

Lab. 22 Refraction, Polarization and Interference of Light

Edited by Ming-Fong Tai, Date: 2007/10/03

Laser Safety Rule: Please refer to the both word file, “[Laser Safety-short summary.doc](#)” and “[Laser Safety-complete summary.doc](#)”. You must read both files before begin to do this experiments related the laser.

Lab22A: Refraction of Prism

1. Object:

To measure the refraction index of prism based on the refraction properties of light.

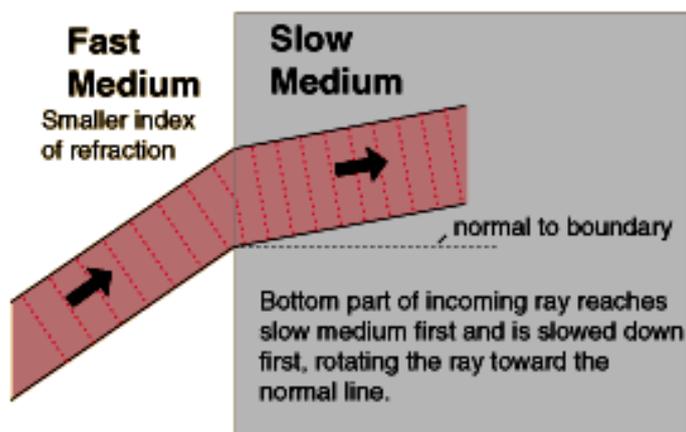
2. Principle:

Referred from <http://hyperphysics.phy-astr.gsu.edu/hbase/hframe.html>, “Light and Vision”, in web site “HyperPhysics”, hosted by the department of Physics and Astronomy, Georgia State University, GA, US

A-1 Refraction of Light

Refraction is the bending of a wave when it enters a medium where it's speed is different. The refraction of light when it passes from a fast medium to a slow medium bends the light ray toward the normal to the boundary between the two media. The amount of bending depends on the [indices of refraction](#) of the two media and is described quantitatively by [Snell's Law](#).

Refraction is responsible for image formation by [lenses](#) and the [eye](#).



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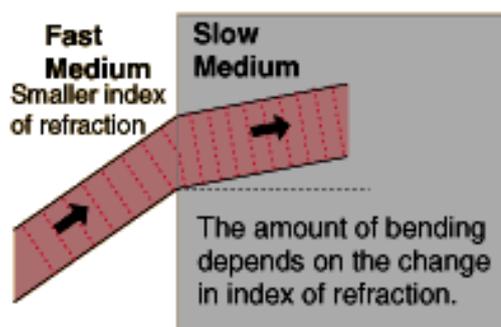


As the [speed of light](#) is reduced in the slower medium, the wavelength is shortened proportionately. The frequency is unchanged; it is a characteristic of the source of the light and unaffected by medium changes.

A-2 Index of Refraction

The index of [refraction](#) is defined as the [speed of light](#) in vacuum divided by the speed of light in the medium.

$$n = \frac{c}{v}$$

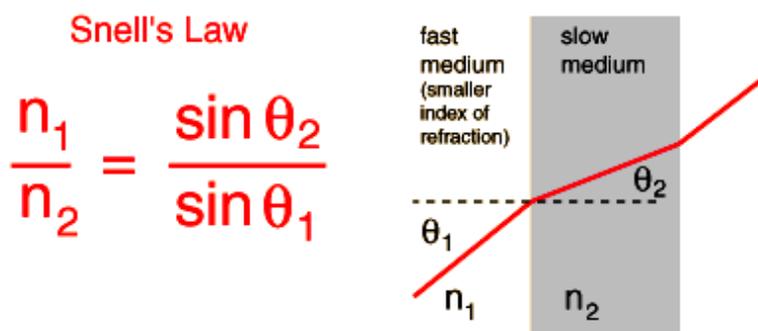


The indices of refraction of some common substances are given below with a more complete description of the indices for [optical glasses](#) given elsewhere. The values given are approximate and do not account for the small variation of index with light wavelength which is called [dispersion](#).

Vacuum	1.000	Ethyl alcohol	1.362
Air	1.000277	Glycerine	1.473
Water	4/3	Ice	1.31
Carbon disulfide	1.63	Polystyrene	1.59
Methylene iodide	1.74	Crown glass	1.50-1.62
Diamond	2.417	Flint glass	1.57-1.75

A-3 Snell's Law

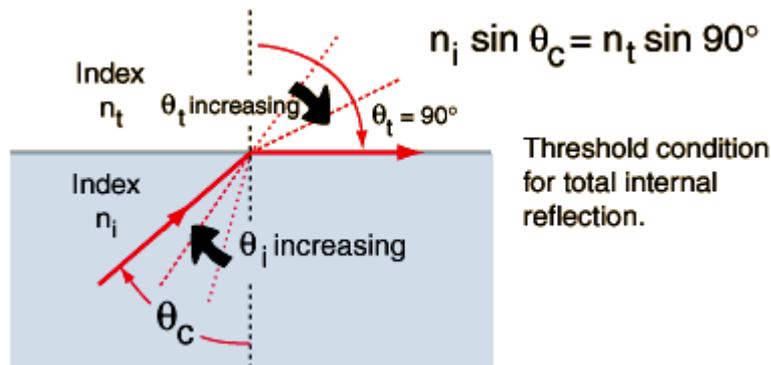
Snell's Law relates the [indices of refraction](#) n of the two media to the directions of propagation in terms of the angles to the normal. Snell's law can be derived from [Fermat's Principle](#) or from the Fresnel Equations.



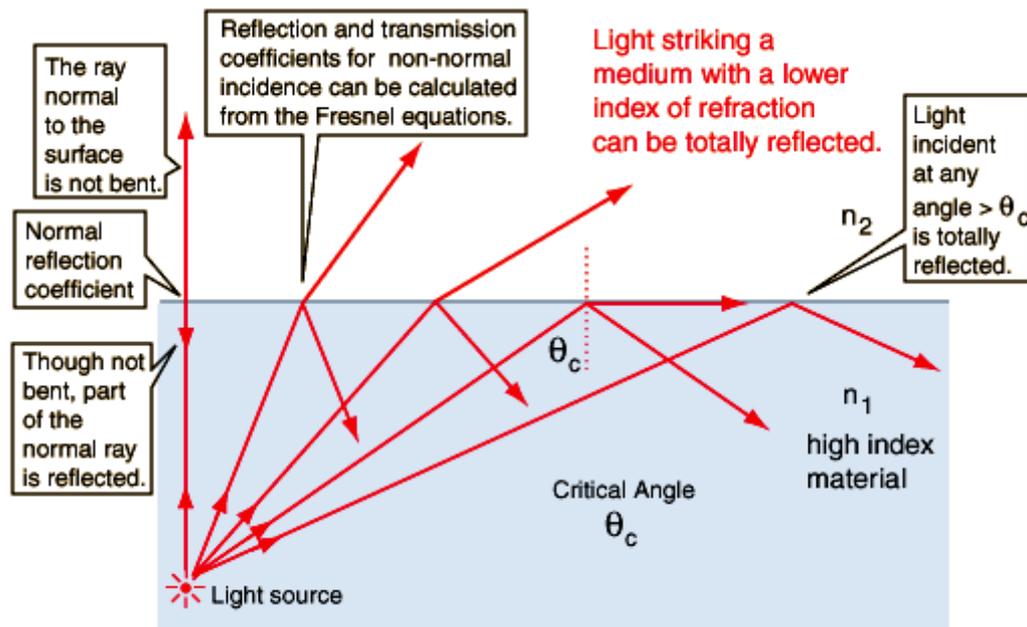
If the incident medium has the larger index of refraction, $n_1 > n_2$, then the angle with the normal is increased by refraction. The larger index medium is commonly called the "internal" medium, since air with $n = 1$ is usually the surrounding or "external" medium. You can calculate the condition for [total internal reflection](#) by setting the refracted angle = 90° and calculating the incident angle. Since you can't refract the light by more than 90° , all of it will reflect for angles of incidence greater than the angle which gives refraction at 90° .

A-4 Total Internal Reflection

When light is incident upon a medium of lesser [index of refraction](#), the ray is bent away from the normal, so the exit angle is greater than the incident angle. Such reflection is commonly called "[internal reflection](#)". The exit angle will then approach 90° for some critical incident angle θ_c , and for incident angles greater than the critical angle there will be total internal reflection.



The critical angle can be calculated from [Snell's law](#) by setting the refraction angle equal to 90° . Total internal reflection is important in [fiber optics](#) and is employed in [polarizing prisms](#).



For any angle of incidence less than the critical angle, part of the incident light will be transmitted and part will be reflected. The normal incidence [reflection coefficient](#) can be calculated from the indices of refraction. For non-normal incidence, the transmission and reflection coefficients can be calculated from the [Fresnel equations](#).

For total internal reflection of light from a medium of index of refraction, $n_1 = n_i =$ 1.5,

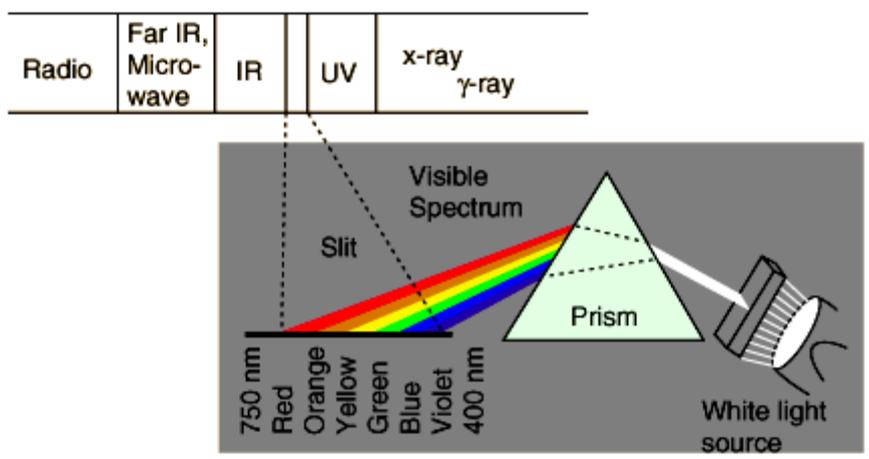
the light must be incident on a medium of lesser index. If the new medium has $n_2 = n_t =$

then the critical angle for internal reflection is $\theta_c =$ degrees.

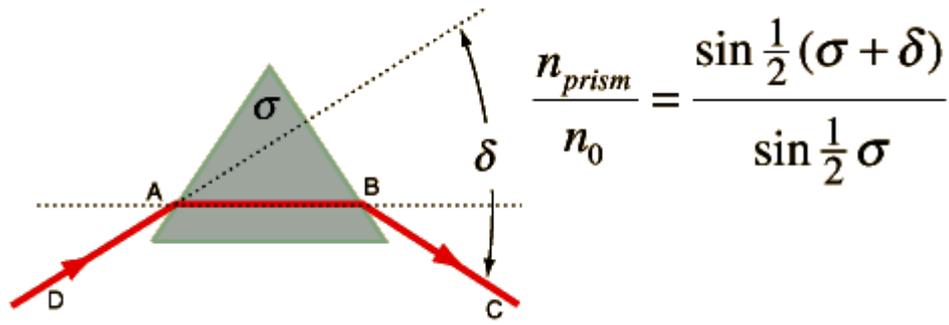
If values for n_1 and n_2 are entered above, the critical angle θ_c for total internal reflection will be calculated. (For example, $\theta_c = 48.6^\circ$ for water and air.) But the angle for total internal reflection can be measured and used to determine the index of refraction of a medium. If a new value of θ_c is entered above, then the corresponding value of n_1 will be calculated.

A-5 Prisms

A refracting prism is a convenient geometry to illustrate [dispersion](#) and the use of the [angle of minimum deviation](#) provides a good way to measure the [index of refraction](#) of a material. Reflecting prisms are used for erecting or otherwise changing the orientation of an image and make use of [total internal reflection](#) instead of [refraction](#).



White light may be separated into its [spectral colors](#) by dispersion in a prism.



$$\frac{n_{prism}}{n_0} = \frac{\sin \frac{1}{2} (\sigma + \delta)}{\sin \frac{1}{2} \sigma}$$

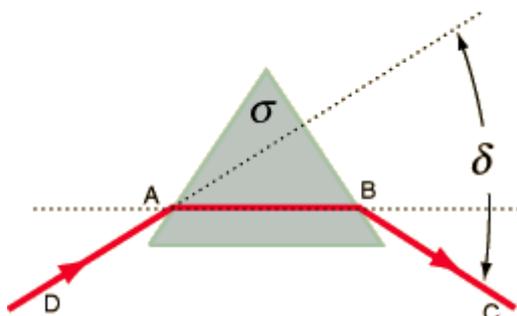
Prisms are typically characterized by their angle of minimum deviation d . This minimum deviation is achieved by adjusting the incident angle until the ray passes through the prism parallel to the bottom of the prism.

An interesting application of refraction of light in a prism occurs in [atmospheric optics](#) when tiny hexagonal ice crystals are in the air. This refraction produces the [22° halo](#) commonly observed in northern latitudes. The fact that these ice crystals will preferentially orient themselves horizontally when falling produces a brighter part of the 22° halo horizontally to both sides of the sun; these bright spots are commonly called "[sundogs](#)".

A-6 The angle of minimum deviation for a Prisms

The angle of minimum deviation for a [prism](#) may be calculated from the prism equation. Note from the illustration that this minimum deviation occurs when the path of the light inside the prism is parallel to the base of the prism. If the incident light beam is rotated in either direction, the deviation of the light from its incident path caused by refraction in the prism will be greater.

White light may be separated into its [spectral colors](#) by dispersion in a prism.



Active formula

$$\frac{n_{\text{prism}}}{n_0} = \frac{\sin \frac{1}{2}(\sigma + \delta)}{\sin \frac{1}{2}\sigma}$$

Enter data below and then click on the quantity you wish to calculate in the active formula above.

For a prism of apex angle $\sigma =$ °

and index of refraction $n_{\text{prism}} =$

the angle of minimum deviation is $\delta = ?$

Unless otherwise specified, the medium will be assumed to be air.

$n_0 =$

3. Equipments and Materials

Laser (雷射), Triangular Prism (三稜鏡), U-shaped support device (U-型支架), Optical platform (光學台), angle-scale disc (角度盤), protractor (量角器) and ruler (直尺).

4. Experimental Procedures

- (1) Let laser beam horizontally incident to the wall or a white paper which has a distance of about 0.5 m far away. To mark the position of laser beam.
- (2) Settle the triangular prism on the optical platform with the U-shaped support device and angular scale disc. To adjust the proper position of prism to locate the path of laser beam.
- (3) Rotate the prism slowly and observe the deviation path of the refracted laser beam by

prism. To mark the beam position when the angle of deviation through a prism is minimum.

Prisms are typically characterized by their angle of minimum deviation d . This minimum deviation is achieved by adjusting the incident angle until the ray passes through the prism parallel to the bottom of the prism.

- (4) To measure the distance of the both positions marked by step (1) and (3), and the distance between the prism and the screen of laser spot. To calculate the angle of minimum deviation, δ , for the prism based on the formula above.
- (5) Change the incident angle of laser into the prism and repeat the procedures (2) to (4), to get the other the angle of minimum deviation, δ .
- (6) To measure the apex angle of the prism σ .
- (7) To determine the refraction index of the prism.

5. Questions

- (1) How does the angle of minimum deviation vary if you use a blue-beam laser in this experiment?
- (2) To prove the laser beam must symmetrically travel through the prism when the output beam refracted by the prism has an angle of minimum deviation. It means that the incident angle is equal to the refraction angle, $\theta_i = \theta_r$, when the laser beam has a minimum deviation through the prism.
- (3) How large error are the both measured apex angles σ and the angle of minimum δ obtained in this experiment? How does these error values affect the accuracy of the calculated index of refraction of the prism? (Hint: the theoretical equations and formula in this experiment are derived based on the approximation estimation, $\sin\theta \approx \theta - 1/(3!)\theta^3 + 1/(5!)\theta^5 - \dots$, to estimate the percentage error of $\sin\theta$)
- (4) How does one reduce the error of the measured apex angles σ and the angle of minimum δ ?

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Lab 22B: Polarization of Light

1. Object:

To measure the polarization properties of light and how does the polarizer work..

2. Principle:

Referred from <http://hyperphysics.phy-astr.gsu.edu/hbase/hframe.html>, “Light and Vision”, in web site “HyperPhysics”, hosted by the department of Physics and Astronomy, Georgia State University, GA, US

*HyperPhysics is hosted by the
Department of Physics and Astronomy*



HyperPhysics

2-1 Study Roadmaps of Light and Polarization

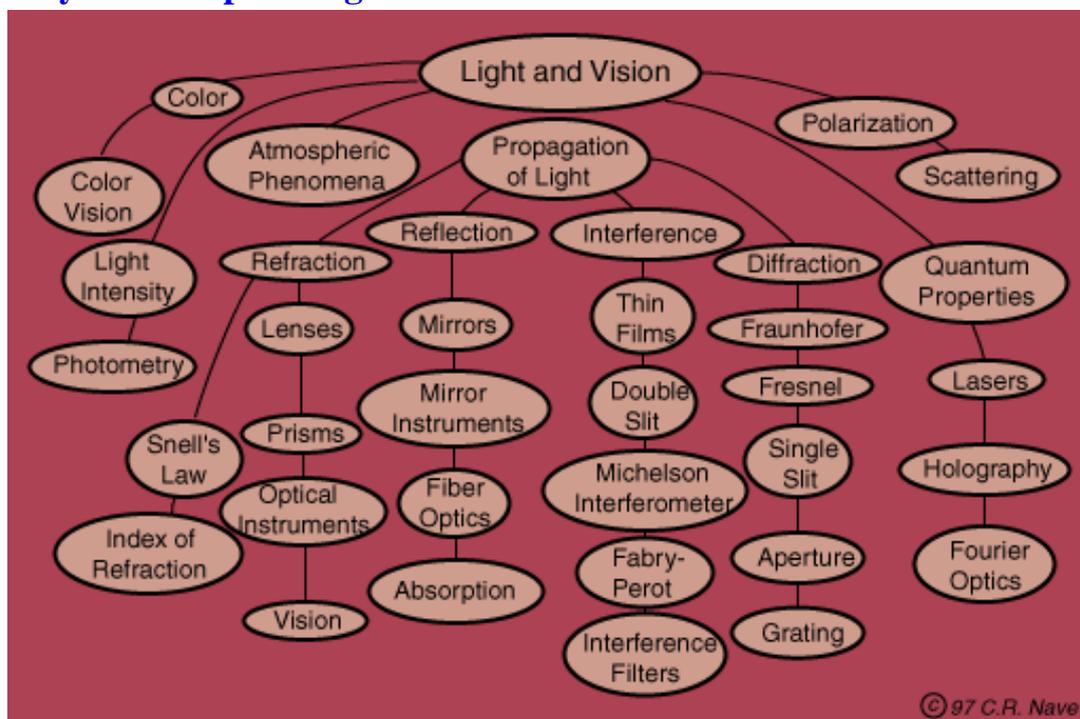


Fig. 1. The study roadmap for light and vision.

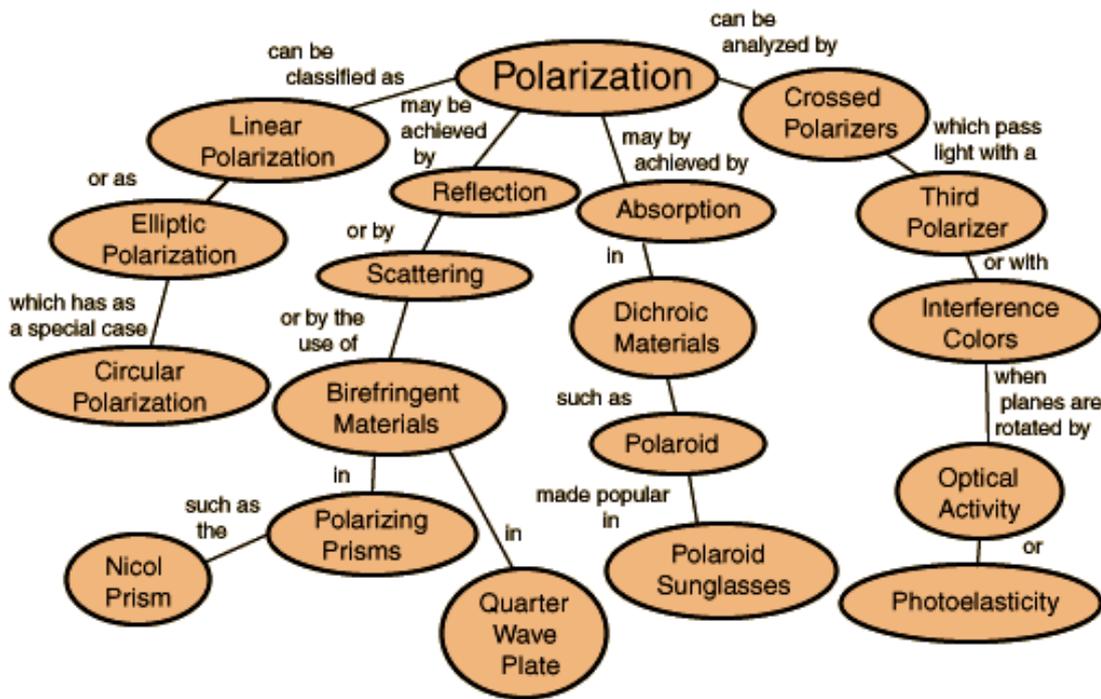
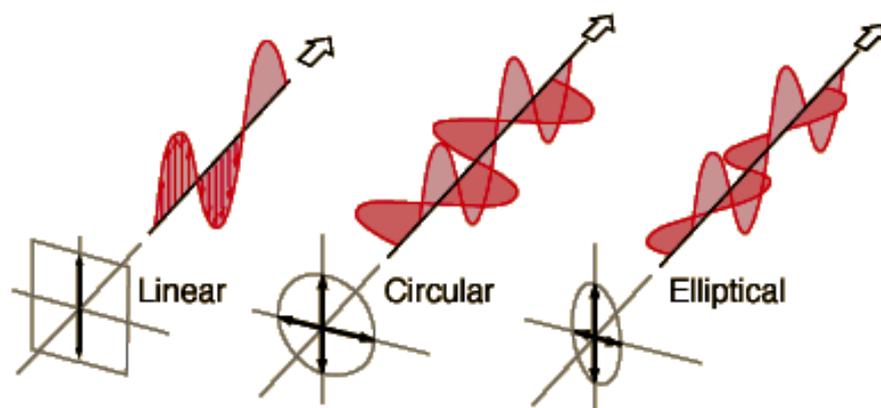


Fig. 2. The study roadmap for polarization of light.

2-2 Classification of Polarization

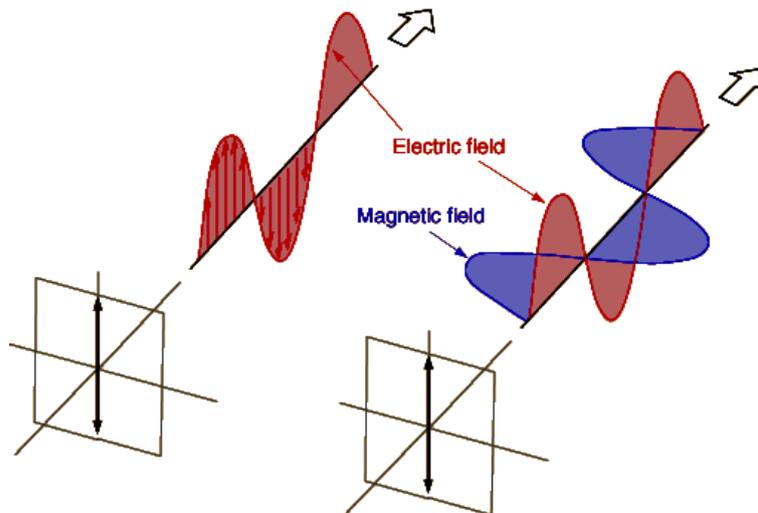
Classification of Polarization

Light in the form of a plane wave in space is said to be linearly polarized. Light is a transverse electromagnetic wave, but natural light is generally unpolarized, all planes of propagation being equally probable. If light is composed of two plane waves of equal amplitude by differing in phase by 90° , then the light is said to be circularly polarized. If two plane waves of differing amplitude are related in phase by 90° , or if the relative phase is other than 90° then the light is said to be elliptically polarized.



Linear Polarization

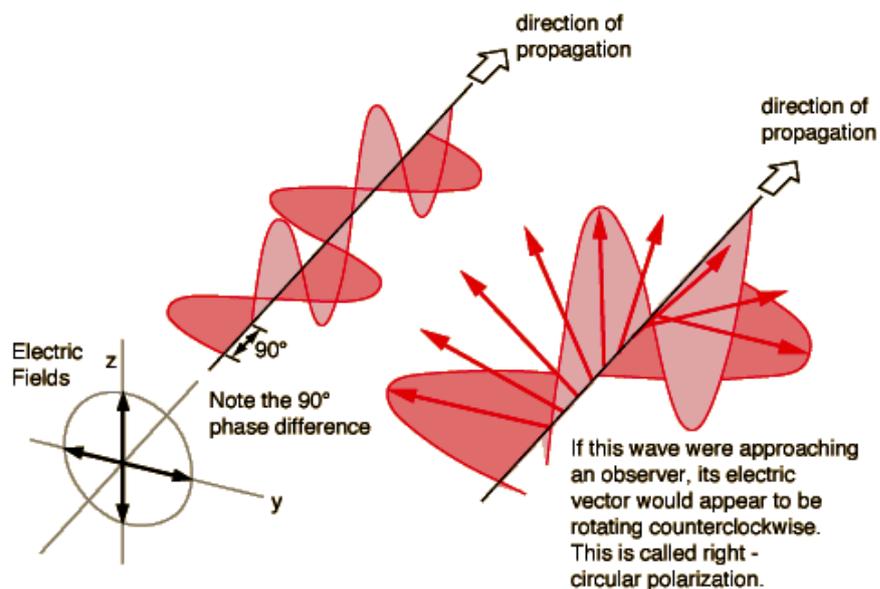
A plane electromagnetic wave is said to be linearly polarized. The transverse electric field wave is accompanied by a magnetic field wave as illustrated.



[Compare with circular and elliptical polarization](#)

Circular Polarization

Circularly polarized light consists of two perpendicular electromagnetic plane waves of equal amplitude and 90° difference in phase. The light illustrated is right- circularly polarized.



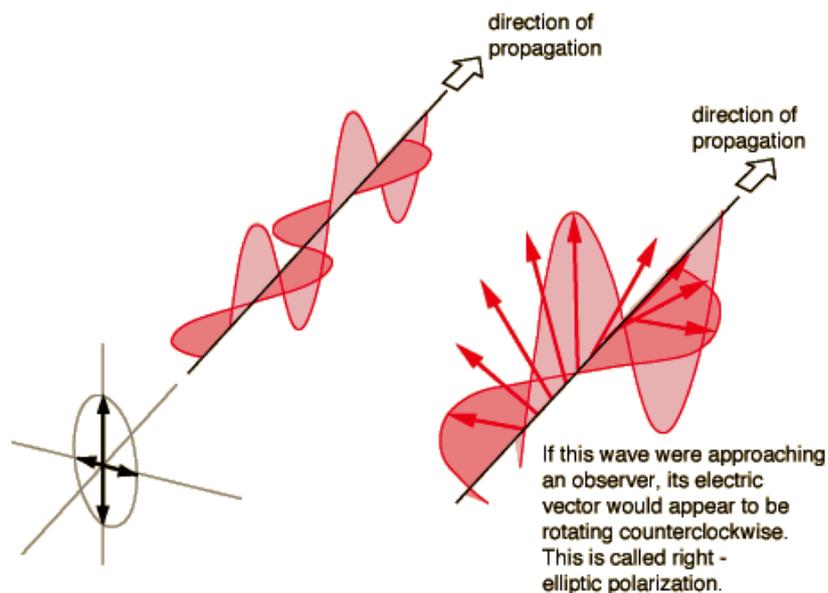
If light is composed of two plane waves of equal amplitude but differing in phase by 90° , then the light is said to be circularly polarized. If you could see the tip of the electric field vector, it would appear to be moving in a circle as it approached you. If while looking at the source, the electric vector of the light coming toward you appears to be rotating clockwise, the light is said to be right-circularly polarized. If counterclockwise, then left-circularly polarized light. The electric field vector makes one complete revolution as the light advances one wavelength toward you.

Circularly polarized light may be produced by passing [linearly polarized](#) light through a [quarter-wave plate](#) at an angle of 45° to the optic axis of the plate.

[Compare with linear and elliptical polarization](#)

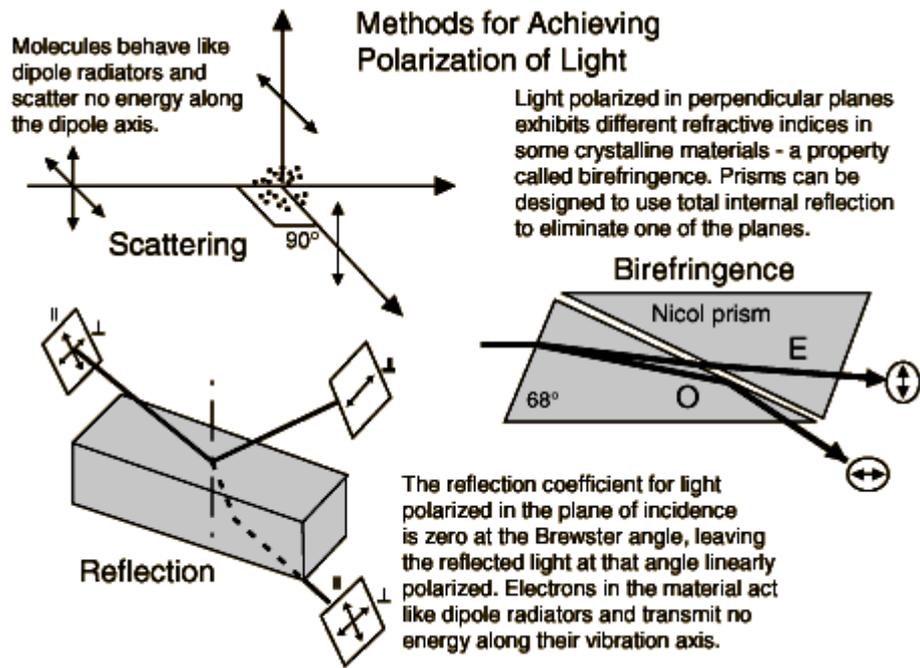
Elliptical Polarization

Elliptically polarized light consists of two perpendicular waves of unequal amplitude which differ in phase by 90° . The illustration shows right- elliptically polarized light.

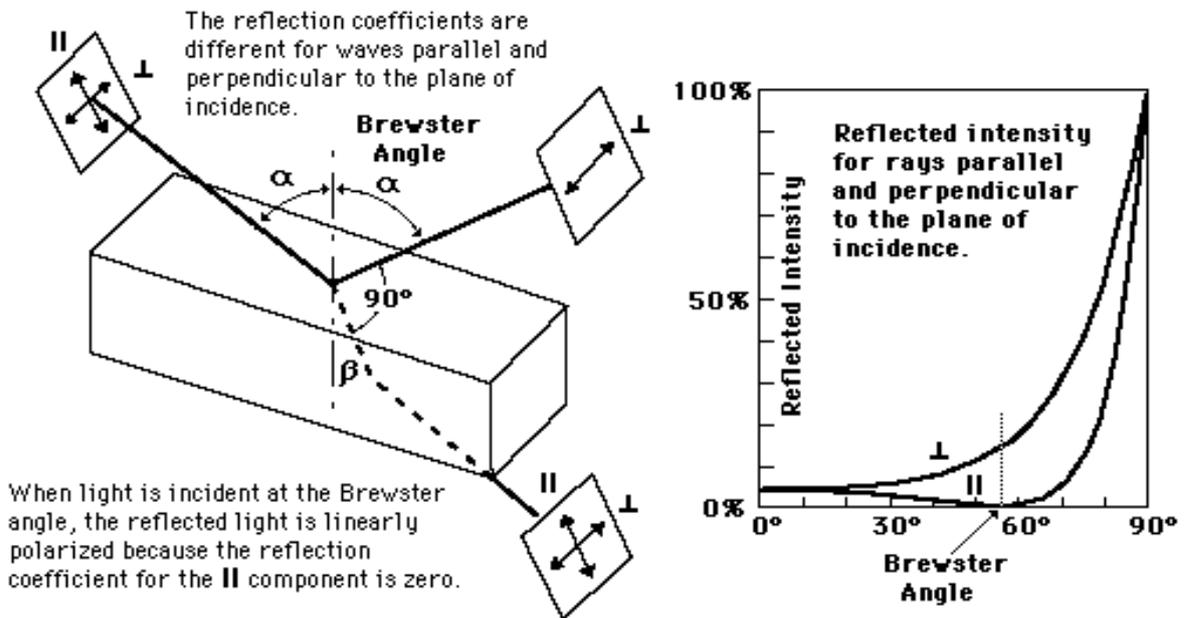


[Compare with linear and circular polarization](#)

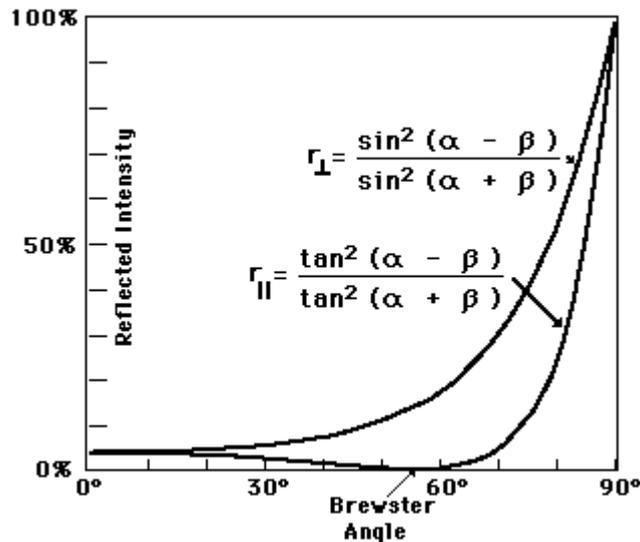
2-3 Methods for Achieving Polarization of Light



(1) Polarization by Reflection



[Calculation](#) [Derivation of Brewster's angle](#) [Methods of achieving polarization](#)



Polarization by Reflection

Since the [reflection coefficient](#) for light which has electric field parallel to the plane of incidence goes to zero at some angle between 0° and 90°, the [reflected light](#) at that angle is [linearly polarized](#) with its electric field vectors perpendicular to the plane of incidence. The angle at which this occurs is called the polarizing angle or the Brewster angle. At other angles the reflected light is partially polarized.

From [Fresnel's equations](#) it can be determined that the parallel reflection coefficient is zero when the incident and transmitted angles sum to 90°. The use of [Snell's law](#) gives an expression for the Brewster angle.

For an incident angle of $\alpha = 30^\circ$ and an index $n = 1.5$,

the transmitted angle is $\beta = 19.47122^\circ$.

The reflection coefficients are.

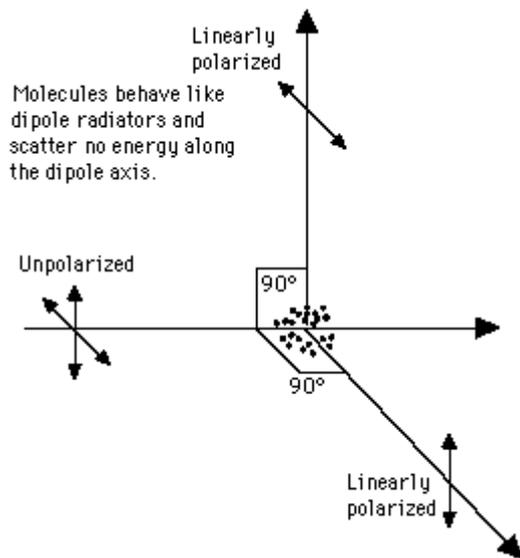
$$r_{\perp} = 0.057796$$

$$r_{\parallel} = 0.025249$$

The overall reflected intensity is 4.152262% of the incident and 69.59591% of that is in the perpendicular plane. The Brewster angle is 56.30993°.

Note: the reflection coefficients used here are the intensities and not the amplitudes as used in the usual presentation of the [Fresnel equations](#). That is, these reflection coefficients are the square of those in the Fresnel expressions.

Polarization by Scattering



The scattering of light off air molecules produces [linearly polarized](#) light in the plane perpendicular to the incident light. The scatterers can be visualized as tiny antennae which radiate perpendicular to their line of oscillation. If the charges in a molecule are oscillating along the y-axis, it will not radiate along the y-axis. Therefore, at 90° away from the beam direction, the scattered light is linearly polarized. This causes the light which undergoes [Rayleigh scattering](#) from the [blue sky](#) to be partially polarized.

3. Equipments and Materials

- (1) He-Ne Laser (氦氖氣體雷射) : 1 set,
- (2) polarizer (偏振片) : 3 pieces
- (3) thick glass plate (厚玻璃片) : 1 piece
- (4) protractor (量角器) : 1 piece

4. Experimental Procedures

- (1) Let laser beam horizontally incident to the wall or a white paper which has a distance of about 0.5 m far away. To mark the position of laser beam.
- (2) Settle the triangular prism on the optical platform with the U-shaped support device and angular scale disc. To adjust the proper position of prism to locate the path of laser beam.
- (3) Rotate the prism slowly and observe the deviation path of the refracted laser beam by prism. To mark the beam position when the angle of deviation through a [prism](#) is minimum.

Prisms are typically characterized by their angle of minimum deviation d . This minimum deviation is achieved by adjusting the incident angle until the ray passes through the prism parallel to the bottom of the prism.

- (4) To measure the distance of the both positions marked by step (1) and (3), and the distance between the prism and the screen of laser spot. To calculate the angle of minimum deviation, δ , for the prism based on the formula above.
- (5) Change the incident angle of laser into the prism and repeat the procedures (2) to (4), to get the other the angle of minimum deviation, δ .

- (6) To measure the apex angle of the prism σ .
- (7) To determine the refraction index of the prism.

5. Questions

- (1) How does the angle of minimum deviation vary if you use a blue-beam laser in this experiment?
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- (4) How does one reduce the error of the measured apex angles σ and the angle of minimum δ ?

Lab. 23 Diffraction and Interference of Light

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I. Diffraction:

Information in this section comes from Wikipedia, <http://en.wikipedia.org/wiki/Diffraction>

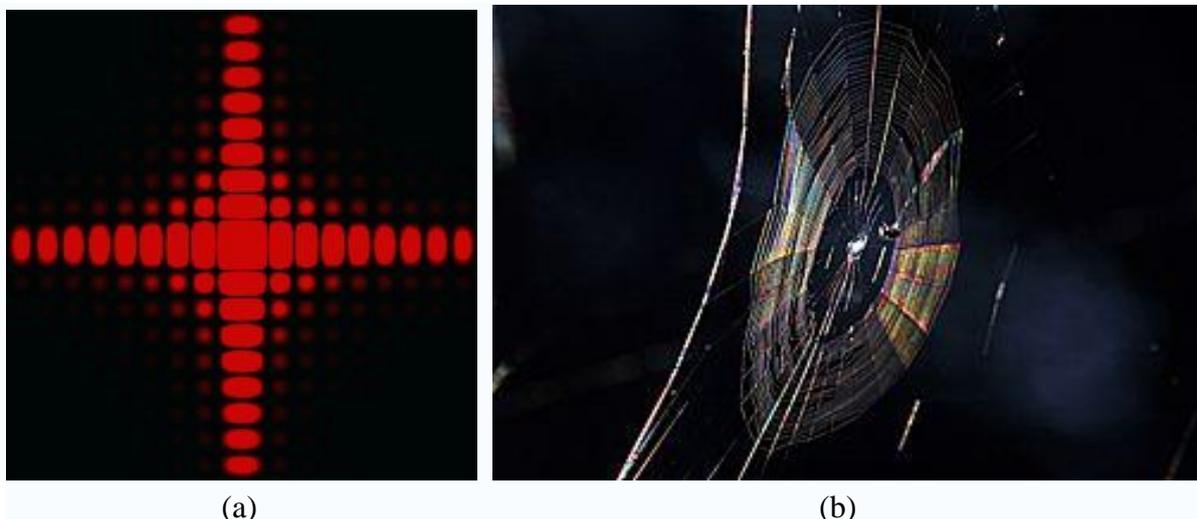


Fig. 1 (a) The intensity pattern formed on a screen by diffraction from a square aperture; (b) Colors seen in a [spider web](#) are partially due to diffraction, according to some analyses.^[1]

Diffraction refers to various phenomena associated with wave propagation, such as the bending, spreading and [interference](#) of [waves](#) passing by an object or aperture that disrupts the wave. It occurs with any type of wave, including [sound waves](#), [water waves](#), [electromagnetic waves](#) such as [visible light](#), [x-rays](#) and [radio waves](#). Diffraction also occurs with matter – according to the principles of [quantum mechanics](#), any physical object has [wave-like](#) properties. While diffraction always occurs, its effects are generally most noticeable for waves where the wavelength is on the order of the feature size of the diffracting objects or apertures. The complex patterns in the intensity of a diffracted wave are a result of interference between different parts of a wave that traveled to the observer by different paths.

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- 6. Particle diffraction
- 7. Bragg diffraction
- 8. Coherence
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1. Examples of diffraction in everyday life

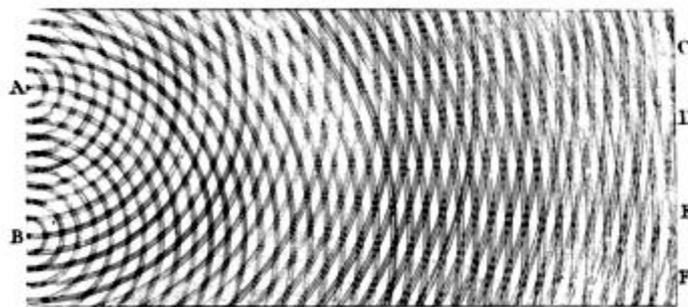
The effects of diffraction can be readily seen in everyday life. The most colorful examples of diffraction are those involving light; for example,

- (1) The closely spaced tracks on a CD or DVD act as a [diffraction grating](#) to form the familiar rainbow pattern we see when looking at a disk.
- (2) This principle can be extended to engineer a grating with a structure such that it will produce any diffraction pattern desired; the [hologram](#) on a credit card is an example.
- (3) [Diffraction in the atmosphere](#) by small particles in it can cause a bright ring to be visible around a bright light source like the sun or the moon.
- (4) A shadow of a solid object, using light from a compact source, shows small fringes near its edges.

All these effects are a consequence of the fact that light is a wave.

Diffraction can occur with any kind of wave. Ocean waves diffract around jetties and other obstacles. Sound waves can diffract around objects, this is the reason we can still hear someone calling us even if we are hiding behind a tree. Diffraction can also be a concern in some technical applications; it sets a [fundamental limit](#) to the resolution of a camera, telescope, or microscope.

2. History



Thomas Young's sketch of two-slit diffraction, which he presented to the [Royal Society](#) in 1803.

The effects of diffraction of light were first carefully observed and characterized by [Francesco Maria Grimaldi](#), who also coined the term *diffraction*, from the Latin *diffringere*, 'to break into pieces', referring to light breaking up into different directions.

- (1) The results of Grimaldi's observations were published posthumously in 1665.^{[2][3]} [Isaac Newton](#) studied these effects and attributed them to *inflexion* of light rays.
- (2) [James Gregory](#) (1638–1675) observed the diffraction patterns caused by a bird feather, which was effectively the first [diffraction grating](#).
- (3) In 1803 [Thomas Young](#) did his famous experiment observing diffraction from two closely spaced slits. Explaining his results by interference of the waves emanating from the two different slits, he deduced that light must propagate as waves.
- (4) [Augustin-Jean Fresnel](#) did more definitive studies and calculations of diffraction, published in 1815 and 1818, and thereby gave great support to [the wave theory of light](#) that had been advanced by [Christiaan Huygens](#) and reinvigorated by Young, against Newton's particle theory.

3. The mechanism of diffraction



Photograph of single-slit diffraction in a circular [ripple tank](#).

The very heart of the explanation of all diffraction phenomena is [interference](#). When two waves combine, their displacements add, causing either a lesser or greater total displacement depending on the phase difference between the two waves. The effect of diffraction from an opaque object can be seen as interference between different parts of the wave beyond the diffraction object. [The pattern formed by this interference is dependent on the wavelength of the wave](#), which for example gives rise to the rainbow pattern on a CD. Most diffraction phenomena can be understood in terms of a few simple concepts that are illustrated below.

The most conceptually simple example of diffraction is single-slit diffraction in which the slit is narrow, that is, significantly smaller than a [wavelength](#) of the wave. After the wave passes through the slit a pattern of semicircular ripples is formed, as if there were a simple wave source at the position of the slit. This semicircular wave is a diffraction pattern.

If we now consider two such narrow apertures, the two radial waves emanating from these apertures can interfere with each other. Consider for example, a water wave incident on a screen with two small openings. The total displacement of the water on the far side of the screen at any point is the sum of the displacements of the individual radial waves at that point. Now there are points in space where the wave emanating from one aperture is always in phase with the other, *i.e.* they both go up at that point, this is called *constructive interference* and results in a greater total amplitude. There are also points where one radial wave is out of phase with the other by one half of a wavelength, this would mean that when one is going up, the other is going down, the resulting total amplitude is

decreased, this is called *destructive interference*. The result is that there are regions where there is no wave and other regions where the wave is amplified.

Another conceptually simple example is diffraction of a plane wave on a large (compared to the wavelength) plane mirror. The only direction at which all electrons oscillating in the mirror are seen oscillating in phase with each other is the [specular](#) (mirror) direction – thus a typical mirror reflects at the angle which is equal to the angle of incidence of the wave. This result is called the [law of reflection](#). Smaller and smaller mirrors diffract light over a progressively larger and larger range of angles.

Slits significantly wider than a wavelength will also show diffraction which is most noticeable near their edges. The center part of the wave shows limited effects at short distances, but exhibits a stable diffraction pattern at longer distances. This pattern is most easily understood and calculated as the interference pattern of a large number of simple sources spaced closely and evenly across the width of the slit.

This concept is known as the [Huygens–Fresnel principle](#): The propagation of a wave can be visualized by considering every point on a wavefront as a point source for a secondary radial wave. The subsequent propagation and interference of all these radial waves form the new wavefront. This principle mathematically results from interference of waves along all allowed paths between the source and the detection point (that is, all paths except those that are blocked by the diffracting objects).

4. Qualitative observations of diffraction

Several qualitative observations can be made of diffraction in general:

- The angular spacing of the features in the diffraction pattern is inversely proportional to the dimensions of the object causing the diffraction, in other words: the smaller the diffracting object the 'wider' the resulting diffraction pattern and vice versa. (More precisely, this is true of the [sines](#) of the angles.)
- The diffraction angles are invariant under scaling; that is, they depend only on the ratio of the wavelength to the size of the diffracting object.
- When the diffracting object has a periodic structure, for example in a diffraction grating, the features generally become sharper. The third figure, for example, shows a comparison of a [double-slit](#) pattern with a pattern formed by five slits, both sets of slits having the same spacing, between the center of one slit and the next.

5. Quantitative description of diffraction

For more details on this topic, see [Diffraction formalism](#).

To determine the pattern produced by diffraction we must determine the phase and amplitude of each of the Huygens wavelets at each point in space. That is, at each point in space, we must determine the distance to each of the simple sources on the incoming wavefront. If the distance to each of the simple sources differs by an integer number of wavelengths, all the wavelets will be in phase, resulting in constructive interference. If the distance to each source is an integer plus one half

of a wavelength, there will be complete destructive interference. Usually it is sufficient to determine these minimums and maximums to explain the effects we see in nature. The simplest descriptions of diffraction are those in which the situation can be reduced to a 2 dimensional problem. For water waves, this is already the case, water waves propagate only on the surface of the water. For light, we can often neglect one direction if the diffracting object extends in that direction over a distance far greater than the wavelength. In the case of light shining through small circular holes we will have to take into account the full three dimensional nature of the problem.

5-1. Diffraction from an array of narrow slits or a grating

See also: [Diffraction grating](#)

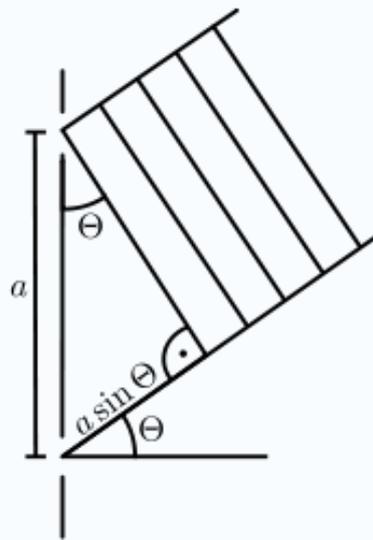


Diagram of two slit diffraction problem, showing the angle to the first minimum, where a path length difference of a half wavelength causes destructive interference.

Multiple-slit arrangements can be described as multiple simple wave sources, if the slits are narrow enough. For light, a slit is an opening that is infinitely extended in one dimension, which has the effect of reducing a wave problem in 3-space to a simpler problem in 2-space.

The simplest case is that of two narrow slits, spaced a distance a apart. To determine the maxima and minima in the amplitude we must determine the difference in path length to the first slit and to the second one. In the Fraunhofer approximation, with the observer far away from the slits, the difference in path length to the two slits can be seen from the image to be

$$\Delta S = a \sin \theta$$

Maxima in the intensity occur if this path length difference is an integer number of wavelengths:

$$a \sin \theta = n \lambda$$

where:

n is an [integer](#) that labels the *order* of each maximum,

λ is the wavelength,

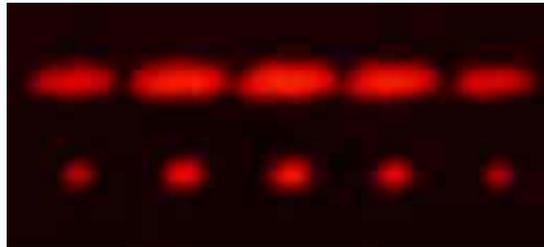
a is the distance between the slits,

and θ is the angle at which constructive interference occurs.

And the corresponding minima are at path differences of an integer number plus one half of the wavelength:

$$a \sin \theta = \lambda(n + 1/2)$$

For an array of slits, positions of the minima and maxima are not changed, the *fringes* visible on a screen however do become sharper as can be seen in the image. The same is true for a surface that is only reflective along a series of parallel lines; such a surface is called a reflection grating.

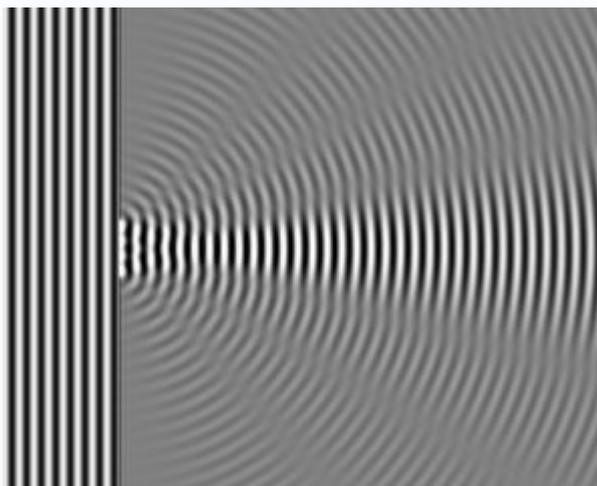


2-slit and 5-slit diffraction of red laser light

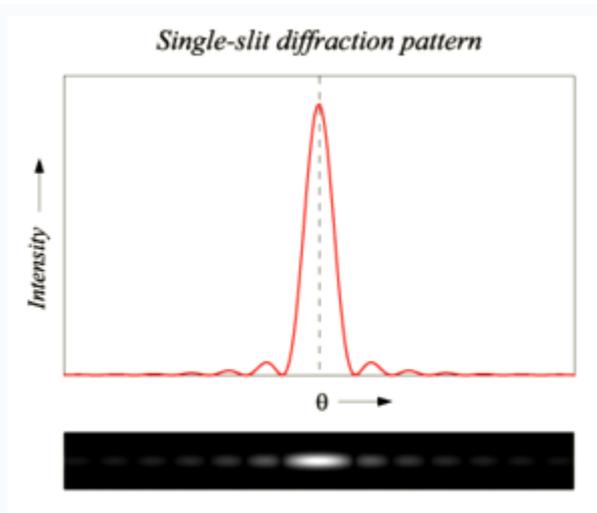
We see from the formula that the diffraction angle is wavelength dependent. This means that different colors of light will diffract in different directions, which allows us to separate light into its different color components. Gratings are used in [spectroscopy](#) to determine the properties of atoms and molecules, as well as stars and interstellar dust clouds by studying the spectrum of the light they emit or absorb.

Another application of diffraction gratings is to produce a monochromatic light source. This can be done by placing a slit at the angle corresponding to the constructive interference condition for the desired wavelength.

5-2 Single-slit diffraction



Numerical approximation of diffraction pattern from a slit of width four wavelengths with an incident plane wave. The main central beam, nulls, and phase reversals are apparent.



Graph and image of single-slit diffraction

Slits wider than a wavelength will show diffraction at their edges. The pattern is most easily understood and calculated as the interference pattern of a large number of simple sources spaced closely and evenly across the width of the slit. We can determine the *minima* of the resulting intensity pattern by using the following reasoning. If for a given angle a simple source located at the left edge of the slit interferes destructively with a source located at the middle of the slit, then a simple source just to the right of the left edge will interfere destructively with a simple source located just to the right of the middle. We can continue this reasoning along the entire width of the slit to conclude that the condition for destructive interference for the entire slit is the same as the condition for destructive interference between two narrow slits a distance apart that is half the width of the slit. The result is a formula that looks very similar to the one for diffraction from a grating with the important difference that it now predicts the minima of the intensity pattern.

$d\sin(\theta_{min}) = n\lambda$ n is now an integer greater than 0.

The same argument does not hold for the maxima. To determine the location of the maxima and the exact intensity profile, a more rigorous treatment is required; a [diffraction formalism](#) in terms of integration over all unobstructed paths is required. The intensity profile is then given by

$$I(\theta) = I_0 \left[\text{sinc} \left(\frac{\pi a}{\lambda} \sin \theta \right) \right]^2$$

5-3 Multiple extended slits

For an array of slits that are wider than the wavelength of the incident wave, we must take into account interference of wave from different slits as well as interference between waves from different locations in the same slit. Minima in the intensity occur if either the single slit condition or the grating condition for complete destructive interference is met. A rigorous mathematical treatment shows that the resulting intensity pattern is the product of the grating intensity function with the single slit intensity pattern.

$$I(\theta) = I_0 \left[\text{sinc} \left(\frac{\pi a}{\lambda} \sin \theta \right) \right]^2 \cdot \left[\frac{\sin \left(\frac{N\pi d}{\lambda} \sin \theta \right)}{\sin \left(\frac{\pi d}{\lambda} \sin \theta \right)} \right]^2$$

When doing experiments with gratings that have a slit width being an integer fraction of the grating spacing, this can lead to 'missing' orders. If for example the width of a single slit is half the separation between slits, the first minimum of the single slit diffraction pattern will line up with the first maximum of the grating diffraction pattern. This expected diffraction peak will then not be visible. The same is true in this case for any odd numbered grating-diffraction peak.

6. Particle diffraction

See also: [neutron diffraction](#) and [electron diffraction](#)

Quantum theory tells us that every particle exhibits wave properties. In particular, massive particles can interfere and therefore diffract. Diffraction of electrons and neutrons stood as one of the powerful arguments in favor of [quantum mechanics](#). The wavelength associated with a particle is the [de Broglie wavelength](#)

$$\lambda = \frac{h}{p}$$

where h is [Planck's constant](#) and p is the [momentum](#) of the particle (mass \times velocity for slow-moving particles). For most macroscopic objects, this wavelength is so short that it is not meaningful to assign a wavelength to them. A Sodium atom traveling at about 3000 m/s would have a De Broglie wavelength of about 5 pico meters.

Because the wavelength for even the smallest of macroscopic objects is extremely small, diffraction of matter waves is only visible for small particles, like electrons, neutrons, atoms and small molecules. The short wavelength of these matter waves makes them ideally suited to study the atomic crystal structure of solids and large molecules like proteins.

Relatively recently, larger molecules like [buckyballs](#),^[4] have been shown to diffract. Currently, research is underway into the diffraction of [viruses](#), which, being huge relative to [electrons](#) and other more commonly diffracted particles, have tiny wavelengths so must be made to travel very slowly through an extremely narrow slit in order to diffract.

7. Bragg diffraction

For more details on this topic, see [Bragg diffraction](#).

Diffraction from a three dimensional periodic structure such as atoms in a crystal is called [Bragg diffraction](#). It is similar to what occurs when waves are scattered from a [diffraction grating](#). Bragg diffraction is a consequence of interference between waves reflecting from different crystal planes. The condition of constructive interference is given by *Bragg's law*:

$$m\lambda = 2d\sin\theta$$

where

λ is the [wavelength](#),

d is the distance between crystal planes,

θ is the angle of the diffracted wave, and m is an integer known as the *order* of the diffracted beam.

Bragg diffraction may be carried out using either light of very short wavelength like [x-rays](#) or matter waves like [neutrons](#) whose wavelength is on the order of the atomic spacing. The pattern produced gives information of the separations of crystallographic planes d , allowing one to deduce the crystal structure.

8. Coherence

Main article: [Coherence \(physics\)](#)

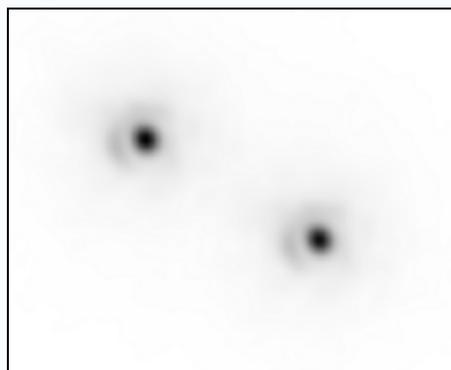
The description of diffraction relies on the interference of waves emanating from the same source taking different paths to the same point on a screen. In this description, the difference in phase between waves that took different paths is only dependent on the effective path length. This does not take into account the fact that waves that arrive at the screen at the same time were emitted by the source at different times. The initial phase with which the source emits waves can change over time in an unpredictable way. This means that waves emitted by the source at times that are too far apart can no longer form a constant interference pattern since the relation between their phases is no longer time independent.

The length over which the phase in a beam of light is correlated, is called the [coherence length](#). In order for interference to occur, the path length difference must be smaller than the coherence length. This is sometimes referred to as spectral coherence as it is related to the presence of different frequency components in the wave. In the case light emitted by an [atomic transition](#), the coherence length is related to the lifetime of the excited state from which the atom made its transition.

If waves are emitted from an extended source this can lead to incoherence in the transversal direction. When looking at a cross section of a beam of light, the length over which the phase is correlated is called the transverse coherence length. In the case of Young's double slit experiment this would mean that if the transverse coherence length is smaller than the spacing between the two slits the resulting pattern on a screen would look like two single slit diffraction patterns.

In the case of particles like electrons, neutrons and atoms, the coherence length is related to the spacial extent of the wave function that describes the particle.

9. Diffraction limit of telescopes



The [Airy disc](#) around each of the stars from the 2.56m telescope aperture can be seen in this [lucky image](#) of the [binary star zeta Boötis](#).

For diffraction through a circular aperture, there is a series of concentric rings surrounding a central [Airy disc](#). The mathematical result is similar to a radially symmetric version of the equation given above in the case of single-slit diffraction.

A wave does not have to pass through an aperture to diffract; for example, a beam of light of a finite size also undergoes diffraction and spreads in [diameter](#). This effect limits the minimum diameter d of spot of light formed at the focus of a [lens](#), known as the [diffraction limit](#):

$$d = 1.22\lambda \frac{f}{a},$$

where λ is the wavelength of the light, f is the focal length of the lens, and a is the diameter of the beam of light, or (if the beam is filling the lens) the diameter of the lens. The diameter given is enough to contain about 70% of the light energy; it is the radius to the first null of the [Airy disk](#), in approximate agreement with the [Rayleigh criterion](#). Twice that diameter, the diameter to the first null of the [Airy disk](#), within which 83.8% of the light energy is contained, is also sometimes given as the diffraction spot diameter.

By use of [Huygens' principle](#), it is possible to compute the diffraction pattern of a wave from any arbitrarily shaped aperture. If the pattern is observed at a sufficient distance from the aperture, it will appear as the two-dimensional [Fourier transform](#) of the function representing the aperture.

10. References

1. [^](#) Dietrich Zawischa. [Optical effects on spider webs](#). Retrieved on [2007-09-21](#).
2. [^](#) Jean Louis Aubert (1760). [Memoires pour l'histoire des sciences et des beaux arts](#). Paris: Impr. de S. A. S.; Chez E. Ganeau, 149.
3. [^](#) Sir David Brewster (1831). [A Treatise on Optics](#). London: Longman, Rees, Orme, Brown & Green and John Taylor, 95.
4. [^](#) Brezger, B.; Hackermüller, L.; Uttenthaler, S.; Petschinka, J.; Arndt, M.; Zeilinger, A. (February 2002). "[Matter-Wave Interferometer for Large Molecules](#)" (reprint). *Physical Review Letters* **88** (10): 100404. [DOI:10.1103/PhysRevLett.88.100404](#). Retrieved on [2007-04-30](#).

11. See also

- [Prism](#)
- [Diffraction formalism](#)
- [Diffractometer](#)
- [Atmospheric diffraction](#)
- [Bragg diffraction](#)
- [Diffraction grating](#)
- [Electron diffraction](#)
- [Neutron diffraction](#)

- [X-ray diffraction](#)
- [Dynamical theory of diffraction](#)
- [Fraunhofer diffraction](#)
- [Fresnel diffraction](#)
- [Fresnel number](#)
- [Fresnel zone](#)
- [Powder diffraction](#)
- [Schaefer-Bergmann diffraction](#)
- [Airy disk](#)

12. External links



Wikimedia Commons has media related to: [Diffraction](#)



Think free. Learn free.

Wikibooks has more about this subject: [Nanowiki](#)

- [How to build a diffraction spectrometer](#)
- [- Diffraction and acoustics.](#)
- [Wave Optics](#) - A chapter of an online textbook.
- [2-D wave java applet](#) - Displays diffraction patterns of various slit configurations.
- [Diffraction java applet](#) - Displays diffraction patterns of various 2-D apertures.
- [Diffraction approximations illustrated](#) - MIT site that illustrates the various approximations in diffraction and intuitively explains the Fraunhofer regime from the perspective of linear system theory.
- [Diffraction Limited Photography](#) - Understanding how airy disks, lens aperture and pixel size limit the absolute resolution of any camera.
- [Gap Obstacle Corner](#) - Java simulation of diffraction of water wave.
- [Google Maps](#) - Satellite image of Panama Canal entry ocean wave diffraction.

Lab 23D: Diffraction of Multiple slits-Diffraction Grating

Laser Safety Rule: Please refer to the both word files, “Laser Safety-short summary.doc” and “Laser Safety-complete summary.doc”. You must read both files before begin to do the experiments which need use laser.

1. Object:

To observe the diffraction phenomena of light through multiple slits and to determine the wavelength of laser beam using the diffraction how does the polarizer work.

2. Principle:

Referred from <http://hyperphysics.phy-astr.gsu.edu/hbase/hframe.html>, “Light and Vision”, in web site “HyperPhysics”, hosted by the department of Physics and Astronomy, Georgia State University, GA, US

*HyperPhysics is hosted by the
Department of Physics and Astronomy*

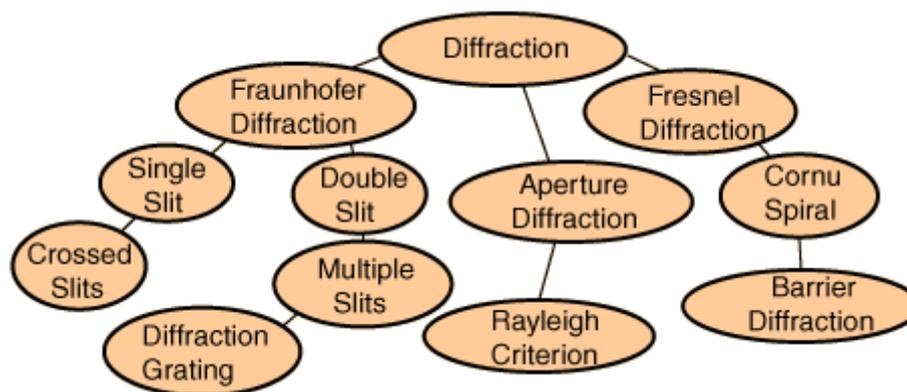


HyperPhysics

2-1 Study Roadmaps of diffraction

Roadmap of Diffraction

Diffraction manifests itself in the apparent bending of waves around small obstacles and the spreading out of waves past small openings.

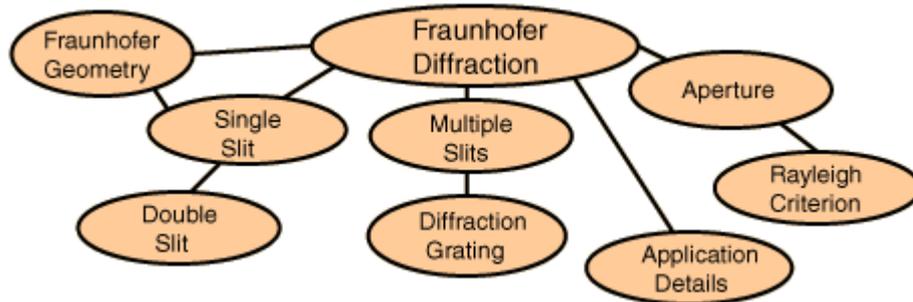


[Diffraction reveals the geometry of the diffracting object.](#)

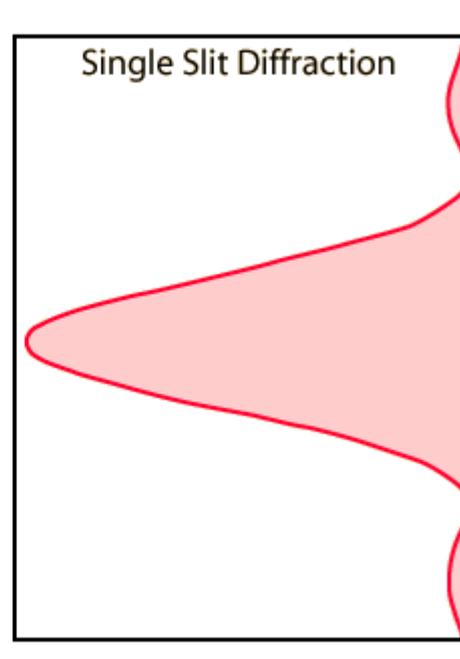
Fig.1 The roadmap of diffraction

Fraunhofer Diffraction

Fraunhofer diffraction deals with the limiting cases where the light approaching the diffracting object is parallel and monochromatic, and where the image plane is at a distance large compared to the size of the diffracting object. The more general case where these restrictions are relaxed is called [Fresnel diffraction](#).



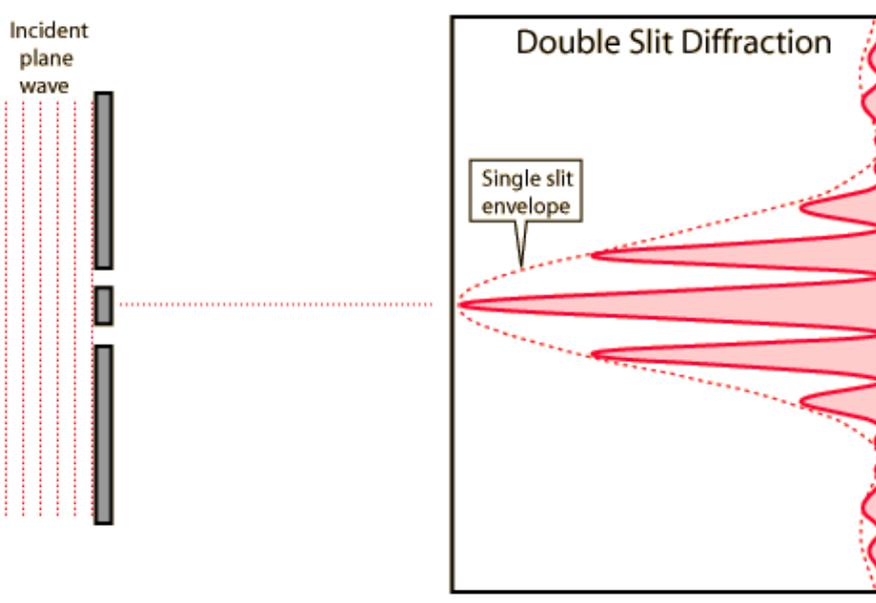
Single Slit Diffraction



- Single slit
- [Double slit](#)
- [Three slits](#)
- [Five slits](#)
- Diffraction and interference
- [Interference only](#)

Under the [Fraunhofer conditions](#), the light curve of a multiple slit arrangement will be the interference pattern multiplied by the single slit diffraction envelope. This assumes that all the slits are identical.

Double Slit Diffraction

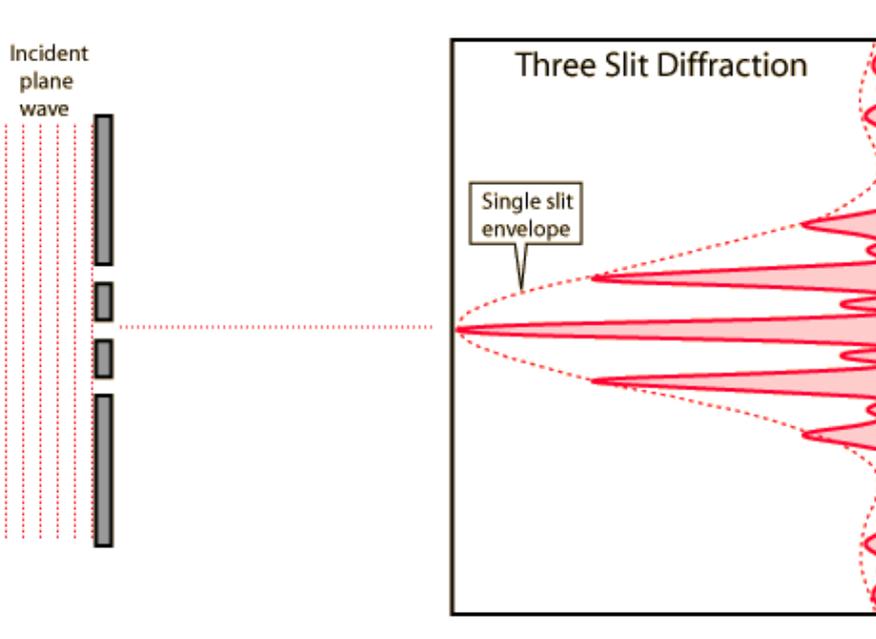


- [Single slit](#)
- [Double slit](#)
- [Three slits](#)
- [Five slits](#)

- Diffraction and interference
- [Interference only](#)

Under the [Fraunhofer conditions](#), the light curve of a multiple slit arrangement will be the interference pattern multiplied by the single slit diffraction envelope. This assumes that all the slits are identical.

Three Slit Diffraction



- [Single slit](#)

- Diffraction and

Under the [Fraunhofer conditions](#), the light curve

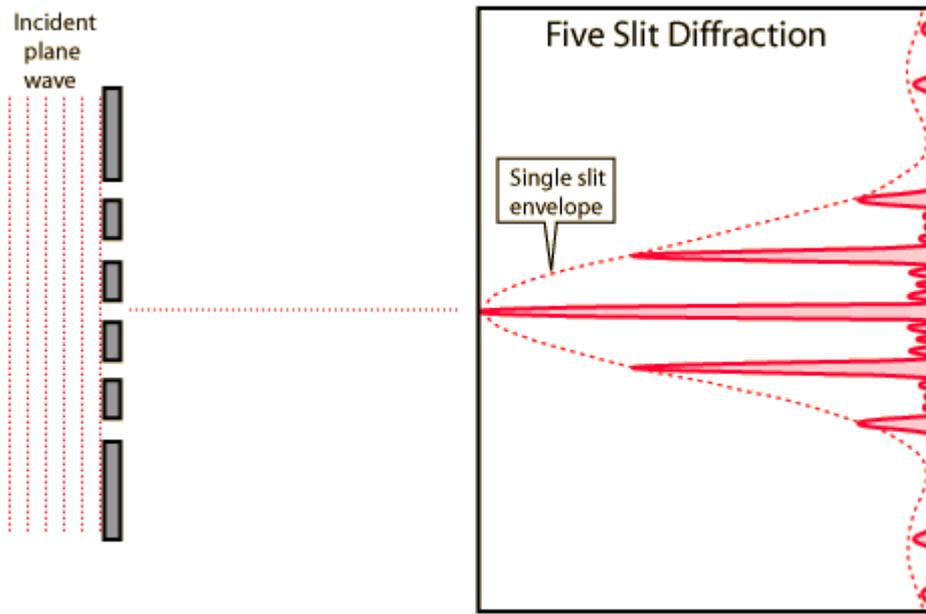
- [Double slit](#)
- [Three slits](#)
- [Five slits](#)

- interference
- [Interference only](#)

of a multiple slit arrangement will be the interference pattern multiplied by the single slit diffraction envelope. This assumes that all the slits are identical.

[Show intensity comparison](#)

Five Slit Diffraction



- [Single slit](#)
- [Double slit](#)
- [Three slits](#)
- [Five slits](#)

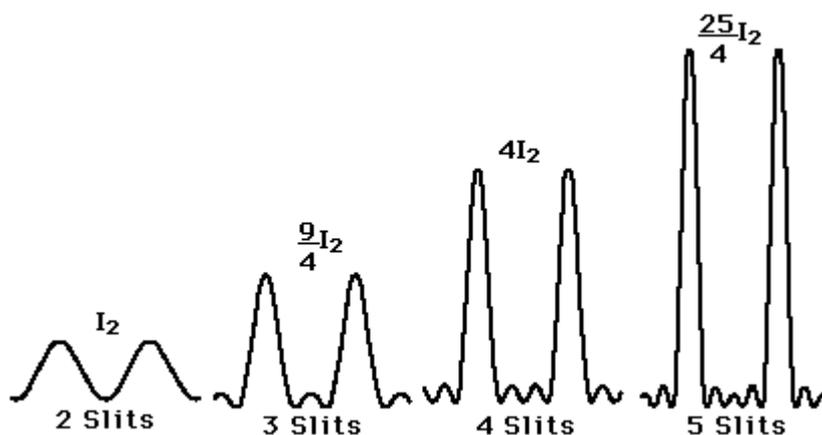
- Diffraction and interference
- [Interference only](#)

Under the [Fraunhofer conditions](#), the light curve of a multiple slit arrangement will be the interference pattern multiplied by the single slit diffraction envelope. This assumes that all the slits are identical.

The progression to a larger number of slits shows a pattern of narrowing the high intensity peaks and a relative [increase in their peak intensity](#). This progresses toward the [diffraction grating](#), with a large number of extremely narrow slits. This gives very narrow and very high intensity peaks that are separated widely. Since the positions of the peaks depends upon the wavelength of the light, this gives high resolution in the separation of wavelengths. This makes the diffraction grating like a "super [prism](#)".

Grating Intensity Comparison

The [grating intensity](#) expression gives a peak intensity which is proportional to the square of the number of slits illuminated. Increasing the number of slits not only makes the diffraction maximum sharper, but also much more intense. If a mm diameter laser beam strikes a line/mm grating, then it covers slits and the resulting line intensity is x that of a double slit.



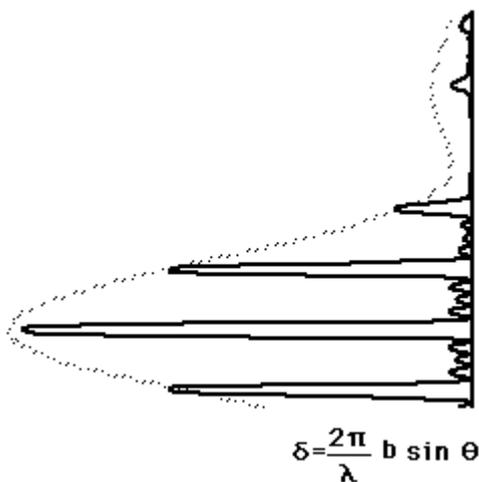
Grating Intensity

The two aspects of the grating intensity relationship can be illustrated by the diffraction from five slits. The intensity is given by the interference intensity expression

$$I = I_0 \frac{\sin^2 \left[\frac{N\delta}{2} \right]}{\sin^2 \left[\frac{\delta}{2} \right]} \quad \text{for } N \text{ slits}$$

modulated by the single slit diffraction envelope for the slits which make up the grating:

$$I = I_0 \frac{\sin^2 \left[\frac{\delta}{2} \right]}{\left[\frac{\delta}{2} \right]^2}$$



This gives a total intensity expression:

$$I = I_0 \frac{\sin^2 \left[\frac{\delta}{2} \right] \sin^2 \left[N \frac{\delta}{2} \right]}{\left[\frac{\delta}{2} \right]^2 \sin^2 \left[\frac{\delta}{2} \right]}$$
