6.1 Diffraction

Diffraction grating
Single slit diffraction
Circular diffraction

Diffraction and Interference

- Diffraction and interference are similar phenomena.
- Interference is the effect of superposition of 2 coherent waves.
- Diffraction is the superposition of many coherent waves.

Diffraction grating

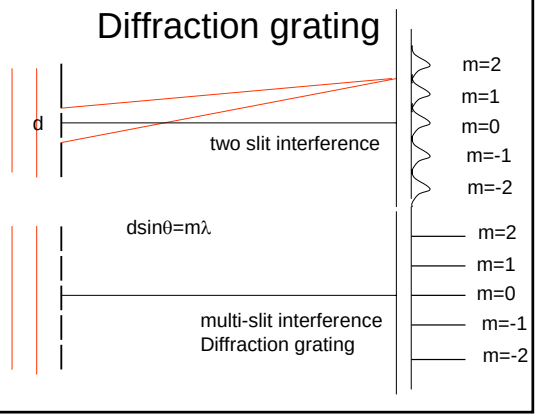
- Consists of a flat barrier which contains many parallel slits separated by a short distance d.
- A parallel monochromatic light beam passing through the grating is diffracted by an angle θ

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

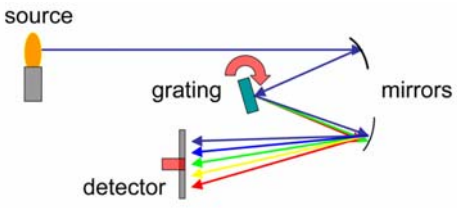
similar to two slit interference.

However, the intensity of the diffracted light is higher and the peaks are much narrower.

Diffraction grating



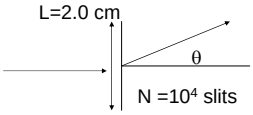
Use of a diffraction grating in a spectrometer



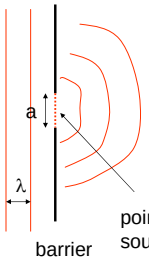
Dispersion of light of different wavelengths

Question

A grating in a spectrometer has a length of 2 cm and has contains 10^4 lines. Find the first order diffraction angle for light with a wavelength of 500 nm.

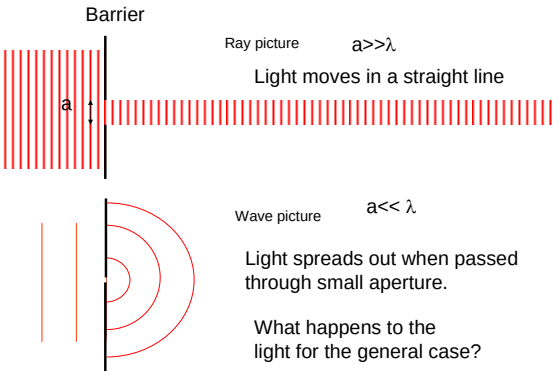


Single slit diffraction

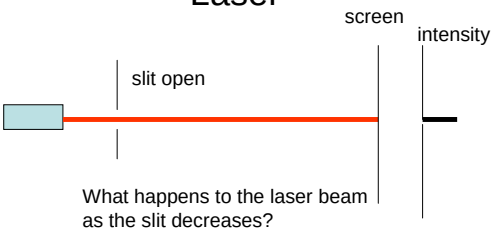


For single slit diffraction the complex behavior of the wave as a function of the aperture a is explained by interference between multiple coherent point sources in the slit.

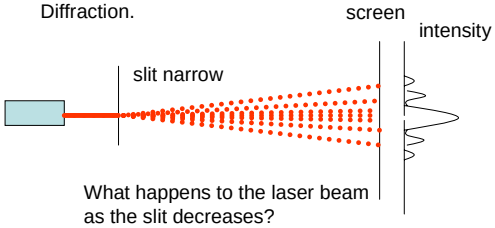
Two Limiting Cases



Laser



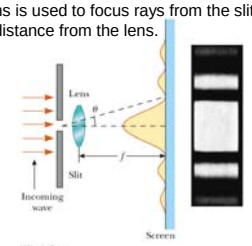
The pattern spreads out due to Diffraction.



Single slit diffraction pattern

Single slit diffraction

- Assume Fraunhoffer diffraction conditions
  Rays leaving the slit are parallel.
- This is true
  - if the screen is far from the slit
  - if a lens is used to focus rays from the slit on a screen at the focal distance from the lens.

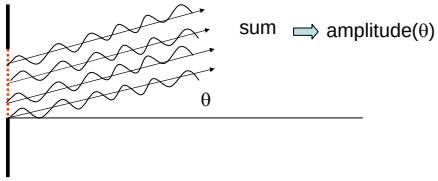


How do we account for the minima and maxima?

Single slit diffraction

Huygens principle – Each point in the wave in the slit acts as a source of spherical waves.

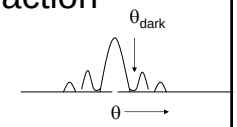
sum the waves with different phases



Single slit diffraction

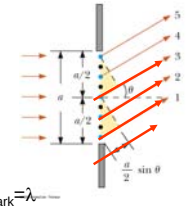
Find the angle at the first minimum

amplitude = 0



Divide the slit into 2 halves

Light from the top half interferes destructively with the light from the bottom half when the angle θ is

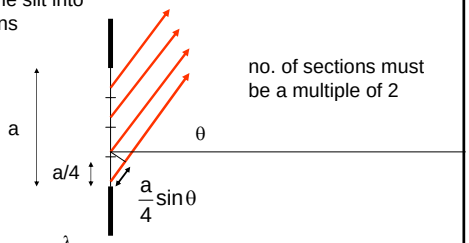


$$\frac{a}{2}\sin\theta_{dark} = \frac{\lambda}{2} \Rightarrow a\sin\theta_{dark}=\lambda$$

Single slit diffraction

For the second minimum.

Divide the slit into 4 sections



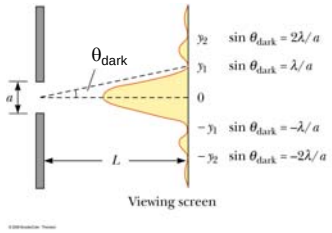
no. of sections must be a multiple of 2

$$\frac{a}{4}\sin\theta_{dark} = \frac{\lambda}{2} \quad a\sin\theta_{dark} = 2\lambda$$

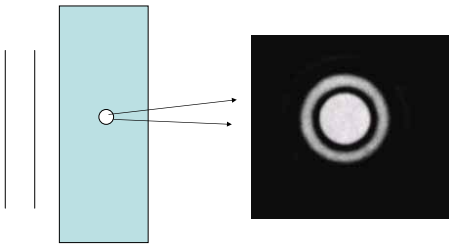
Condition for a minimum

$$a\sin\theta_{dark} = m\lambda$$

m=$\pm$ 1, $\pm$ 2, ...



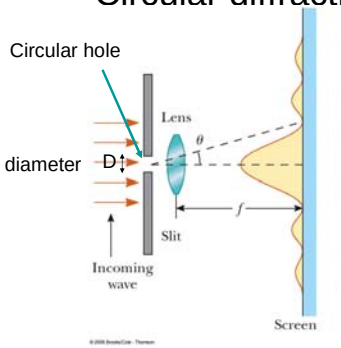
Circular diffraction



Waves passing through a circular hole forms a a circular diffraction pattern.

Circular diffraction.

Circular hole



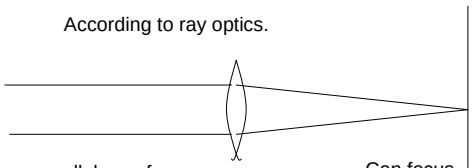
The first minimum occurs at

$$\theta_{min} = 1.22\frac{\lambda}{D}$$

Circular diffraction pattern

Circular diffraction limits the minimum size do the spot that can be formed by a lens.

According to ray optics.

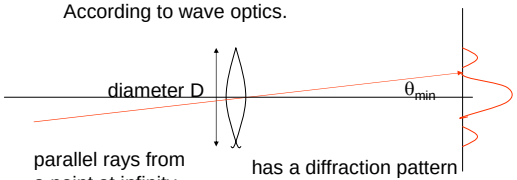


parallel rays from a point at infinity

Can focus on a point at the focal point of the lens

Circular diffraction limits the minimum size do the spot that can be formed by a lens.

According to wave optics.

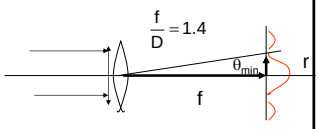


parallel rays from a point at infinity

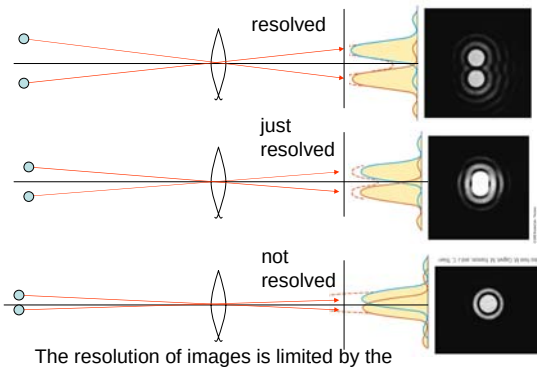
has a diffraction pattern with a width of θ_{min}

Example

A camera lens with an f- number (f/D) equal to 1.4 is used to focus light from a distant source. What is the diffraction limited diameter of the spot that can be formed for 500 nm light?



Resolution of two images by a lens

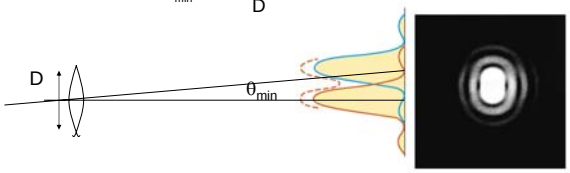


The resolution of images is limited by the diffraction pattern.

Rayleigh criterion

For resolution of two object by a circular lens of diameter D the diffraction limit of resolution occurs when the image of the second object is at position of the first minimum of the diffraction pattern of the first object.

$$\theta_{min} = 1.22\frac{\lambda}{D}$$



Resolution limit of the eye

Two light sources (λ= 500nm) are separated vertically by 2.0 mm. How far away can these objects be resolved by the eye Assume a diameter of the pupil of 2.0 mm. n_{water} =1.33