Diffraction gratings

B.Tech-I

Introduction

- Diffraction grating can be understood as an optical unit that separates polychromatic light into constant monochromatic composition.
- Uses are tabulated below

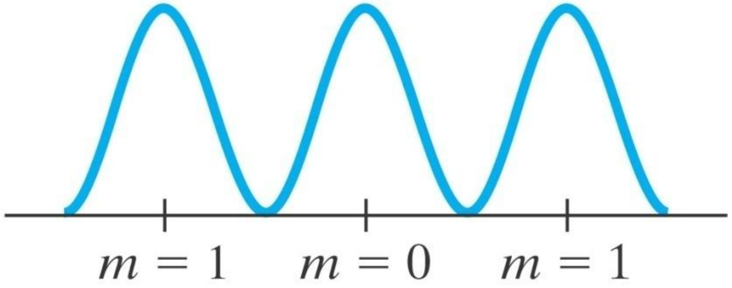
FIELD	**USE**
Quantum Mechanics	Verification of Hydrogen spectrum
Astrophysics	Composition and processes in stars and planetary atmospheres
chemistry	Concentration of chemical species in samples
Telecommunications	Increase the capacity of fiber optic networks using WDM

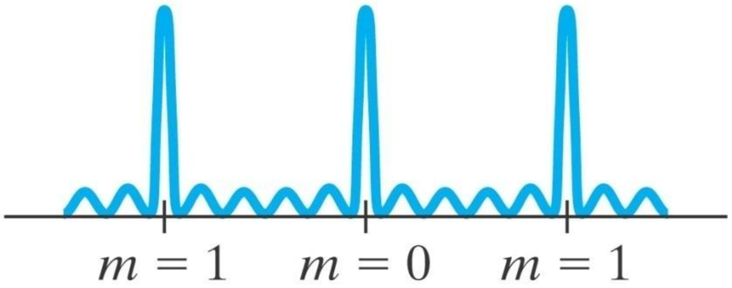
When an Electromagnetic radiation falls on a Diffraction Grating, the electric field and Phase are modified in a predictable manner.

Diffraction Grating

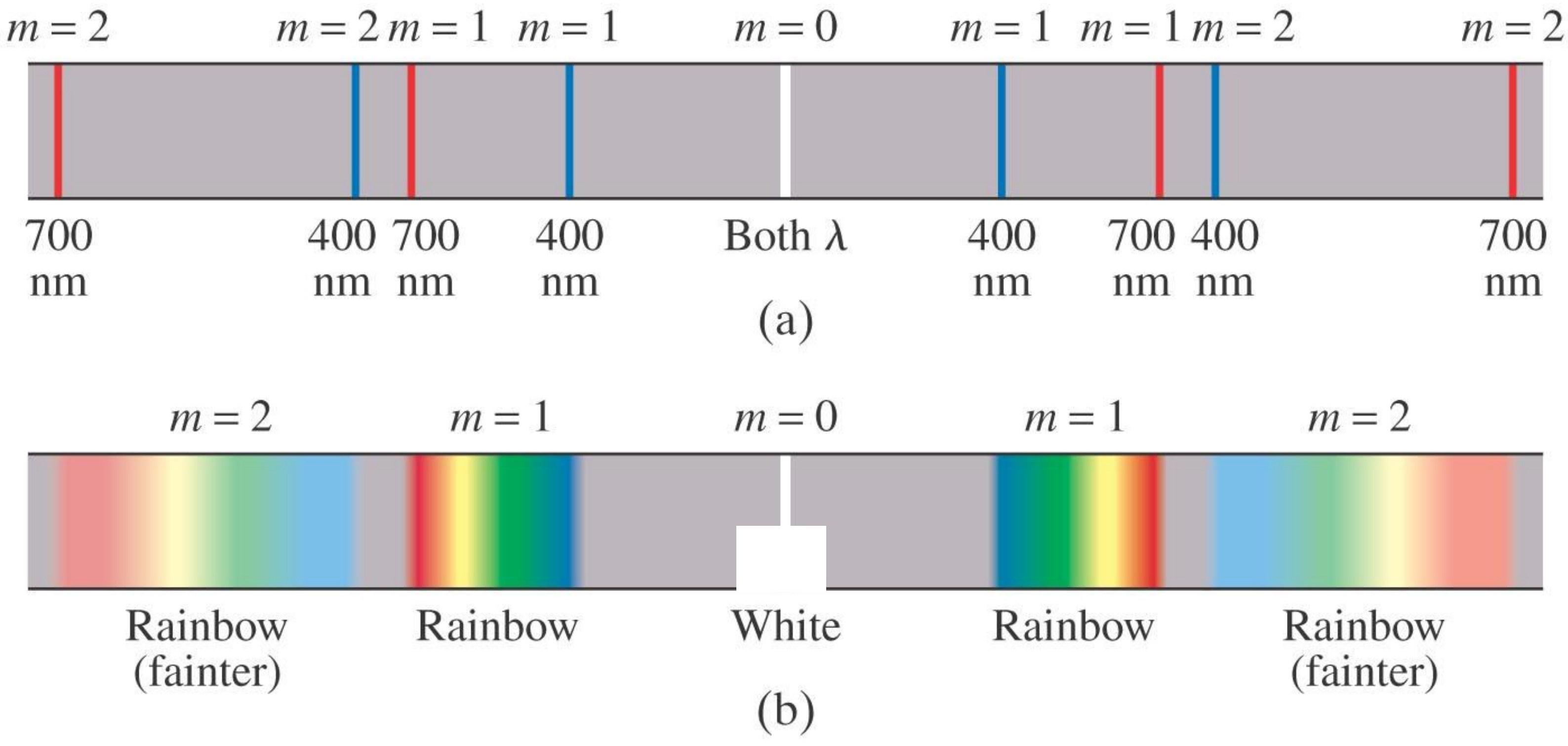
A diffraction grating consists of a large number of equally spaced narrow slits or lines. A transmission grating has slits, while a reflection grating has lines that reflect light.

The more lines or slits there are, the narrower the peaks.





Diffraction Grating



Diffraction Grating

The maxima of the diffraction pattern are defined by

$$d \sin\theta = m\lambda, \qquad m = 0, 1, 2, \ldots$$

d **is the grating width between slits.** ***m*** **denotes the principal maxima.**

Diffraction Grating

Diffraction grating: lines.

Determine the angular positions of the first- and second-order maxima for light of wavelength 400 nm and 700 nm incident on a grating containing 10,000 lines/cm.

Diffraction Grating

Spectra overlap.

White light containing wavelengths from 400 nm to 750 nm strikes a grating containing 4000 lines/cm. Show that the blue at λ = 450 nm of the third-order spectrum overlaps the red at 700 nm of the second order.

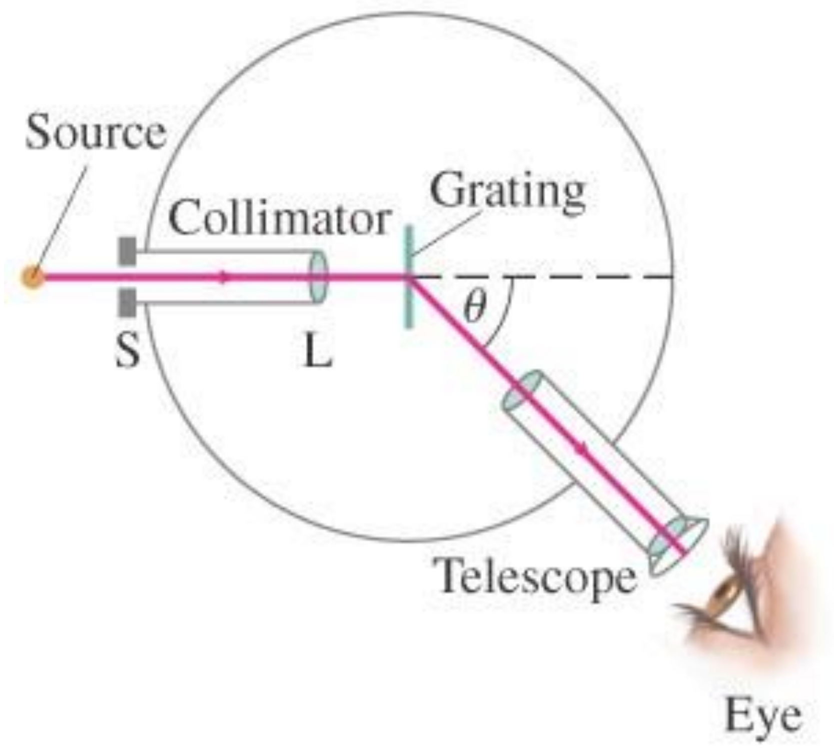
Diffraction Grating

Compact disk.

When you look at the surface of a music CD, you see the colors of a rainbow. (a) Estimate the distance between the curved lines (to be read by the laser). (b) Estimate the distance between lines, noting that a CD contains at most 80 min of music, that it rotates at speeds from 200 to 500 rev/min, and that 2/3 of its 6-cm radius contains the lines.

The Spectrometer and Spectroscopy

A spectrometer makes accurate measurements of wavelengths using a diffraction grating or prism.



The Spectrometer and Spectroscopy

The wavelength can be determined to high accuracy by measuring the angle at which the light is diffracted:

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

The Spectrometer and Spectroscopy

Atoms and molecules can be identified when they are in a thin gas through their characteristic emission lines.

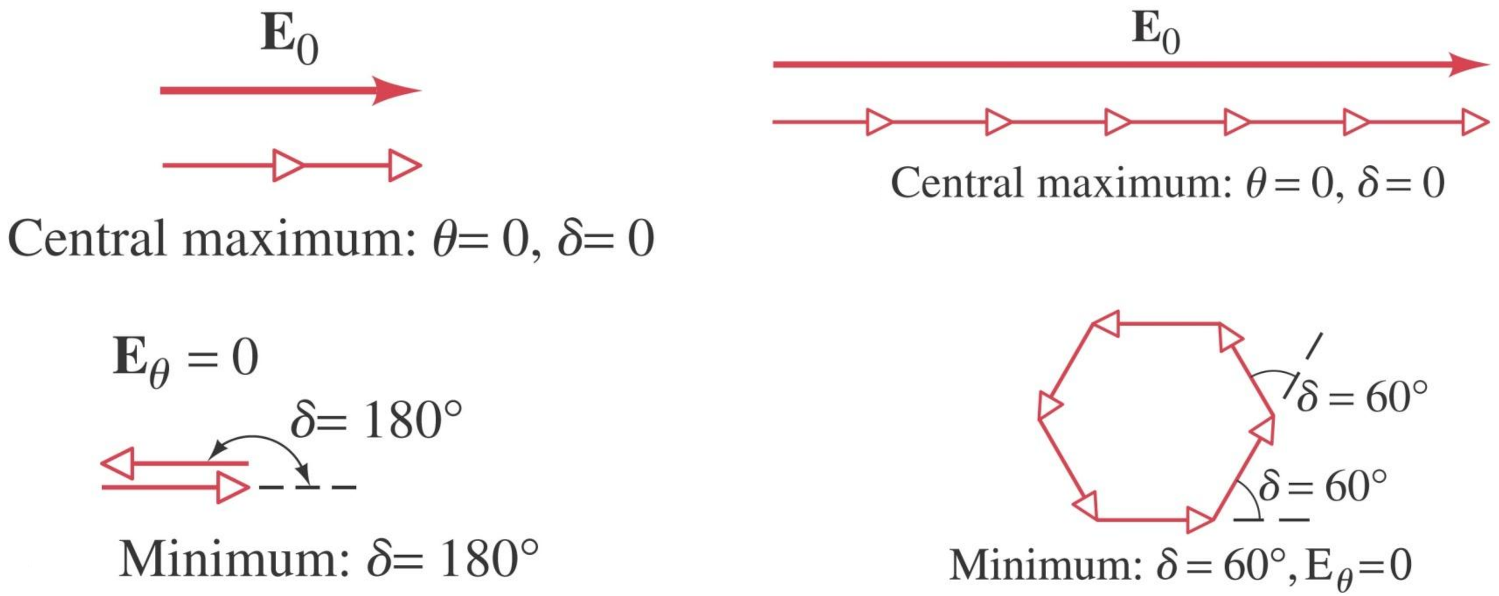
The Spectrometer and Spectroscopy

Hydrogen spectrum.

Light emitted by hot hydrogen gas is observed with a spectroscope using a diffraction grating having 1.00 x 10^4 lines/cm. The spectral lines nearest to the center (0°) are a violet line at 24.2°, a blue line at 25.7°, a blue-green line at 29.1°, and a red line at 41.0° from the center. What are the wavelengths of these spectral lines of hydrogen?

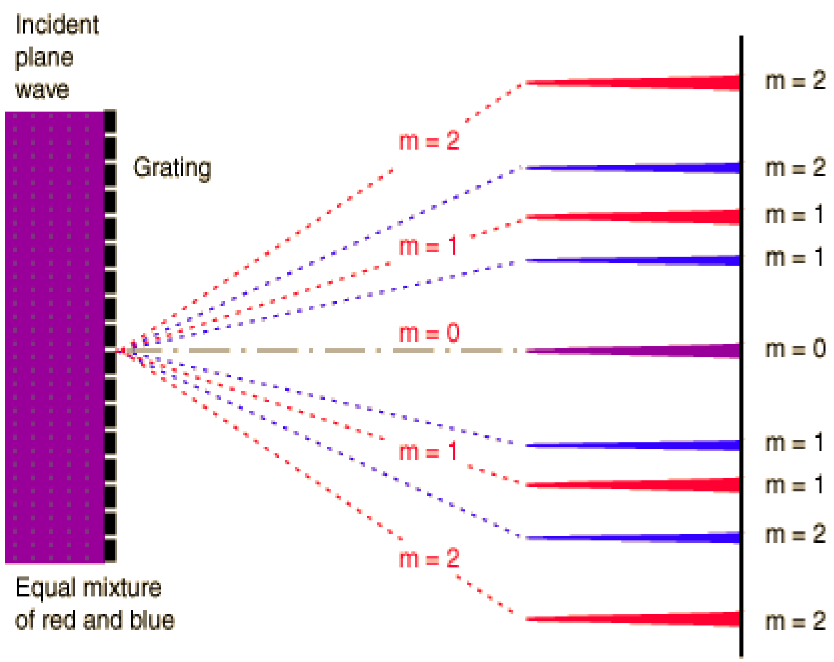
Peak Widths and Resolving Power

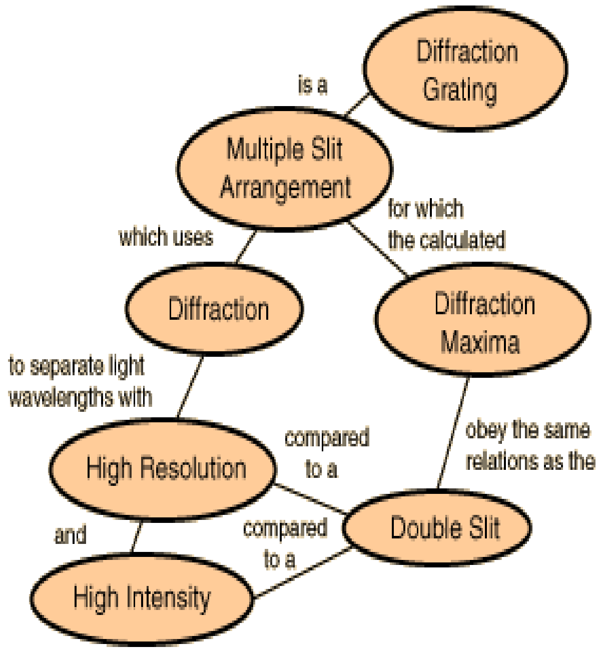
These two sets of diagrams show the phasor relationships at the central maximum and at the first minimum for gratings of two and six slits.



Physicist view of Diffraction grating

A Multi-slit arrangement which uses diffraction to separate light wavelengths with high resolution and high intensity. The resolving power is achieved by interference of light.

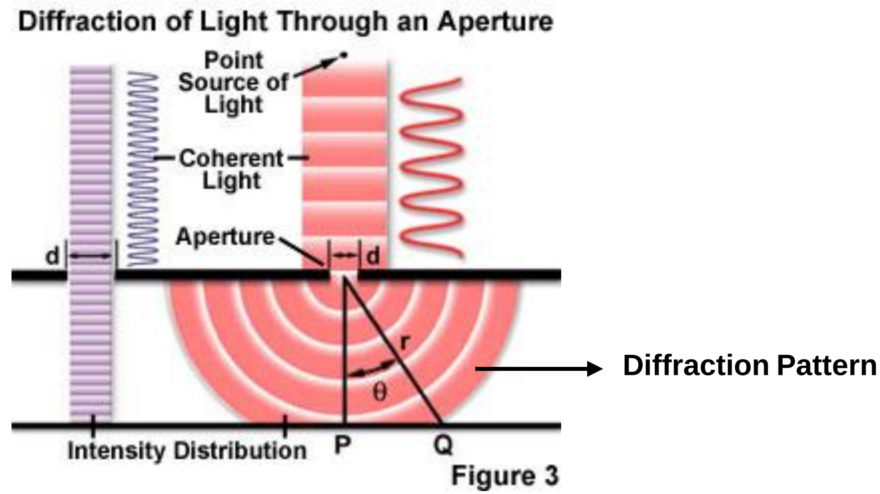


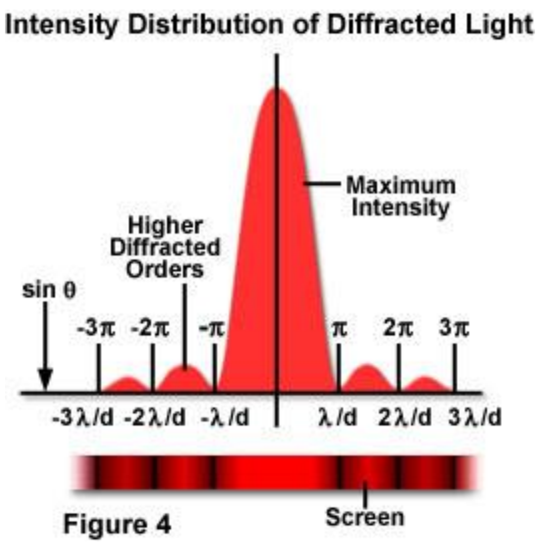


Basics of diffraction

- Single slit interference

P– 1st maximum
Q– 1st secondary maximum
$\theta = n\lambda/d$





Intensity of the beam is governed by

$$I = I_0 \{ \sin\beta / \beta \}^2$$

Where $\beta = (\pi / \lambda)\, d \sin\theta$

Two Slit Interference :

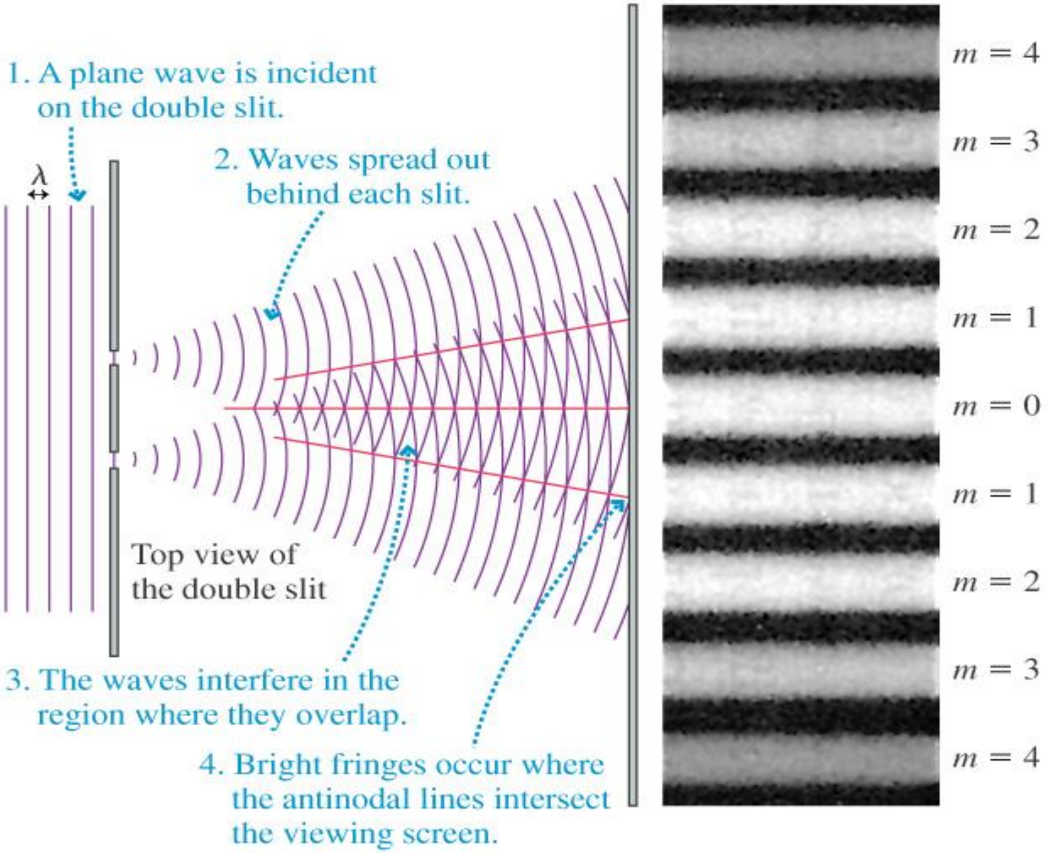
Slit width b

Distance between the slits d

$$I = I_0 \{ \sin \beta / \beta \}^2 \cos^2 \mu$$

Where $\beta = (\pi/\lambda).b \sin \theta$

$\mu = (\pi/\lambda).d \sin \theta$



Intensity distribution is similar to single slit and the spacing between the fringes is determined by (λ/d) and width of the envelop by λ/b.

Multiple slit interference

- A N-slits interference pattern is the diffraction pattern and we develop diffraction gratings based on N-slit interference pattern.
- Intensity transmission function is

$$I = I_0 \{ \sin\beta / \beta \}^2 \{(\sin N\mu)/ (N \sin\mu) \}^2$$

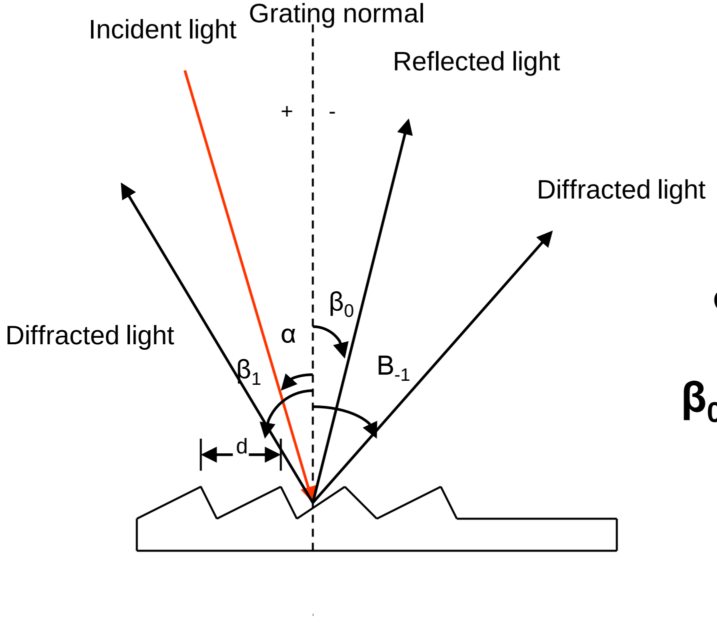
$$\text{Where } \beta = (\pi/\lambda).b \sin\theta$$

$$\mu = (\pi/\lambda).d \sin\theta$$

- Principle fringes occur at $\mu = n\pi \Rightarrow n\lambda = d \sin\theta$
- Secondary fringes occur at $\mu = 3\pi/2N, 5\pi/2N, \ldots$

Physics of diffraction

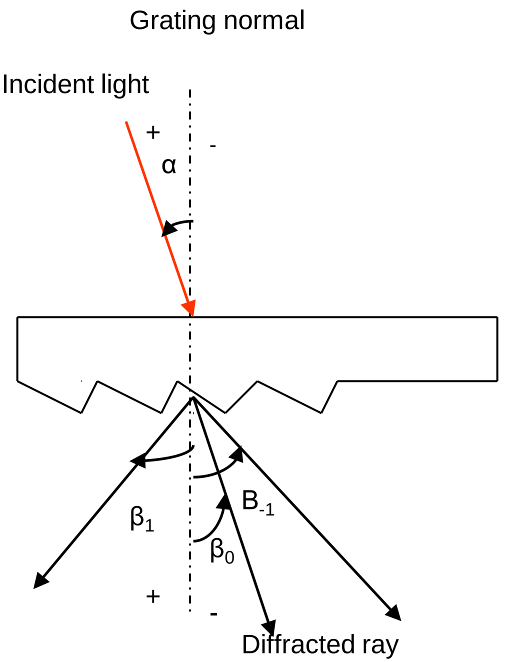
- Ray Propagation through the grating



A Reflection grating

$\alpha > 0, \beta_1 > 0$

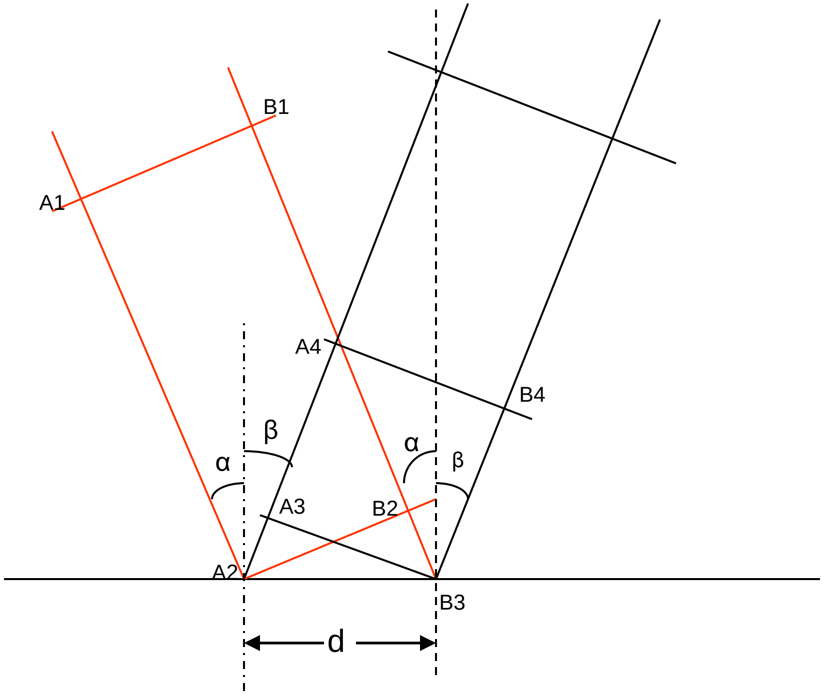
$\beta_0 < 0, \beta_{-1} < 0$



A transmission grating

Light diffracted in the same direction of the incident ray ➔ +ve angle

- Wave front propagation through the grating



Path difference = A2A3 ~ B2B3 = d sinα + d sin β

Classical diffraction:

Grating equation: $m\lambda = d(\sin\alpha + \sin\beta)$

➔ $Gm\lambda = \sin\alpha + \sin\beta$

➔ $Gm\lambda = 2\cos K \sin Ø$

G – groove frequency = 1/d

λ – wavelength of the diffracted light

K – deviation angle = ½(α-β)

Ø – scan angle = ½(α+β)

Littrow configuration : α=β

➔ $m\lambda = 2d\sin\alpha$

Conical diffraction:

$Gm\lambda = \cos\varepsilon (\sin\alpha + \sin\beta)$

ε – angle between the incident light path and the plane perpendicular to the grooves.

Characteristics of Diffraction Grating

- Dispersion:
  - angular dispersion
  - linear dispersion
- Resolving power
- Spectral resolution
- Band pass
- Focal length and f-number
- Anamorphic magnification
- Free spectral range
- Energy distribution
- Scattered and stray light
  - scattered light
  - instrumental stray light
- Signal to noise ratio.

DISPERSION

- **Angular Dispersion** is the measure of the separation between diffracted light of different wavelengths. It gives the spectral range per unit angle.

  Mathematically,

  $$D = \partial\beta/\partial\lambda = G.m.\sec\beta$$

  $$= (2/\lambda)\tan\beta \qquad \text{--- Littrow condition}$$

- **Linear dispersion** is the product of angular dispersion D and effective focal length r'(β)

  linear dispersion (l) = r'D = r'.G.m.secβ

  Platefactor is change in wavelength when we move along the spectrum and is given by P = 1/l = dcosβ / r'm

  Obliquity factor is the factor that governs the platefactor when the incident ray is not perpendicular to the grooves and is = 1/sinØ

RESOLVING POWER

- This is the ability to separate adjacent spectral lines of average wavelength λ. Mathematically,

$R = \lambda/\Delta\lambda$ $\Delta\lambda$ -- limit of resolution, difference in wavelength of equal intensity

Theoretically, it is the product of diffraction order and the total number of grooves illuminated.

$$R = N.d.(\sin\alpha + \sin\beta)/\lambda \Rightarrow R_{max} = 2n.d/\lambda$$

SPECTRAL RESOLUTION:

- $\Delta\lambda$ is the spectral resolution and is measured by convoluting the image of the entrance aperture with the exit aperture.