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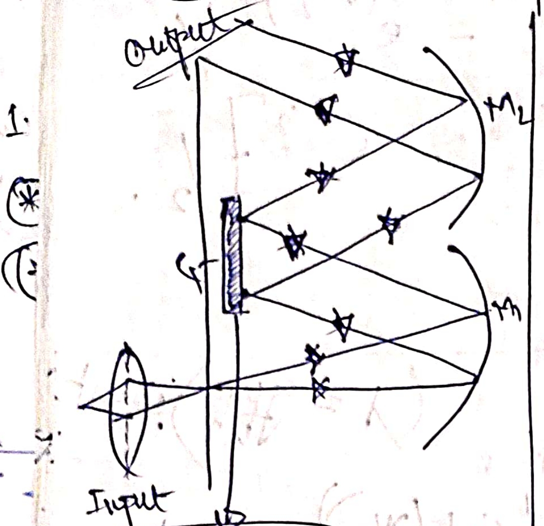
Laser

27/1/25.

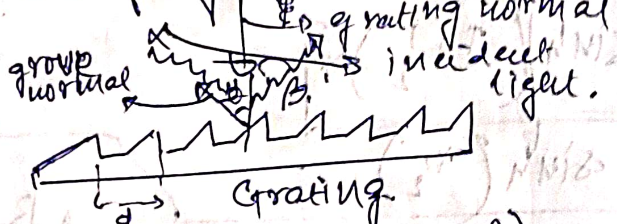


Grating Spectrometer.

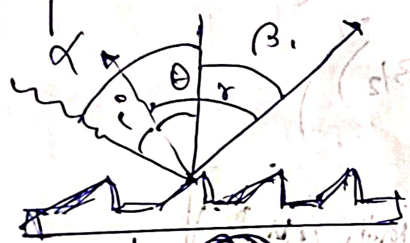
Modern spectrometer.

Reflection grating is happening.

# of grooves: 100/mm.



Path $\Delta = d(\sin\alpha \pm \sin\beta) = m\lambda$



Maximum reflection

Specular reflection.

$i = r$.

$\alpha - \theta = \beta + \theta$.

$2\theta = \alpha - \beta$.

$\theta = \left(\frac{\alpha - \beta}{2}\right)$

Blaze angle

G

grating property

related to λ

উল্টো দিকে (-ve)

SAME side একই (+ve)

Intensity Distribution.

$$I = RI_0 \cdot \frac{\sin^2 \frac{N\phi}{2}}{\sin^2 \phi/2} \quad \Big\} \quad \phi = \frac{2\pi}{\lambda} d(\sin\alpha \pm \sin\beta).$$

Maximum condition: $\phi = 2m\pi$. $\left(\lim \frac{0}{0}\right)$. $\frac{\left(\frac{N\phi}{2}\right)^2}{(\phi/2)}$

$\approx I = RI_0 N^2$

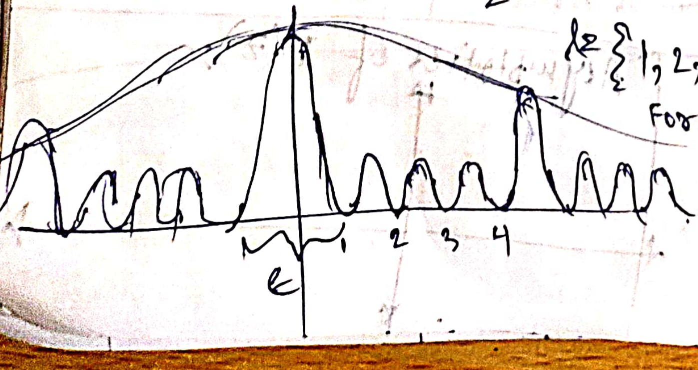
Minimum condition: $\frac{N\phi}{2} = l\pi$

$l = \{1, 2, 3 \ldots N-1\}$

For $N = 5$.

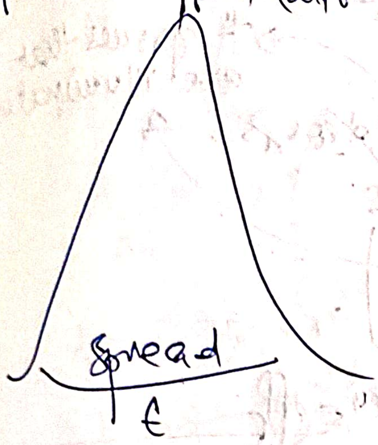
# of minima = 4.

1, 2, 3, 4



$\beta \Rightarrow$ Diffraction $\angle\beta$.

β_m (diff $\angle$)



$\sin(\beta_m + \epsilon) = \sin\beta_m \cos\epsilon + \cos\beta_m \sin\epsilon.$

~~$= \beta_m \cos\epsilon + \sin\epsilon$ for small~~

$= \epsilon\cos\beta_m + \sin\beta_m$

$\phi = \frac{2\pi}{\lambda} d\left[\sin\alpha + \sin\beta_m + \epsilon\cos\beta_m\right].$

$I = I_0 R_0 \frac{\sin^2 \frac{N\phi}{2}}{\sin^2 \phi/2}$

for max $= \phi = 2m\pi + \frac{2\pi}{\lambda} d\,\epsilon\cos\beta_m$

$= 2m\pi + \delta$

$\boxed{\delta = \frac{2\pi d}{\lambda}\epsilon\cos\beta_m.}$

For max: $(N\phi/2)$

$I = I_0 R_0 N^2 \frac{\sin^2 \frac{N\delta}{2}}{\left(\frac{N\delta}{2}\right)^2}$

$\frac{N\delta}{2} = \pi.$

Total reflected power from grating.

Depends on reflectivity only.

$\epsilon = \frac{\lambda}{Nd\cos\beta_m}$

$\frac{N\pi}{\lambda} d\epsilon\cos\beta_m = \pi.$

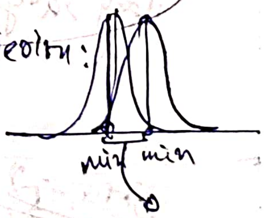
$\epsilon = \frac{\lambda}{Nd\cos\beta_m}$

For large N, per group power dist more & less each one gets.

But total power is invariant of N

Power of resolution:

Rayleigh's criterion:

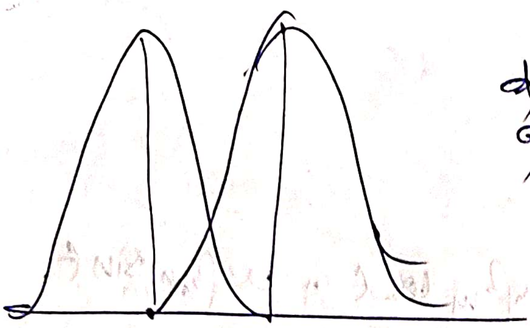


Resolution / Resolving power.

$d(\sin\alpha + \sin\beta) = m\lambda.$

Angular dispersion: $\frac{d}{d\lambda}\beta \Rightarrow \left(d\cos\beta \frac{d\beta}{d\lambda}\right) = m.$

$\frac{d\beta}{d\lambda} = \frac{m}{d\cos\beta}.$



$$\frac{d\beta}{d\lambda}\Delta\lambda = \frac{\lambda}{Nd\cos\beta}$$

→ # grooves that are illuminated

$$\frac{\lambda}{\Delta\lambda} = \frac{m\,Nd\cos\beta}{d\cos\beta}$$

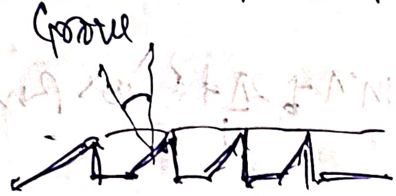
$$\boxed{\frac{\lambda}{\Delta\lambda} = mN}$$

Intensity – Resolution tradeoff

Grating Spectrometer.

Types of grating:

0.8 | 1 | 0.5



Δ path

$d(\sin\alpha \pm \sin\beta) = m\lambda$.

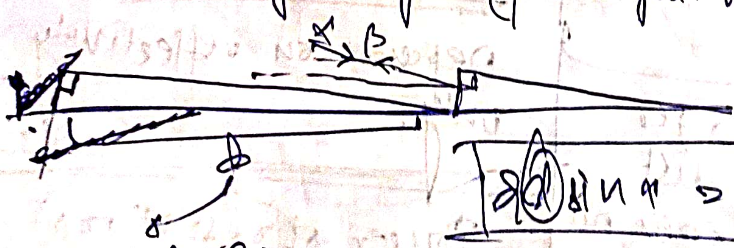
1. Littrow grating [design]. → Not isolated occurrence

$\alpha = \beta$.

$\therefore 2d\sin\alpha = m\lambda$.

[wavelength selective grating].

2. Echelle grating: (for higher order 'm').



$$\boxed{2d\sin\alpha = m\lambda.}$$

$\alpha = 90 - \theta$.

$$\boxed{2d\cos\theta = m\lambda}$$

~~Doubt~~

(Ex) Grating size : $10 \times 10\ cm^2$.
$\# N = 10^3$ grooves/mm.
m(order) = 2.

$\frac{\lambda}{\Delta\lambda} = 2 \times 10^5$

$\lambda = 500$ nm.

$\Delta\lambda = \cancel{2.5 \times 10}$
2.5×10^{-3} nm.

$\cancel{0.5 \times 10^{-8} \times 10}$

Littrow grating

$\Delta\lambda = \left(\frac{\lambda}{a} + \frac{b}{f}\right)\left(\frac{d\theta}{d\lambda}\right)^{-1}$.

$\lambda = 500$ nm.
$\beta = \alpha = 30^\circ$
f = 1 m
b = 50 μm
m = 2, $d = 10^{-3}$ mm

$\frac{d\beta}{d\lambda}$ → corresponds to δ (deviation) as diffraction deviation.

$\frac{d\beta}{d\lambda} = \frac{m}{d\cos\beta} = \frac{2d\sin\beta}{d\cos\beta\,\lambda}$

$= \frac{2\tan\beta}{\lambda}$

$= \frac{2}{\sqrt{3}}$

$\frac{500 \times 10^{-9}}{10^{-3}}$ m.

$\cancel{50 \times 10^{-6}}$

$$\left[\frac{500 \times 10^{-9}}{10^{-3}} + 50 \times 10^{-6}\right]\left(\frac{2}{\sqrt{3} \times 500 \times 10^{-9}}\right)^{-1}$$

$$\cancel{\frac{550 \times 500\sqrt{3} \times 10}{2}} = 238156.98 \times 10^{-56} \times 10$$
$= 0.23$.

$$\left(550 \times 10^{-6}\right)\left[\frac{2}{\sqrt{3} \times 500 \times 10^{-9}}\right]^{-1}$$

$$= \frac{550 \times 500 \times \sqrt{3} \times 10^{-6}}{2} \text{ nm}$$

$= 238{,}156.98 \times 10^{-7}$

$\Delta\lambda = \cancel{0.0228\ nm} \rightarrow \boxed{0.0238\ nm}$

Angular dispersion

focal length = 1000 mm.

$\frac{dx}{d\lambda} = f\frac{d\beta}{d\lambda}$

$\frac{dx}{d\lambda} = \frac{f\,2\tan\beta}{\lambda}$

$= \frac{2f\tan\beta}{\lambda}$.

$\frac{dx}{d\lambda} = \frac{2 \times 10^3}{\sqrt{3} \times 500 \times 10^{-6}}$

$= .0023 \times 10^9$

$= 2.31 \times 10^6$

More focal length, less resolution
(f) ($\Delta\lambda$).

$\frac{dx}{d\lambda}$ ⇒ কতটা λ change হবে যদি x 1 unit change হলে।

Detector.

(1) Thermal Detector

- Resistance changes with temperature
- λ insensitive

(2) Photodetector:

- change in bandgap.
- λ sensitive.
- current starts when e^- goes from valence to conduction band.

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Characteristics of Detectors

(1) Spectral response $(R(\lambda))$: (1) spectral range.

(2) Two relative intensity

$$= \frac{I(\lambda_1)}{I(\lambda_2)} = \frac{R(\lambda_1)}{R(\lambda_2)}$$

(2) Sensitivity :

$$\left(\frac{\text{Volt}}{\text{watt}}, \frac{\text{Amp}}{\text{watt}}, \frac{\text{Volt}}{\text{Area} \times \text{irradiance}}\right)$$

(3) Signal to Noise ratio (S/N) :

i. Electronic noise
ii. Thermal noise.

NOISE equivalent of input power → power level for which $S/N = 1$. [NEP].

(4) Time Response : Time dependent measurements

$R_2C << \tau$

$R_2C << \frac{1}{f}$

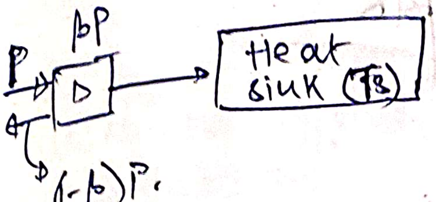
$f >> [R_2C]^{-1}$.

τ : pulse time.

(5) Cost of the Detector :

THERMAL DETECTOR

- (*) Power measurement of cw laser.
- (*) output energy of pulse laser.



H: Heat capacity of detector.

G: Thermal conductance to sink

$$\beta P = H\frac{dT}{dt} + G(T - T_s).$$

$$\frac{(\beta P + G T_s)}{H} = \frac{H}{H}\frac{dT}{dt} + \frac{G}{H}T.$$

$$\frac{dT}{dt} + \left(\frac{G}{H}\right)T = \left(\frac{\beta P + G T_s}{H}\right)$$

$$\ln(IF) = \int \frac{G}{H}\,dt. \quad IF = e^{\frac{Gt}{H}}$$

$$T e^{Gt/H} = \int \left(\frac{\beta P + G T_s}{H}\right) e^{Gt/H}\,dt.$$

$$\left[T e^{Gt/H}\right]_{l=T_s}^{u=T} = \left[\frac{\beta P + G T_s}{\cancel{H}} \cdot \frac{\cancel{H}}{G}\, e^{Gt/H}\right]_{l=T_s}^{u=T}$$

$$u = T. \quad T = T_s + \frac{\beta P + G T_s}{G}\left(1 - e^{-\frac{Gt}{H}}\right).$$

$$\cancel{T/e^{Gt/H}}$$

$$T(t) = b/a + (T_s - b/a)e^{-at}$$

$$T(t) = \frac{\beta P + G T_s}{\cancel{H}} \cdot \frac{\cancel{H}}{G} + \left[T_s - \left(\frac{\beta P + G T_s}{H} \cdot \frac{H}{G}\right)\right]e^{-\frac{Gt}{H}}$$

$$T(t) = \left(\frac{\beta P + G T_s}{G}\right) + \left[T_s - \frac{\beta P + G T_s}{G}\right]e^{-\frac{Gt}{H}}.$$

$$T = T_s + \frac{\beta P + G T_s}{G}\left(1 - e^{-G/H\,t}\right)$$

Response time = G/H.

Rise in temp gives sensitivity.

$$\cancel{H\frac{dT}{dt} + T = \left(\frac{\beta P + G T_s}{G}\right)}.$$

$$P = P_0 (1 + a\cos(\Omega t))$$

$$T = T_s + \Delta T \left[1 + a\cos(\Omega t + \phi)\right]$$

$$\Delta T = \frac{a\beta P}{\sqrt{1 + \frac{\Omega^2 H^2}{G^2}}}$$

$$\tan\phi = \frac{\Omega H}{G}$$

$$\phi = \tan^{-1}\left(\frac{\Omega H}{G}\right)$$

Delete

For continuous laser

$$\int_0^t \beta P \, dT = H \int_0^t dT$$

$$\beta P t = H \Delta T$$

$$\Delta T = \left(\frac{\beta P t}{H}\right)$$

Some examples of Thermal detector

(1) Thermistor.
(2) Bolometer.
(3) Golay cell
(4) Thermo couple detector