5. Monochromatic light from a helium-neon laser (λ = 632.8 nm) is incident normally on a diffraction grating containing 6,000 lines per cm. Find the angle of the first order maximum and its distance from the central maximum on a screen 2.5 meters away.

$S = \frac{\lambda D}{d}$

a) Find the distance between the slits on the grating.

$\frac{1 cm}{6000} = 1.67 \mu m$

b) Find the angles at which one would observe the first order fringes.

$n\lambda = d\sin\theta \rightarrow \theta \sim 22°$

(1)

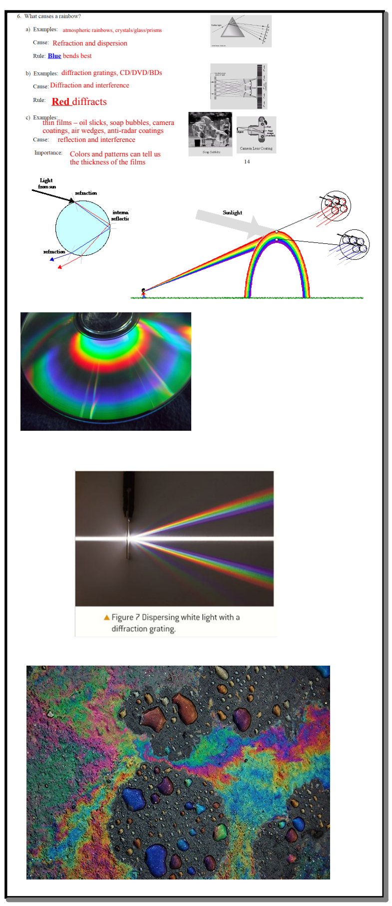
c) Determine how far each of these fringes is from the central maximum on a screen 2.5 meters away.

$\sin\theta \neq \tan\theta$

$\frac{S}{D} = \frac{\lambda}{d}$

~~$S = \frac{\lambda D}{d}$~~ → ~~S = .95 cm~~

$\tan\theta = \frac{S}{D} \rightarrow S = 1.05 m$



6. What causes a rainbow?

a) Examples: atmospheric rainbows, crystals/glass/prisms

Cause: Refraction and dispersion

Rule: **Blue** bends best

b) Examples: diffraction gratings, CD/DVD/BDs

Cause: Diffraction and interference

Rule: **Red** diffracts

c) Examples: thin films – oil slicks, soap bubbles, camera coatings, air wedges, anti-radar coatings

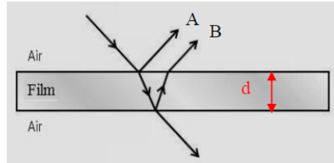
Cause: reflection and interference

Importance: Colors and patterns can tell us the thickness of the films

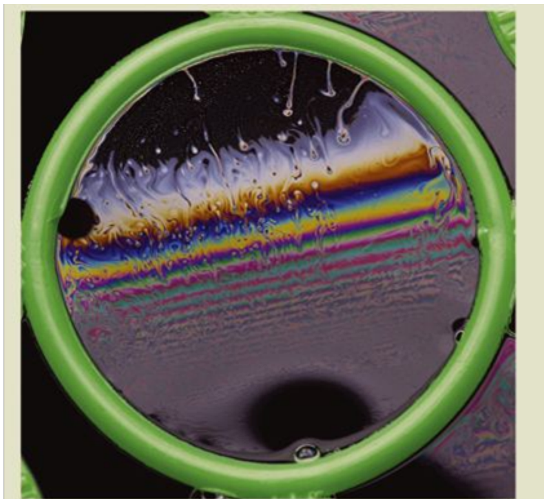
14

Figure 7 Dispersing white light with a diffraction grating.

When an incoming light ray hits the upper boundary, it both reflects (A) and refracts (B). Part of light ray B also reflects at the lower boundary. Light rays A and B will then interfere either constructively or destructively as seen when viewed from above, depending on whether or not they are in phase when they recombine. If the incoming light ray was white light, destructively interfering wavelengths will not be seen and constructively interfering wavelengths will be seen. This produces the rainbow effect. Two things will determine which wavelengths interfere constructively and destructively:



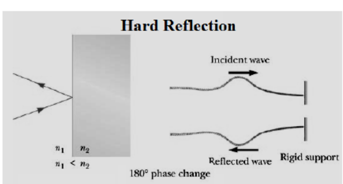
a) path difference b) phase difference



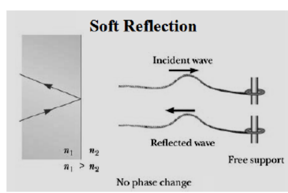
▲ Figure 10 Thin film interference in a vertical soap film.

Before we derive the appropriate formulas, here are two reminders:

I. The phase of a wave can change upon reflection.

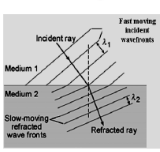


Phase change:



Phase change:

II. The wavelength of a wave can change as it enters a new medium.



Formula:

$$\lambda_f = \frac{\lambda_{air}}{n_{film}} \qquad \frac{\lambda_2}{\lambda_1} = \frac{n_1}{n_2}$$

where:

λ = wavelength in air

λ_f = wavelength in film

n = index of refraction of film

Constructive interference of rays A and B will occur if the two rays are . . . in phase

Formula:

Path difference = mλ + phase difference

$$2d = m\lambda_f + \lambda_f/2$$

$$(m+\tfrac{1}{2})\lambda/n$$

$$2dn = (m+\tfrac{1}{2})\lambda$$

Where:

m = 0, 1, 2, ...

d = thickness of film

n = index of refraction

Destructive interference of rays A and B will occur if the two rays are . . .

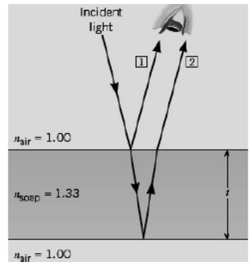
Formula: Path difference = (m+ ½)λ + phase difference

$$2d \quad m + \tfrac{1}{2}\lambda_f + \tfrac{1}{2}\lambda_f$$

$$2dn = m\lambda$$

NOTE: The above two formulas are derived for the case where the two rays undergo only one hard reflection. In the case where the light rays undergo two hard reflections (or two soft reflections) then…

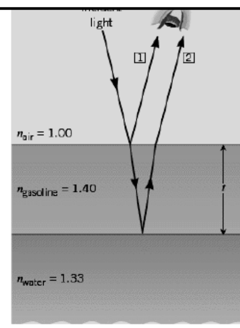
1. A soap film ($n = 1.33$) is surrounded on both sides by air. Sunlight strikes the film nearly perpendicularly and several colored fringes are seen. One particular shade of red light whose wavelength is 665 nm is seen. What is the minimum thickness of the film at this point to cause constructive interference for this color?



$$2dn = (m + \tfrac{1}{2})\lambda$$

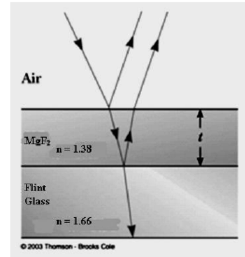
$$d = \frac{\lambda}{4n} = 125 \text{ nm}$$

2. A thin film of gasoline floats on a puddle of water. Sunlight falls almost perpendicularly on the film and reflects up. Determine the minimum thickness of the film that will result in destructive interference for blue light whose wavelength is 469 nm.



168 nm

3. A thin film of Magnesium Fluoride is often applied to the surface of high quality lenses in cameras and telescopes. Find the minimum thickness of a layer of magnesium fluoride (n = 1.38) on flint glass (n = 1.66) that will cause destructive interference of reflected light of wavelength 550 nm near the middle of the visible spectrum.



fast-slow-fast

constructive

$2dn = (m+\frac{1}{2})\lambda$

destructive

$2dn = m\lambda$

99.6 nm

fast-slow-slower

constructive

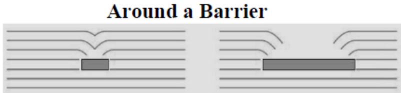
$2dn = m\lambda$

destructive

$2dn = (m+\frac{1}{2})\lambda$

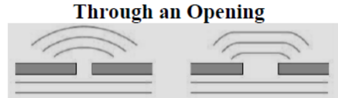
Diffraction: the bending or spreading of a wave when it passes through a small opening (aperture) or around a barrier

Around a Barrier



The larger the barrier size compared to the wavelength of the wave, the less the wave diffracts.

Through an Opening



The larger the aperture size (slit width) compared to the wavelength of the wave, the less the wave diffracts.

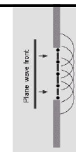
Condition for noticeable diffraction:

Size of opening or width of barrier should be approximately equal to the wavelength

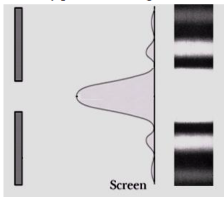
Single Slit Diffraction and Interference

Why is there an interference pattern when light travels through a single slit?

White light – white central maximum, rainbow secondary maxima



The intensity pattern for single slit diffraction

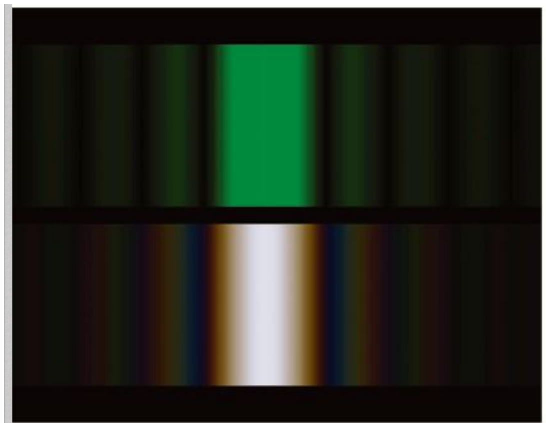


Features of the Single Slit Intensity Pattern

a) Wide and bright central maximum

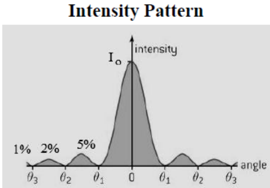
b) Equal and dim secondary maxima

c) different parts of the wave interfere with itself as it spreads



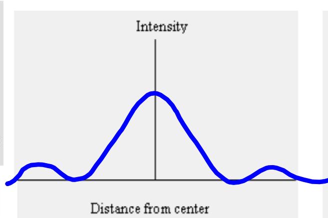
▲ Figure 3 Single slit with monochromatic and white light.

Intensity Pattern

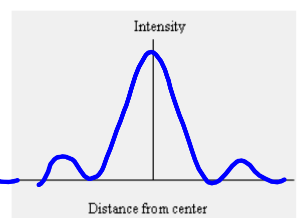


Approximate ratios of successive intensity maxima:

Effect of slit width on diffraction pattern

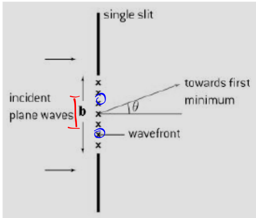


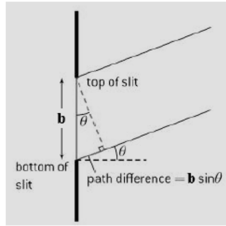
Narrow slit

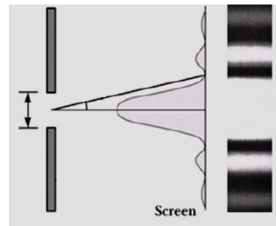


Wide slit

Single slit diffraction formula







θ/d

$\frac{\frac{1}{2}\lambda}{d} = \frac{s}{D} = \theta$

↑ b/2

Position of first minimum (angular half-width of central maximum): $\theta = \frac{\lambda}{b}$

Note: θ must be in radians

Half-width of central maximum: location of first dark fringe

Angular half-width: θ Angular width: 2θ

Linear half-width: s Linear width: $2s$

Ratio

$\frac{\lambda}{b} = \frac{s}{D}$

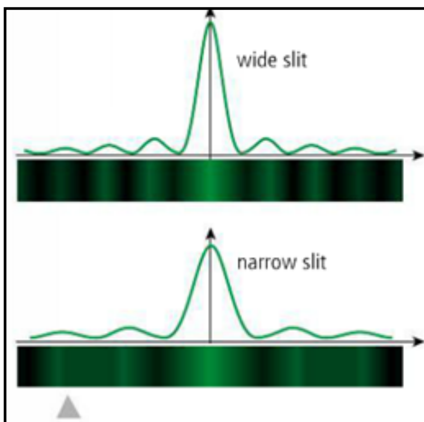


Figure 5.94 Notice that with a narrower slit the pattern is wider but less intense.

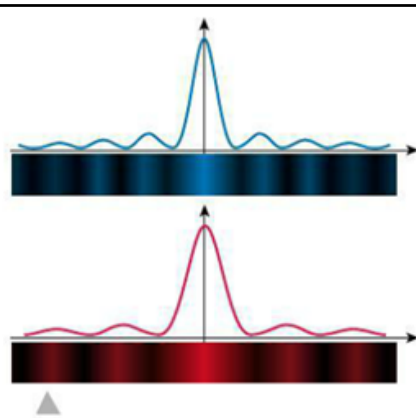


Figure 5.95 Same size slit but different wavelength light, longer wavelength gives a wider pattern.