Diffraction

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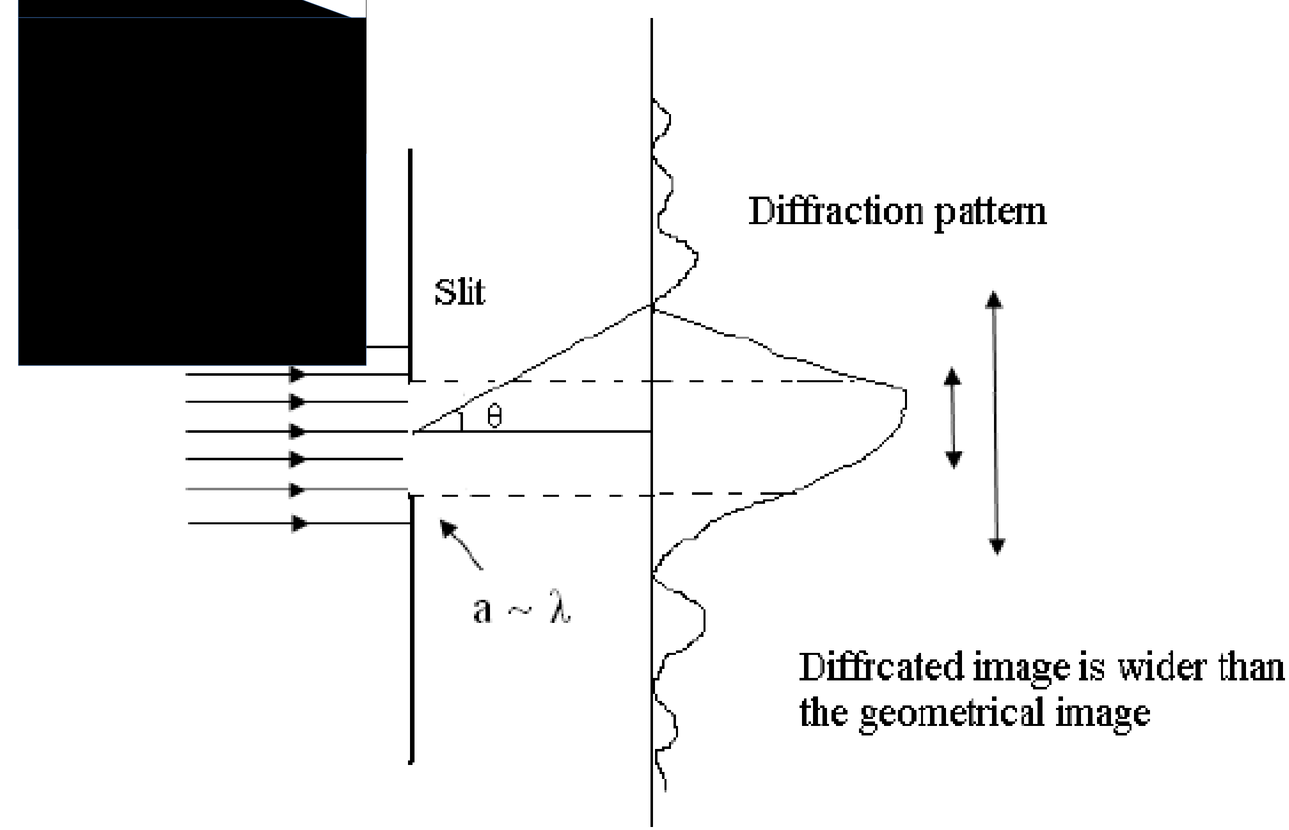
Content

- Diffraction of waves
- Importance of diffraction in Engineering and Technology
- Fraunhofer diffraction at single slit (without derivation, all formulae just to be stated)
- Conditions for maxima and minima
- Diffraction grating, its properties and uses (all without derivations, formulae just to be stated)

Diffraction of waves

"Difractus" --- Latin word--- Break in to pieces



- **Spreading of a wave, when it passes through a narrow opening (slit)**
- **Bending of a wave at the edges of the obstacle**

Defination

When a wave encounter with an obstacle, they bend arround the edges of the obstacle, if the the dimension of the obstacle is comparable with the wavelength of the wave

Bending depend on sizeof the obstacle(d),

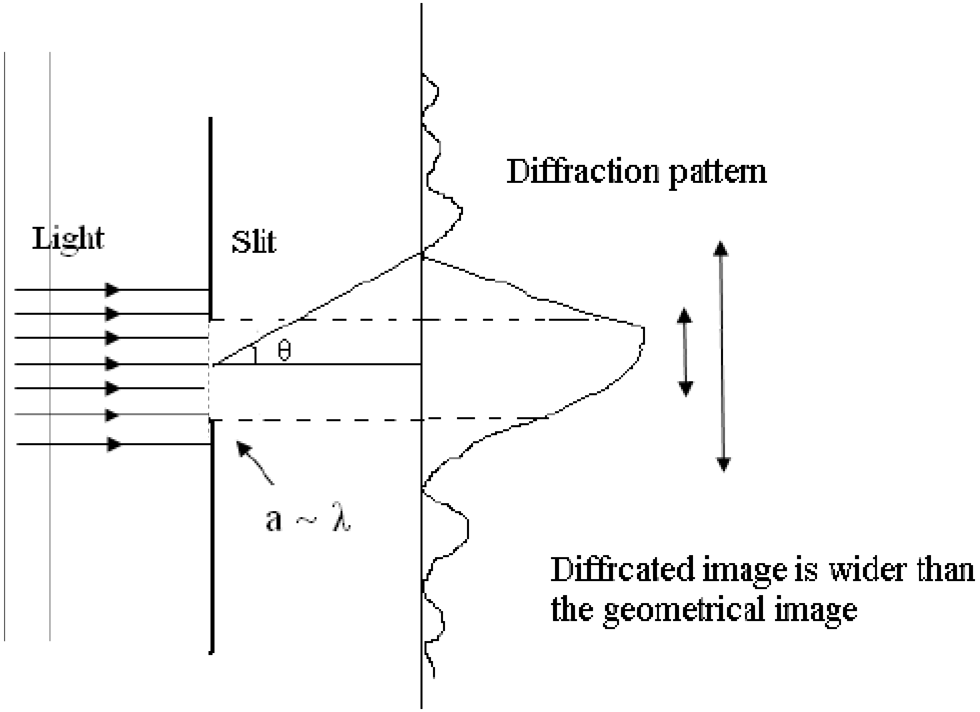
λ--- Wavelength
$d>\lambda$ --- Bending is very less
$d\approx\lambda$ or $d<\lambda$ --- Bending is more

Technical Importance

- **Difraction Grating-Super Prism**
- **Resolution of an optical instruments**
  - **Telescope, Microscope, etc**
- **X-Ray Difractometer- Crystallography**
- **Electron microscopes**

Single Slit Difraction

- **When a wavefront is obstructed by a slit, difraction takes place and a diffraction is produced**



Huygen's Explanation:

- **When a wavefront passes through a slit every point in the slit becomes a source of secondary wavelets**
- **These wavelets generates waves which propogate in all directions**
- **The waves originating from seconadary wavelets, undergo superposition and result in a pattern of maxima and minima called difraction**

I_θ --- Intensity at any point with an angle of diffraction θ,

I_m --- Maximum Intensity at θ=0

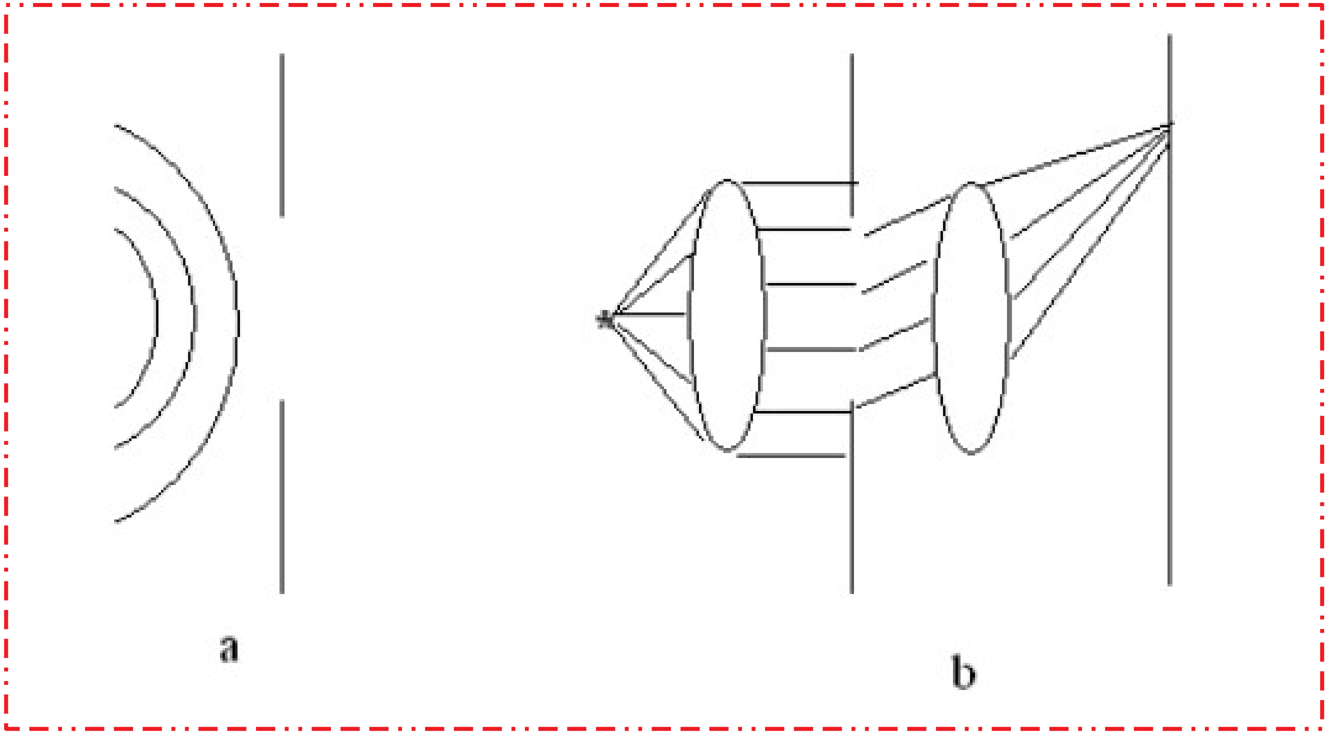
$$I_\theta = I_m \left(\frac{sin\alpha}{\alpha}\right)^2 \qquad \alpha = \pi \frac{a}{\lambda} sin\theta$$

Condition for Maxima and Minima

Type of maxima/minima	Intensity	α	θ
Central maximum,	$I_\theta = I_m$,	$\alpha = 0^o$,	$\theta = 0^o$
Minima,	$I_\theta = 0$,	$\alpha = m\pi$,	$asin\theta = m\lambda$
Secondary maxima	I_θ : very small,	$\alpha = \left(m + \frac{1}{2}\right)\pi$,	$asin\theta = \left(m + \frac{1}{2}\right)\lambda$

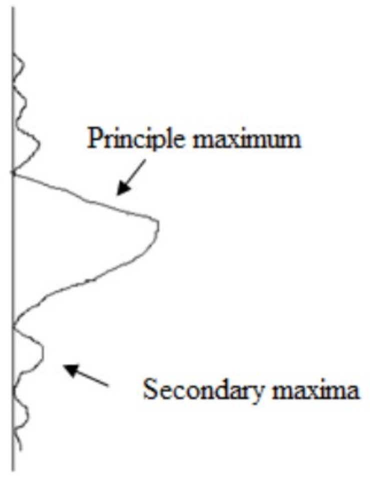
- **Characteristics of Single Slit**
- Results in widening of images
  - If thin wire is placed as obstacle, relatively large shadow of thin wire is formed, so that thickness of the thin wire can be easily measured
- Difraction depends on wavelength of the wave and size of obstacle
  - Bigger the telescope better it is
  - Resolving Power of electron microscope is incredibly higher than optical microscope
- $\Theta \; \alpha \; \lambda$
  - Separates diffrent colored light
  - Can be used as dispersive device (dipersive power is too small)
  - It may produce the spectrum of light but the intensity is too low

Fresnel and Fraunhofer diffraction

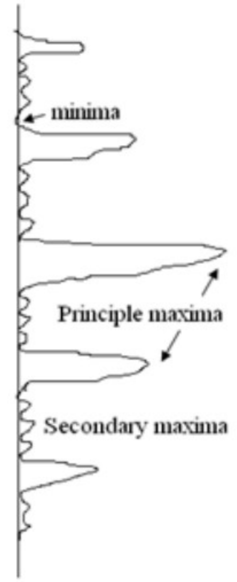


Multiple Slits

- It is used to overcome demerits of single slit
- Due to this
  - Maxima becomes more sharp and bright
  - Several secondary maxima are introduced between the consecutivemaxima
  - In a system of N slits, at (N-1) minima and at (N-2) Secondary maxima were formed



Single Slit Diffraction Pattern

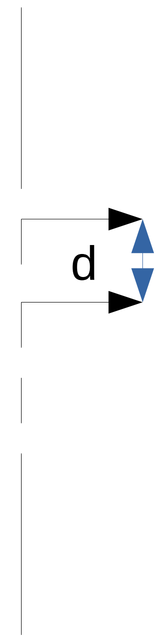


Multiple Slit Diffraction Pattern

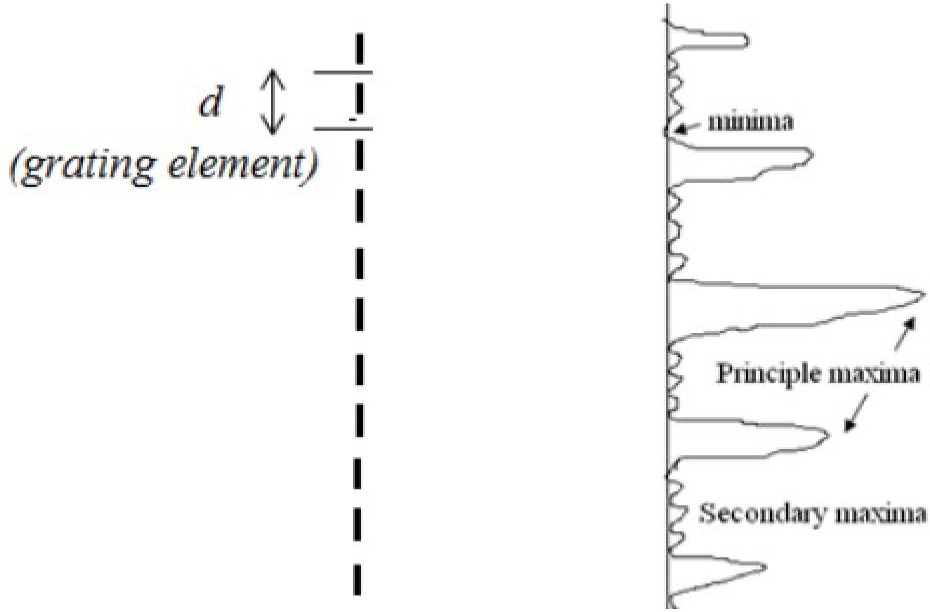
I_θ --- Intensity at any point with an angle of diffraction θ,

$$I_\theta = I_m \left(\frac{sin\alpha}{\alpha}\right)^2 \left(\frac{sinN\beta}{sin\beta}\right)^2$$

$$\alpha = \pi\frac{a}{\lambda}sin\theta \qquad \beta = \pi\frac{d}{\lambda}sin\theta$$



a --- width of individual slit
d --- center to center distance between consecutive slits
d = + = *ith f slit* **+** *ith f it i t th sli***t**



Position of Maxima and Minima in Multiple slits

Type of maxima/minima	**Intensity**	$\boldsymbol{\beta}$	$\boldsymbol{\theta}$
Principle maxima	$I_\theta = N^2 I_m \left(\frac{sin\alpha}{\alpha}\right)^2$	$\beta = m\pi$	$dsin\theta = m\lambda$
Minima,	$I_\theta = 0$	$N\beta = m'\pi$	$dsin\theta = \frac{m'}{N}\lambda, (m' \neq mN)$

Diffraction Grating

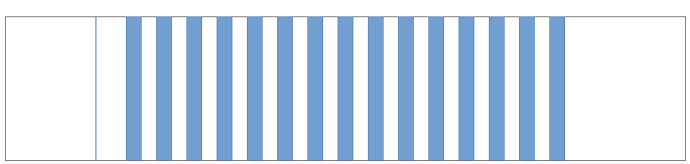
- Mesh ---Super Prism

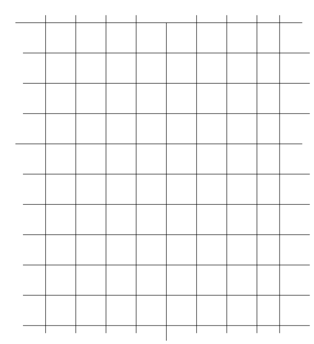
- It is an optical component, which contains large number of evenly spaced parallel slits

- It disperses composite light in to light components by wavelength (color)

- It is made by ruling or grooving a series of closely spaced parallel lines with a diamond point on an optically transparent material

- The Scratched part become opaque
- Unscratched part become transparent, which acts like slit

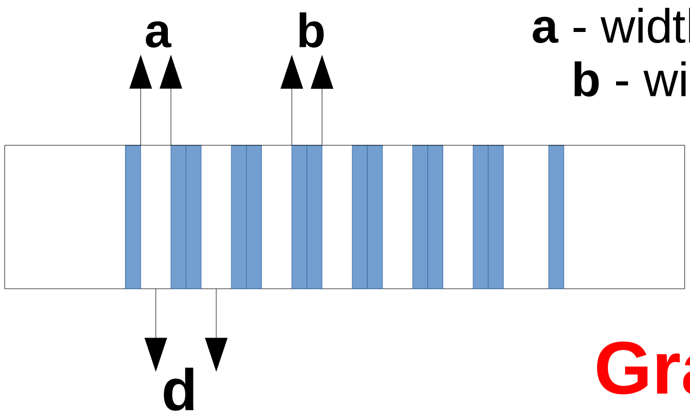




Grating Element (d) tells quality

$$d = 1/N = a+b$$

N - Number of lines per unit length
a - width of the transparent portion
b - width of the opaque portion



Grating Equation

$$d\sin\theta = nN\lambda$$

n=1, 2, 3,4,...
λ- Wavelength
θ- angle of diffraction
θ can not exceeds 90^o , number of orders limited by N

Properties of Diffraction Grating

Dispersive Power

- Ability to produce maximum possible angular separation between two wavelengths

$$Dispersive\ power\ of\ a\ grating = \frac{d\theta}{d\lambda} = \frac{m}{d\cos\theta} \approx mN$$

dθ --- Angular separation for wavelength differing dλ

$d\theta=\theta_1-\theta_2$
$d\lambda=\lambda_1-\lambda_2$

Dispersive Power depends on,

I. **Directly proportional to the number of lines per unitlength of the grating (N)**
II. **Directly proportional to m**
III. **Inversly proportional to cosθ**
IV. **Smaller the grating element larger will be the angular dispersion**

Properties of Diffraction Grating

Resolving Power:

Color Separation at its minimum limit

It's the ability to distinguish the colors when they are extreemely close to each other

It is the ability of the instrument to descriminate wavelength $\lambda+d\lambda$

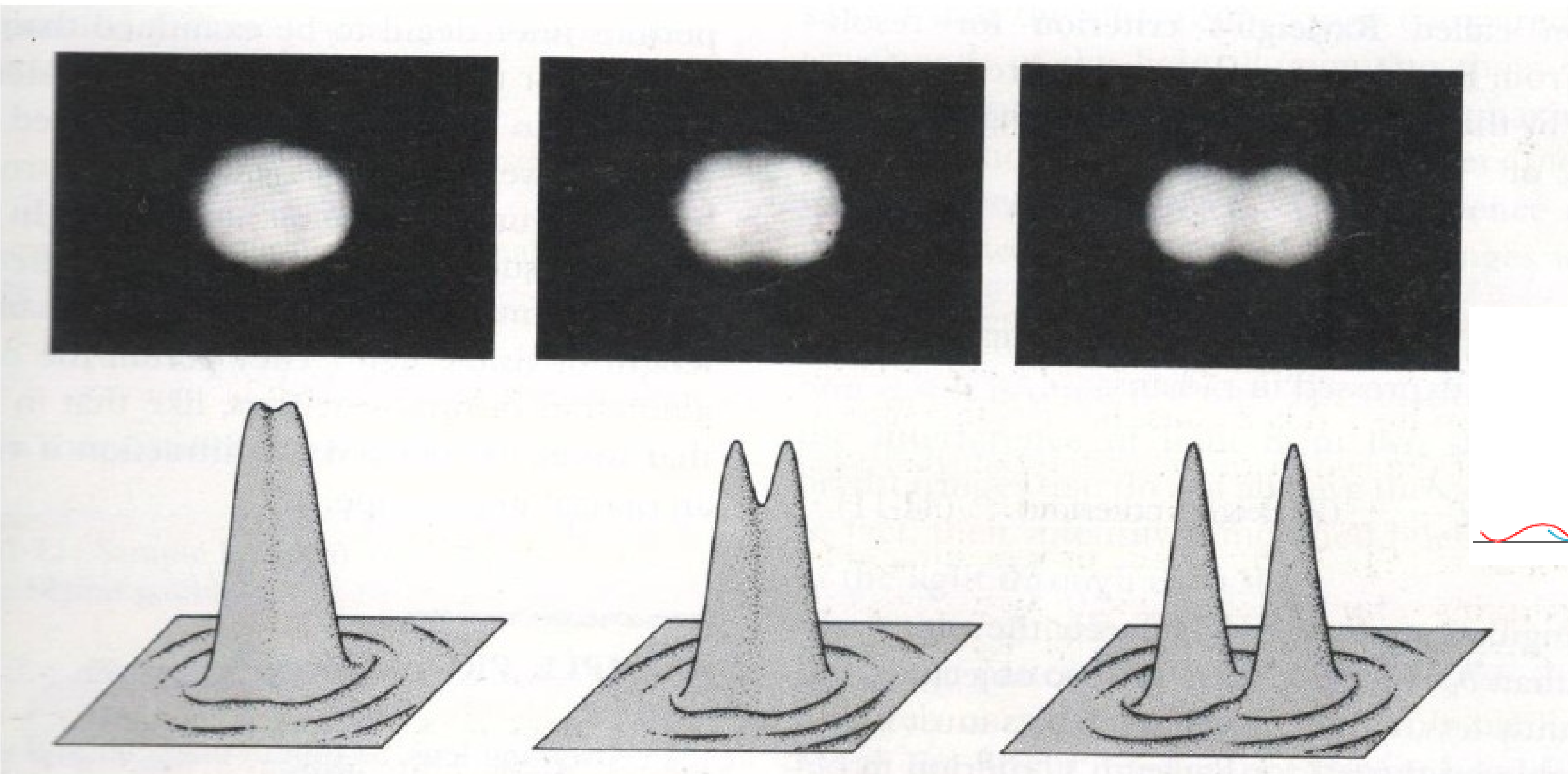
ie $$RP = \lambda/d\lambda$$

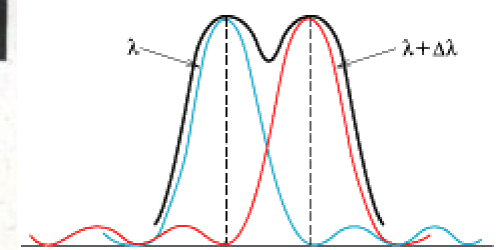
If $d\lambda$ tends to Zero, spectral lines overlap with each other.

By increasing number of lines sharpness and resolution will be increased

Rayleigh Criterian

The wavelengths λ and λ+dλ can be resolved, if the principal maximum corresponding to wavelength λ+dλ falls on the first minimum of the wavelength λ.





By applying Rayleigh's criterion of resolution, it can be shown for telescopes and telescope-like instruments that

$$R.P. = \frac{1}{\theta_R} = \frac{d}{1.22\lambda}$$

APPLICATION

HUMAN EYE, TELESCOPES, MICROSCOPES, CAMERAS ETC.

Bigger telescopes are better

When the size of the obstacle or the ratio widens, the diffraction effect becomes gradually weak and thus the central maximum becomes narrower.

A telescope of large lens is chosen, the diffracted images of the stars will be narrow (owing to weakened).

It may be noted that, the angle subtended by the stars at the telescope (due to extremely large distance between them and the telescope) becomes extremely narrow, the images overlap, but their narrowness allows resolution.

Electron microscopes are better

Electrons, have extremely small (1 to 10 lakh times smaller wavelengths) as compared to light.
Thus electron microscope offers incredible resolution and magnification as compared to optical microscopes.
Electron microscope and its successor, Scanning Tunneling Microscope have made nanotechnology possible

Radars with bigger antennas and multi-antenna radars

based on the fact that a precise control on diffraction effects leads to better resolution

X-RAY DIFFRACTION

References

Concepts of Engineering Physics, Dr. Narendra Mathakari, MITWPU

Physics Principles with Applications, Douglas C. Giancoli

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