Making Sense of Diffraction

Huygen's Principle (again) In Diffraction
Single Slit Diffraction
Diffraction Gratings
Circular Apertures
Rectangular Apertures
Resolution (Diffraction Limited System)
Rayleigh's Criterion
Minimum Angle of Resolution
Visual Acuity

Information in ***italicized bold*** print refer to Discussion Topics

Diffraction

There are two types of refraction:
Fraunhofer Diffraction: light source and screen are located at infinite distances.
Fresnel Diffraction: either the light source or the screen, or both are located at a finite distance.

Huygens Principle & Diffraction

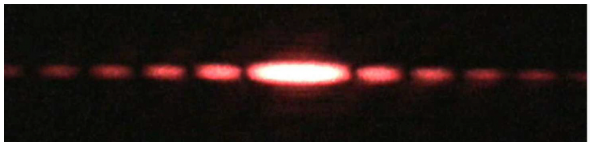
Huygen's principle states that each point on a wavefront is a source of a secondary wavefront. ***Light spreads out in all directions allowing it to bend around edges and spreading the light beyond the region of the slit or aperture***.

Diffraction is the spreading of light (or bending of light) because of wavelets.
Wavelets interfere with each other, and the wavefront interferes with itself.

If light did not propagate as wavelets, the wave would pass undeviated through an opening.
A wave spreads out ***only when the opening is small relative to the size of the wavelength***.
If the opening is large relative to the size of the wavelength the wave does not spread out and instead looks like it is traveling in a straight line.

Single Slit Diffraction

When light passes through a single vertical slit in a film the wavelengths will interfere with each other to form a horizontal pattern.



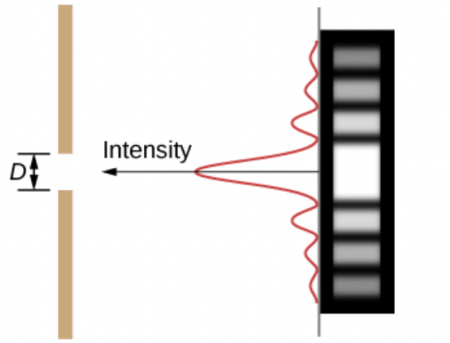
Compared to Young's double slit experiment ($\Delta y = s\lambda / na$), ***the single slit creates a wider, brighter central maximum***. For double slit a = distance between slits.

The variables involved when observing the diffraction pattern can be determined by examining the formula for the width between minima of the diffraction pattern:

$\Delta y = s\lambda / nb$ (where b is the width of the single slit).
For calculations of Δy (width between minima):
- s = distance between aperture and pattern (screen)
- λ = wavelength of light in air
- n = index of medium (usually air)

For single slit: $\Delta y = s\lambda / nb$, where b is width of slit and Δy is the distance between minima.
The narrower the slit width the more spread out the diffraction pattern.
The width of the Central Maximum: $2\Delta y$.

Single Slit Diffraction



Credit: UCF Physics 3 (Ling, Sanny, & Moebs)

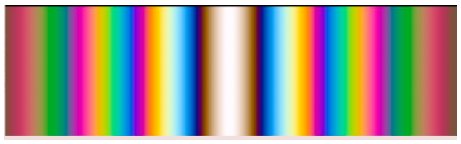
Note: in this illustration the D is the slit width (which we are referring to as b)

The intensity of the maxima decreases quickly from the central maximum outward.
The central maximum has a width of $2\Delta y$.

Diffraction & Interference (single vs double slit apertures)

Single Slit: pattern produced is due to diffraction.
Double Slit: interference fringes due to interference and brightness difference due to diffraction.

Single Slit Diffraction with White Light



For white light, each wavelength has a different ΔY.

The center maxima is white because all wavelengths have central maxima in the middle of the pattern.

Diffraction Grating

When light passes through many closely spaced slits, the wavelets form a unique pattern:

Maxima are very narrow and bright (constructive interference) with well-defined edges and minima are wide (destructive interference) and spread out.

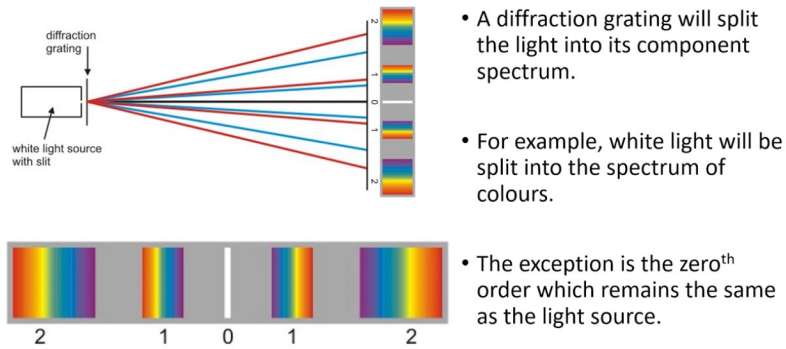
For diffraction grating: $\Delta y = s\lambda / nh$, where h is spacing of the grating.

Δy: distance between minima

To use h (in meters) convert from grooves per mm or grooves per cm.

Diffraction from a Diffraction Grating (monochromatic light)

Diffraction from a Diffraction Grating (white light)

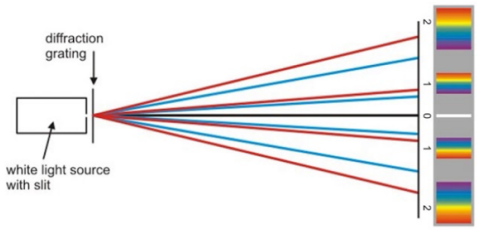


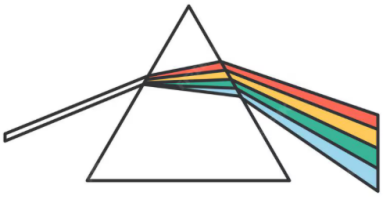
- A diffraction grating will split the light into its component spectrum.
- For example, white light will be split into the spectrum of colours.
- The exception is the zeroth order which remains the same as the light source.

Credit: https://ar.inspiredpencil.com/pictures-2023/diffraction-grating

Diffraction Grating vs Diffraction from a prism

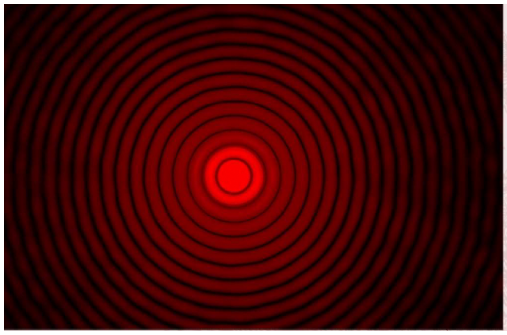
With a diffraction grating, longer wavelengths of light have more dispersion.
With a prism, short wavelengths have more dispersion.





Airy Disc & Diffraction with a Circular Aperture

When light passes through a circular aperture, the wavelets interfere and form this type of pattern:



The central maximum in a diffraction pattern created with a circular aperture is called an Airy Disc.

The Airy Disc of the pattern is inversely proportional to the aperture size.
The pattern is circular because diffraction occurs evenly in all directions.

Airy Disc

Radius of the Airy Disc: $\Delta Y = 1.22\, s\lambda/nd$

Where:

ΔY = distance from center to first minimum

s = distance to screen

λ = wavelength of light

n = index of medium

d = diameter of aperture

note: the coefficient for Airy Disc is 1.22, but it increases for each minima

Applications of Diffraction

Diffraction is used in spectrometry.
As λ increases, Δy increases.
With diffraction grating long wavelengths have more dispersion (larger diffraction Δy).

Limits of Resolution & Minimum Angle of Resolution (MAR)

The eye and most optical instruments have circular apertures.
A larger aperture creates a smaller Airy Disc (less diffraction) and a sharper image point.

Resolution: the ability of an optical system to create distinct images for distinct object points

Diffraction Limited System: ***an optical system with no aberrations or scatter where diffraction is the only cause of image degradation. Diffraction is the only source of image degradation. An ametropic eye is not a diffraction limited system.***

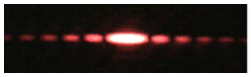
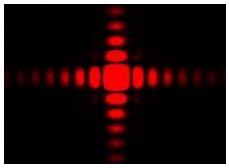
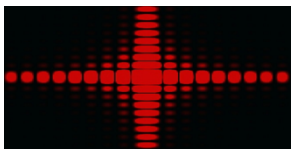
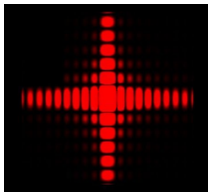
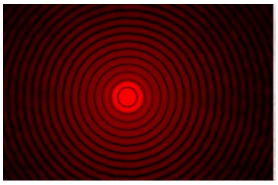
For any imaging system there will be a limit on the system's ability to distinguish detail in an image.
Consider two monochromatic point sources (only one Airy pattern for each source) and their images.
Smaller Airy discs mean to objects can be closer together before their images start overlapping.
A smaller Airy Disc results in greater resolution.

Two object points can be resolved if the center of one diffraction pattern falls on the first dark ring of the other (Rayleigh's Criterion).

The limit of resolution, the smallest angle subtended by two point objects that can just be resolved is:

MAR = 1.22 λ/d (where MAR is minimum angle of resolution)
MAR to Snellen Acuity: multiply MAR(minutes) by 20 to get denominator.

Summary of Diffraction Patterns

				
Single Slit (vertical)	Square	Rectangle Vertical Larger	Rectangle Horizontal Larger	Circular

Diffraction Problems

Single Slit Diffraction

What is the width of the central maximum?

1. What is the width of the central maximum of diffraction pattern created by a light source with a wavelength of 600nm on a screen 10m away if the width of the slit is 0.5mm:

What is the effect of changing the width of the slit on the diffraction pattern?

2. What is the effect on the width of the central maximum in the previous problem if the width of the slit is decreased to 0.25mm:

What is the effect of changing the wavelength of the source on the diffraction pattern?

3. What is the width of the central maximum in problem 1 if the wavelength is decreased to 450nm:

What is the effect of changing the distance to the screen on the diffraction pattern?

4. What is the width of the central maximum on problem 1 if the screen distance is decreased to 5m:

Diffraction Grating

What is distance between maxima?

5. What is the distance between maxima of the pattern created on a screen 1m away by a diffraction grating with 1000 lines per cm and an incident light source of 650nm:

What happens is line spacing changes?

6. What is the effect on the distance between maxima If the spacing in problem 5 is changed to 500 lines per cm?

Circular Apertures

What is Airy Disc size?

7. What is the radius of the Airy Disc formed by a diffraction pattern created when light of 650nm is incident on a circular aperture of 2.0mm on a screen 1.0m from the aperture:

What is angle subtended by ½ the Airy Disc?

8. What is the angle subtended by the Airy Disc in problem 7:

Minimum Angle of Resolution?

9. What is the minimum angle of resolution in problem 7:

Visual Acuity and MAR

10. What is the expected visual acuity of a person with an MAR of 1.5 minutes: