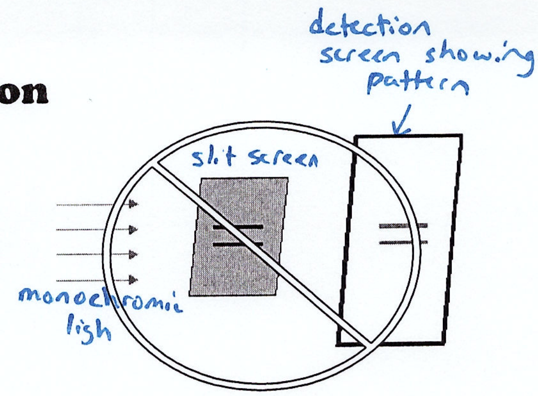
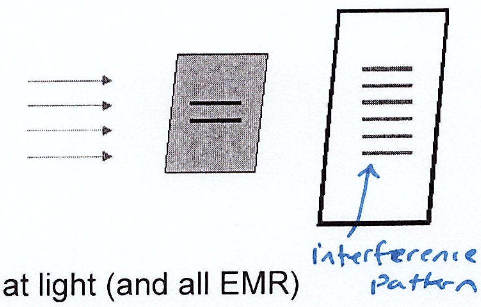
Interference and Diffraction

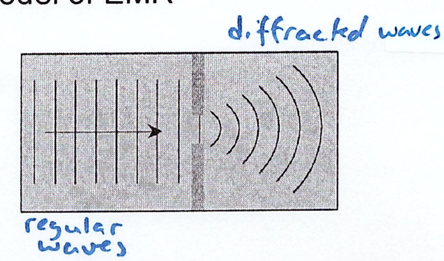
- Young predicted that if he shown monochromic light (light of one color/wavelength) through two narrow slits, he would expect to see two bright bands produced on a screen on the other side.
  - However, this did not occur!

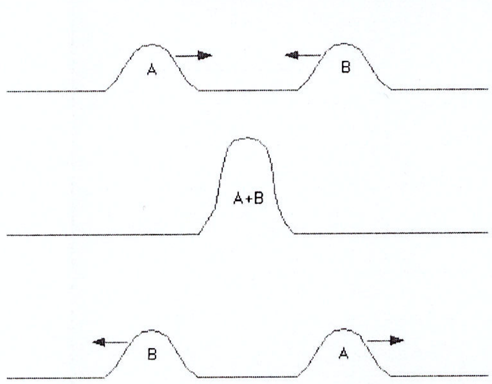


- Young discovered that when monochromic light passes through two narrow slits, an *interference pattern* of bright and dark fringes/bands was produced on the screen
  - This experiment is known as *Young's Double Slit Experiment*

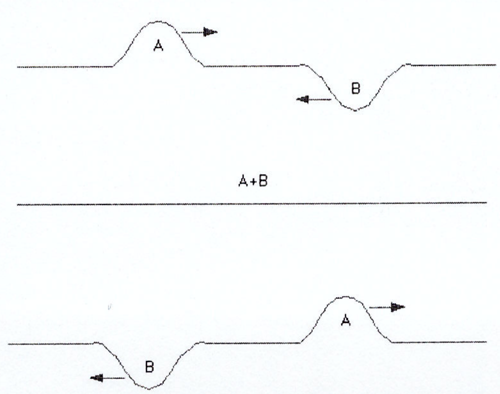


- In order to explain his observations, Young concluded that light (and all EMR) must have the ability to **diffract** and **interfere**.
  - ✳ Diffraction and interference strongly support the wave-model of EMR
  - ✳ **Diffraction** is the ability of a wave to spread out as it passes through an opening or the ability of a wave to bend around small openings or obstacles
  - When the light passed through the two slits in Young's experiment, the light would diffract/bend around the openings and the two waves from each opening would start to *interfere* with one another on the other side of the slit screen
  - The bright bands in the interference pattern could be explained by **constructive interference**. *Constructive interference* occurs when two waves that are in phase overlap each other resulting in an increase in amplitude (ie. a bright band is seen).
  - The dark bands in the interference pattern could be explained by **destructive interference**. *Destructive interference* occurs when two waves that are out phase overlap each other resulting in a decrease in amplitude. In this case, since the waves are identical, they cancel each other out completely resulting in not light being seen (ie. a dark band).

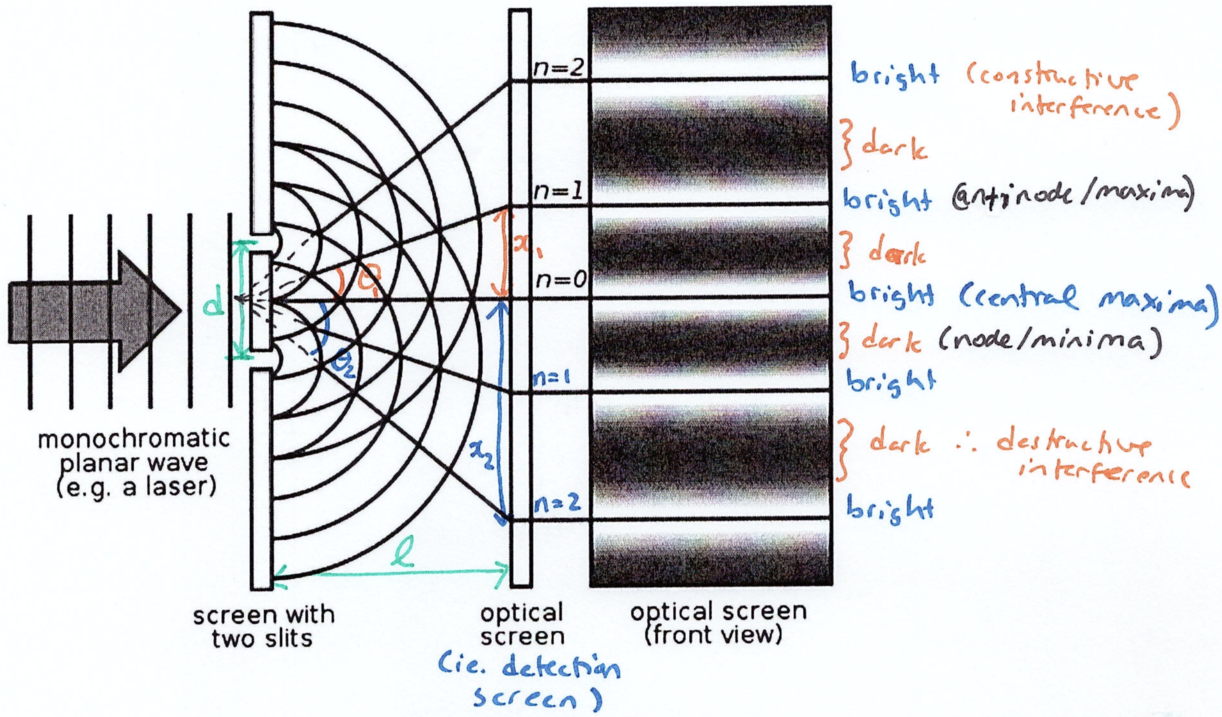




Constructive Interference



Destructive Interference



- The bright bands/fringes are also called **maxima** or **antinodals** and are areas where constructive interference occurs
- The dark areas or fringes are called **minima** or **nodals** and are areas where destructive interference occurs

- Young's double slit experiment/diffraction experiment can be explained using two formulas.

$$\lambda = \frac{dx}{nl} \quad \text{and} \quad \lambda = \frac{d\sin\theta}{n}$$

where

any unit for distance, as long as units are consistent!

λ is the wavelength of the light/EMR

d is the distance between the slits

x is the distance from the central bright band to another bright band

l is the distance from the slit screen to the screen displaying the interference pattern

Θ is the angle from the center of the slits to a bright band

n is the order number of the bright band (if not indicated, assume n=1)

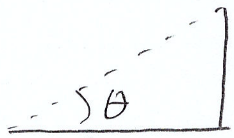
✱ ○ The distance between the slits in the screen (d) can also be indicated by a **diffraction grating**. A *diffraction grating* simply indicates the numbers of slits there are per a set distance. Using a diffraction grating with multiple slits instead of only two slits produces a sharper and clearer interference pattern, which is better for making more accurate measurements.

$$d = \frac{1}{diffraction\ \ grating}$$

✱ • The equation $\lambda = \frac{d\sin\theta}{n}$ can be used for any diffraction calculation, whereas $\lambda = \frac{xd}{nl}$ can only be used when θ is less than 10°.

Very important!

- To calculate the angle, simply use trigonometry



x (distance b/w bright band & central band)

l (distance b/w screens)

$\therefore \tan\theta = \frac{x}{l}$

EXAMPLES

1. Light falls on a pair of slits $1.28\text{x}10^{-5}$m apart. The maxima are $1.15\text{x}10^{-1}$m apart and the screen is 0.550m from the slits. What is the wavelength of the light?

$d = 1.28\times10^{-5}\text{m}$

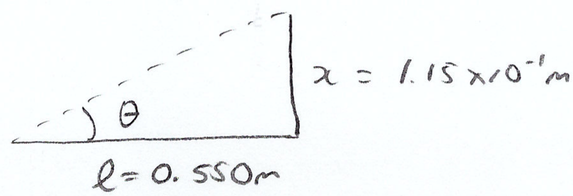
$x = 1.15\times10^{-1}\text{m}$

$l = 0.550\text{m}$

$\lambda = ?$

$n = 1$

* first solve for angle!



$\theta = \tan^{-1}\left(\frac{1.15\times10^{-1}\text{m}}{0.550\text{m}}\right) = 11.8098...^\circ$

$\therefore$ cannot use $\lambda = \frac{dx}{nl}$

$\lambda = \frac{d\sin\theta}{n} = \frac{(1.28\times10^{-5}\text{m})\sin(11.8098...^\circ)}{1} = 2.6197...\times10^{-6}\text{m}$

$\boxed{\lambda = 2.62\times10^{-6}\text{m}}$

2. Calculate the angle of diffraction of the 2nd order maximum produced by directing monochromic light with a wavelength of 4.30×10^{-7}m through a diffraction grating with 2.00×10^{5} lines/m.

$\theta = ?$

$n = 2$

$\lambda = 4.30\times10^{-7}\,m$

$d = \dfrac{1}{2.00\times10^{5}\ \text{lines/m}}$

$d = 5.00\times10^{-6}\,m$

$$\lambda = \frac{d\sin\theta}{n} \Rightarrow \sin\theta = \frac{\lambda n}{d}$$

$$\sin\theta = \frac{(4.30\times10^{-7}m)(2)}{5.00\times10^{-6}m} = 0.172$$

$$\therefore \theta = \sin^{-1}(0.172) = 9.90412...^{\circ}$$

$$\boxed{\theta = 9.90^{\circ}}$$

3. If the distance between the slits was increased in a diffraction experiment similar to Young's experiment, how would the angle of diffraction change?

$$\lambda = \frac{d\sin\theta}{n} \Rightarrow \sin\theta = \frac{\lambda n}{d} \quad \therefore \quad \sin\theta \propto \frac{1}{d}$$

as "d" increases, sin θ would decrease; causing θ to decrease!

4. If a blue laser was initially used in Young's double slit experiment, how would the distance between the bright bands change if a red laser was used instead?

changing lasers causes λ to increase

$$\lambda = \frac{xd}{nl} \Rightarrow x = \frac{\lambda n l}{d} \quad \therefore \quad x \propto \lambda$$

as λ increases, so does the distance b/w the bright bands (x)

*****Now try pg. 238 #2, 5, P.P. #1 (acceptable), pg. 239 #7, 9, P.P. #2-6 (intermediate), pg. 243 #17 (excellence)*****

Practice Problems

1. A monochromic beam of light is passed through two slits and forms an interference patter on a screen. The distance between the slits is 0.0250cm and the distance to the slit screen and the interference pattern screen is 5.00m. The distance from the central bright to the second bright fringe is 2.38cm.
   a. Determine the wavelength of the incident light. **[595 nm]**
   b. Identify the color of the incident light used. **[yellowish]**

2. Monochromic light of 720nm is passed through two narrow slits imprinted onto a slide. The distance between the two slits is $3.00\text{x}10^{-6}$ m and the screen is located 110cm away from the slide. Determine the distance between the bright lines in the interference pattern formed on the screen. **[27.2 cm]**

3. An argon laser used in retinal surgery has a frequency of $6.148\text{x}10^{14}$ Hz. It is incident on a diffraction grating ruled with 60 lines/cm. The diffraction grating and screen are 1.50m apart. What is the distance between the bright lines in the diffraction pattern? **[4.39 mm]**

4. If a green laser was used instead of a red laser in a diffraction experiment, what would happen to the angle of diffraction of the light? **[angle of diffraction would decrease]**

5. If the slit screen and the detection screen for the interference pattern are placed closer together, what will happen to the distance between the bright bands on the interference pattern? **[the distance between the bright bands would decrease]**

6. During a diffraction experiment, students changed from a purple laser to a green laser. In order to keep the bright bands in the interference pattern the same distance apart from each other, where will the detection screen need to be moved in reference to the slit screen? **[closer to the slit screen]**