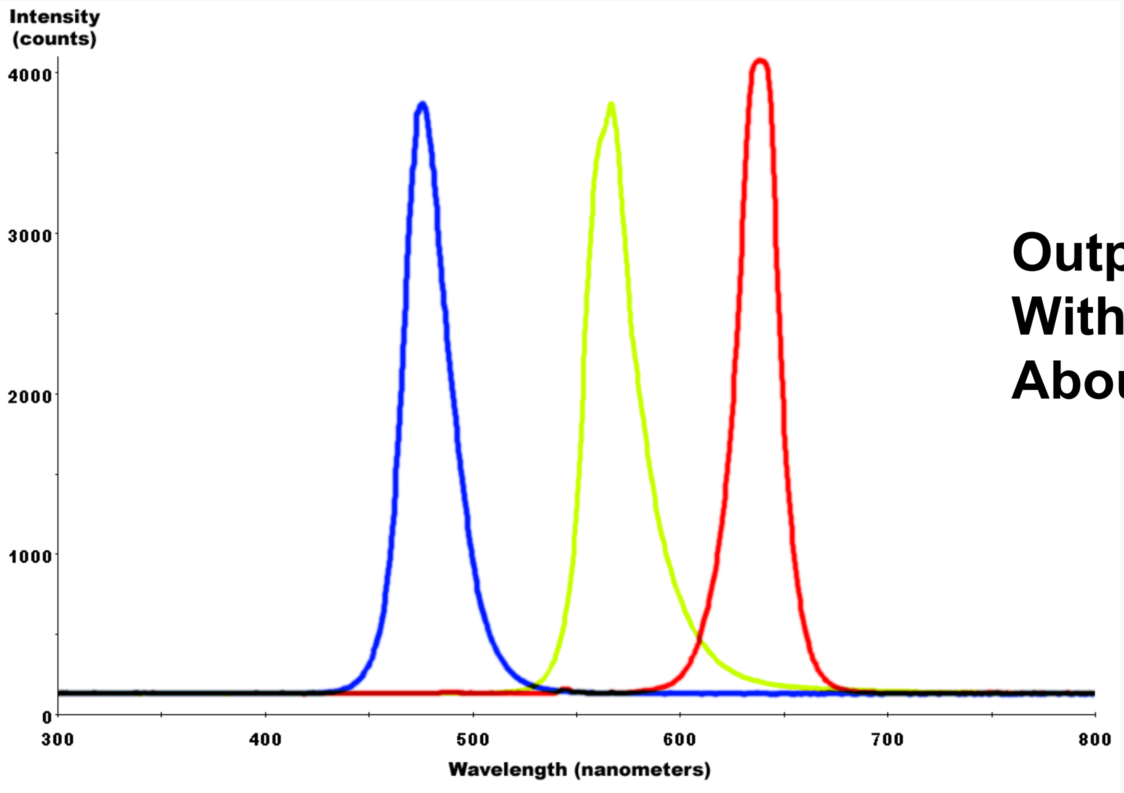
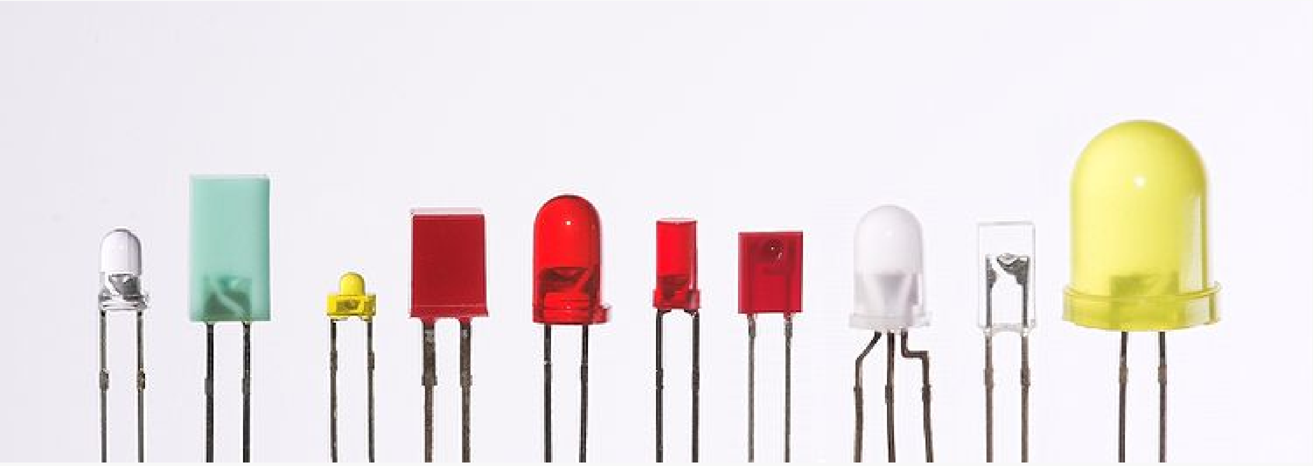
Light Emitting Diodes (LEDs)

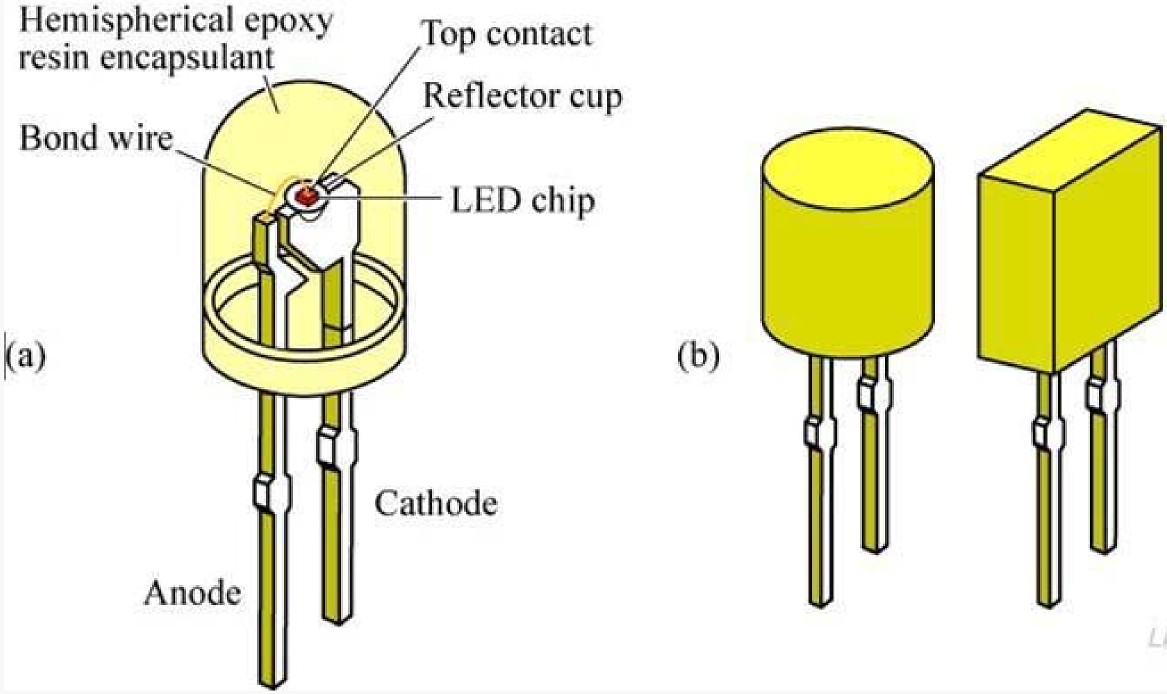
- Semiconductor device that very efficiently produces light as a line source



Output of 3 LEDs With bandwidths of About 25 nm

LED Packages



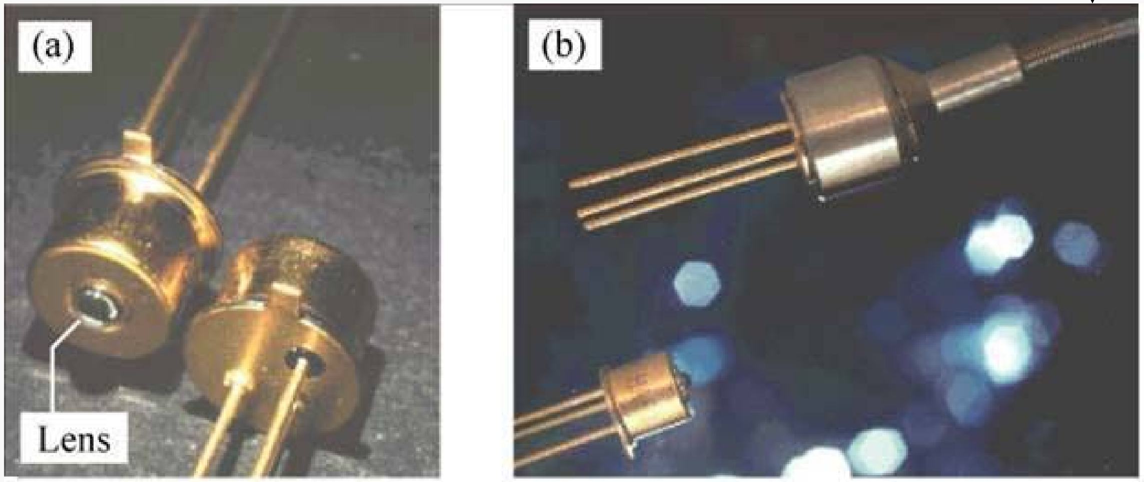


Typical packages; (a) LED with hemispherical encapsulant; (b) LEDs with cylindrical and rectangular encapsulant.

E. F. Schubert
Light-Emitting Diodes (Cambridge Univ. Press)
www.LightEmittingDiodes.org

Older Communications LED

Fiber optic pig tail



(a) Packaged (TO package) RCLED emitting at 650 nm suited for plastic optical fiber applications. (b) Pig-tailed RCLED (courtesy of Mitel Corporation, Sweden, 1999).

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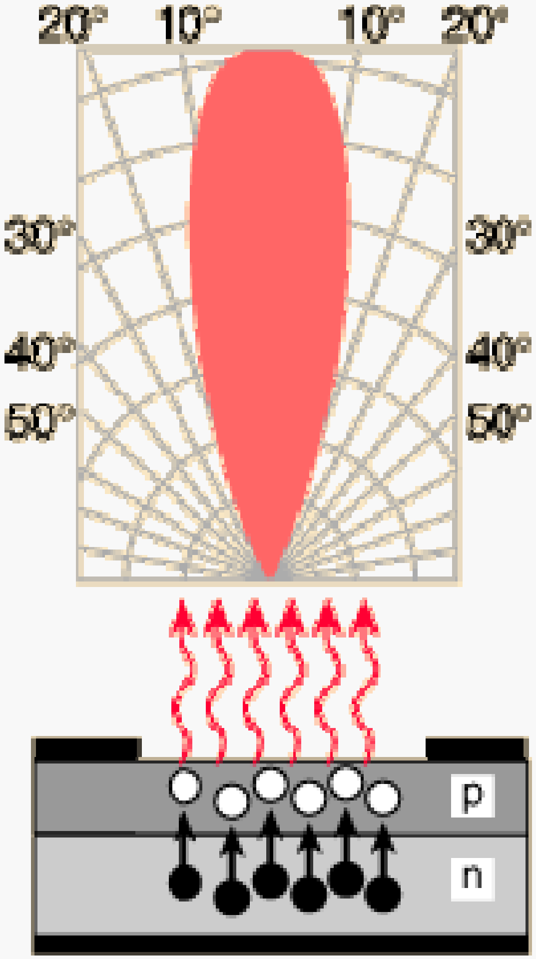
Light-Emitting Diodes (Cambridge Univ. Press)
www.LightEmittingDiodes.org

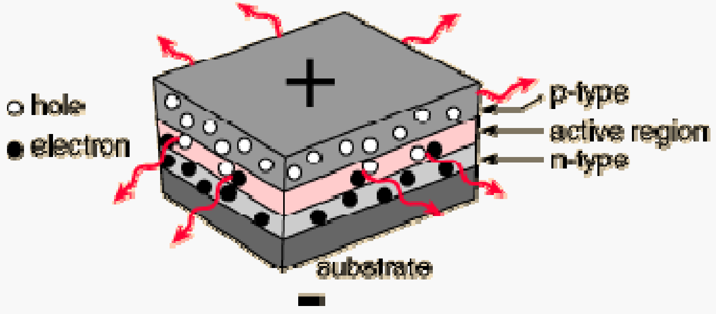
LED Radiation Patterns

An LED is a directional light source, with the maximum emitted power in the direction perpendicular to the emitting surface. The typical radiation pattern shows that most of the energy is emitted within 20° of the direction of maximum light. Some packages for LEDs include plastic lenses to spread the light for a greater angle of visibility.

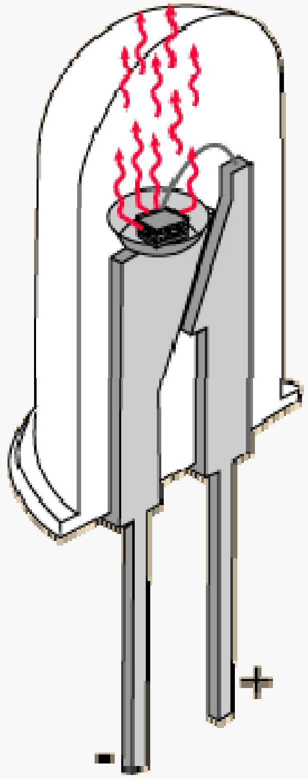


LED Device Structure

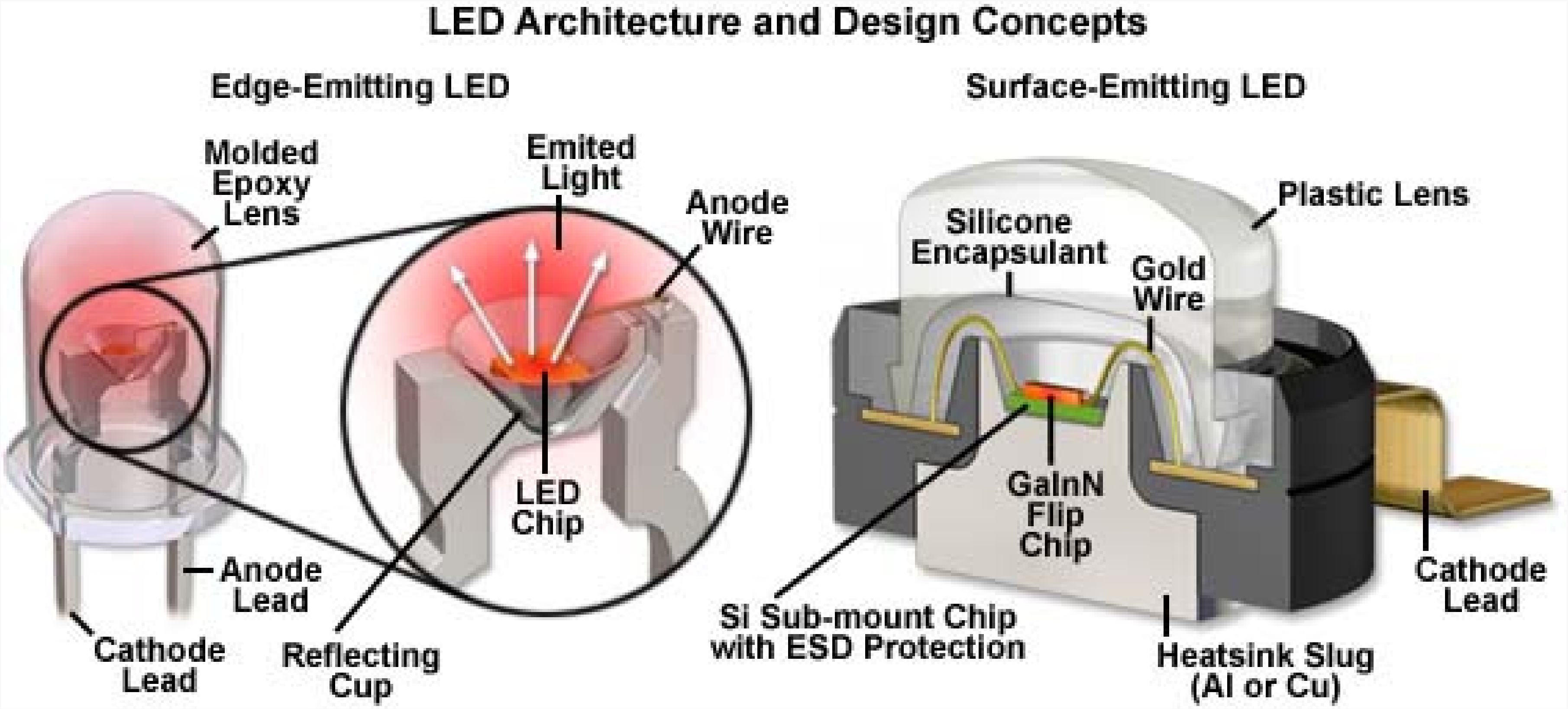
(Edge Emitting LED)



One type of LED construction is to deposit three semiconductor layers on a substrate. Between p-type and n-type semiconductor layers, an active region emits light when an electron and hole recombine. The light is produced by a solid state process called electroluminescence. In this particular design, the layers of the LED emit light all the way around the layered structure, and the LED structure is placed in a tiny reflective cup so that the light from the active layer will be reflected toward the desired exit direction.



Two Basic Device Designs



Wavelength Selection

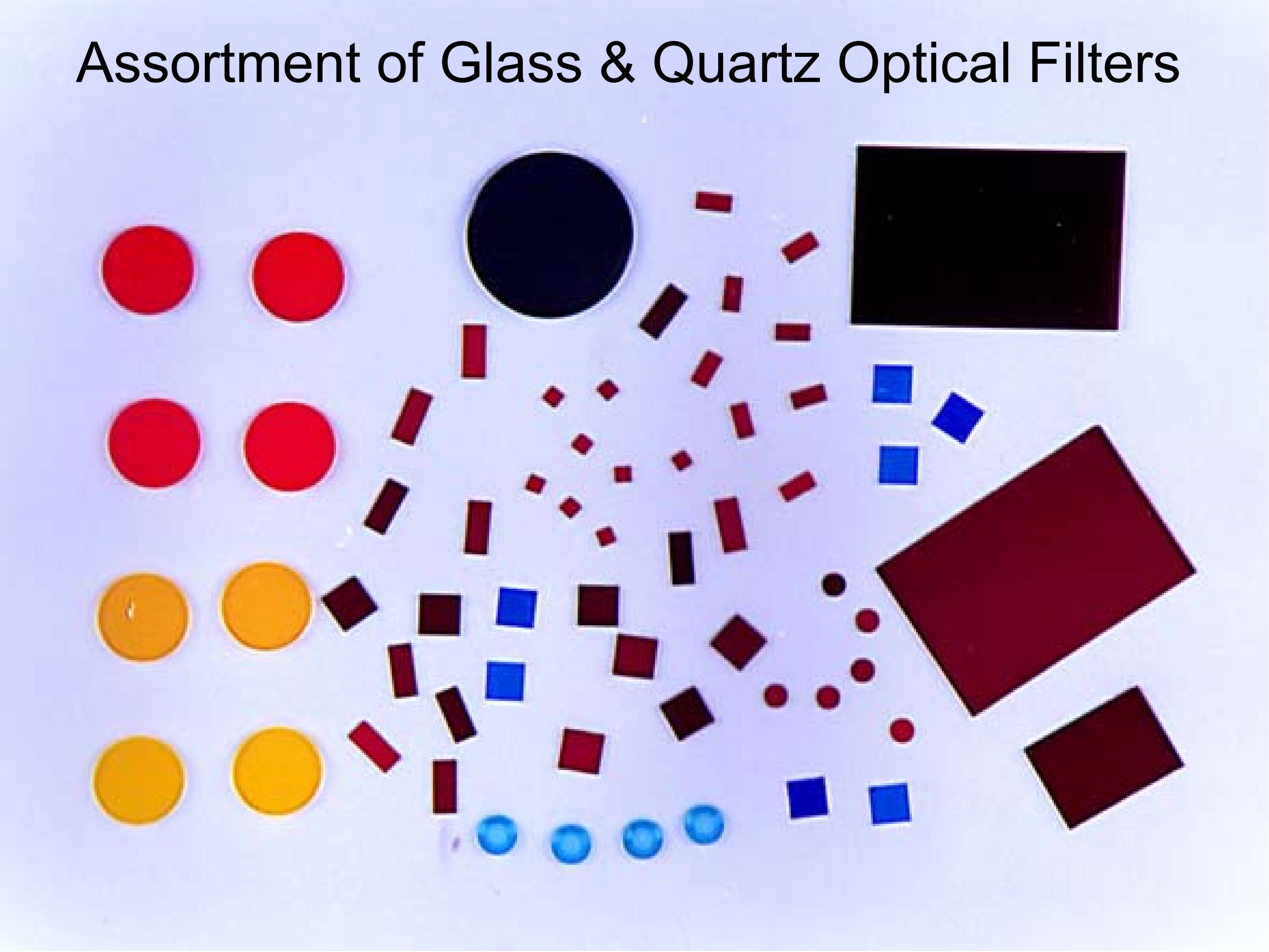
Three main approaches:

1) Block off unwanted radiation – optical filters
2) Disperse radiation & select desired band – monochromator
3) Modulate wavelengths at different frequencies - interferometer

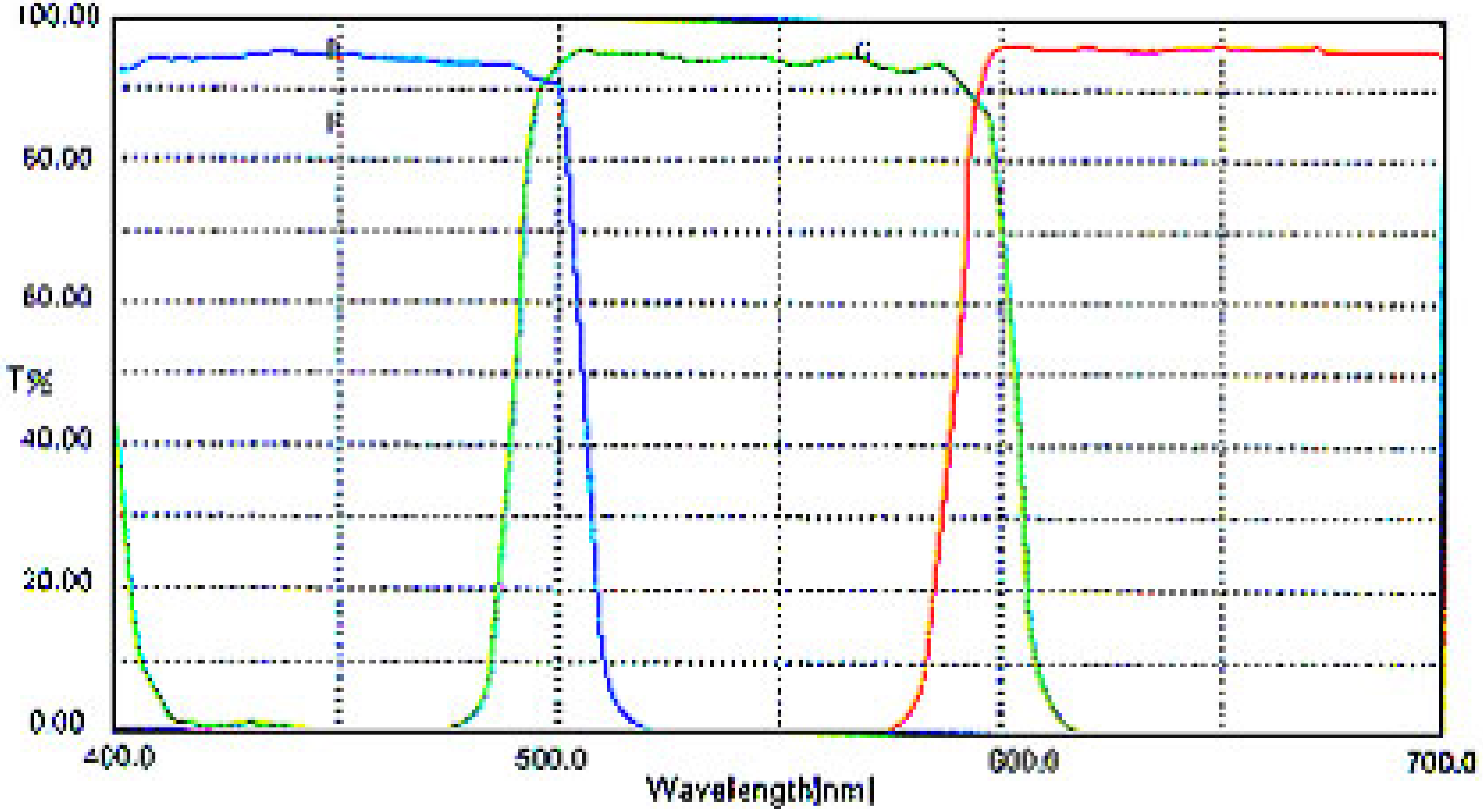
FILTERS

1) **Absorption** – colored glass, colored film, colored solutions – cheapest way

Assortment of Glass & Quartz Optical Filters

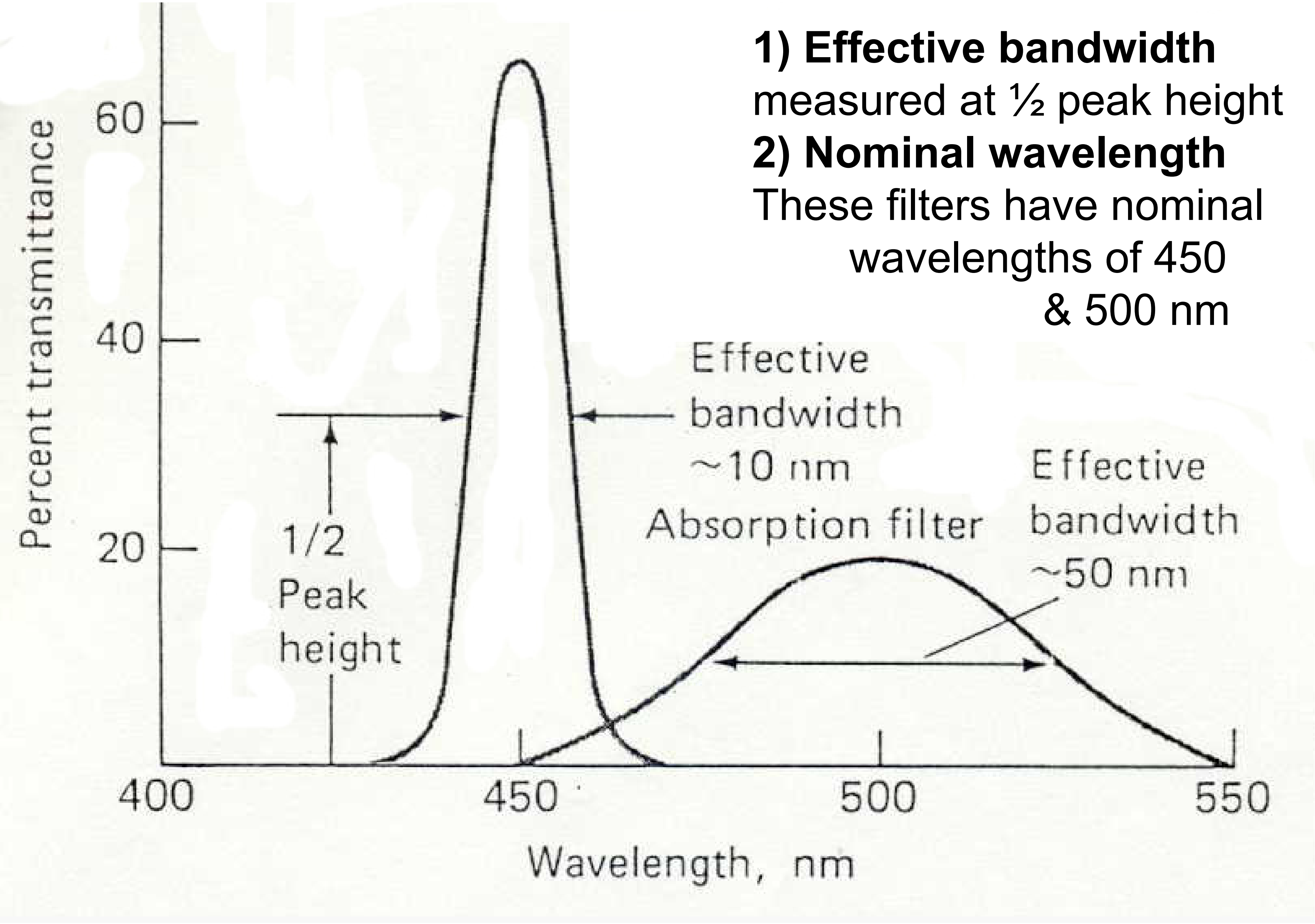


Combining two appropriate cut-off filters produces a bandpass filter. The example shown here comes from 3 filters producing bands at 500 & 600 nm.

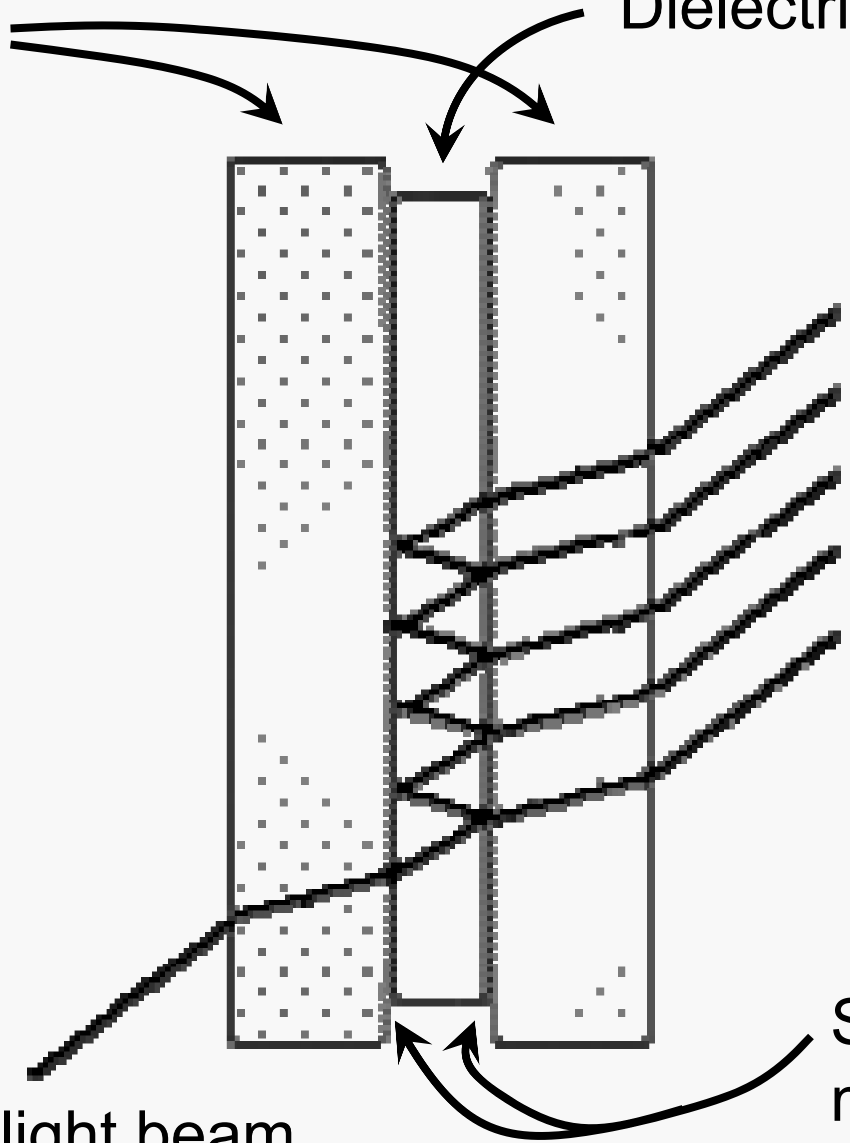


Two terms associated with optical filters are:

1) Effective bandwidth
measured at ½ peak height
2) Nominal wavelength
These filters have nominal wavelengths of 450 & 500 nm



2) **Interference filters** – usually Fabrey-Perot type



Glass layers

Dielectric material (CaF or MgF)

Transmitted radiation

Light bounces back & forth & gets out of phase with itself unless it meets conditions for constructive interference

Semi-reflective metal layers

Incident light beam

Condition for constructive interference

order of interference

$$2d = \frac{m\lambda}{\eta}$$

distance between
semi-reflective layers

refractive index
of dielectric

If distance (d) is multiple (m) of wavelength (λ) then it won’t be interfered with

Concept of Order – constructive & destructive interference causes waves with different phase angles to be eliminated except if they are multiples of each other

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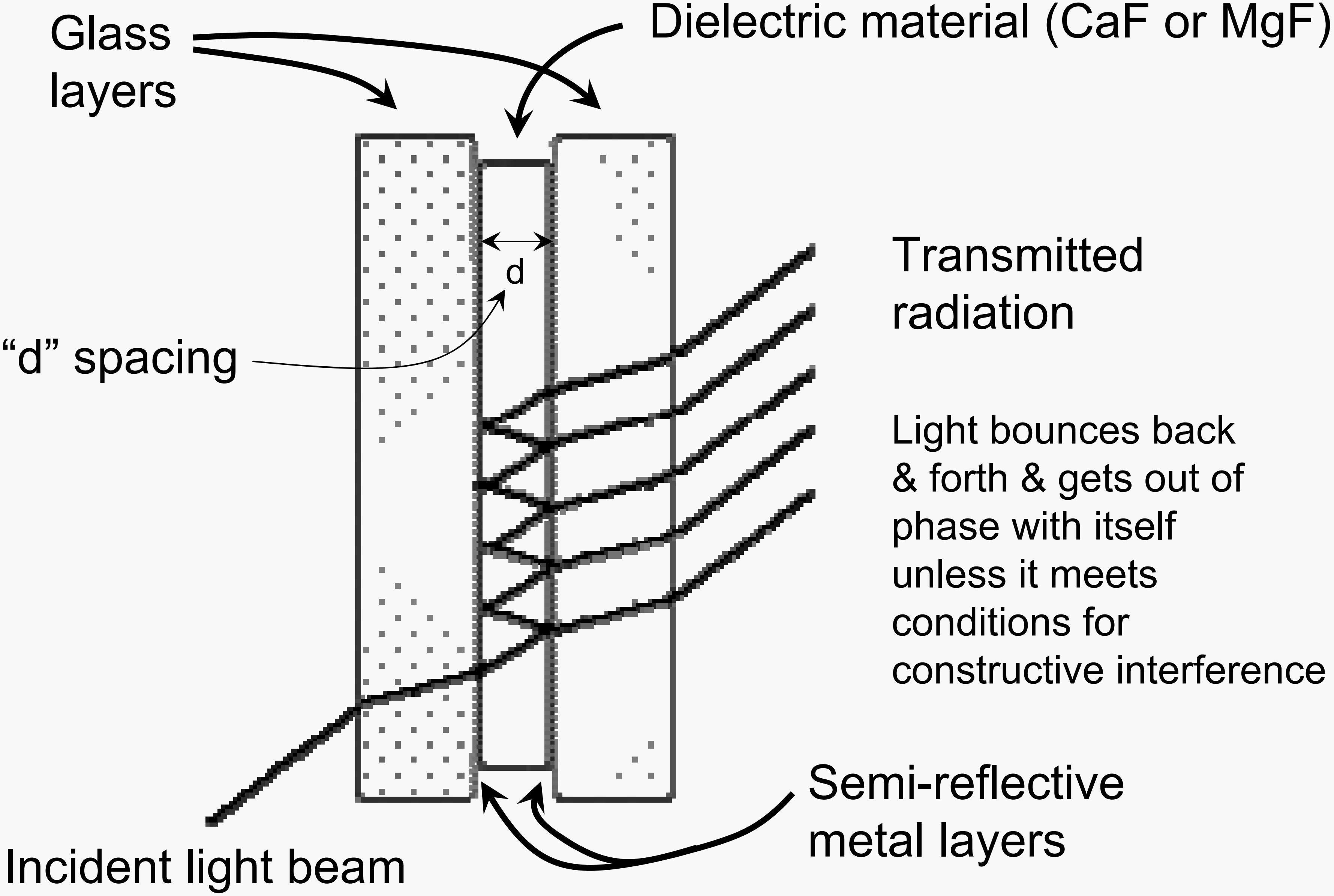

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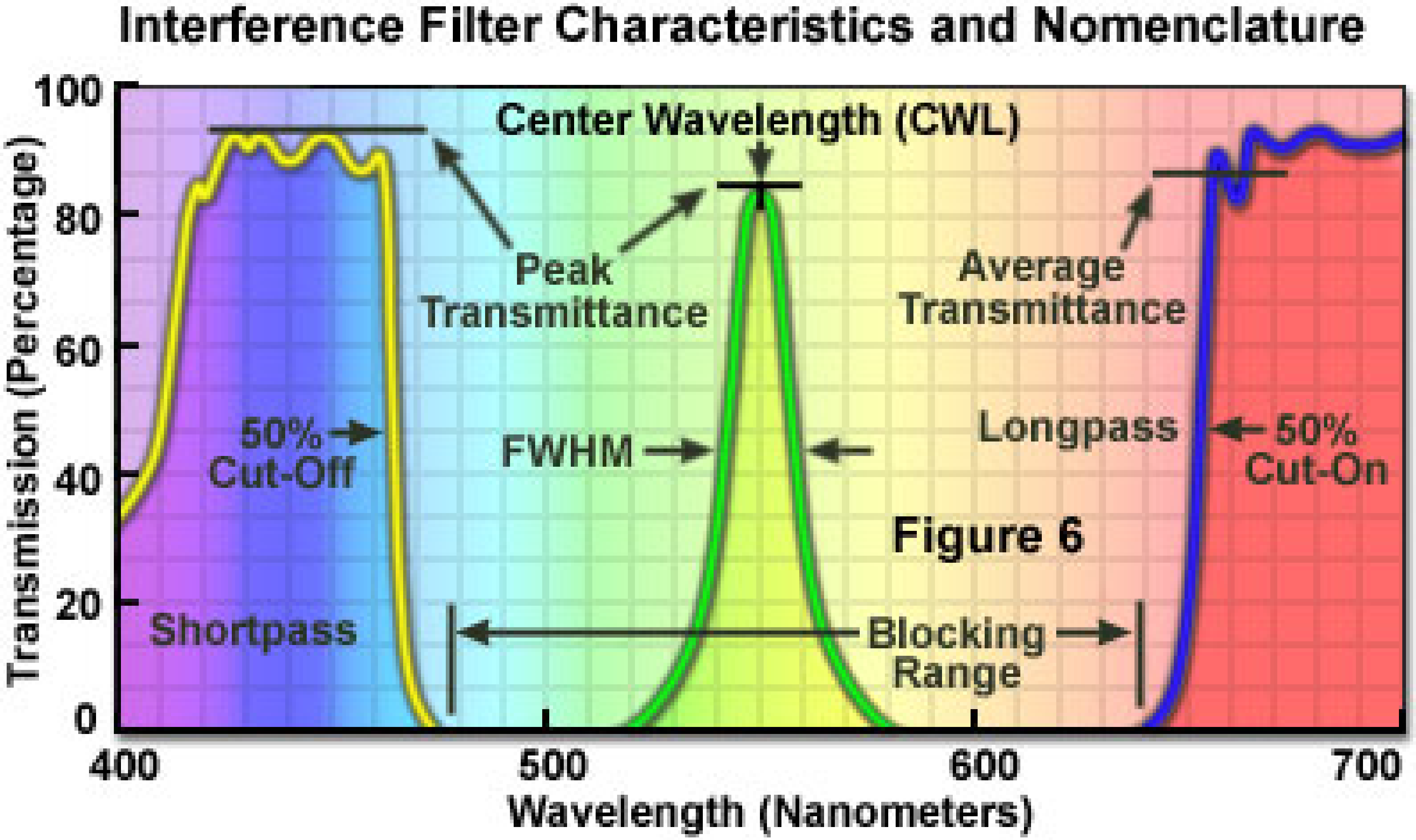
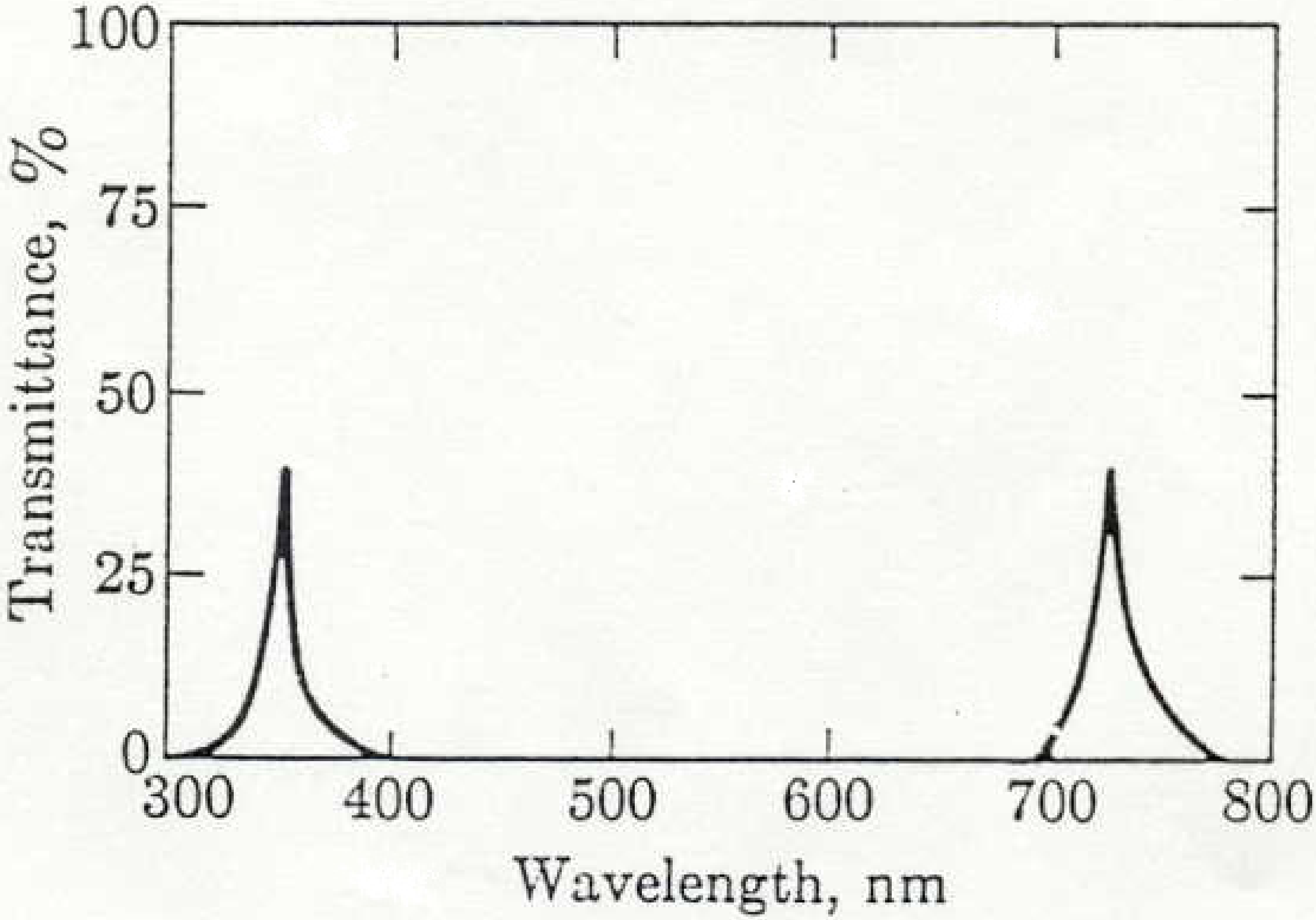
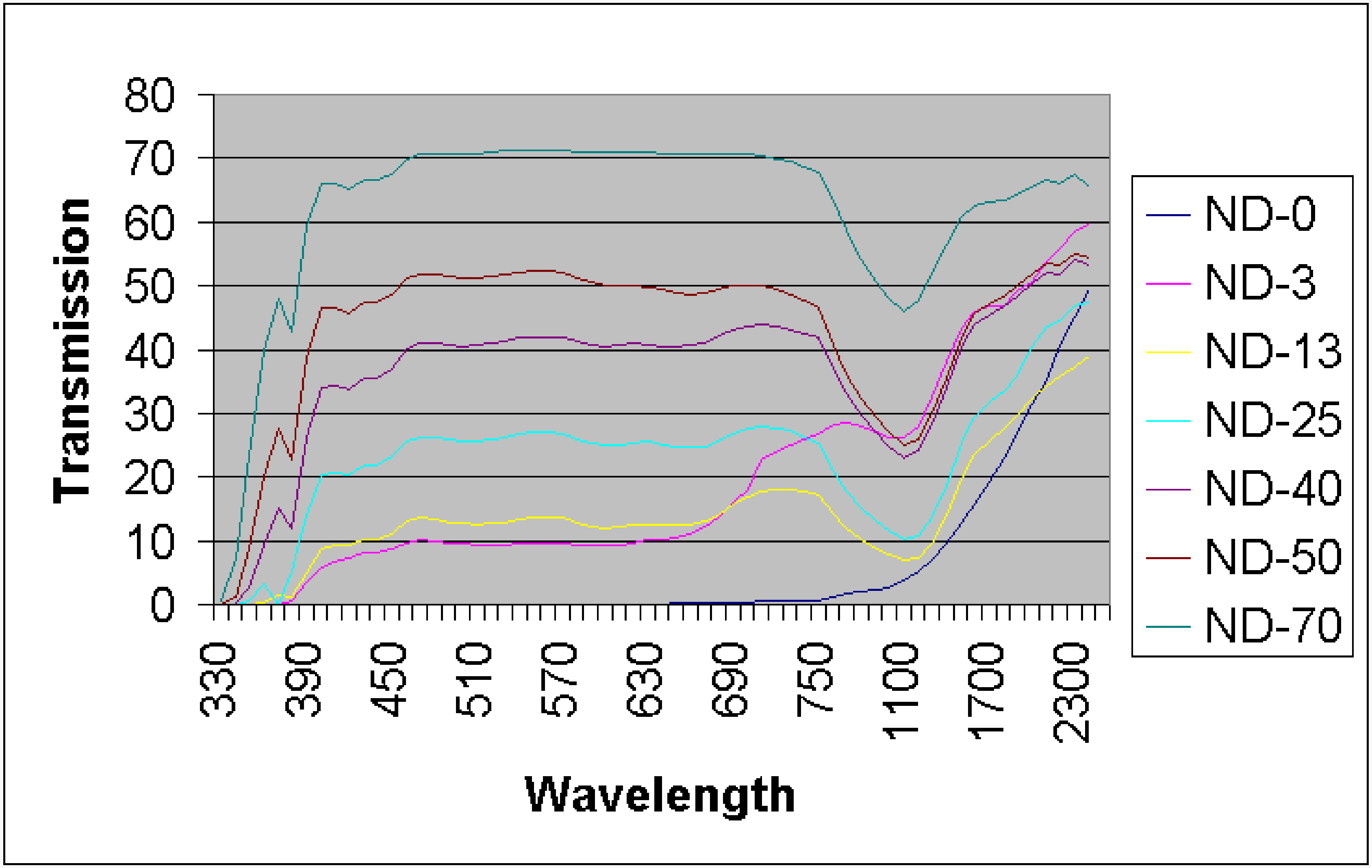


FWHM – full width at half maximum

Transmittance vs. wavelength for typical Fabrey-Perot Interference filter showing first and second order λ's (m = 1 & m = 2)

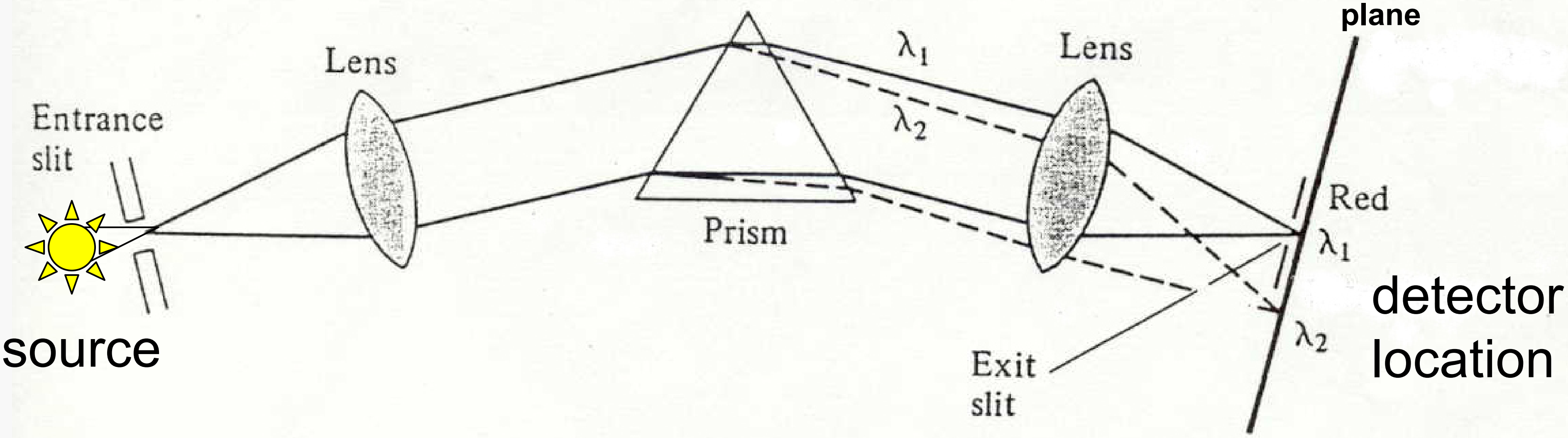


3) **<u>Neutral density filters</u>** – reduces intensity without any λ discrimination



II) MONOCHROMATORS

Simple Prism Monochromator



Entrance slit allows source radiation to illuminate the first lens which collimates the light spreading it across the face of the **prism**. Prism disperses radiation into component wavelengths and the second lens focuses the spectrum at the **focal plane**. An **exit slit** selects the band of radiation to reach the detector. Dispersing element can be a **prism** or a **diffraction grating**. Focusing elements can be **lenses** or **mirrors**.

- Optical Materials – need optically transparent materials for lenses, prisms & sample cells
- In visible region – can use glass down to 350 nm
- In the UV region – quartz is material of choice
- In the IR region – NaCl, KBr, etc. The heavier the atoms of the salt, the farther into the IR region (i.e., longer λ) before significant absorption occurs

Problem – sensitivity to moisture

Resolution – ability to distinguish as separate, nearly identical frequencies; measured in terms of closest frequencies $\Delta\nu$ in a spectrum that are distinguishable

$$R = \frac{\nu}{\Delta\nu} \quad \text{or} \quad \frac{\lambda}{\Delta\lambda} \quad \text{(both dimensionless)}$$

Dispersion – spread of wavelengths in space

Angular Dispersion – angular range dθ over which waveband dλ is spread → $\frac{d\theta}{d\lambda}$ in $\frac{\text{rad}}{\text{nm}}$

Linear Dispersion – distance dx over which a waveband dλ is spread in the focal plane of a monochromator →

$$\frac{dx}{d\lambda} \quad \text{in} \quad \frac{mm}{nm}$$

Linear Reciprocal Dispersion – range of λ's spread over a unit distance in the plane of a monochromator →

$$\frac{d\lambda}{dx} \quad \text{in} \quad \frac{nm}{mm}$$

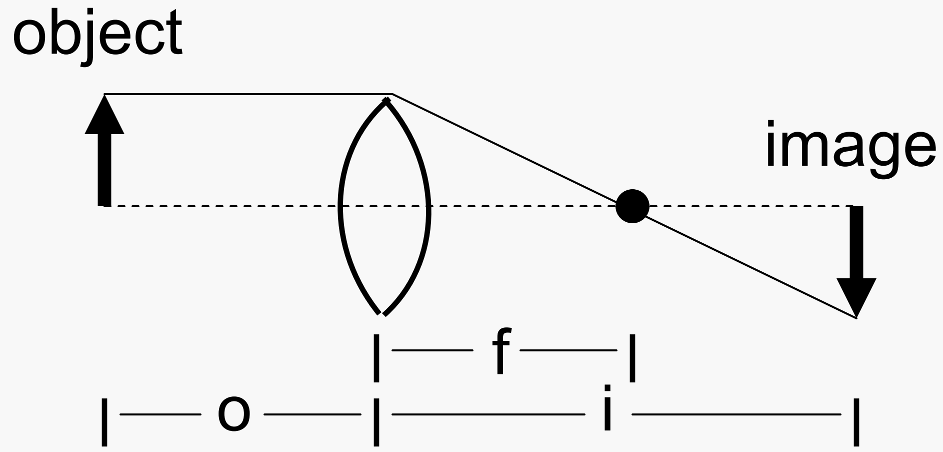
Related terms **spectral slit width** or **bandwidth** or **bandpass** = range of λ's included in a beam of radiation measured at half max intensity

Lenses – lens equation (for a thin lens)

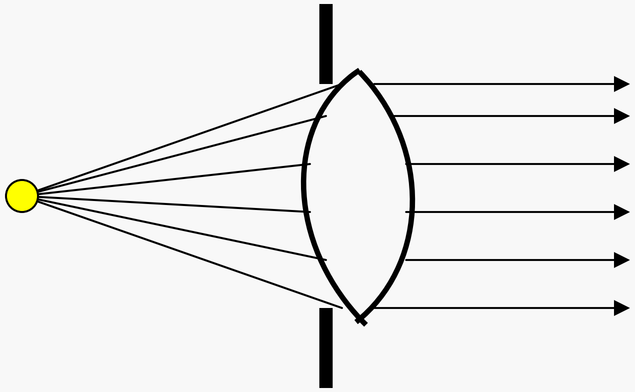
$$\frac{1}{f} = (\eta - \eta')\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$$

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



$$\frac{1}{f} = \underset{\text{distance to image}}{\frac{1}{i}} - \underset{\text{distance to object}}{\frac{1}{o}}$$



Point source
at f (focal point
or focal length)

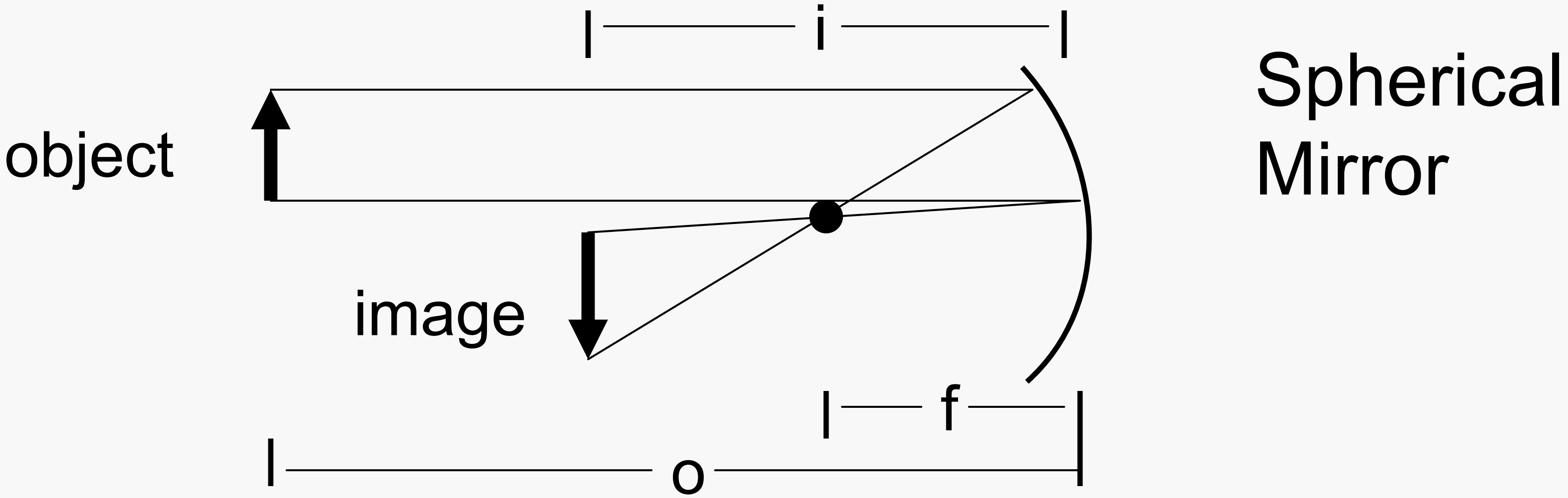
Parallel
beams

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 ~ $1/(f/)^2$

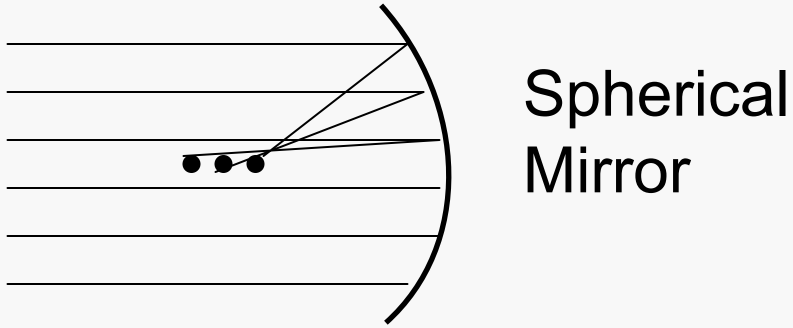
Mirrors – high quality instruments use front-surfaced mirrors for focusing which avoids chromatic aberrations



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

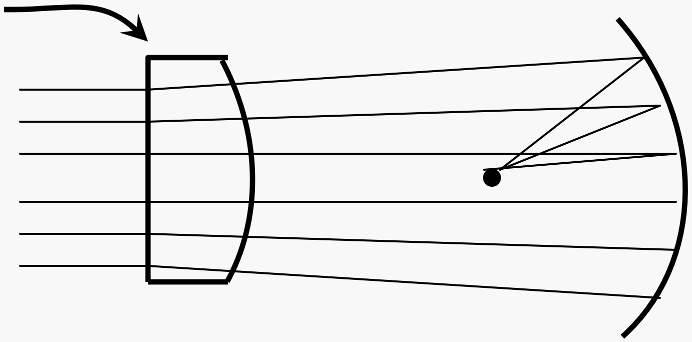
Problem → spherical aberrations

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



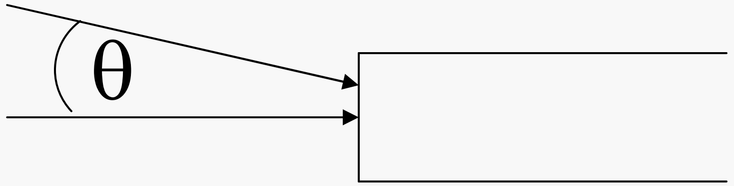
Several solutions:

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

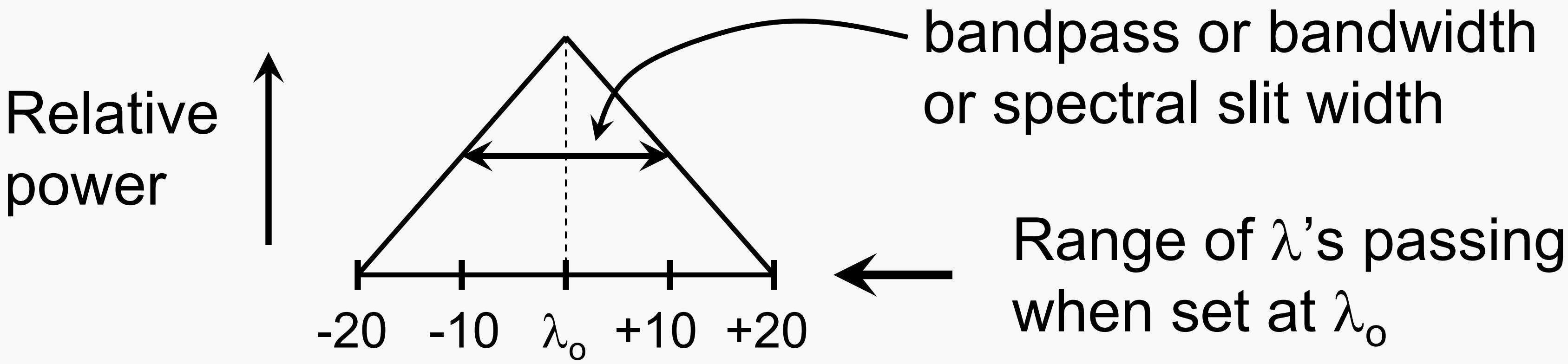
Open slits wider → increase signal (throughput) but lose resolution

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

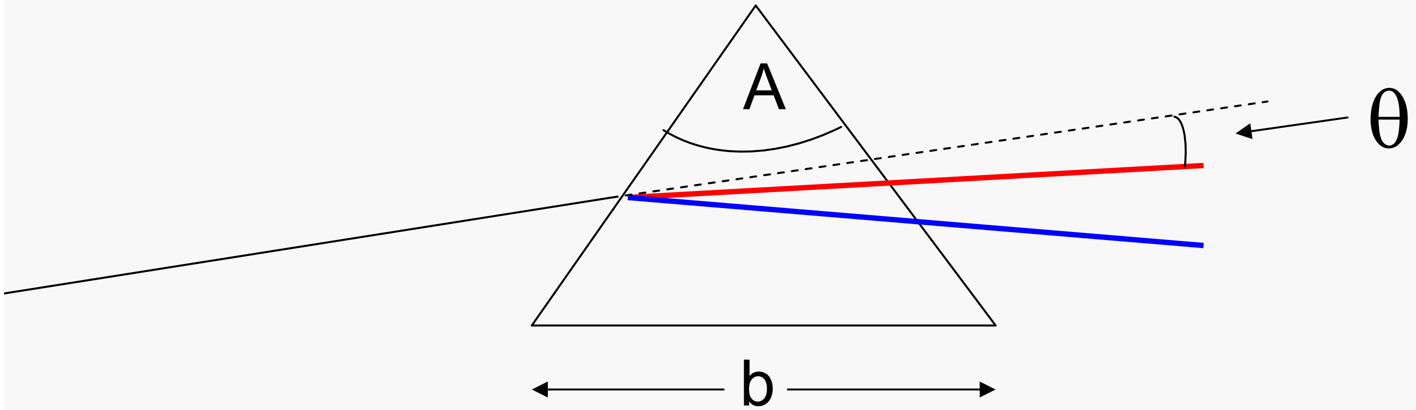
Good criterion for comparing optical systems

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)

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

function of prism material

Angle changes with λ → the larger the better

Dispersion Devices

1) Prisms

A = apical angle
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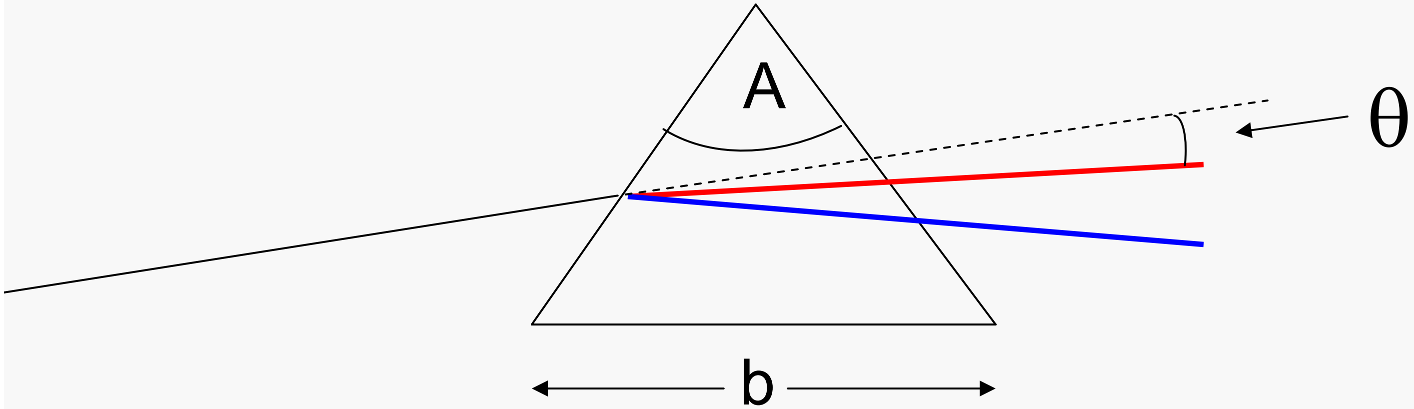

Increasing A → $\frac{d\theta}{d\eta}$ increases but internal reflection is also greater (typical A value is 60^o)

Dispersion Devices

1) Prisms

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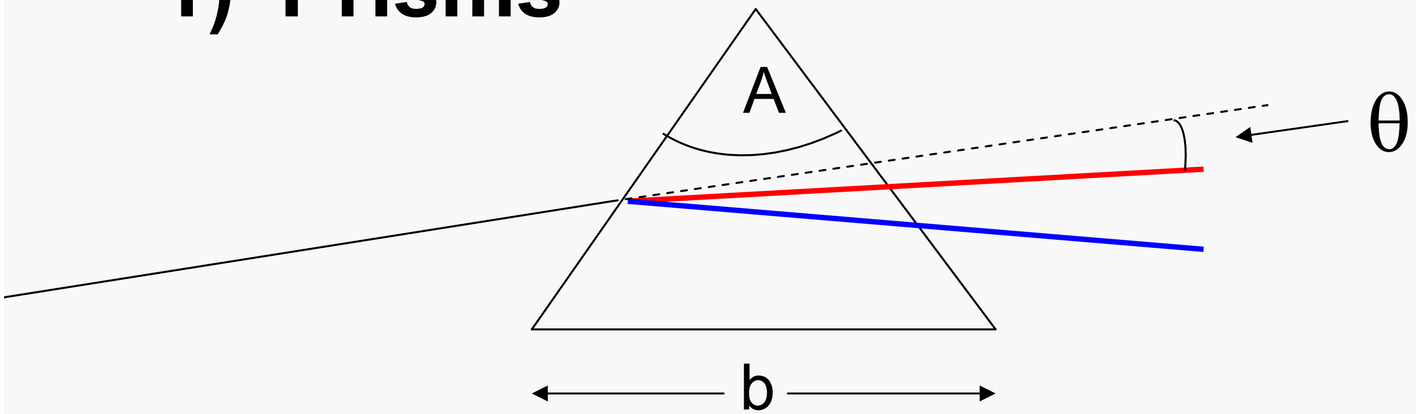
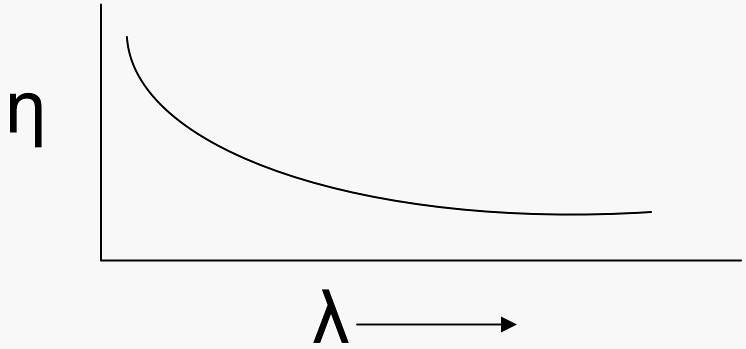
b = base length



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



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

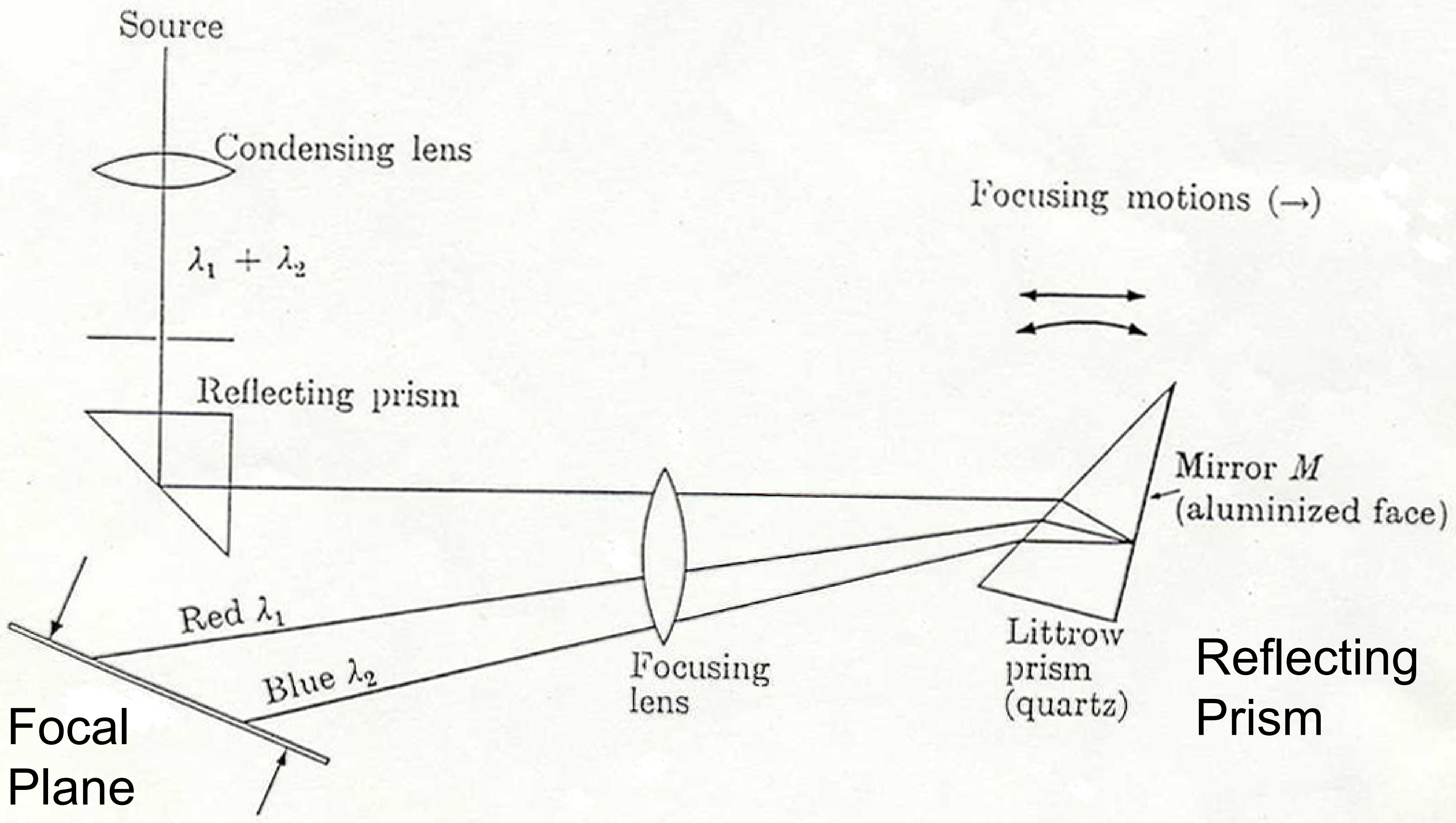
Depends on angular dispersion and focal length

For constant bandwidth, slit widths must be varied with λ to compensate for variations in $d\eta/ d\lambda$

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

Kinds of Prisms

Littrow Prism & Mounting – compact design

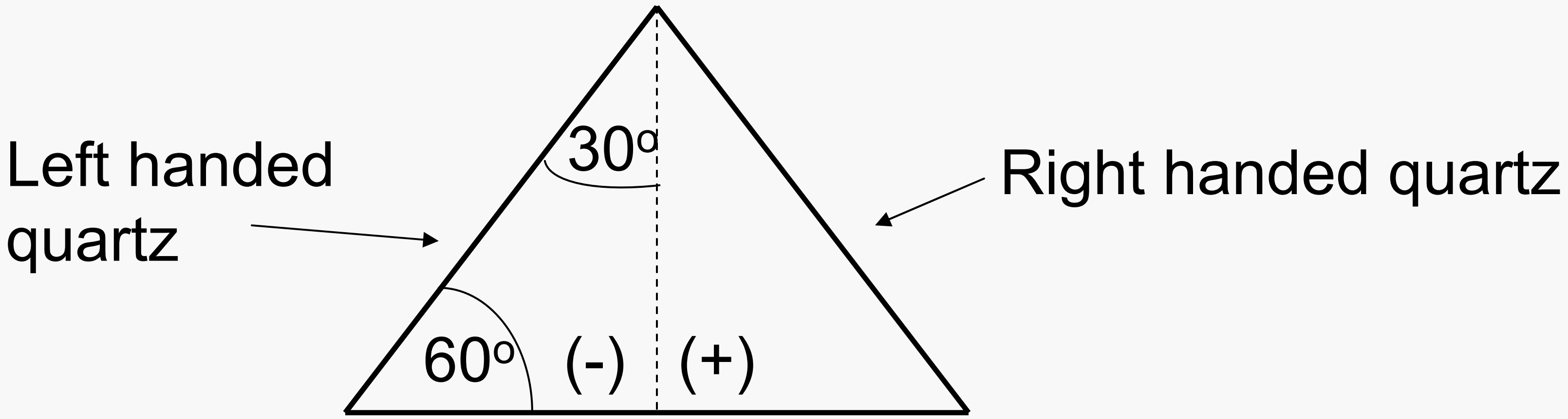


Reflecting
Prism

Focal
Plane

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.

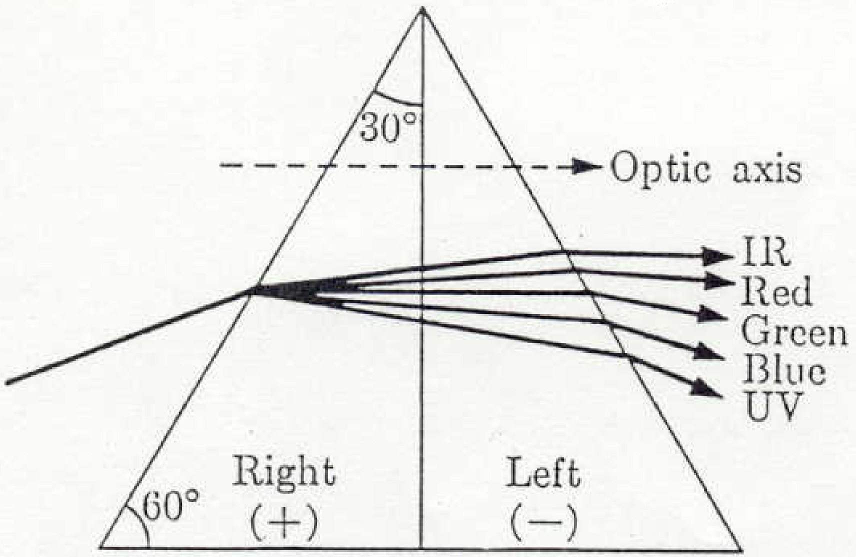
Lens Summary:

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

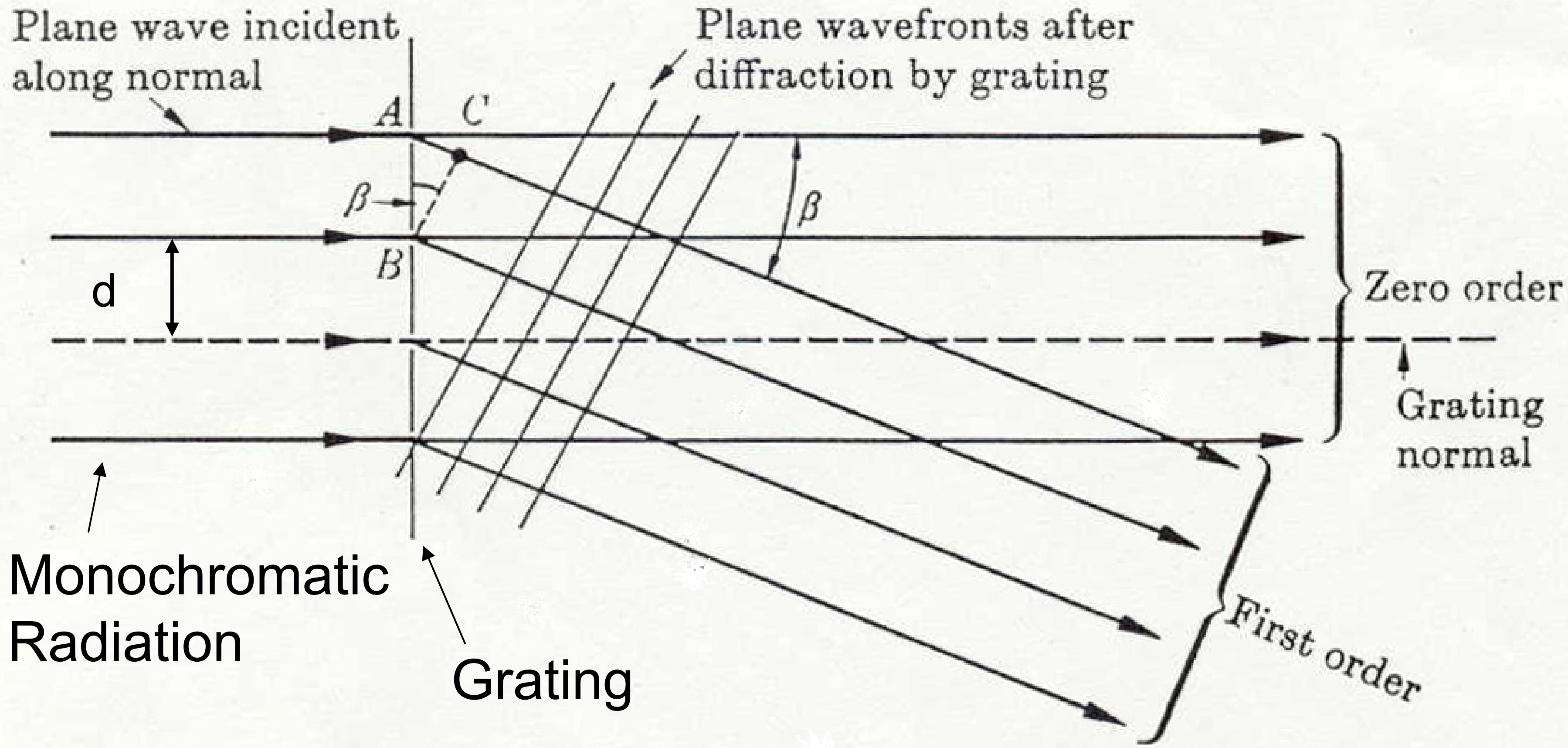
Another view of a Cornu prism



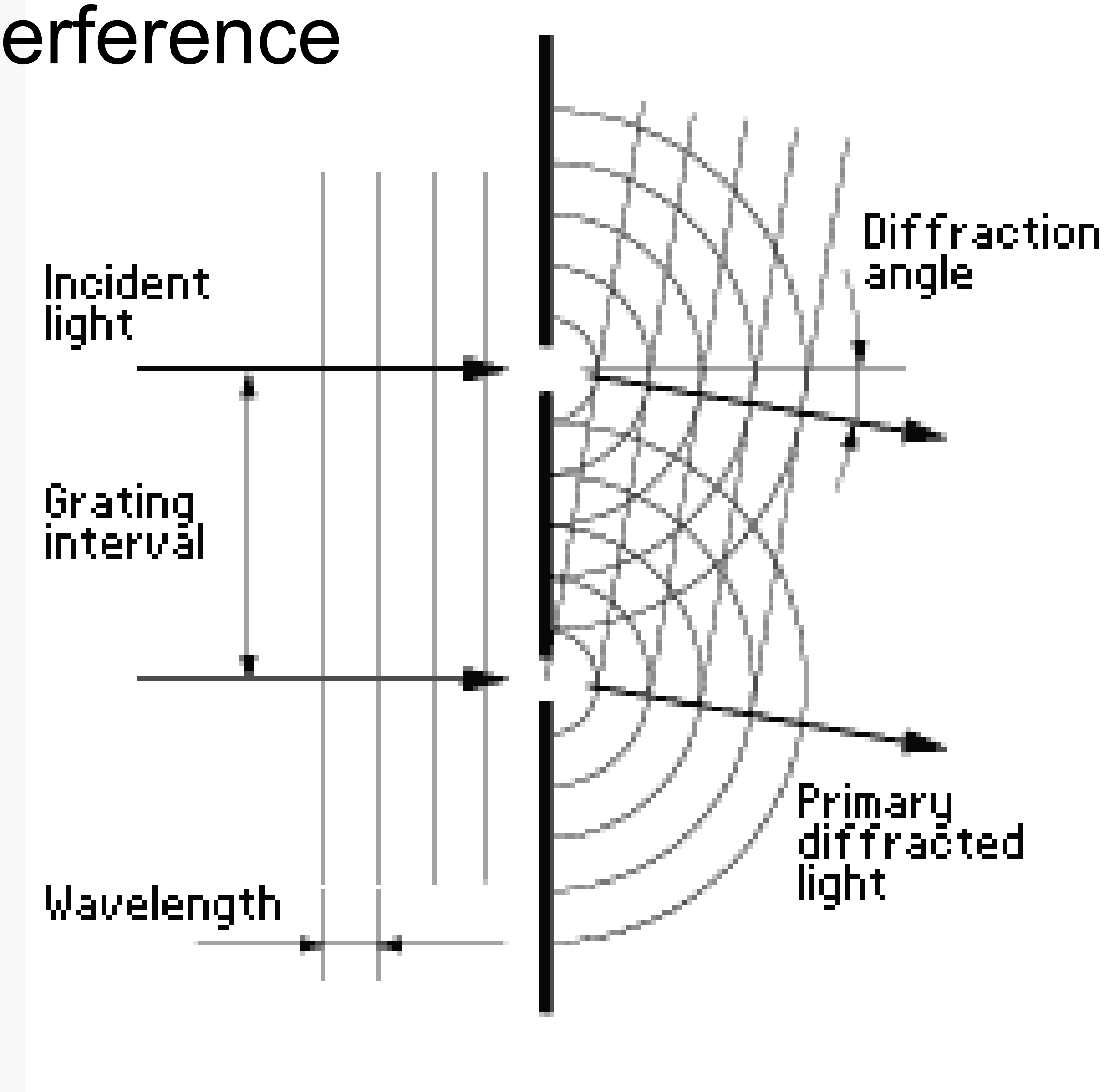
Cornu prism of quartz. The circular double refraction (not shown) produced by the first half is just offset by the equal and opposite effect in the second half. Two overlapping spectra would result if the prism were all of one kind of crystalline quartz.

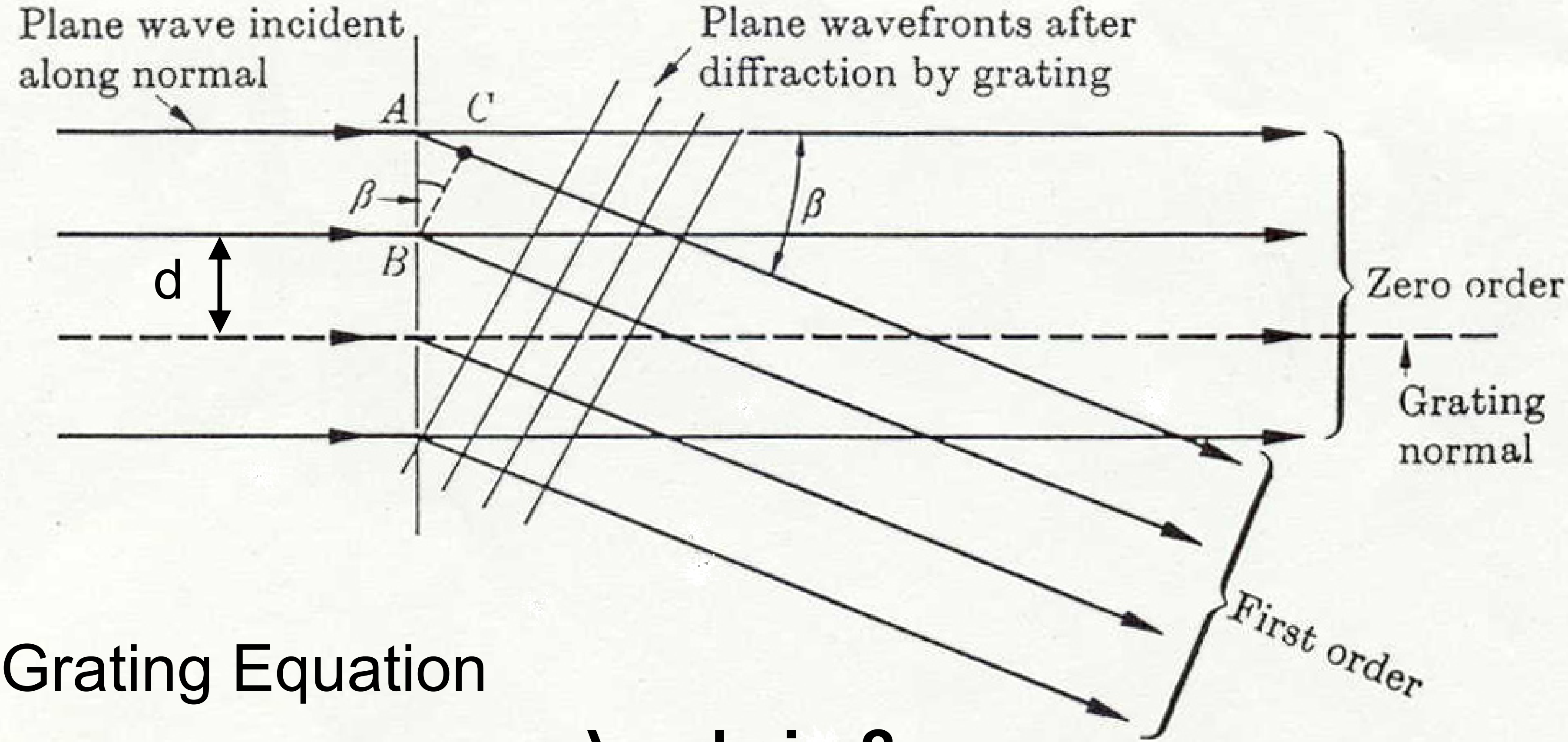
Gratings – based on diffraction & interference

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

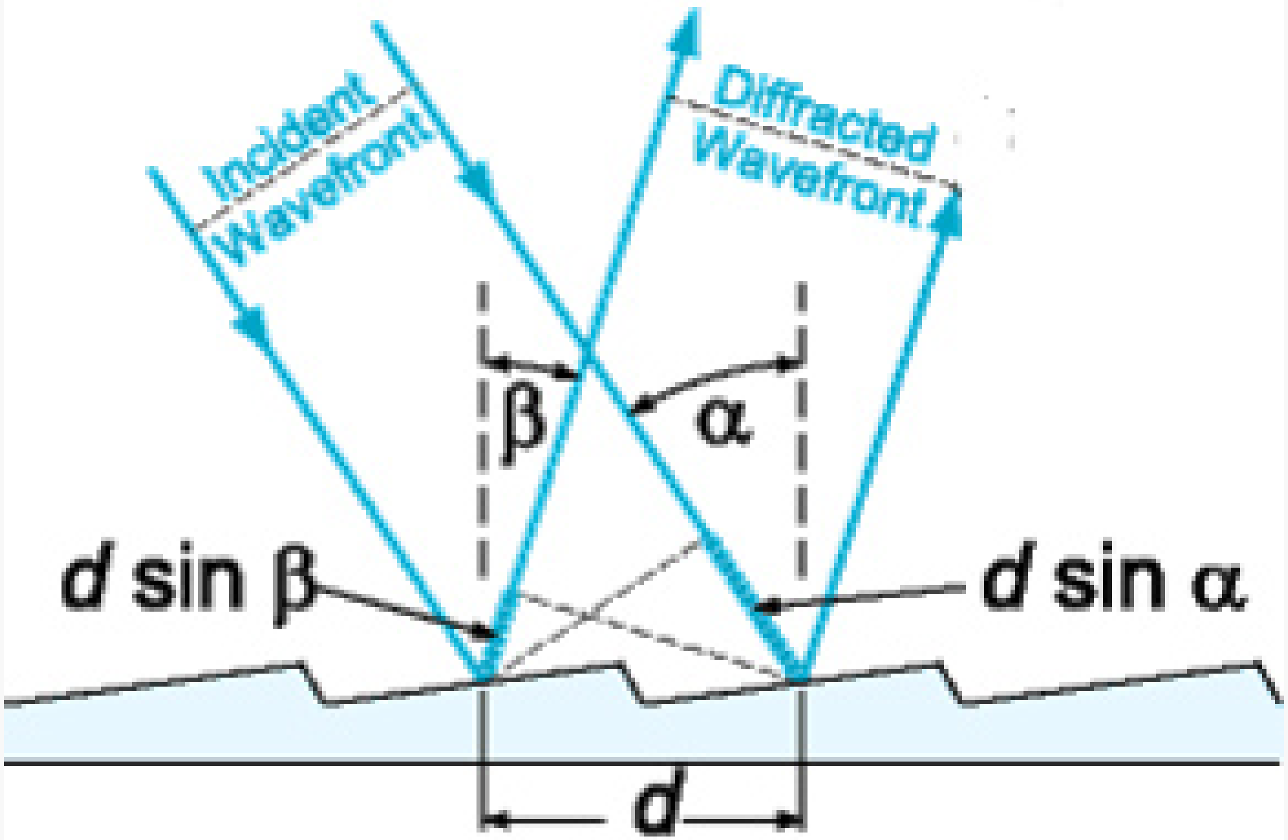
$$m \lambda = d \sin \beta$$

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



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