Chapter 2

- Newton believed that light was made up of small particles. This point was debated by scientists for many years and it was not until the 1800's when a series of experiments demonstrated wave nature of light. (But be patient we will see the particle nature of light in the next chapter.)
- There are a number of features that show us that light can behave like a wave.

  a) Interference from a double (or more) slits
  (We have seen interference in 1-D)

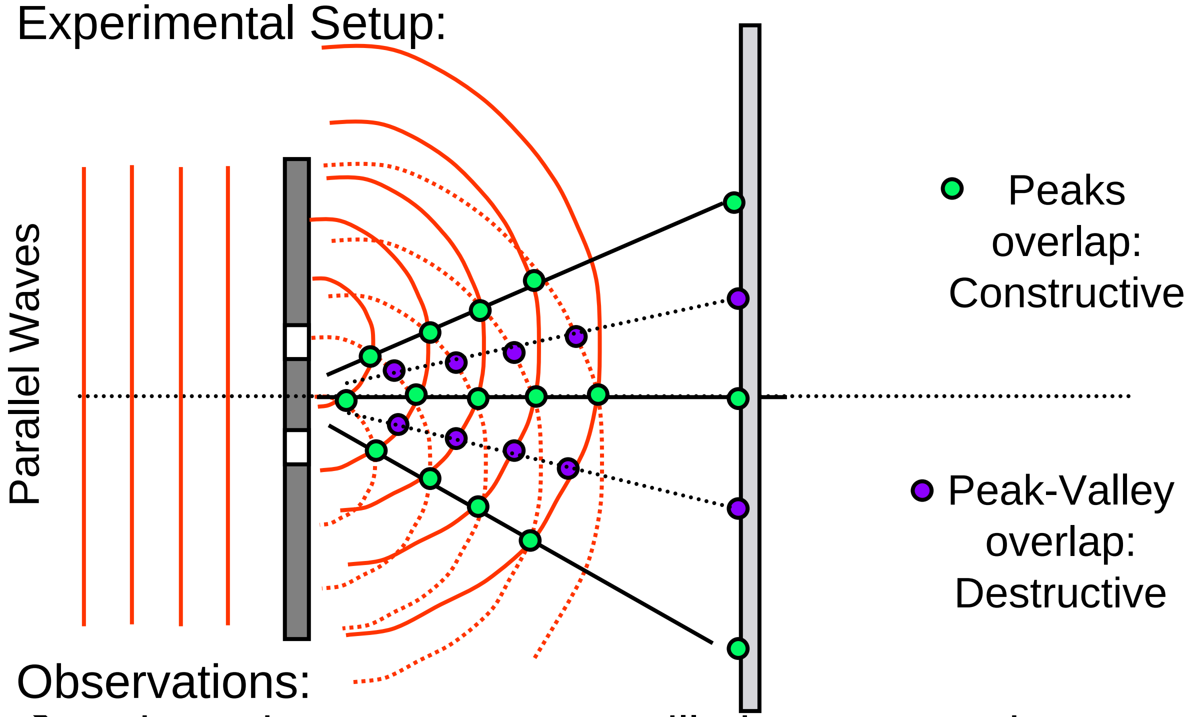
  b) Diffraction from a single slit.

  These are features of any 2 or 3 dimensional waves (light, water, sound, etc.)
- We will start with 2-slit interference

  ➔ Assumption: If the slit width is small enough, the two slits act approx. as point sources emitting circular waves. (*We will learn more about this with diffraction.)*

Two Slit Interference

- Experimental Setup:



- Observations:
  ➔ Points where crests meet will give constructive interference.

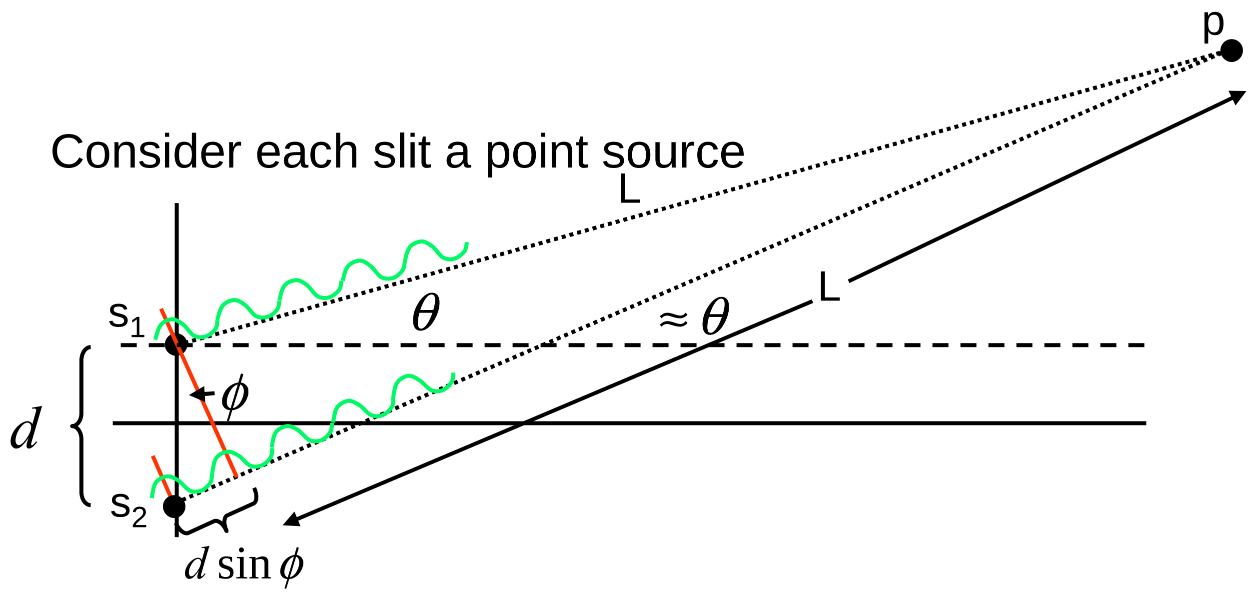
  ➔ Points where crests and trough meet will give destructive interference. (**Note: This is based on the principle of superposition from Chapter 1.**)

  ➔ The constructive and destructive interference seems to fall along lines that radiate from a point midway between the slits. (At least at points far from the two slits.)

- Let's derive an expression that gives the angle relative to the horizontal line.

Two Slit Interference

- Consider each slit a point source



- Limiting assumptions: P is far from slits
  ➔ $\phi \sim \theta$ (You do the geometry)
- If there is <u>constructive</u> interference at point P the crest from s_1 must arrive at the same time as a crest from s_2. For this to be true an integer number of wavelengths must fit in the distance $d\sin\theta$.
  Mathematically,

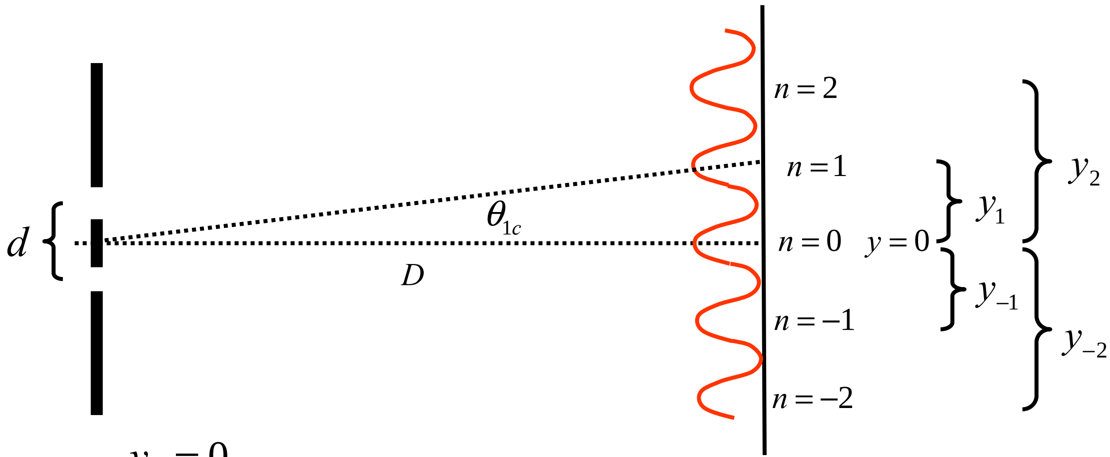
$$d \sin \theta_{nc} = n\lambda$$

$$\theta_{nc} = \sin^{-1}(n\lambda/d) \quad n = 0,1,2,\ldots$$

  Notes:
  "nc" – n is the number of maxima
  – c means "constructive"
  λ – wavelength
  d – distance between slits (center-to-center)
- For n=0 there is a maximum at $\theta_{nc}=0$ (centered between the slits). We could of developed an expression for destructive interference. (Condition=?)

Two Slit Interference

- Let's examine where the maxima are located:



$$y_o = 0$$

$$y_{\pm 1} = \pm D \tan\theta_{1c} = \pm D \tan\left(\sin^{-1}\frac{\lambda}{d}\right)$$

$$y_{\pm 2} = \pm D \tan\theta_{2c} = \pm D \tan\left(\sin^{-1}\frac{2\lambda}{d}\right)$$

- Small Angle approximation

$$\frac{n\lambda}{d} = \sin\theta_{nc} \approx \theta_{nc} \qquad y_{\pm n} = \pm D\tan\theta_{\pm nc} \approx \pm D\theta_{\pm nc}$$

$$y_{\pm n} \approx \pm D\left(\frac{n\lambda}{d}\right)$$

$$\frac{\pm n\lambda}{d} \approx \frac{y_{\pm n}}{D}$$

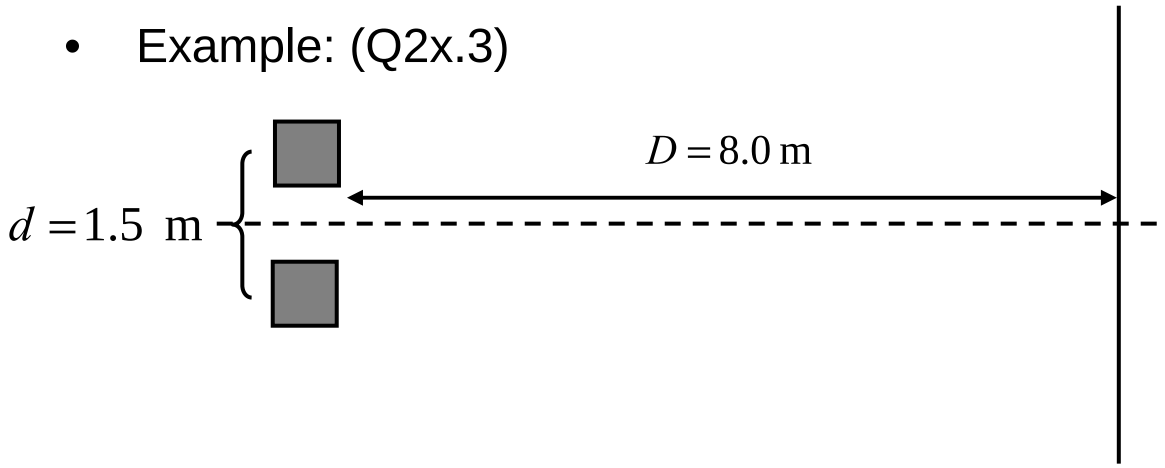
- For n=1

$$\lambda = y_1 d/D$$

- If you know d, D and measure y_1 (distance to first maximum) you can deduce λ.

Example

- Example: (Q2x.3)

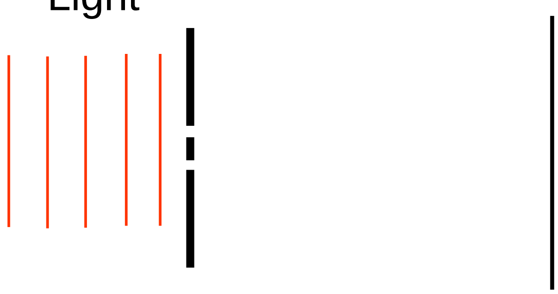


Two Slit Interference with Light

- It was a two-slit experiment that Thomas Young performed in the early 1800's that showed light was a wave.

If light was a particle, …

Monochromatic Light



If light is a wave, ...

- Other observations: (use small angle approx.)
  a) For a wave:

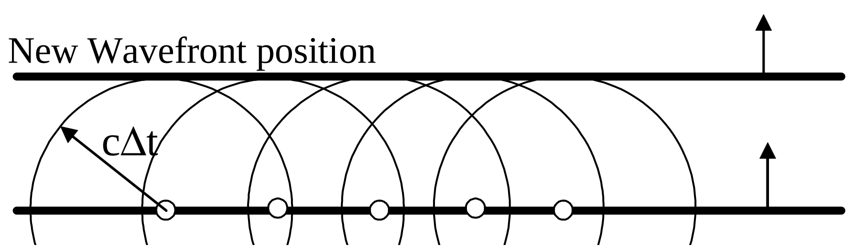
  b) Changing λ:

Diffraction

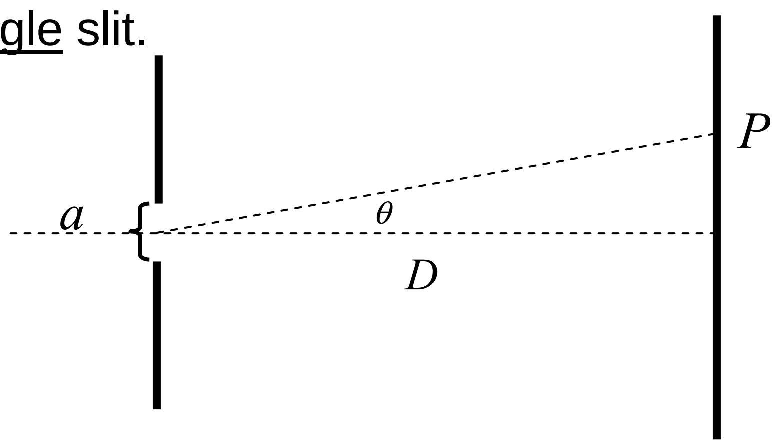
- Interesting Question: *Why do the second, third, n^{th} maxima have different intensities?*
- Answer: *Because of diffraction.* To understand what we mean by diffraction we need to first state:

Huygens's Principle:

Consider each point on a wave front as a source for a circular (spherical) wavelet. At a later time Δt, the new position of the wave is a curve tangent to the wavelets.



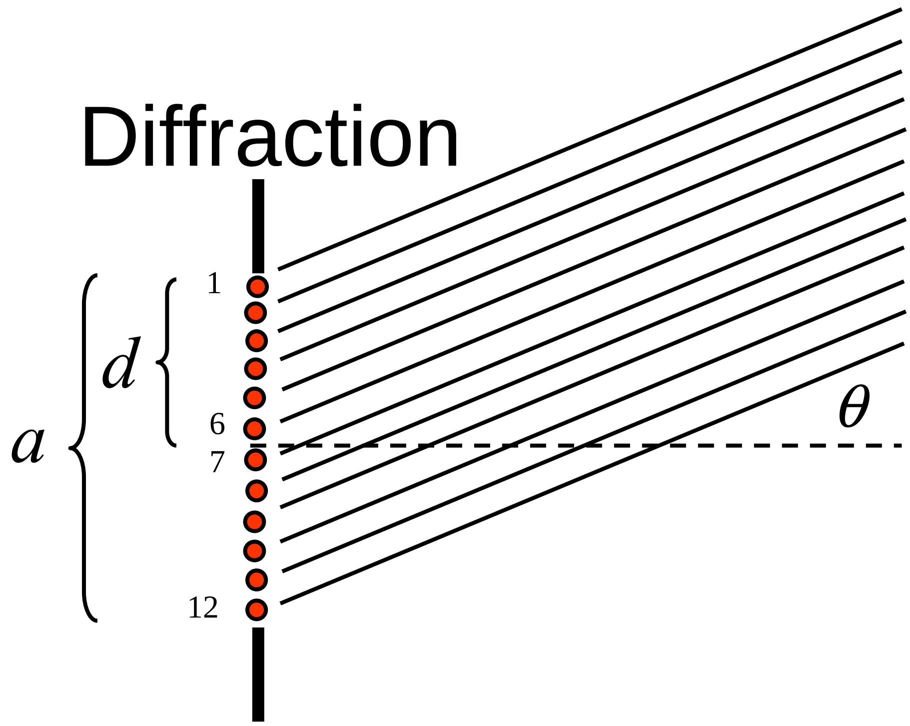
Now consider what happens when we pass light through a <u>single</u> slit.



We have the condition $D \gg a$

Diffraction

- Now zoon in on the slit:



(a) Consider θ=0. All sources have approximately the same distance so there is constructive interference.

(b) As θ increases the distance that each source must travel is slightly different. These in general will be out of phase so the interference will reduce the amplitude (destructive (partially)).

(c) There is a critical angle where the interference is <u>totally</u> destructive:

Pairs 1 and 7: d=a/2 a/2 sin θ = ½ λ

➔ total destructive interference

Pairs 2 and 8: d=a/2 a/2 sin θ = ½ λ

➔ total destructive interference

It is the same for all other pairs.

$$\boxed{a \sin \theta_{1d} = \lambda}$$

(d) As we increase the angle not all pairs will cancel so the light will grow slightly.

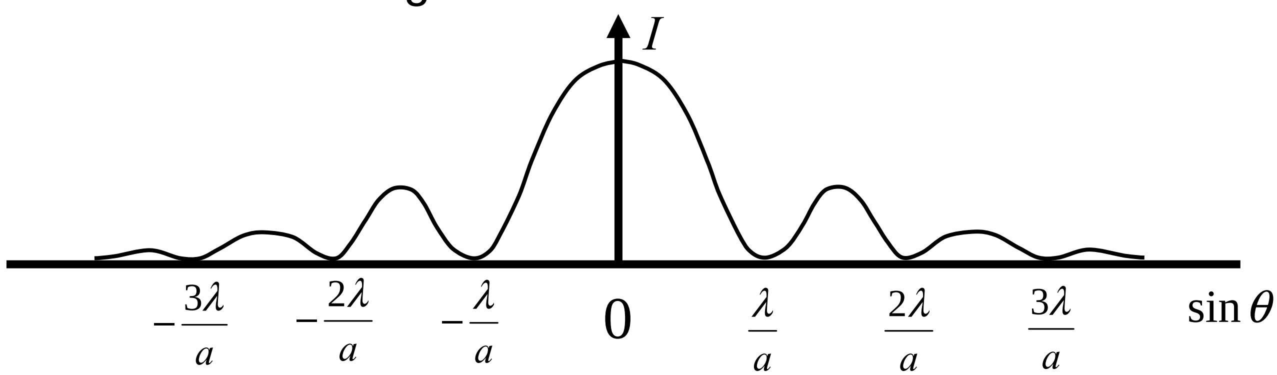
Diffraction

(e) However, we will hit a new angle where the interference will be totally destructive:

$$\boxed{a \sin\theta_{nd} = n\lambda}$$

Limitations: Slit height must be much larger than width and P is far from slit

Note that these angles are the *minima*



Notice that these secondary peaks <u>smaller</u> than the central maximum. We have not really shown why. Let's consider a specific example to convince ourselves this is true.

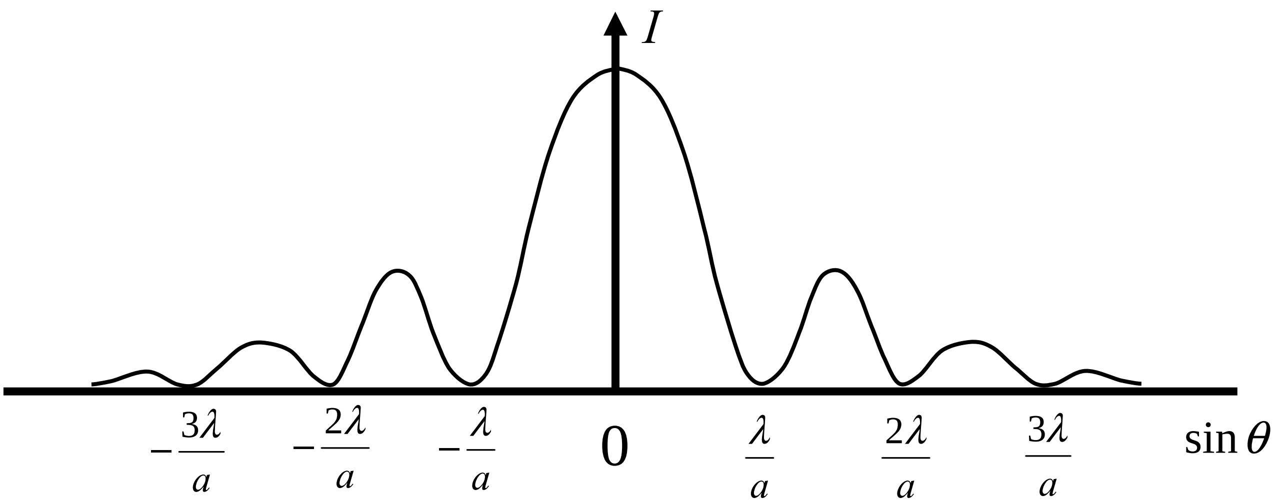
Consider: $\sin\theta = 3\lambda/(2a)$

Points 1 and 5: $d = \frac{1}{3}a$ $\quad \frac{1}{3}a\sin\theta = \frac{1}{3}a\left(\frac{3\lambda}{2a}\right) = \frac{\lambda}{2}$

➔ Condition for destructive interference. Pairs 2 & 6, 3 & 7, 4 & 8 also cancel. That leaves 9,10,11, and 12 but even 9 and 12 *almost* cancel d=(1/4)a. If only 10 and 11 contribute this is 2/12 = 1/6 the total light.

Two Slit Interference Revisited

- Now put the single slit diffraction and the two slit interference together.
- The intensity of the 2 slit interference patterns is modulated by the diffraction.



$$\sin\theta_{nd} = \frac{n\lambda}{a} \qquad \sin\theta_{nc} = \frac{m\lambda}{d}$$

- We can write down an expression for the intensity of light on the screen. Intensity is the square of the amplitude

$$I = I_{\max}\cos^2\left(\frac{\pi d\sin\theta}{\lambda}\right)\left[\frac{\sin\left(\frac{\pi a\sin\theta}{\lambda}\right)}{\frac{\pi a\sin\theta}{\lambda}}\right]^2$$

- Read section 2.4 on optical resolution…you are responsible for it.

Conceptual Example

- Q2T.8

  Consider an experiment where we send monochromatic light to a distant screen through a single narrow slit. The distance between adjacent dark fringes in the diffraction pattern displayed on the screen (A) increases, (B) decreases, or (C) remains the same.