish yellow then what wavelengths or colors is it designed to eliminate completely?

Answer: Blue light (450 nm) and red light (750 nm).

Lens reflection is a problem in optical instruments.

To reduce reflections, at a glass-air interface, the lens can be coated with a very thin film layer.

How a CD Work

Destructive Interference

The information is encoded in the form of a series of "bumps" on an otherwise smooth reflecting surface. A laser beam directed onto the surface is reflected back to a detector, and as the intensity of the reflected beam varies due to the bumps, the information on the CD is decoded.

Polarization

$I = I_0 \cos^2 \Theta$
Longitudinal wave cannot be polarized

Which one of the following statements provides the most convincing evidence that electromagnetic waves have a transverse character?

(a) Electromagnetic waves can be refracted.
(b) Electromagnetic waves can be diffracted.
(c) Electromagnetic waves can be reflected.
(d) Electromagnetic waves exhibit interference.
(e) Electromagnetic waves can be polarized.

Question: The wavelength of light plays no role in
(a) interference
(b) diffraction
(c) refraction
(d) polarization

Answer: d
**Question:** Longitudinal waves do not exhibit
(a) Refraction
(b) Reflection
(c) Polarization
(d) Diffraction

**Answer:** c