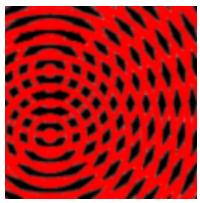
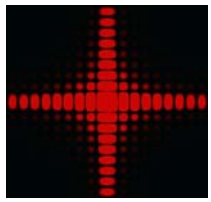
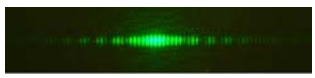
Physical Optics

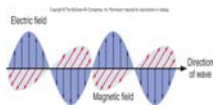


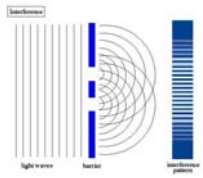




Wave interference

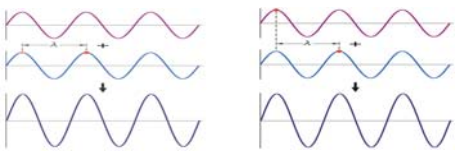
- **Interference** is the superposition of two or more waves resulting in a new wave pattern.
- The **principle of superposition** of waves states that the resultant displacement at a point is equal to the sum of the displacements of different waves at that point.
- An interference pattern is **noticeable** if the waves are coherent (maintain constant phase relationship) with each other, and monochromatic (single wavelength)



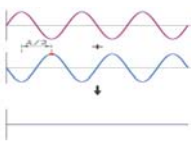


Superposition and interference

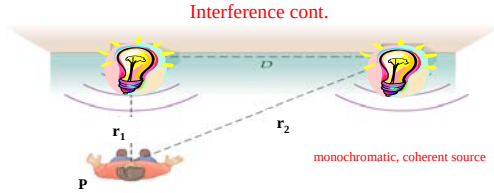
•Waves are one or n wavelengths out of phase: Constructive interference



•Waves are 1/2 or n + 1/2 wavelengths out of phase: Destructive interference



Interference cont.



monochromatic, coherent source

Constructive interference at point P where the waves meet if their phase difference = mλ.

Number of waves lenghts in r_1 distance $= \frac{r_1}{\lambda}$

Number of waves lenghts in r_2 distance $= \frac{r_2}{\lambda}$

phase differnce $= \frac{r_2}{\lambda} - \frac{r_1}{\lambda} = \frac{r_2 - r_1}{\lambda}$

constructive interfence if $\frac{r_2 - r_1}{\lambda} = m$

m = 0, ±1, ± 2...

Destructive interference at point P where the waves meet if their phase difference = (m- ½) λ

Number of waves lenghts in r_1 distance $= \frac{r_1}{\lambda}$

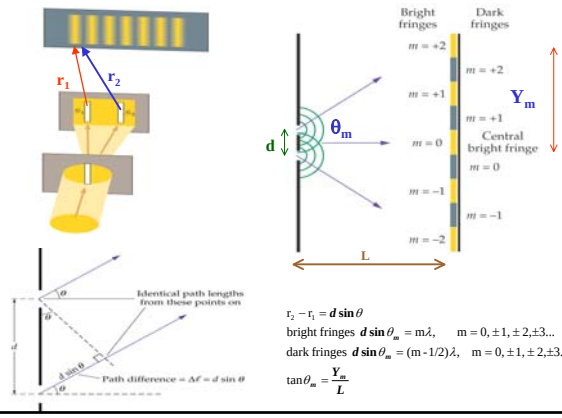
Number of waves lenghts in r_2 distance $= \frac{r_2}{\lambda}$

phase differnce $= \frac{r_2}{\lambda} - \frac{r_1}{\lambda} = \frac{r_2 - r_1}{\lambda}$

destrictive interfence if $\frac{r_2 - r_1}{\lambda} = (m - \frac{1}{2})$

m = 0, ±1, ± 2...

Two slit experiment



$r_2 - r_1 = d\sin\theta$

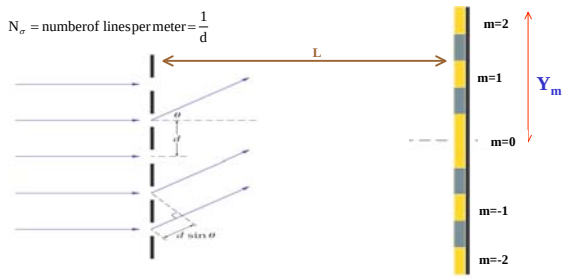
bright fringes $d\sin\theta_m = m\lambda, \quad m = 0, \pm 1, \pm 2, \pm 3...$

dark fringes $d\sin\theta_m = (m - 1/2)\lambda, \quad m = 0, \pm 1, \pm 2, \pm 3...$

$\tan\theta_m = \frac{Y_m}{L}$

Diffraction Gratings

$N_\sigma = \text{numberof lines per meter} = \frac{1}{d}$



constructive interference →

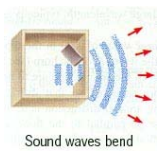
$d\sin\theta_m = m\lambda, \quad m = 0, \pm 1, \pm 2, \pm 3...$

$\frac{1}{N_\sigma}\sin\theta_m = m\lambda, \quad m = 0, \pm 1, \pm 2, \pm 3...$

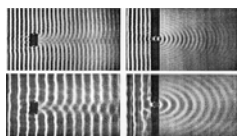
$\tan\theta_m = \frac{Y_m}{L}$

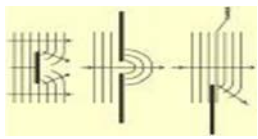
Wave diffraction

- Diffraction is the bending and spreading of waves when they meet an obstruction.
- It can occur with any type of wave, including sound waves, water waves, and electromagnetic waves such as light and radio waves.
- Diffraction also occurs when any group of waves of a finite size is propagating. For example, a narrow beam of light waves from a laser must, because of diffraction of the beam, eventually diverge into a wider beam at a sufficient distance from the laser.



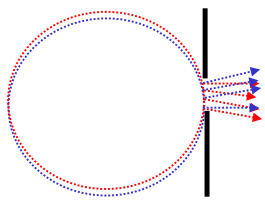
Diffraction Cont.





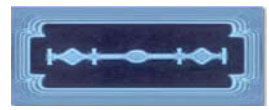
- Huygens–Fresnel principle: The propagation of a wave can be visualized by considering every point on a wave front as a point source for a secondary radial wave.
- The diffraction is then formed by the subsequent propagation and interference of all these radial waves form the new wave front.
- This principle mathematically results from interference of waves along all allowed paths between the source and the detection point , all paths except those that are blocked by the diffracting objects.

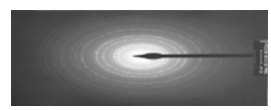
Diffraction of EM waves



•Huygens–Fresnel principle: The propagation of a wave can be visualized by considering every point on a wave front as a point source for a secondary radial wave.

Diffraction Cont.



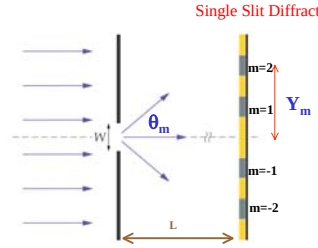


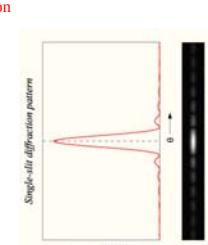
Diffraction Observations

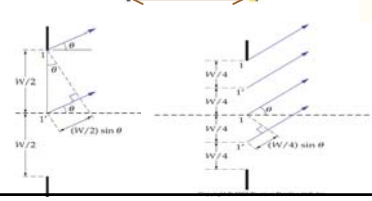
- The angular spacing of the features in the diffraction pattern is inversely proportional to the dimensions of the object causing the diffraction, in other words: the smaller the diffracting object the 'wider' the resulting diffraction pattern and vice versa.
- The diffraction angles are invariant under 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.

http://www.walter-fendt.de/ph14e/doubleslit.htm
http://www.walter-fendt.de/ph14e/singleslit.htm

Single Slit Diffraction





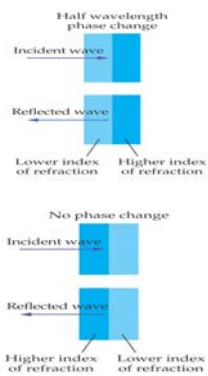


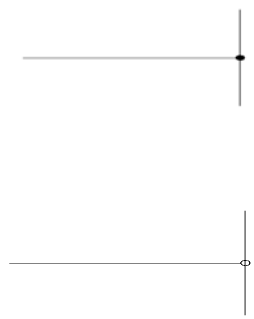
Dark fringes $W \sin\theta_m = m\lambda$

$m = \pm 1, \pm 2, \pm 3 ...$

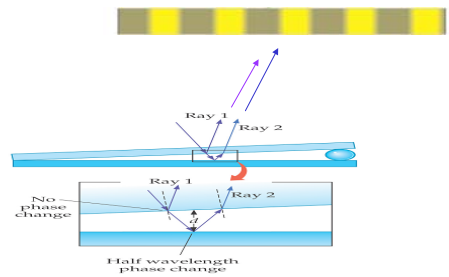
$\tan\theta_m = \frac{Y_m}{L}$

Reflection





Phase changes due to reflection



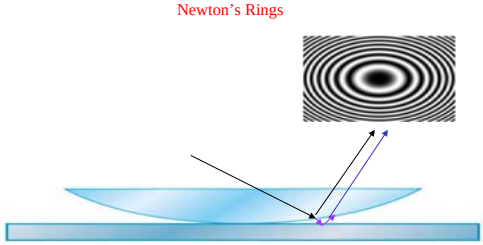
Constructive interference:

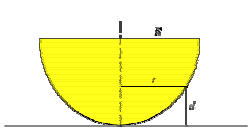
$$\frac{1}{2} + \frac{2d}{\lambda} = m \qquad m = 1, 2, 3, \ldots$$

Destructive interference:

$$\frac{1}{2} + \frac{2d}{\lambda} = m + \frac{1}{2} \qquad m = 0, 1, 2, \ldots$$

Newton's Rings





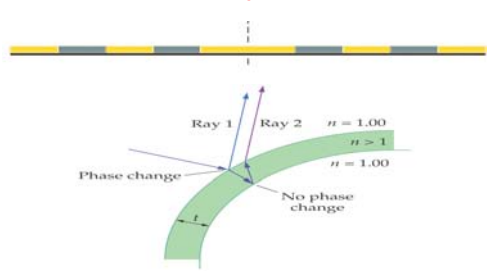
$$r^2 + (d - R)^2 = R^2$$

$$d = R - \sqrt{R^2 + r^2}$$

Distance from center to the m maximum:

$$x_m = \left[\left(m + \frac{1}{2}\right)\lambda R\right]^{1/2}$$

Thin Films



Wavelength of light in a medium of index of refraction n:

$$\lambda_n = \frac{\lambda_{\text{vacuum}}}{n}$$

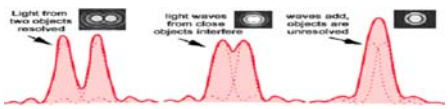
The condition for destructive interference, where t is the thickness of the film, is:

$$\frac{2nt}{\lambda_{\text{vacuum}}} = m \qquad m = 0, 1, 2, \ldots$$

Resolution

Diffraction from two circular objects sources distinguished : resolved

Diffraction from two circular objects Sources undistinguished: unresolved



First dark ring for diffraction pattern of a circular opening

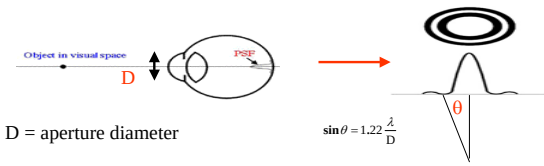
$$\sin\theta = 1.22\frac{\lambda}{D}$$

Raleigh's criterion for resolution

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

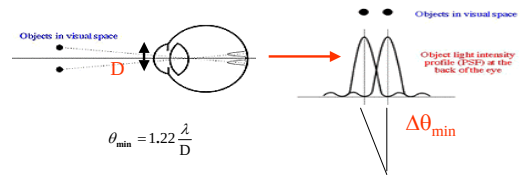
Two objects are resolved if angular separation $\Delta\theta$ is greater that θ_{min}

Resolution Cont



D = aperture diameter

$$\sin\theta = 1.22\frac{\lambda}{D}$$



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