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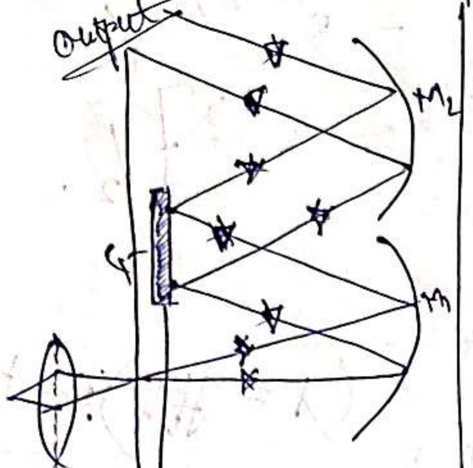
Laser



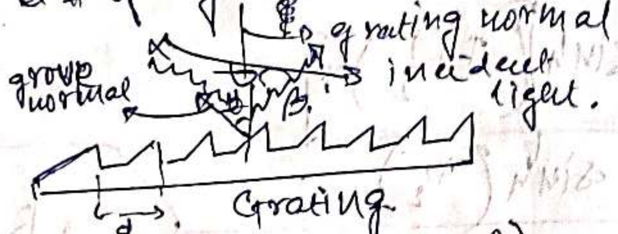
Grating

Spectrometer.

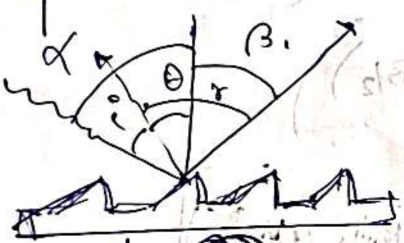
Modern spectrometer.

Reflection grating. is happening.

# of grooves: 100/mm.



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



G

দুই দিকে (-ve)

SAME side একই (+ve)

Grating property

related to λ

Maximum reflection

Specular reflection.

$i = r.$

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

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

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

Blaze angle

Intensity Distribution.

$$I = R I_0 \frac{\sin^2 \frac{N\phi}{2}}{\sin^2 \phi/2} \quad \Big\} \quad \phi = \frac{2\pi}{\lambda} d(\sin\alpha \pm \sin\beta).$$

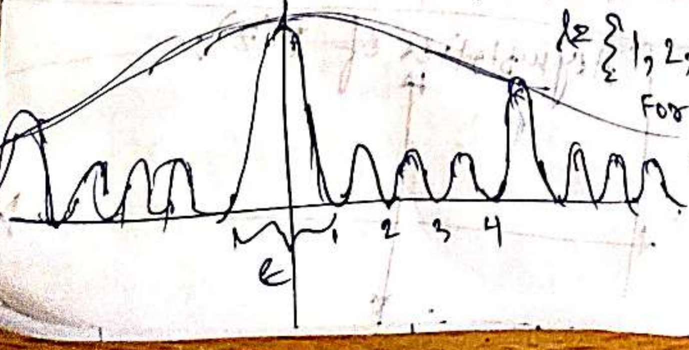
Maximum condition: $\phi = 2m\pi.$ $\left(\lim \frac{0}{0}\right).$

$$\frac{\left(\frac{N\phi}{2}\right)^2}{\left(\frac{\phi}{2}\right)^2} \approx I = R I_0 N^2.$$

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

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

For $N = 5.$

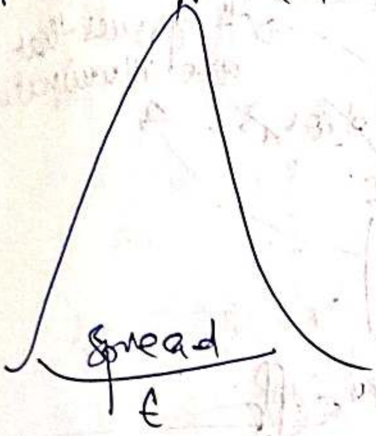


# of minima = 4.

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

$$= 2m\pi + \delta$$

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

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.

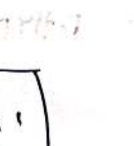
$$\epsilon = \frac{\lambda}{N d \cos\beta_m}$$

$\frac{N 2\pi}{\lambda} d\, \epsilon \cos\beta_m = 2\pi$. $\quad \epsilon = \frac{\lambda}{N d \cos\beta_m}$

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:

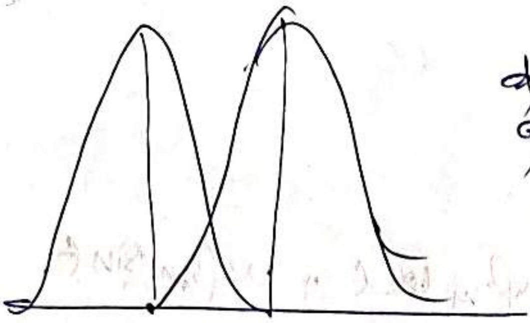


Resolution / Resolving power.

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

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

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



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

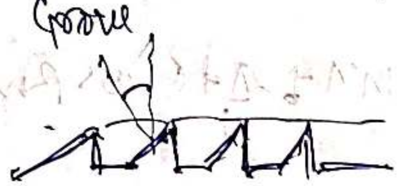
$\frac{\lambda}{\Delta\lambda} = \frac{m N d\cos\beta}{d\cos\beta}$ → # grooves that are illuminated

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

(*) Intensity – Resolution tradeoff

Grating Spectrometer.   0.8 | 1 | 0.5

Types of grating:



Groove

$\underbrace{\Delta\ \text{path}}$

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

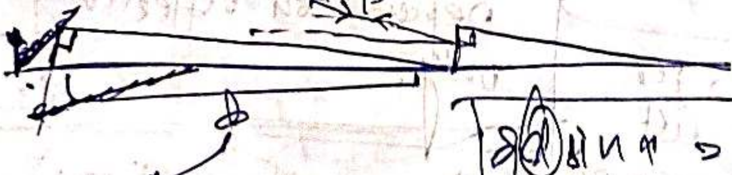
1. Littrow grating [design]. → Not isolated occurrence

$\alpha = \beta$.

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

[wavelength selective grating].

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



very large

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

$\alpha = 90 - \theta$.

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

~~DOUBTS~~

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

$\frac{\lambda}{\Delta\lambda} = 2 \times 10^{6}$.

$\lambda = 500$ nm.

$\Delta\lambda = \cancel{2.5 \times 10^{-8}\ nm}$
2.5×10^{-8} nm.

$\cancel{0.5 \times 10^{-6} \times 10}$

Littrow grating

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

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

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

$$\frac{d\beta}{d\lambda} = \frac{m}{d\cos\beta} = \frac{2\,d\sin\beta}{d\cos\beta\,\lambda} = \frac{2\tan\beta}{\lambda} = 2\left(\frac{2}{\sqrt{3}}\right)$$

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

$$\frac{500 \times 10^{-9}}{10^{-3}}\ m^2.$$

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

$$\cancel{\frac{550 \times 500\sqrt{3} \times 10}{2}} = 238156.98 \times 10^{-6} \times 10 = 0.23.$$

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

$$= \frac{550 \times 500 \times \sqrt{3} \times 10^{-15}}{2}\ nm$$

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

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

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

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

Angular Dispersion

focal length = 1000 mm.

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

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

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

$= .0023 \times 10^{9}$
$= 2.31 \times 10^{6}$

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~~ range.

(2) Two relative intensity

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

(2.) Sensitivity :

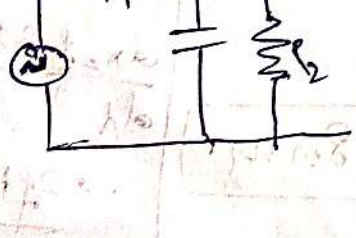
$\left(\frac{\text{Volt}}{\text{watt}}, \frac{\text{Amp}}{\text{watt}}, \frac{\text{Volt}}{\text{Area} \times \text{irradiance}}\right)$

(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



$R_2C \ll \tau$

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

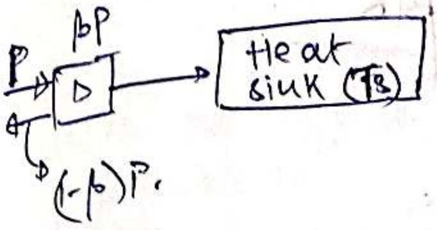
$f \gg [R_2C]^{-1}$

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

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

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

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

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

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

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

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

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

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

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

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

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

Response time = G/H.

Rise in temp gives sensitivity.

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

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

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

$\tan\phi = \dfrac{\Omega H}{G}$.

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

For continuous laser

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

$\beta P t = H \Delta T$

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

Some examples of Thermal detector

(1.) Thermistor.

(2.) Bolometer.

(3.) Golay cell

(4.) Thermo couple detector

Detail P/18