Diffraction

Introduction

- In this presentation, we will be introducing:
  - ✓ Key Terms
  - ✓ How it works
  - ✓ How Light Bends Around Obstacles
  - ✓ Production of Dark and Light Fringes
  - ✓ Resolving Images

Key Terms

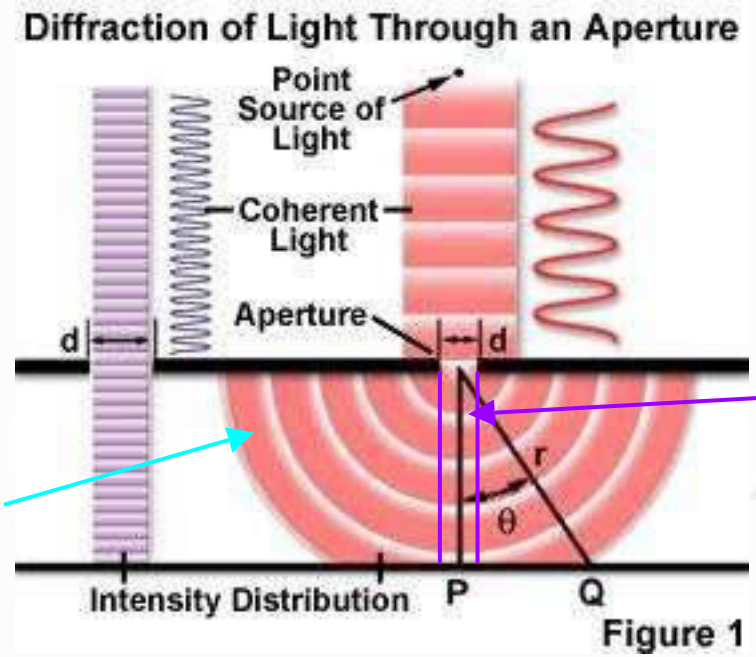
- *Diffraction* - a change in light wave direction as they pass from one point to another point
- *Aperture* - a small slit in which light travels
- *Minima* - the dark regions of the diffraction pattern.
- *Prima Maxima* - bright central region of the diffraction pattern.

What is Diffraction?

- Diffraction is when light passes through an object because of the slits ,causing it to produce a light on the other side of that object.

- There are many different ways diffraction occurs: Light, sound, water, etc.

How Stuff Works



This is the maxima

This is the minima

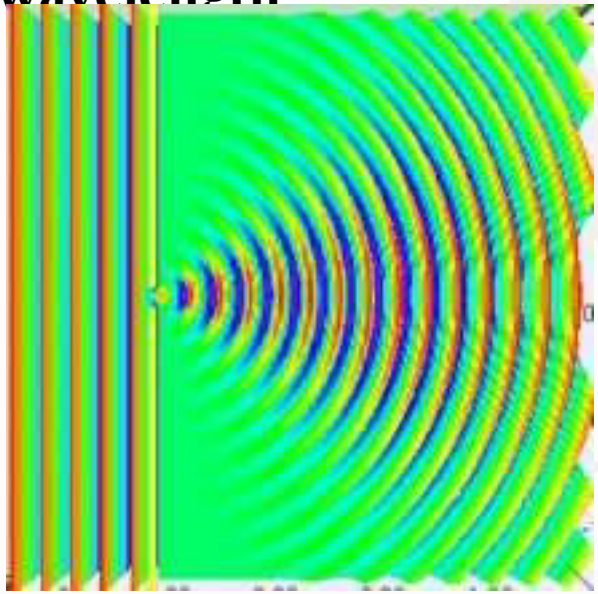
How Light Bends Around an Object

- Light bends around an object by diffraction, obviously; but what does that mean?

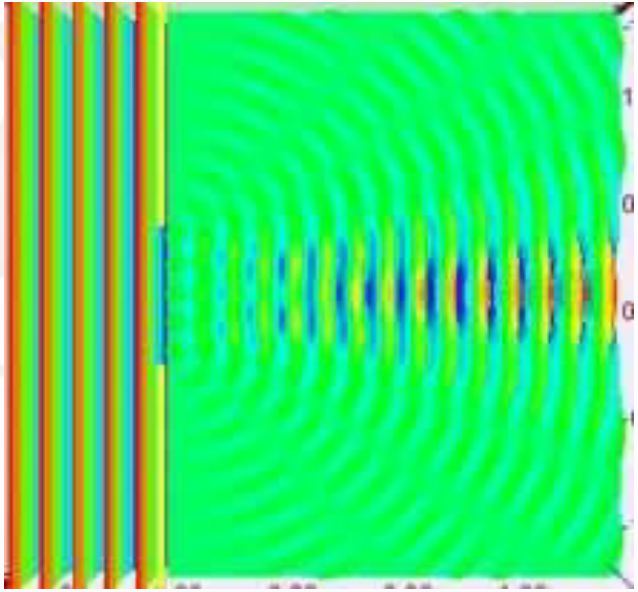
- When an object interferes with the passage of light, the waves will pass through a slit in a objects. Then they will spread out in a certain way on the other side of the object.

Examples

- **Slit size equal to wavelength**



Slit size 5x the wavelength



Resolving Images

- Most people didn't know that diffraction is also occurs in the resolution of images.
- When a camera lens is used, diffraction occurs when light passes through the camera's aperture, causing the picture to be disoriented or unresolved.
- The camera has a certain feature that corrects the disoriented picture.

This picture is what is expected to come out when a camera takes a picture.

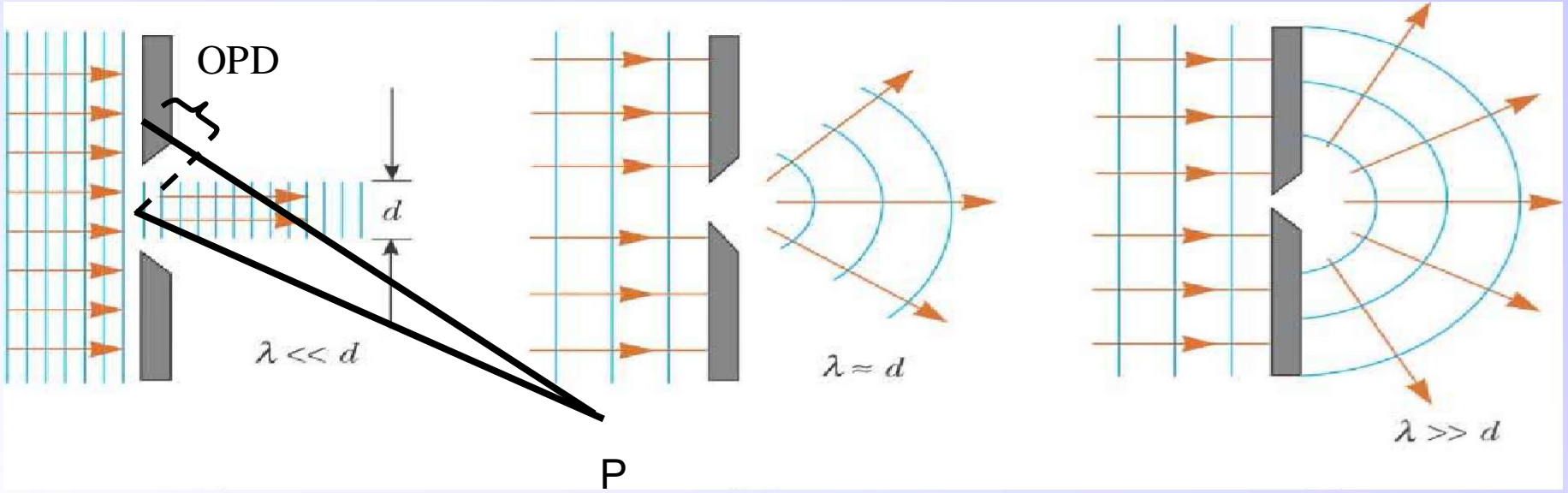
This picture is the result when the resolution is disoriented because of diffraction.

- *Huygen-Fresnel principle:*

Every unobstructed point of a wavefront, at a given instant, serves as a source of spherical secondary wavelets (with the same frequency as that of the primary wave).

The amplitude of the optical field at any point beyond is the superposition of all these wavelets (considering their amplitudes and relative phases).

– Fresnel resolves the inadequacy of Huygen's principle with the addition of the concept of interference.



- Each unobstructed point act as a secondary source.
- Consider an arbitrary point, *P*, far away from the obstruction. The maximum path difference among all those sources are due to the two by the sides, OPD.

Fraunhofer and Fresnel Diffraction

- Diffraction phenomena can be classified either as Fraunhofer diffraction or Fresnel diffraction.

- The observable difference :

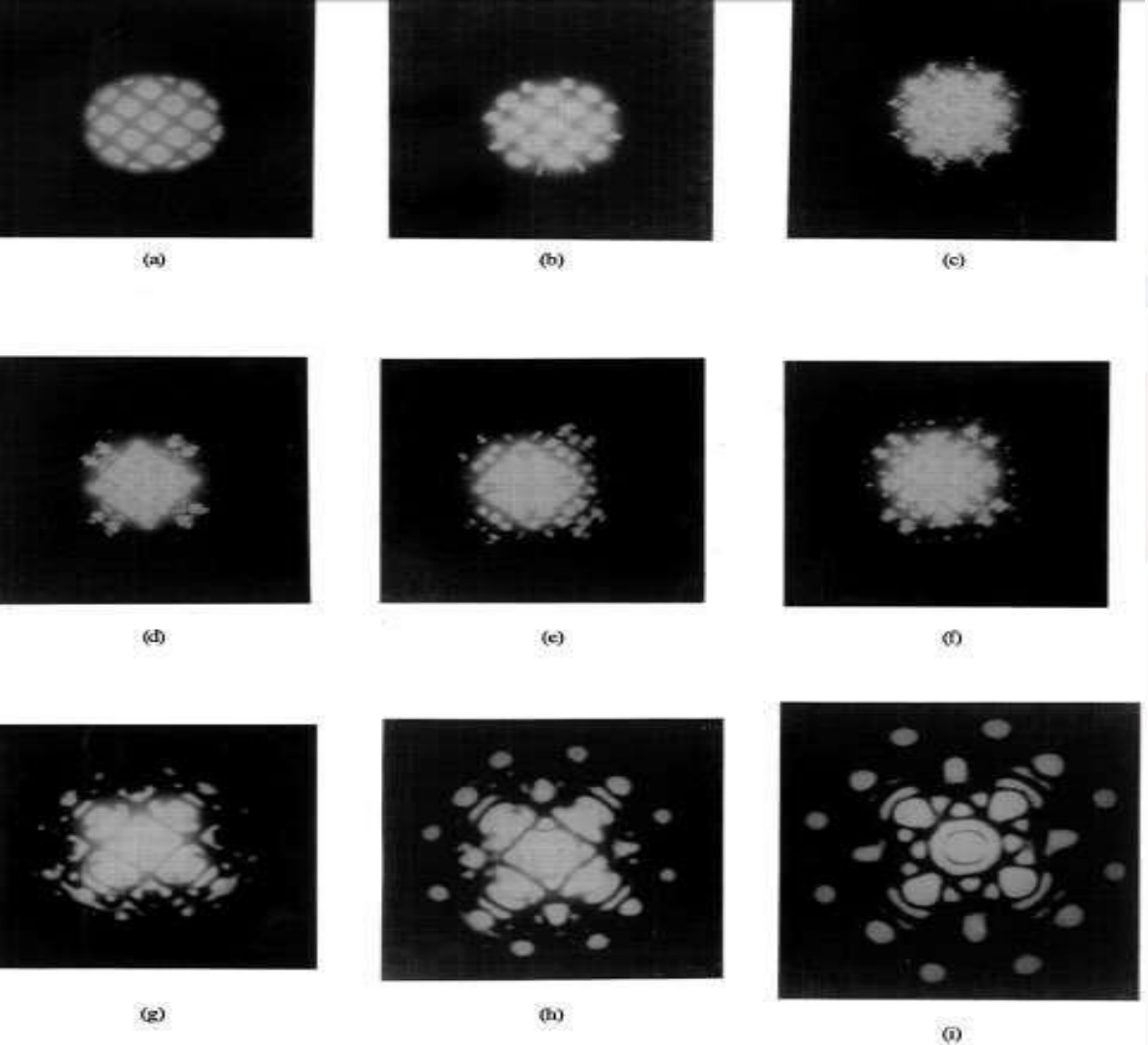
Fresnel diffraction

  - The viewing screen and the aperture are located close together, the image of the aperture is clearly recognisable despite slight fringing around its periphery.

  - As the separation between the screen and the aperture increases, the image of the aperture becomes increasingly more structured; fringes become more prominent.

Fraunhofer diffraction

  - The viewing screen and the aperture separated by a large distance, the projected pattern bears little or no resemblance to the aperture.
  - As the separation increases, the size of the pattern changes but not its shape.



(a) : Aperture – array type

(b)-(h):

Fresnel diffraction pattern

(note the changes in the pattern as the screen moves further away)

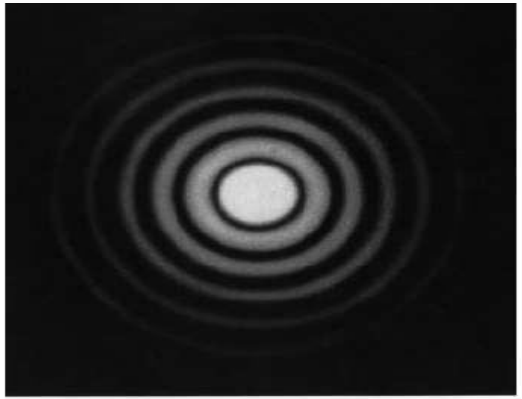
(i) : Fraunhofer diffraction

http://spie.org/etop/1995/20_1.pdf

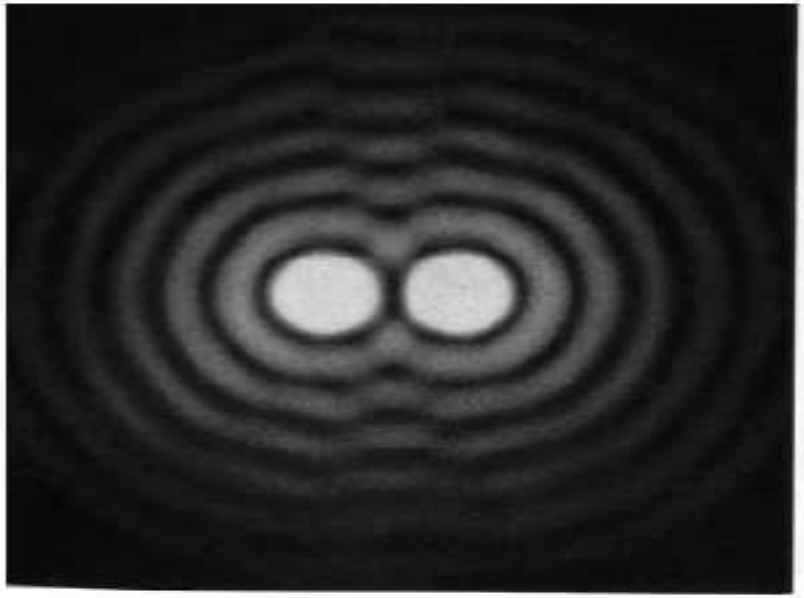
Circular Aperture

- The diagram shows the diffraction pattern formed by plane waves going pass a circular aperture.

- It consist of a bright ring (Airy's disk) surrounded by a number of fainter rings.
  - The rings shade gradually fall off at the edges, being separated by circles of zero intensity.
  - The intensity distribution is very much the same as that which would be obtained with the single-slit pattern, rotated about in the centre of an axis perpendicular to the central maximum.



Rayleigh Resolution Limit



Separated images of 2 incoherent point sources

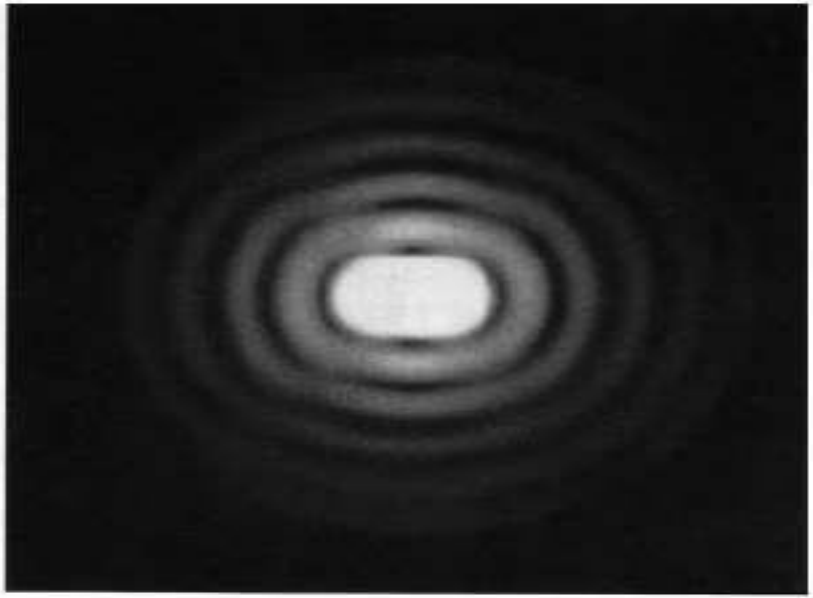


Image of a pair of incoherent point sources at the limit of resolution

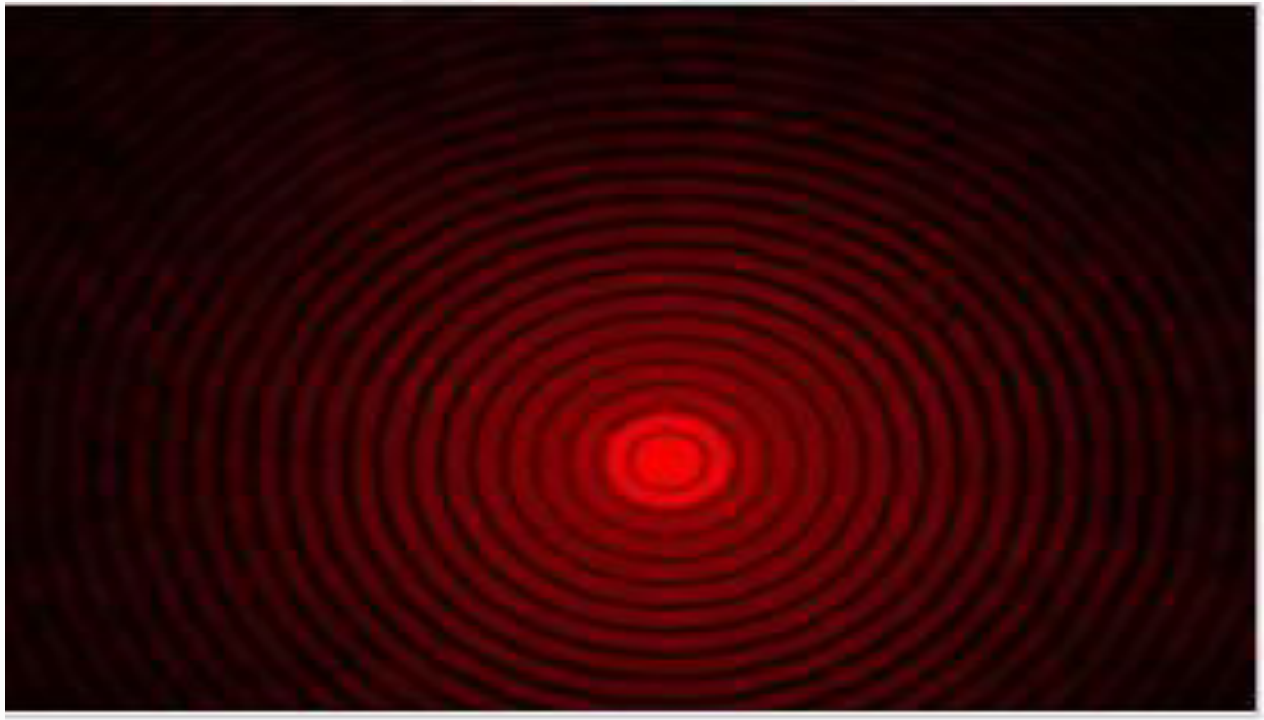
Two stars well separated (left)

Two stars at Rayleigh limit (right)

Diffraction by a circular aperture

- The Airy disk (or Airy disc) and Airy pattern are descriptions of the best focused spot of light that a perfect lens with a circular aperture
- The diffraction pattern resulting from a uniformly-illuminated circular aperture has a bright region in the center, known as the **Airy disk**, which together with the series of concentric bright rings around is called the **Airy pattern**

Airy pattern



- The diffraction pattern is characterized by the wavelength of light illuminating the circular aperture, and the aperture's size.
  The *appearance* of the diffraction pattern is additionally characterized by the sensitivity of the eye or other detector used to observe the pattern.

- The most important application of this concept is in cameras and telescopes. Due to diffraction, the smallest point to which a lens or mirror can focus a beam of light is the size of the Airy disk
- Even if one were able to make a perfect lens, there is still a limit to the resolution of an image created by such a lens. An optical system in which the resolution is no longer limited by imperfections in the lenses but only by diffraction is said to be diffraction limited

- It was shown that for a rectangular aperture, the angular separation is given by $m\lambda/b$, where m is a whole number starting from unity.

- A similar formula can be stated for the circular aperture but in this case m are not integers (Jenkins & White, page 329, table 15B).

- Extending Rayleigh's criterion for the resolution of diffraction patterns to the circular aperture, the patterns are said to be resolved when the central maximum of one falls on the dark ring of the other.

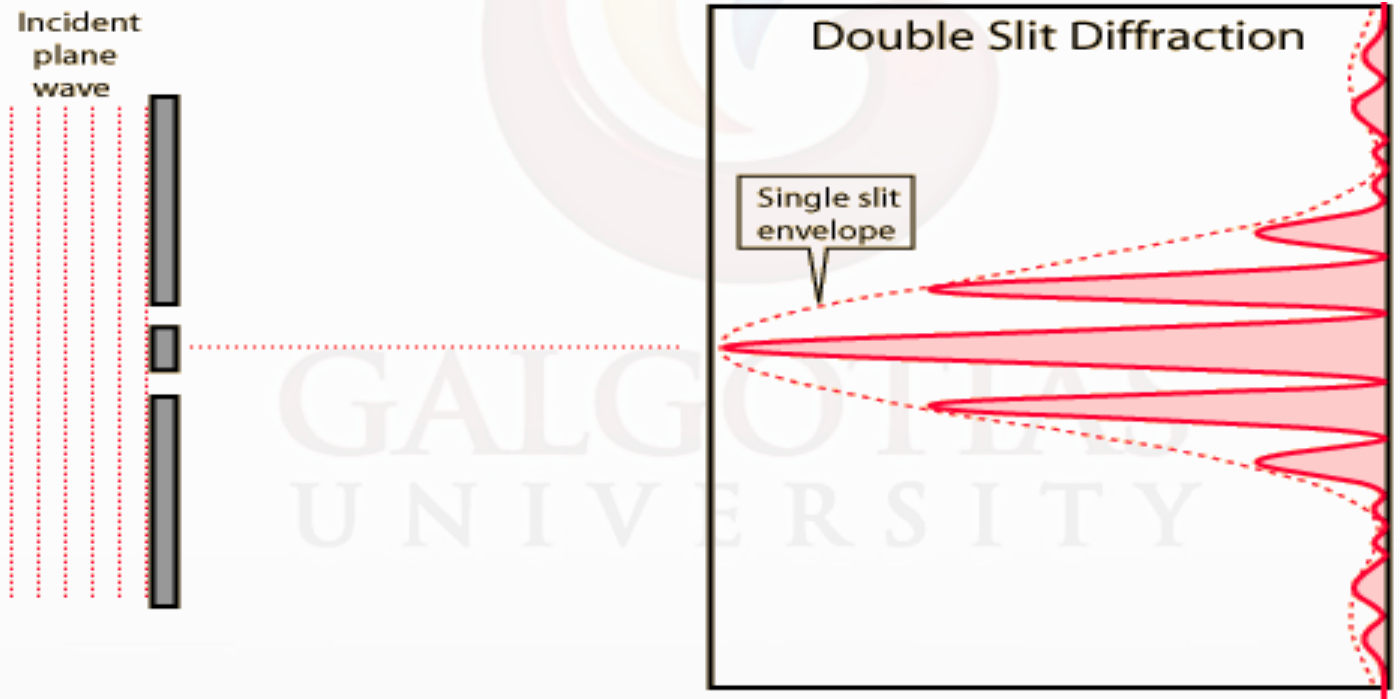
- The minimum angel of resolution is therefore

$$\theta_1 = 1.220\,\frac{\lambda}{D}$$

where D is the aperture diameter.

Double Slits

- The double-slit setup is the same as that of the single slit, but replace the opaque screen with one that has two slits.



- The two slits of width, *b*, have a centre-to-centre separation of *a*.

- Each aperture by itself would produce the same single-slit diffraction on the viewing screen.
  - These two wave are coherent.
  - The secondary wavelets will be coherent as well.

- The contribution from the two slits would overlap, interference occurs.
  - The result is then a rapidly-varying double slit interference fringe modulated by a single-slit diffraction pattern.

•References-

- Clinical Optics, A R Elkington
- Optics for Optometry students
- Geometric,Physical and Visual Optics, Michael Keating
- Geometrical and Visual Optics, 2nd edition, Steven Schwartz