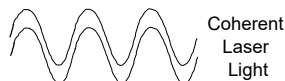# 5.C.1 Diffraction

Light passing through small openings bends around corners!
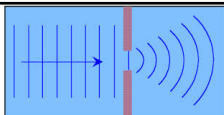
Called diffraction, this was cited as evidence by physicists supporting the wave model of light.

Diffraction manifests as an interference pattern visible on a screen (demo: single slit).
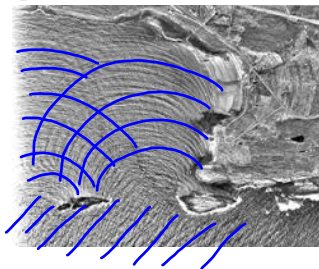
Note: the demo uses a laser: a coherent light source light: photons are the same frequency, and in phase (oscillating identically).

Coherent Laser Light

Ocean Wave Analogue

Sound and water waves diffract too: sound is heard around corners; waves passing through barriers show diffraction patterns.
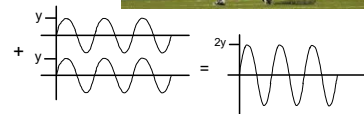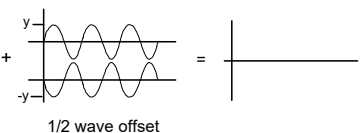
Aerial View of Diffraction

Interference!

When waveforms are added, the resulting waveform can be bigger or smaller - superposition.
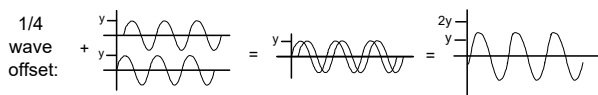
When they perfectly + align: constructive. =
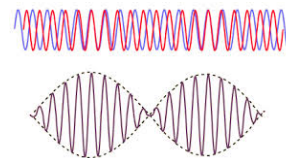
When they DON'T + align: destructive. =

1/2 wave offset

Partial Overlap

For same-frequency waves, there exists an infinite range of amplitudes:

1/4 wave offset: + = =

Also, waves of different wavelengths overlap (DEMO: blue and red lasers together):

Conceptual Aid

To envision diffraction, consider light to be like ripples on a pond, with high points and low points.

As the ripples expand, they overlap constructively at certain points, and destructively at others.

Single Slit

Double Slit

S o u r c e

S o u r c e
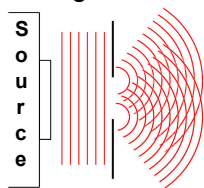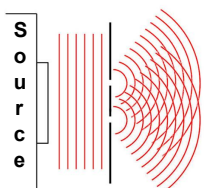
Visual Aid

Double-slit interference is portrayed here.

Note that regions of constructive and destructive interference, while moving, always end up at the same point on the screen.

Slit 1

Slit 2

Source

Screen

Interference

What the ripples look like as oscillations:

(destructive interference) (constructive interference)

θ axis θ axis
λ λ

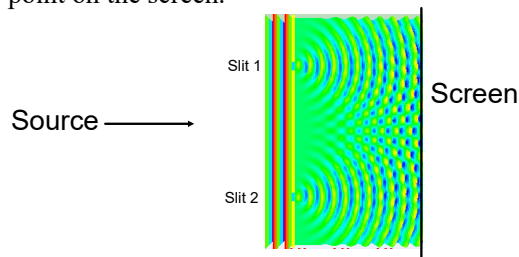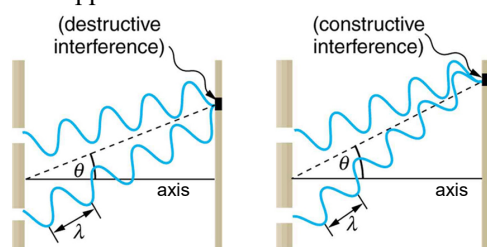Waves begin in-phase (same part of wave), but travel different path lengths to a common point on a screen.

Order Number (m)

Ratio of wavelength (λ) vs. path length difference (ΔL) gives an order number (m).

L_1 Point
Slit 1
θ
L_2
central axis
Slit 2 ΔL

$\boxed{\Delta L = m\lambda}$
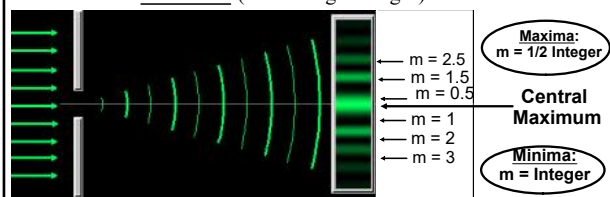AP Equation
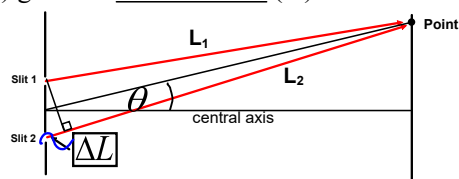
$m = \dfrac{\Delta L}{\lambda}$	ΔL = path difference (m)
	λ = wavelength (m)

Single Slit Pattern (Resources 8: 5.C.1)

A single-slit pattern has a wide central maximum, and several maxima (called bright fringes).

Maxima: m = 1/2 Integer

← m = 2.5
← m = 1.5
← m = 0.5
Central Maximum
← m = 1
← m = 2
← m = 3

Minima: m = Integer
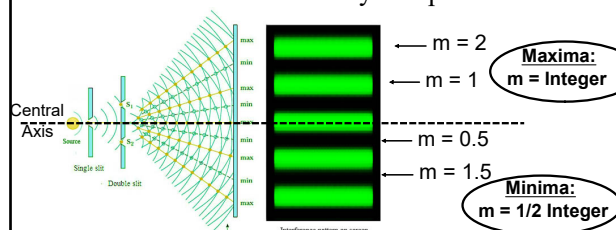
Maxima = constructive: m = 0.5, 1.5, 2.5, . . .

Minima (dark fringes) = destructive, m = 1, 2, 3,. . .

Simplified Double-Slit Pattern

Thomas Young in 1801 did a famous experiment with a slitted barrier followed by two parallel slits.

Central Axis
Source
Single slit
Double slit
Viewing screen
Interference pattern on screen

← m = 2
← m = 1
Maxima: m = Integer

← m = 0.5
← m = 1.5
Minima: m = 1/2 Integer

Maxima = constructive: m = 1, 2, . . .

Minima = destructive, m = 0.5, 1.5, 2.5,. . .

Note: there is a central maximum, but it does not get a counting order number (zeroth order, perhaps).

Actual Multi-Slit Patterns

Diffraction is very complex, simplified for this class.

Multiple slits independently produce single-slit patterns, which interfere with each other, producing the following slit-dependant patterns:

Double Slit Diffraction
Single slit envelope
1 slit
2 slits
3 slits
4 slits
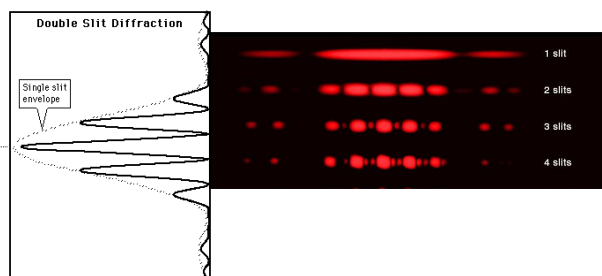
Diffraction Math

Single **and** double-slit diffraction is governed by:

$d\sin\theta = m\lambda$	d = slit width OR slit separation (m)
AP Equation	θ = angle between axis & point (º)
	m = order number (from resource)
	λ = wavelength (m)

Note 1: this is a 2 for 1 AP Equation:

$$\boxed{\Delta L = d\sin\theta = m\lambda}$$

Note 2: Spacing between adjacent maxima OR minima is the same.

Relations

Spacing between axis & fringe, OR between fringes:

$y = \dfrac{mL\lambda}{d}$	m = order number L = distance to screen (m) λ = wavelength (m) d = slit width OR slit separation (m)

Use correct m for single vs. double slit!

Set m = 1 to find spacing between adjacent fringes.

Central maximum width (m) (single slit ONLY):

$y_{central} = \dfrac{2L\lambda}{d}$	L = distance to screen (m) λ = wavelength (m) d = slit width (m)

More Relations:

1. For any slit width (d), the longer the wavelength (λ), the wider the diffraction pattern.

2. For any wavelength (λ), the narrower the slit (d), the wider the diffraction pattern.

3. For single slit, the width of the central max. is twice the width of a side max.

4. Diffraction is more evident as d approaches λ.

Single-Slit Examples

1. How far is the third-order maximum (m = 2.5) from the axis in a single-slit (d = 0.12 mm) experiment? λ = 450 nm, L = 3.2 m.

$$y = \frac{mL\lambda}{d} = \frac{2.5 \cdot 3.2\,m \cdot 4.5\,E-7\,m}{1.2\,E-4\,m} = 0.030\,m\ (3.0\,cm)$$

2. How wide is the central maximum?

$$y_{central} = \frac{2L\lambda}{d} = \frac{2 \cdot 3.2\,m \cdot 4.5\,E-7\,m}{1.2\,E-4\,m} = 0.024\,m\ (2.4\,cm)$$

3. Double-Slit Example

What's the wavelength in a double-slit experiment if the second order maximum (m = 2) occurs at an angle of 0.34° (d = 0.38 cm)?

$$d\sin\theta = m\lambda$$

$$\lambda = \frac{d\sin\theta}{m} = \frac{0.0038\,m \cdot \sin 0.34°}{2} = 1.127\,E-5\,m$$

Diffraction Gratings

Diffraction gratings produce an interference pattern as light passes through a large number of small, parallel slits, or reflects off parallel inclined surfaces.

These can be used to separate the spectra of different elements.

Demo: look at the mercury bulbs through the spectrometers - you can see a distinct color pattern.

Demo: CDs acts as gratings.
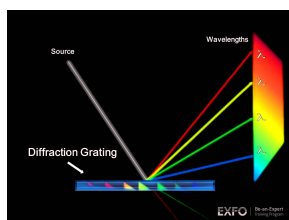
Homework 5.C.1

Problems 5.C.1
Due: Next Class