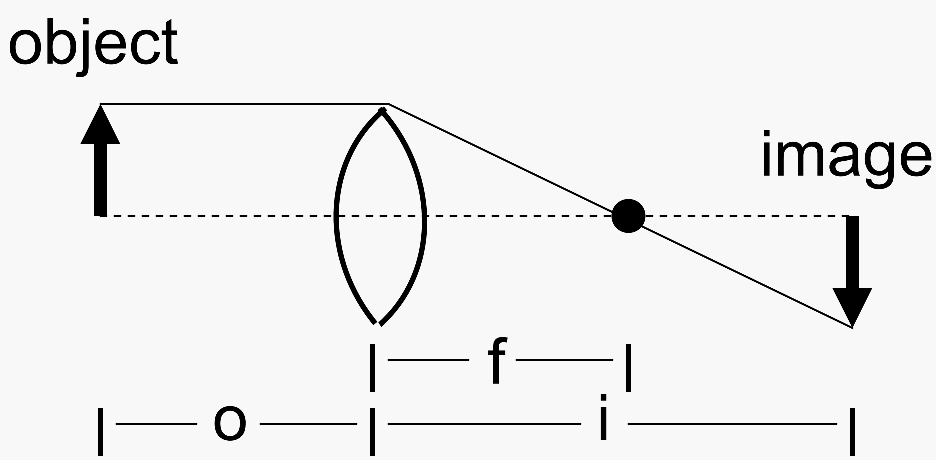
Lenses – lens equation (for a thin lens)

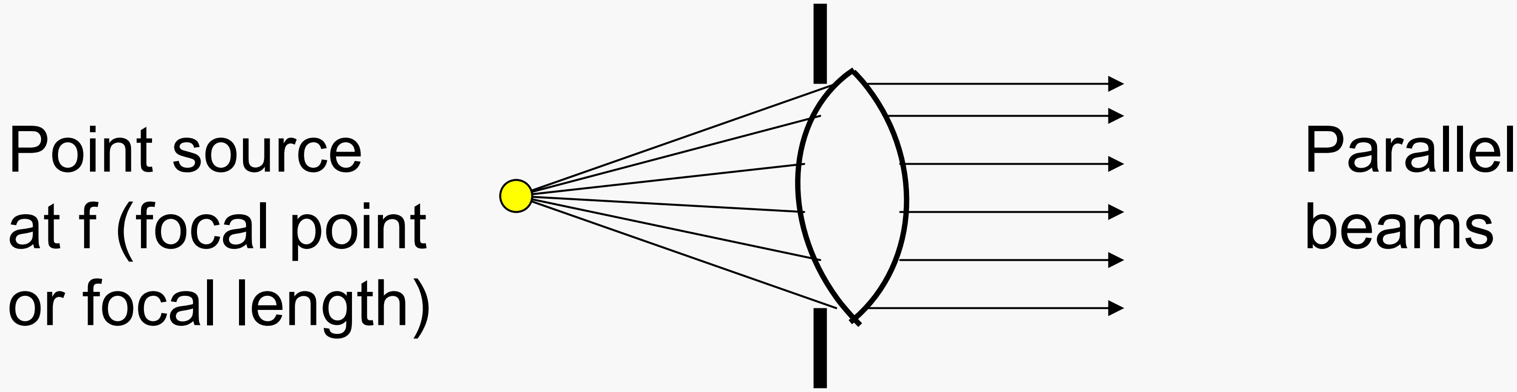
$$\frac{1}{f} = (\eta - \eta') \left(\frac{1}{r_1} - \frac{1}{r_2} \right)$$

Where f = focal length
η = refractive index of lens material
η' = refractive index of adjacent material
r_1 = radius of curvature of first surface
r_2 = radius of curvature of second surface



$$\frac{1}{f} = \frac{1}{i} - \frac{1}{o}$$

i: distance to image
o: distance to object

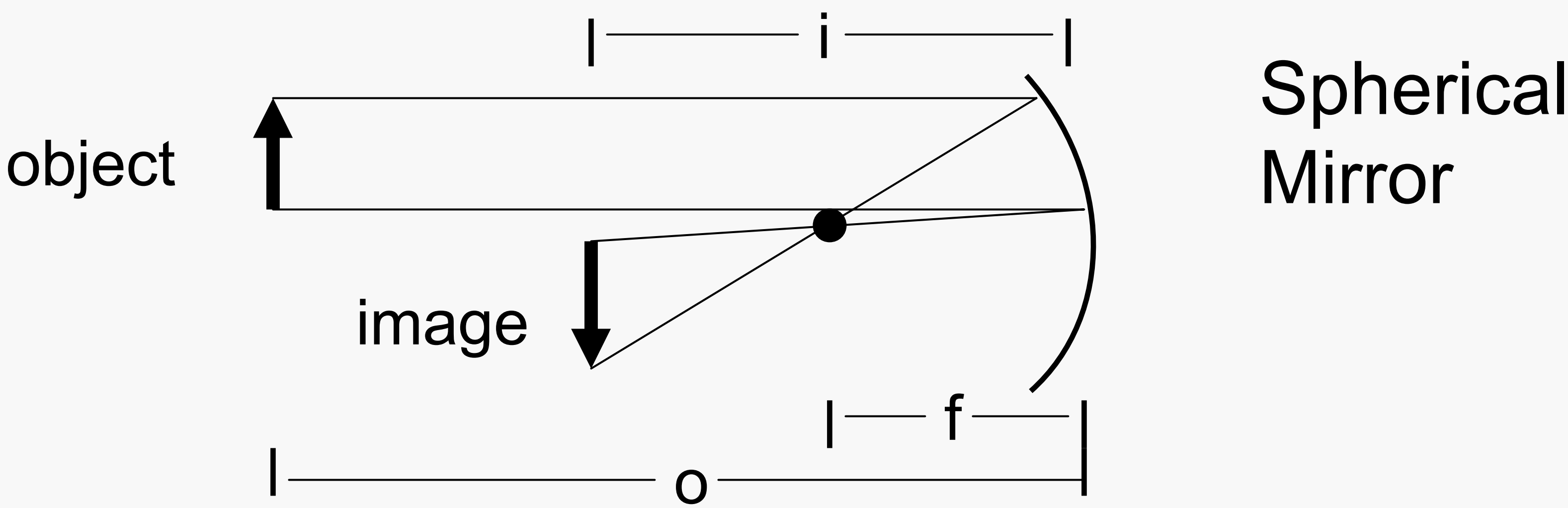


Focal length is important specification of a monochromator

$$\text{f/ (f number)} = \frac{\text{focal length (f)}}{\text{lens clear aperature}}$$

- f/ is measure of light gathering power
- Larger f/ means getting less light
- Light gathering power ~ $1/(f/)^2$

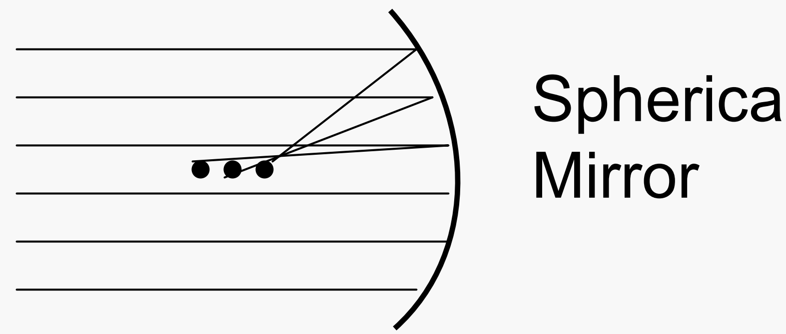
Mirrors – high quality instruments use front-surfaced mirrors for focusing which avoids chromatic aberrations



$$\frac{1}{f} = \frac{1}{i} + \frac{1}{o}$$

Problem → spherical aberrations

Mirror problem → spherical aberrations – f gets shorter as rays go off axis (this can actually be a problem for lenses also)

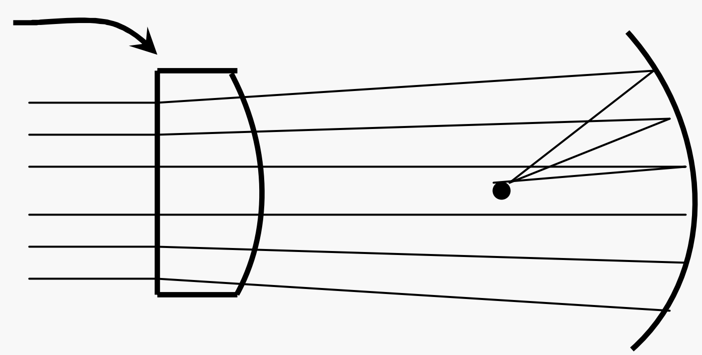


Several solutions:

1) Just use center of mirror (or lens) – but this reduces the light-gathering power (f/ increases)

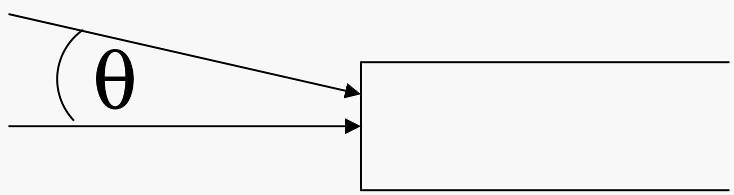
2) Use parabolic mirror (harder to make → $$)

3) Use Schmidt Corrector
   - distorts light beams so they come to a good focus



Astigmatism – for an object off axis, the horizontal and vertical focuses differ – get two images displaced from each other

Numerical Aperture (NA) = sin θ



angle over which a device accepts light

Slits – entrance and exit slits

Slits affect <u>energy throughput</u> & <u>resolution</u>

Decrease slit width → gain resolution & lose energy throughput

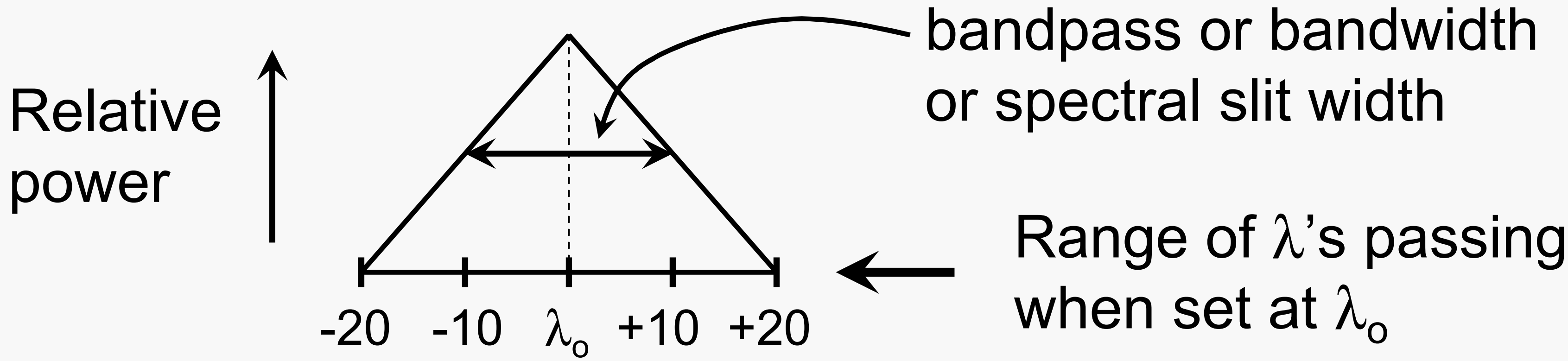
Open slits wider → increase signal (throughput) but lose resolution

Energy throughput must be sufficient for detector to measure signal with adequate precision.

In practice the image of the entrance slit in a monochromator should just fill the exit slit for optimum conditions. Otherwise the larger slit establishes (i.e, limits) the resolution and the smaller slit establishes (or limits) the energy throughput.

There is a theoretical minimum for slit widths imposed by diffraction.

Light exiting a monochromator exit slit has a triangular distribution



Optical Efficiency = throughput x resolution

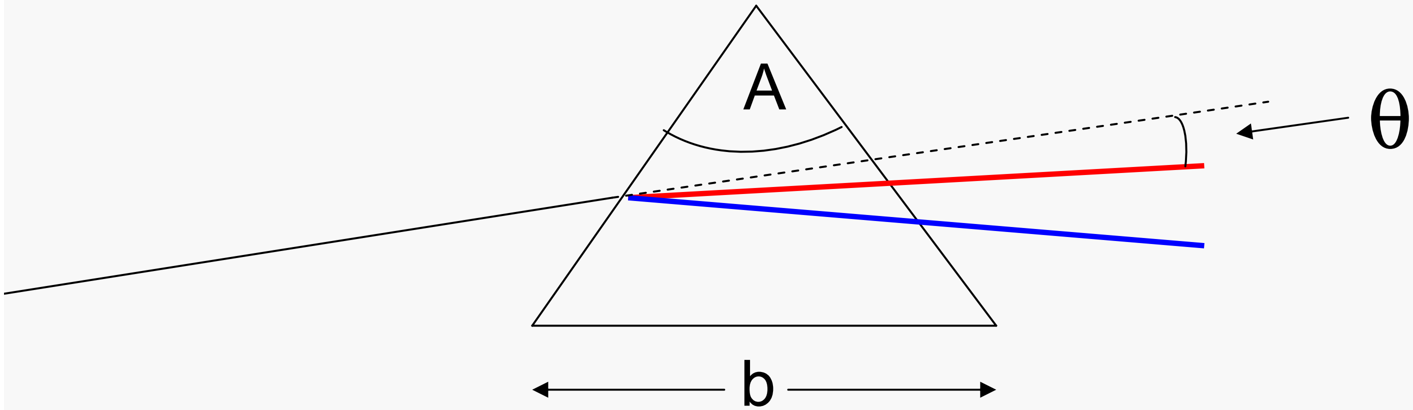
Good criterion for comparing optical systems

Prism Monochromator	<	Grating Monochromator	<	Interferometer

Dispersion Devices

1) Prisms

A = apical angle
b = base length



Light bends due to η $\eta = f(\lambda)$

function of prism design (i.e. angle A)

$$\text{Angular Dispersion} = \frac{d\theta}{d\lambda} = \frac{d\theta}{d\eta} \times \frac{d\eta}{d\lambda}$$

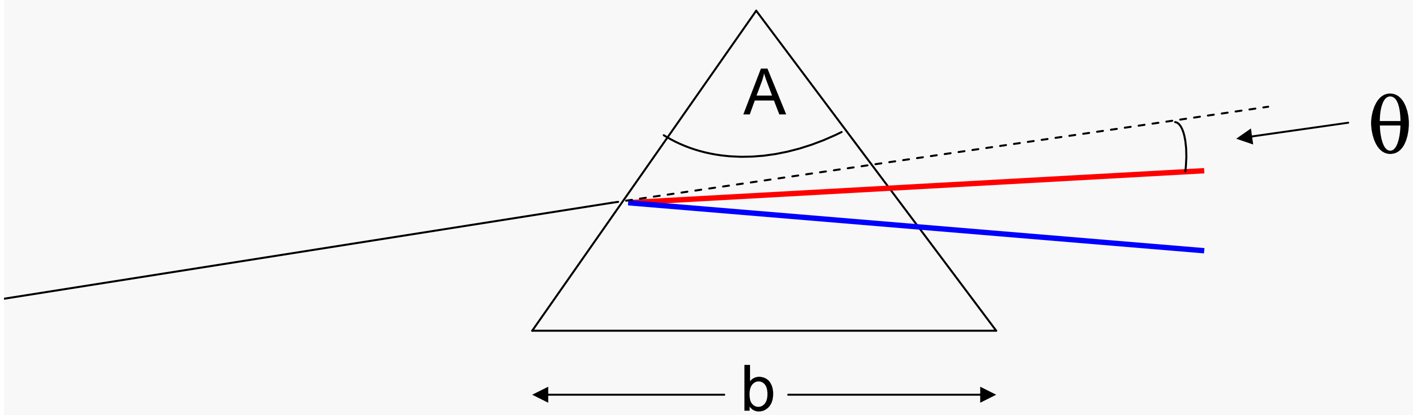
function of prism material

Angle changes with λ → the larger the better

Dispersion Devices

1) Prisms

A = apical angle
b = base length



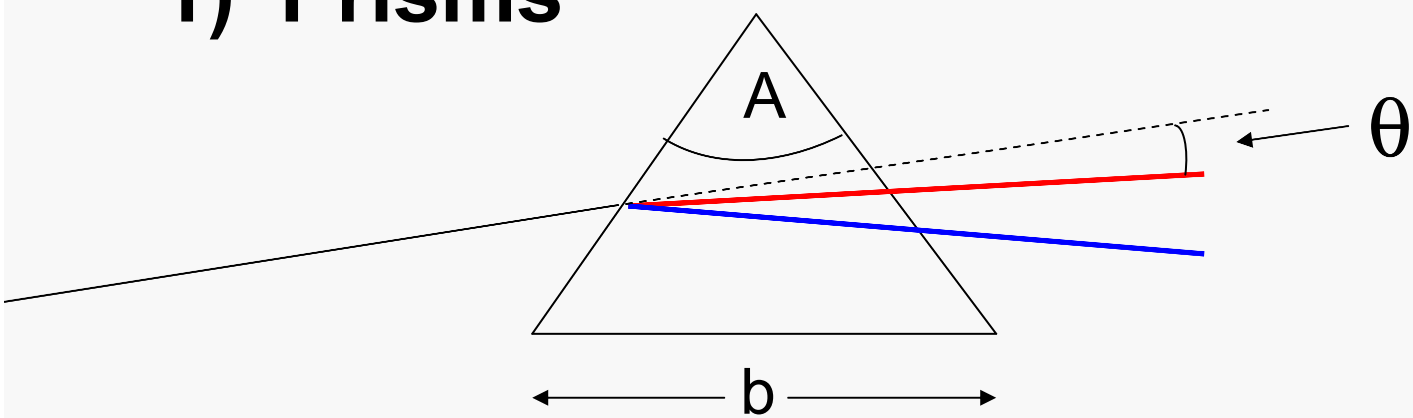
Increasing A → $\frac{d\theta}{d\eta}$ increases but internal reflection is also greater (typical A value is 60^o)

Dispersion Devices

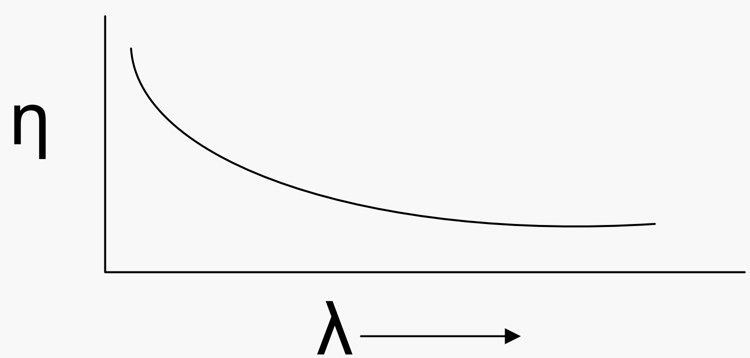
A = apical angle

b = base length

1) Prisms



$$\frac{d\eta}{d\lambda} \text{ depends on material, } \frac{d\eta}{d\lambda} \text{ greatest at shorter } \lambda$$



Linear Dispersion $\left(\frac{mm}{nm}\right) = f \frac{d\theta}{d\lambda}$

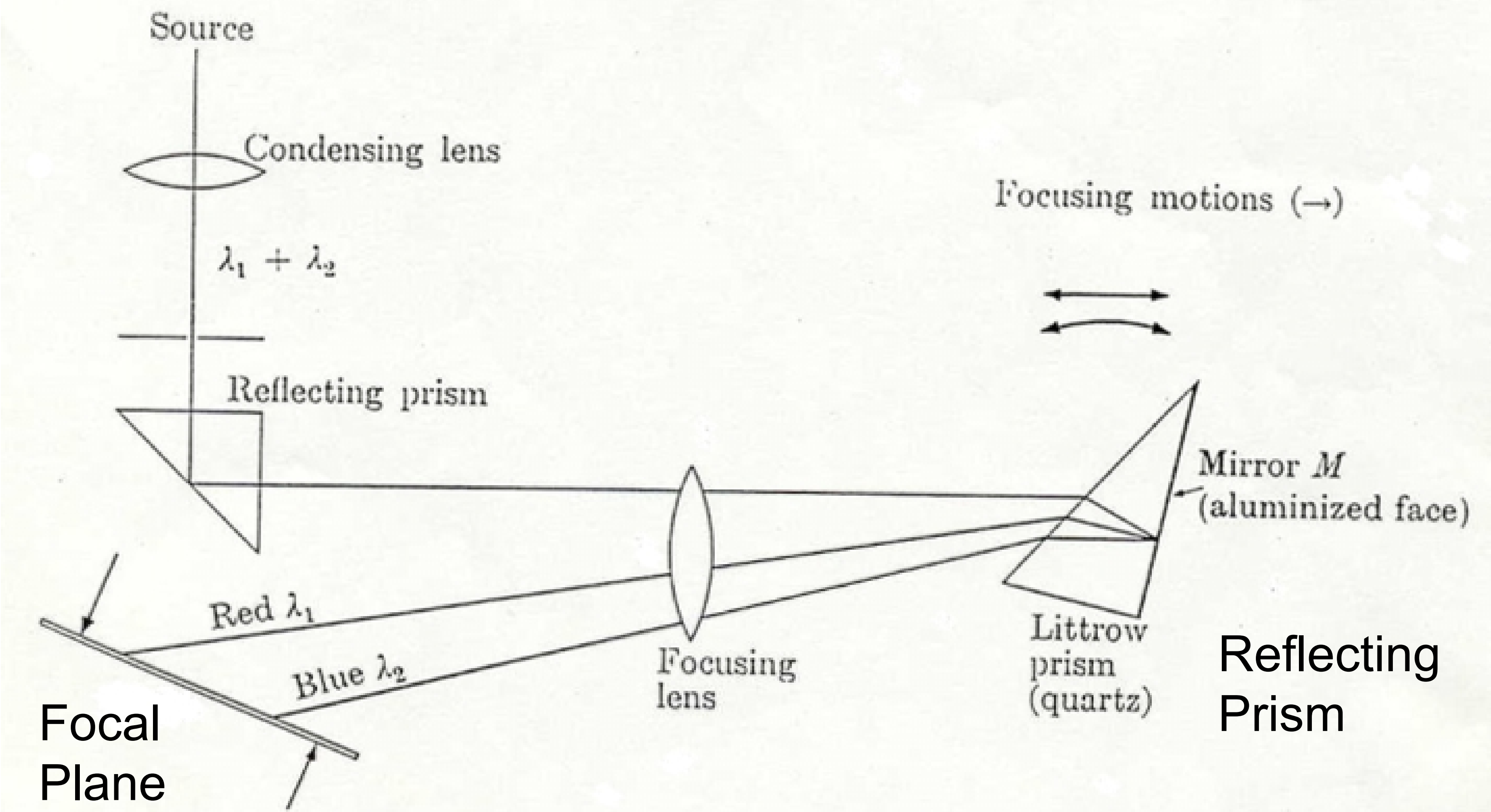
Depends on angular dispersion and focal length

For constant bandwidth, slit widths must be varied with λ to compensate for variations in dη/ dλ

Stated another way, linear dispersion changes in different regions of the spectrum

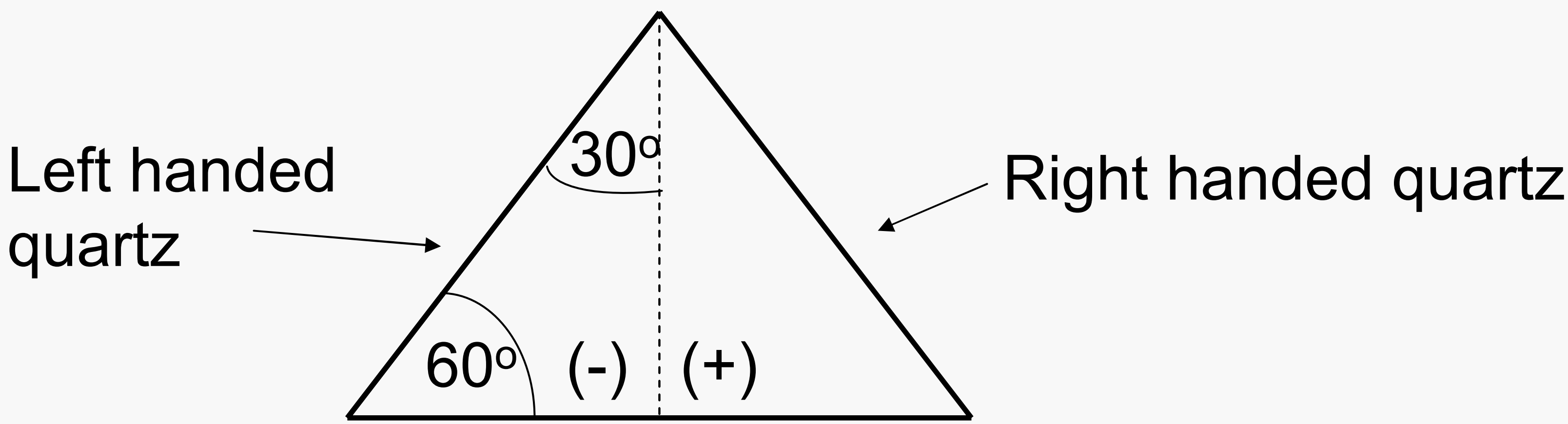
Kinds of Prisms

Littrow Prism & Mounting – compact design



Problem with quartz prisms is that quartz is optically active (optically anisotropic). With the Littrow prism or any reflecting prism, the light travels essentially the same path in both directions and this effect is eliminated.

Cornu Prism



f/ of a monochromator is important if have a weak source. For lenses in series, the smallest f/ sets the overall f/ for the system.

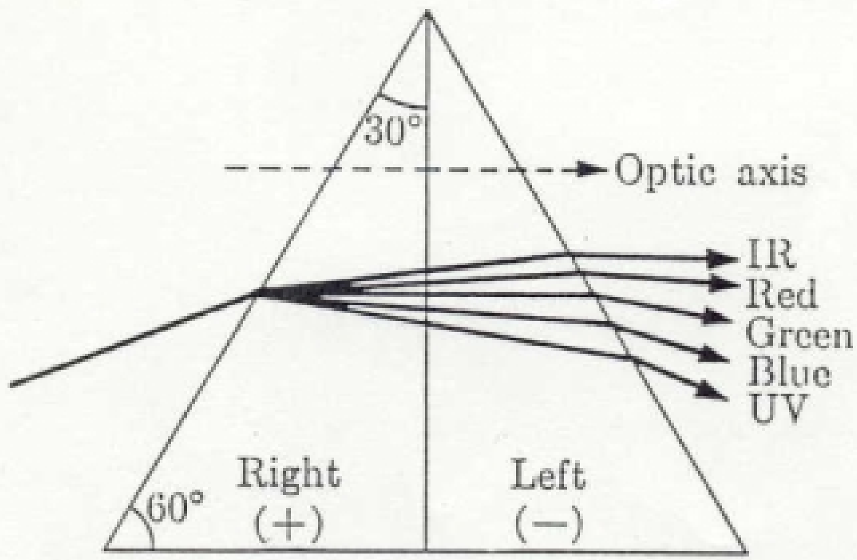
Lens Summary:

1) rugged, easy to use, inexpensive

2) can have chromatic aberrations = focal length depends on η which varies with λ – solution is to fabricate lenses out of a composite glasses so η is constant with λ. This increases cost

3) Each lens results in some light loss due to reflection

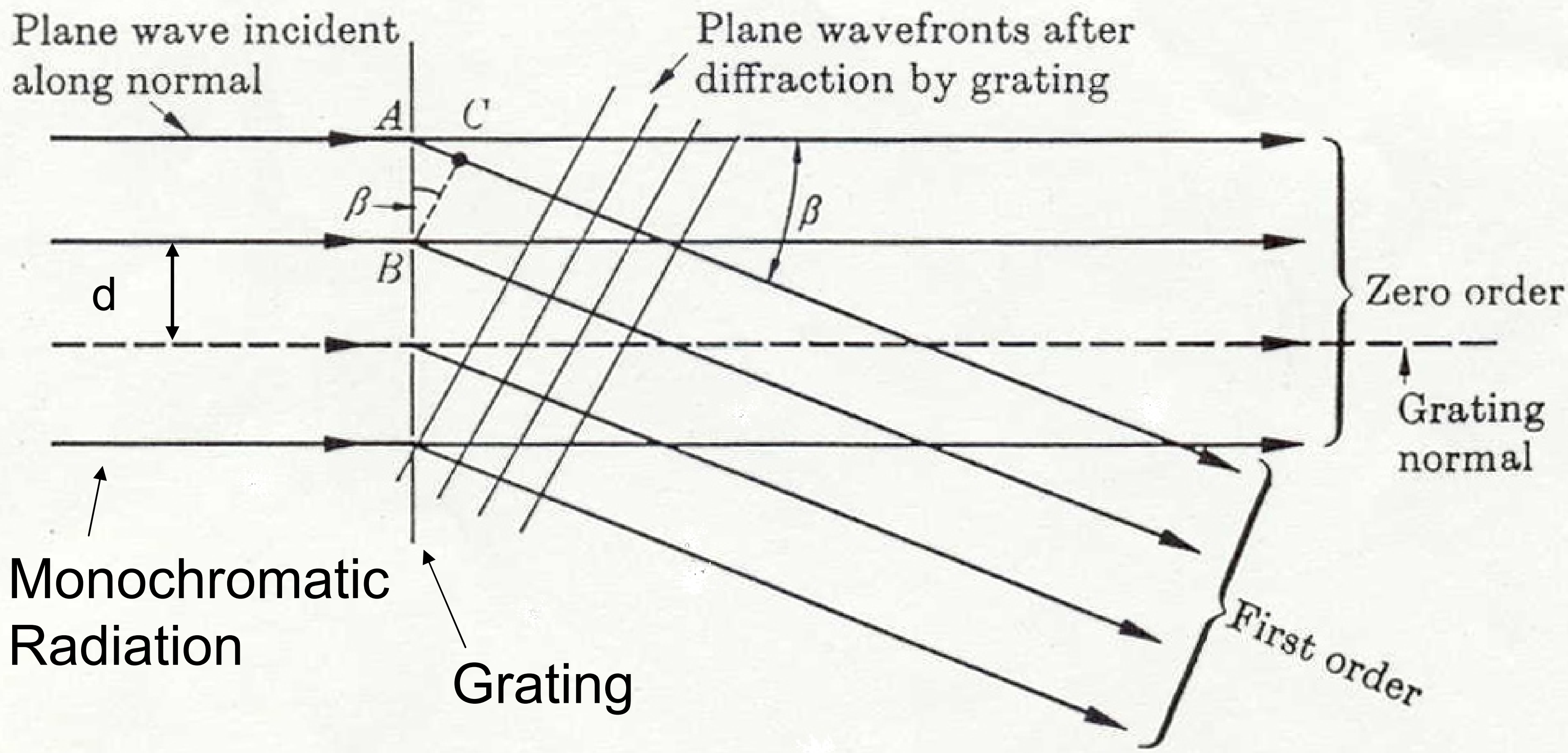
Another view of a Cornu prism



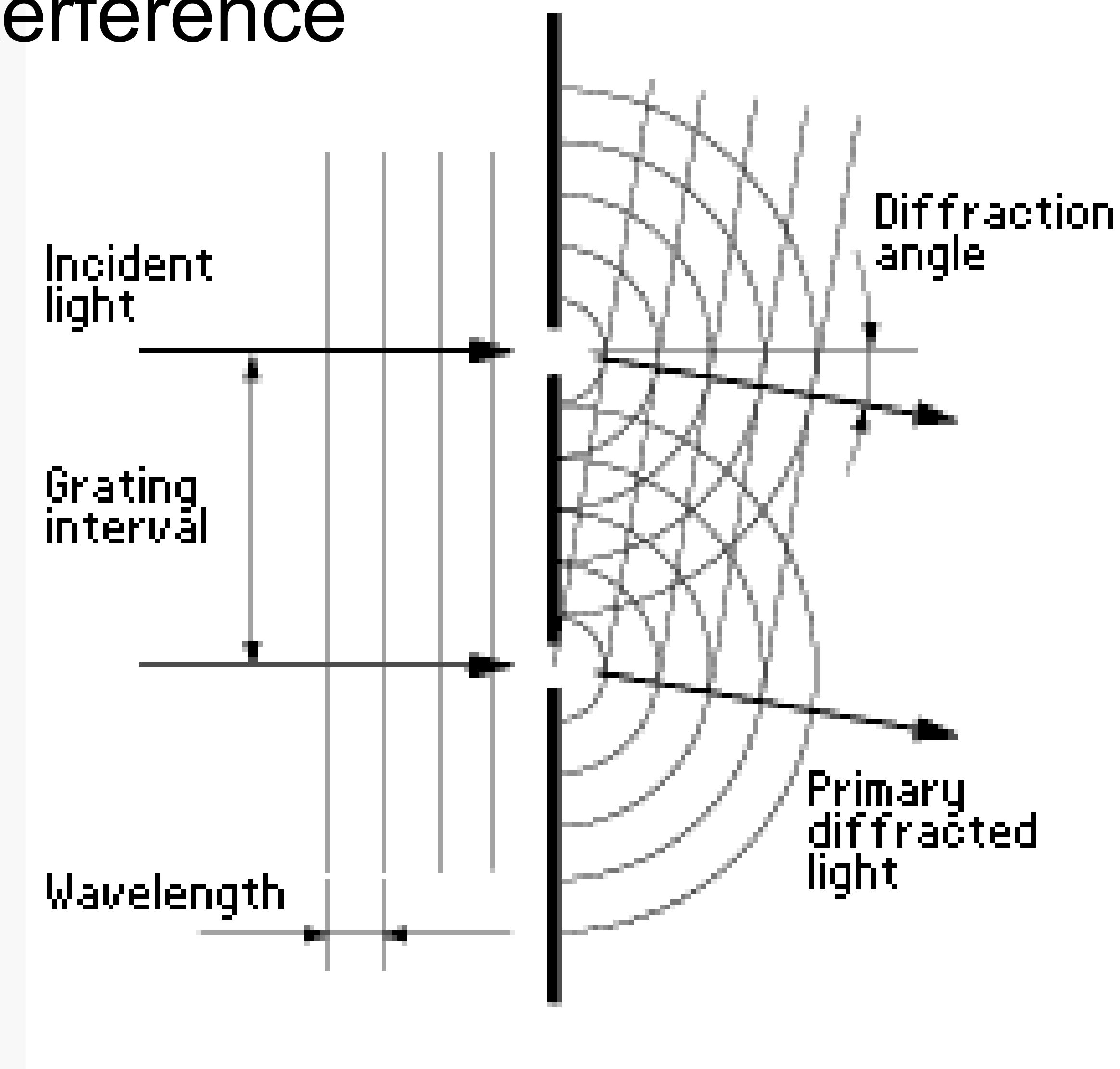
Cornu prism of quartz. The circular double refraction (not shown) produced by the first half is just offset by the equal and opposite effect in the second half. Two overlapping spectra would result if the prism were all of one kind of crystalline quartz.

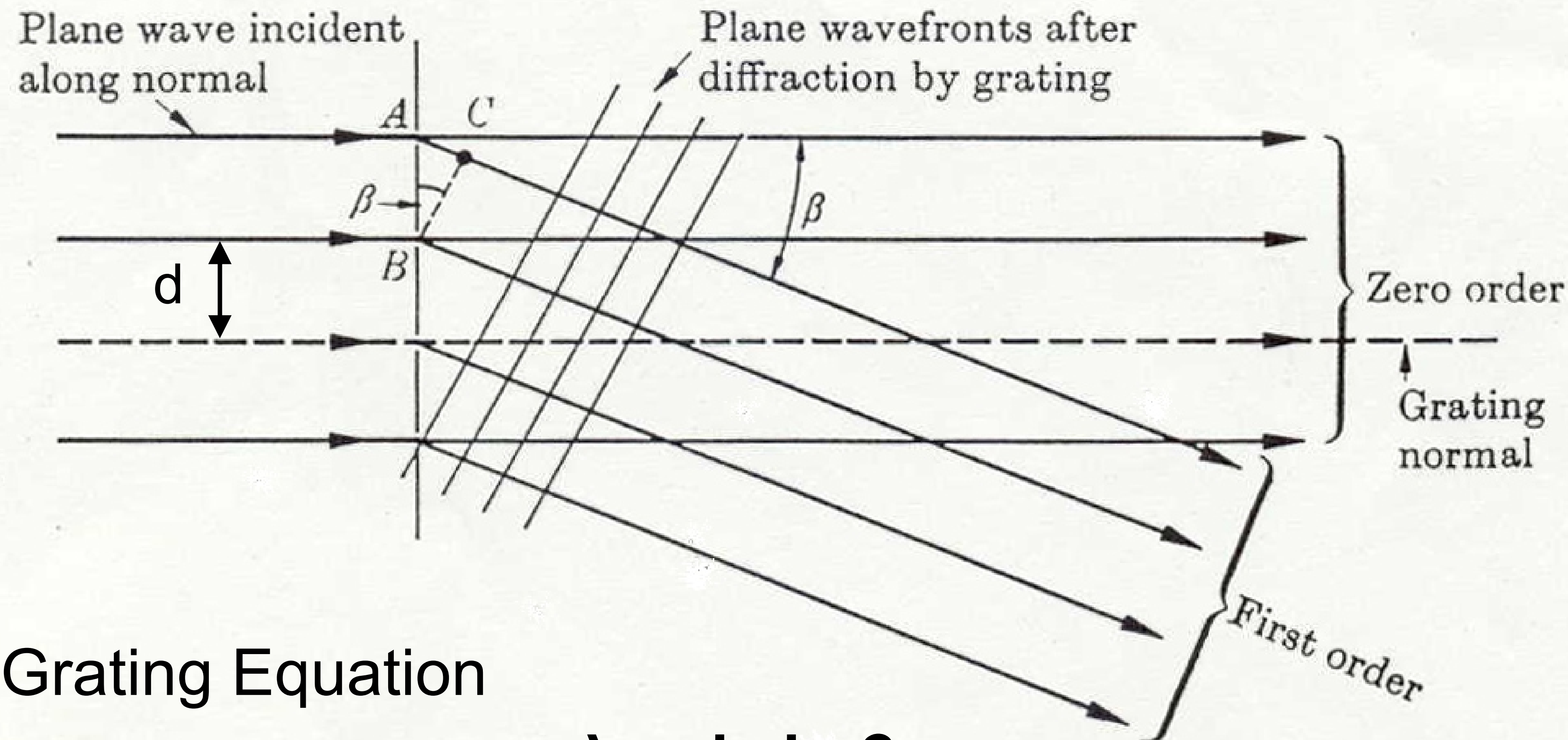
Gratings – based on diffraction & interference

Transmission Gratings & Reflection Gratings consist of a series of grooves in glass or quartz or a mirror (usual kind)



Gratings work on the principles of diffraction & interference





Grating Equation

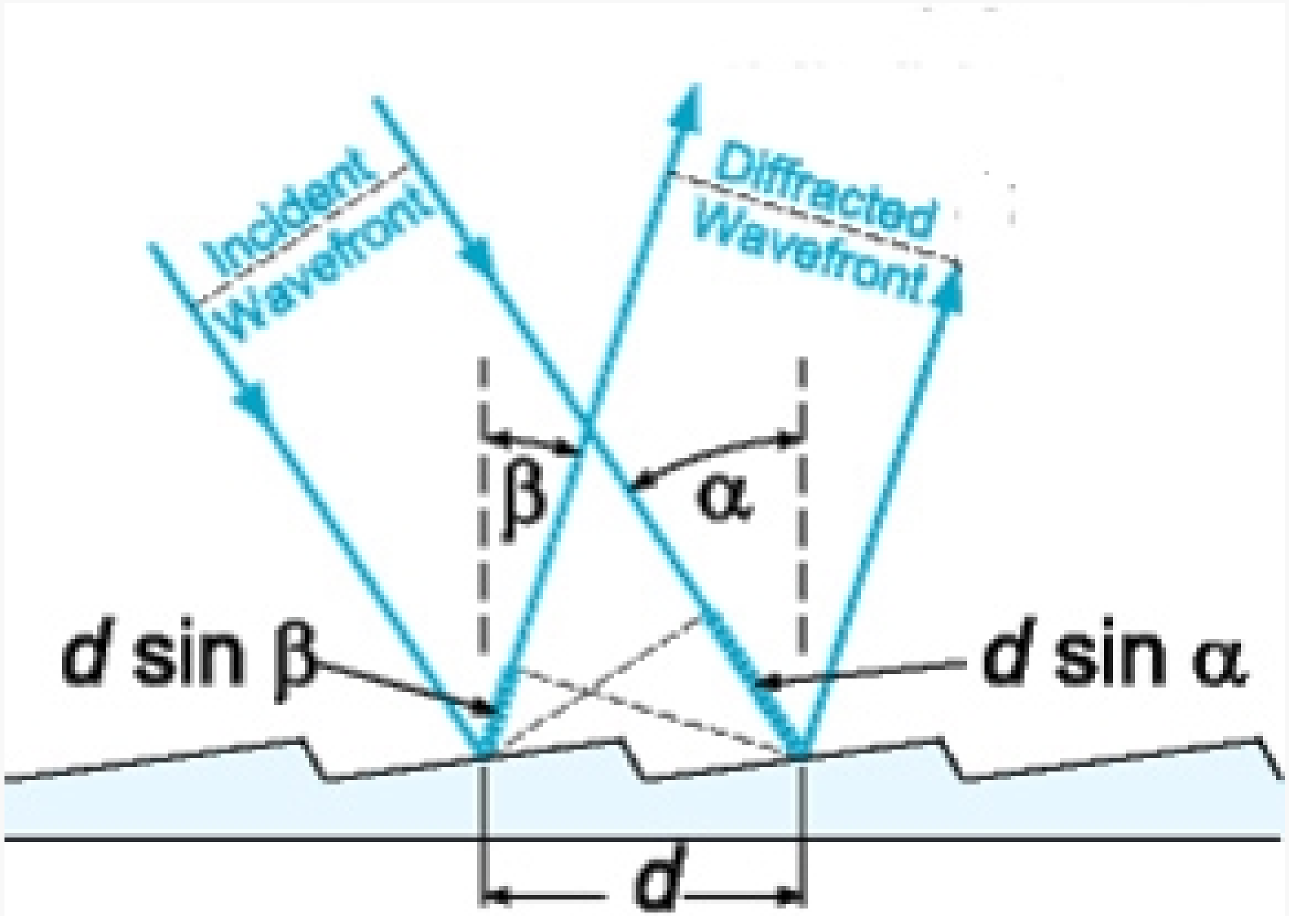
$$m \lambda = d \sin \beta$$

Condition for constructive interference

AC = extra distance light travels for first order = $d \sin \beta$

For higher orders the distance gets longer

Reflection grating with non-normal incidence



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