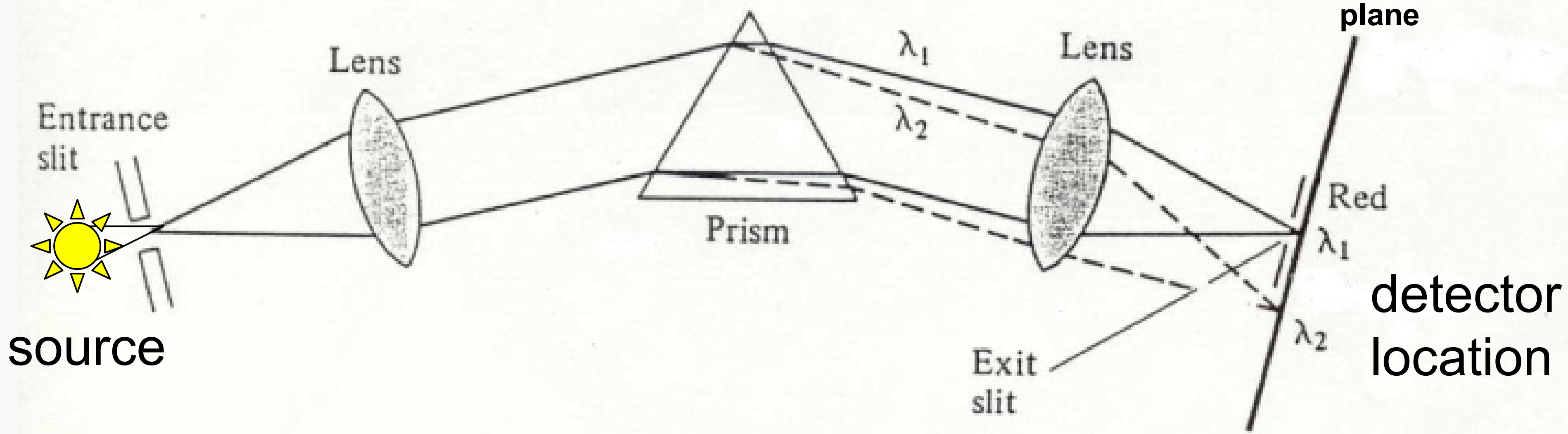
Skoog – Chapter 7
Components of Optical Instruments

- General Design of Optical Instruments
- Sources of Radiation
- **Wavelength Selectors (Filters, Monochromators, Interferometers)**
- Sample Containers
- Radiation Transducers (Detectors)
- Signal Processors and Readouts
- Fiber Optics

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

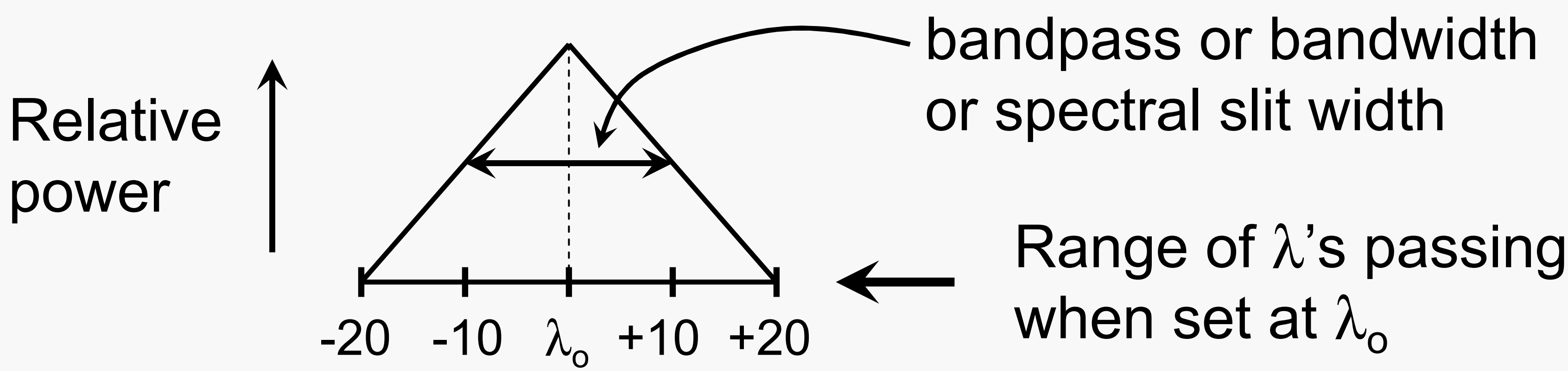
Angular Dispersion – angular range $d\theta$ over which waveband $d\lambda$ is spread → $\dfrac{d\theta}{d\lambda}$ in $\dfrac{\text{rad}}{\text{nm}}$

Linear Dispersion – distance dx over which a waveband dλ is spread in the focal plane of a monochromator → $\frac{dx}{d\lambda}$ in $\frac{mm}{nm}$

Linear Reciprocal Dispersion – range of λ's spread over a unit distance in the plane of a monochromator → $\frac{d\lambda}{dx}$ in $\frac{nm}{mm}$

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

Light exiting a monochromator exit slit has a triangular distribution



Optical Efficiency = throughput x resolution

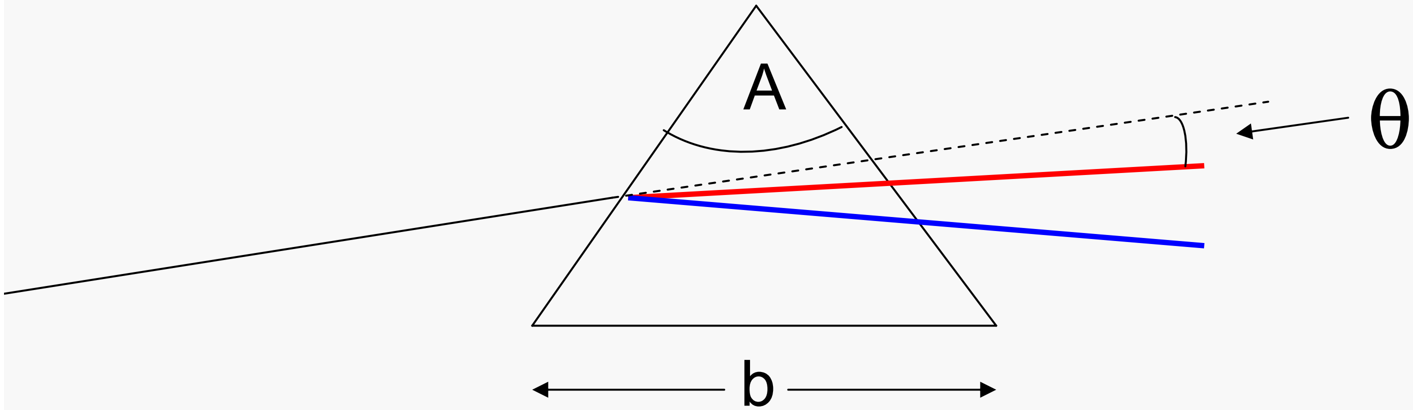
Good criterion for comparing optical systems

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)

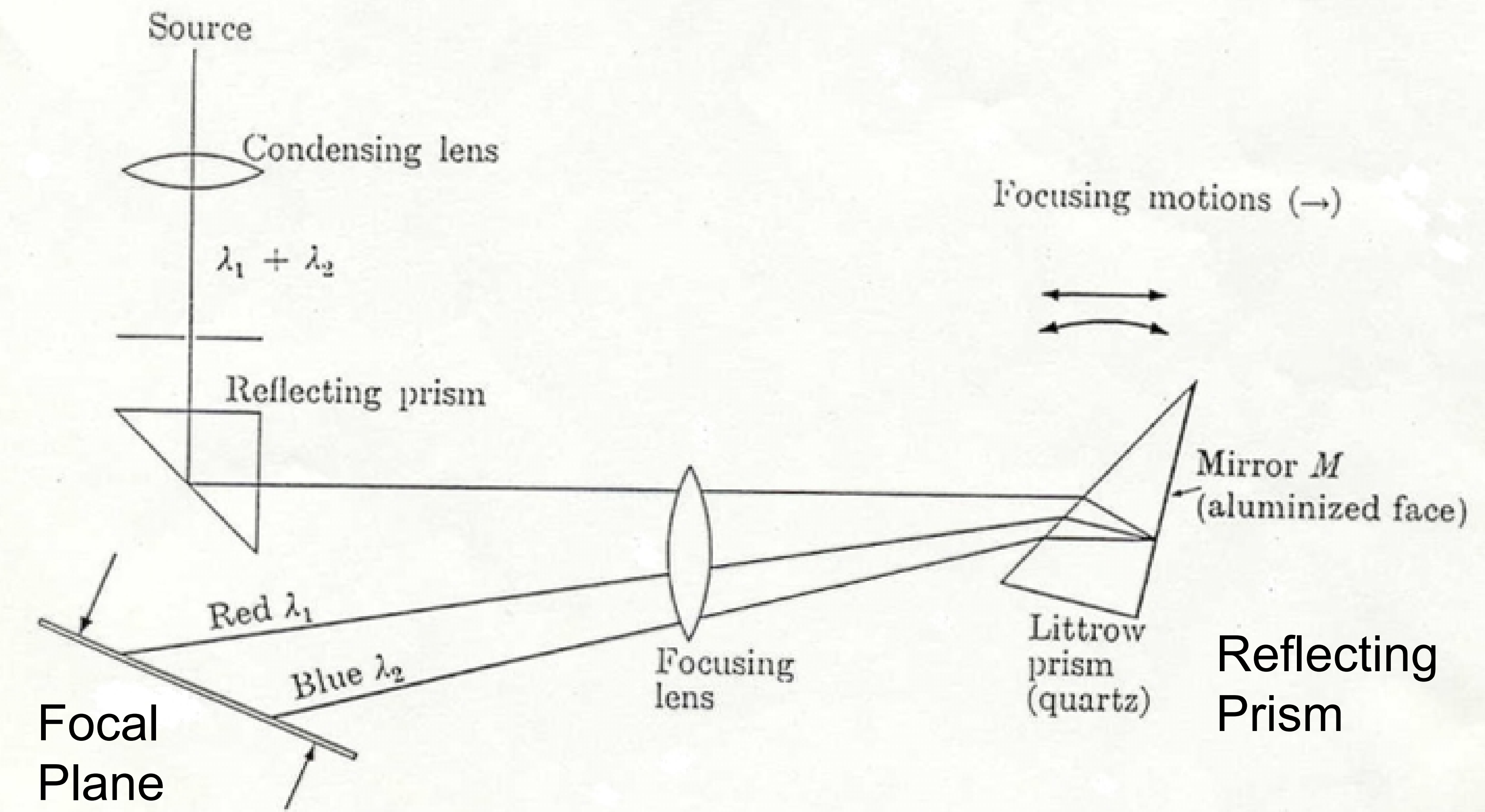
$$\underline{\text{Angular Dispersion}} = \frac{d\theta}{d\lambda} = \frac{d\theta}{d\eta} \times \frac{d\eta}{d\lambda}$$

function of prism material

Angle changes with λ → the larger the better

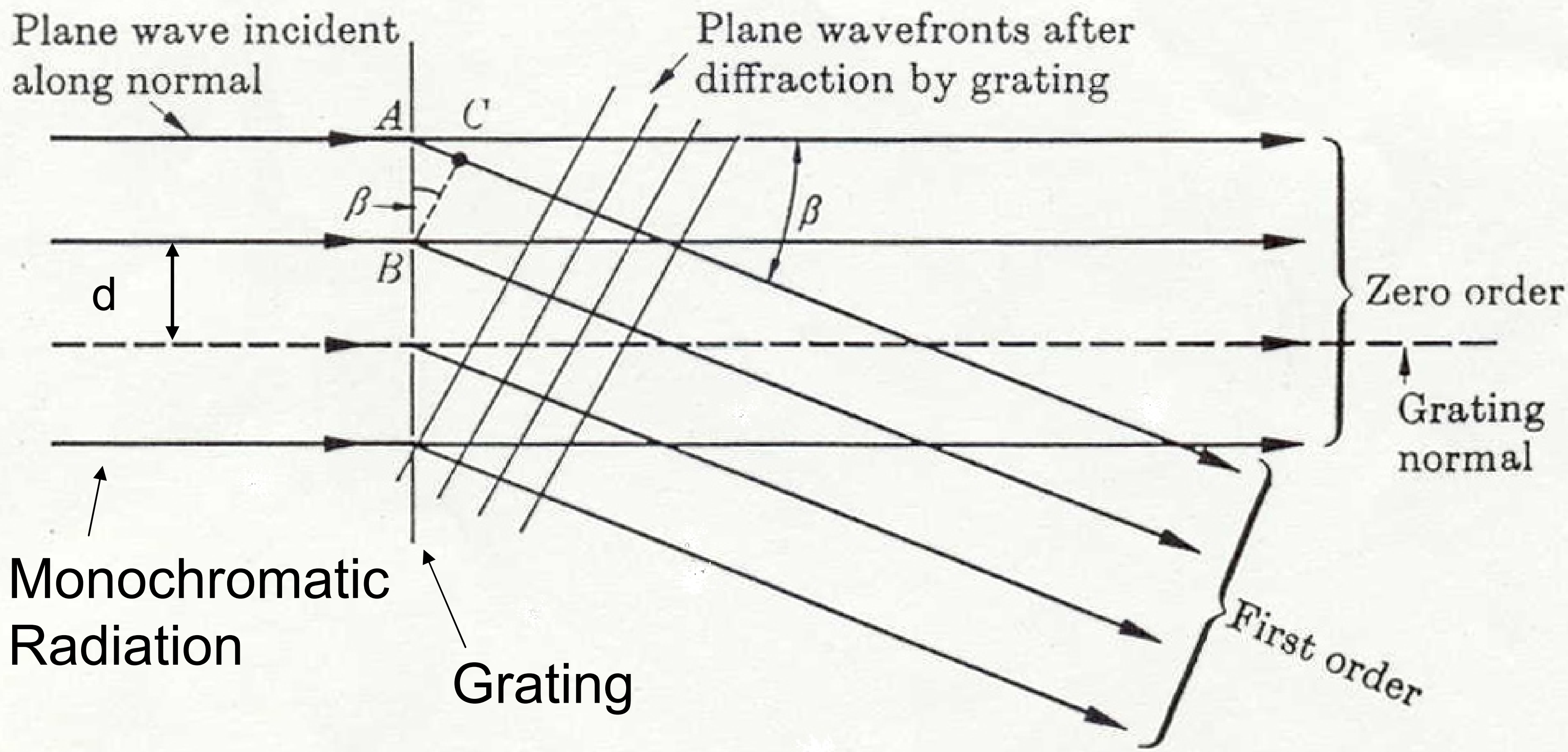
Kinds of Prisms

Littrow Prism & Mounting – compact design

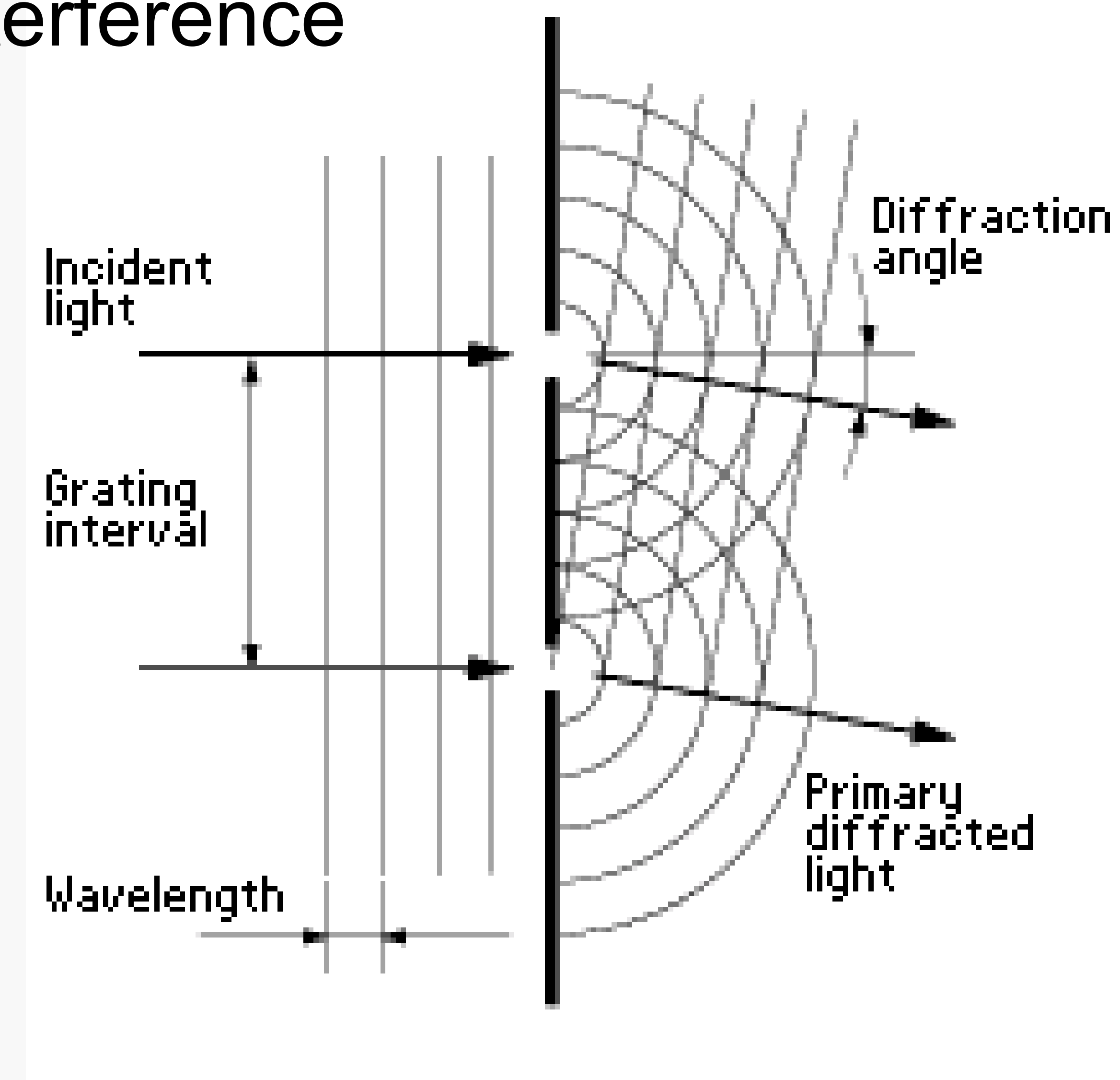


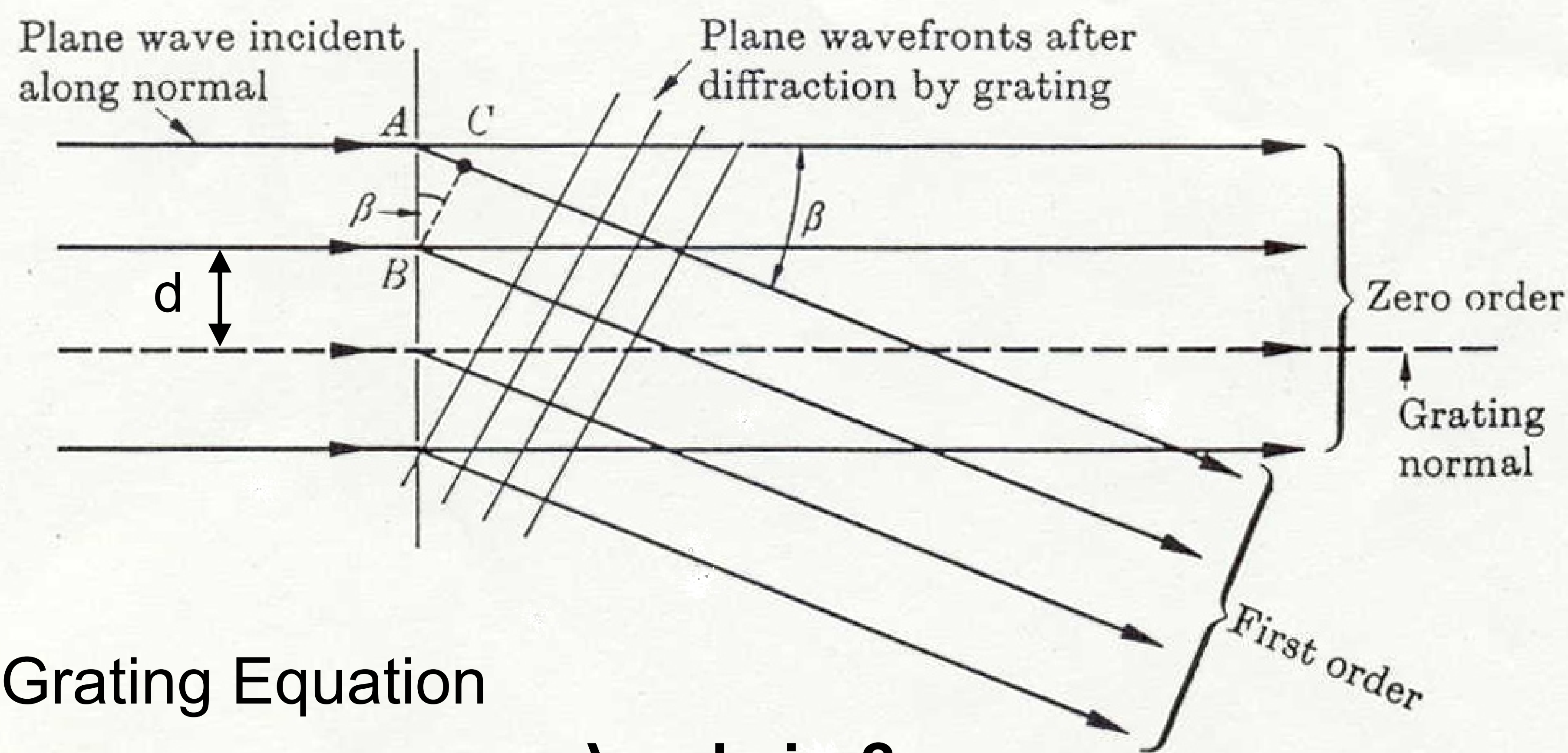
Gratings – based on diffraction & interference

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

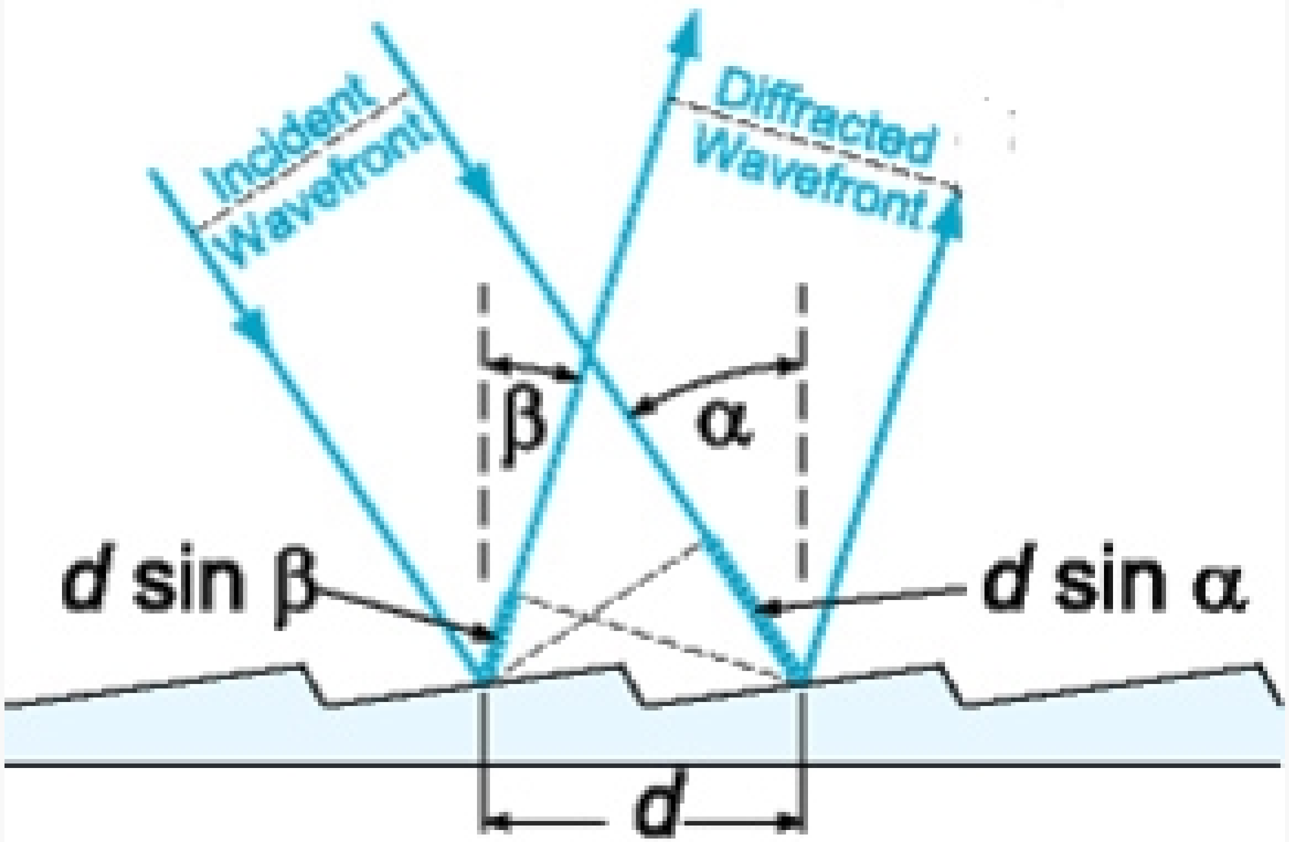
$$m \lambda = d \sin \beta$$

Condition for constructive interference

AC = extra distance light travels for first order = d sin β

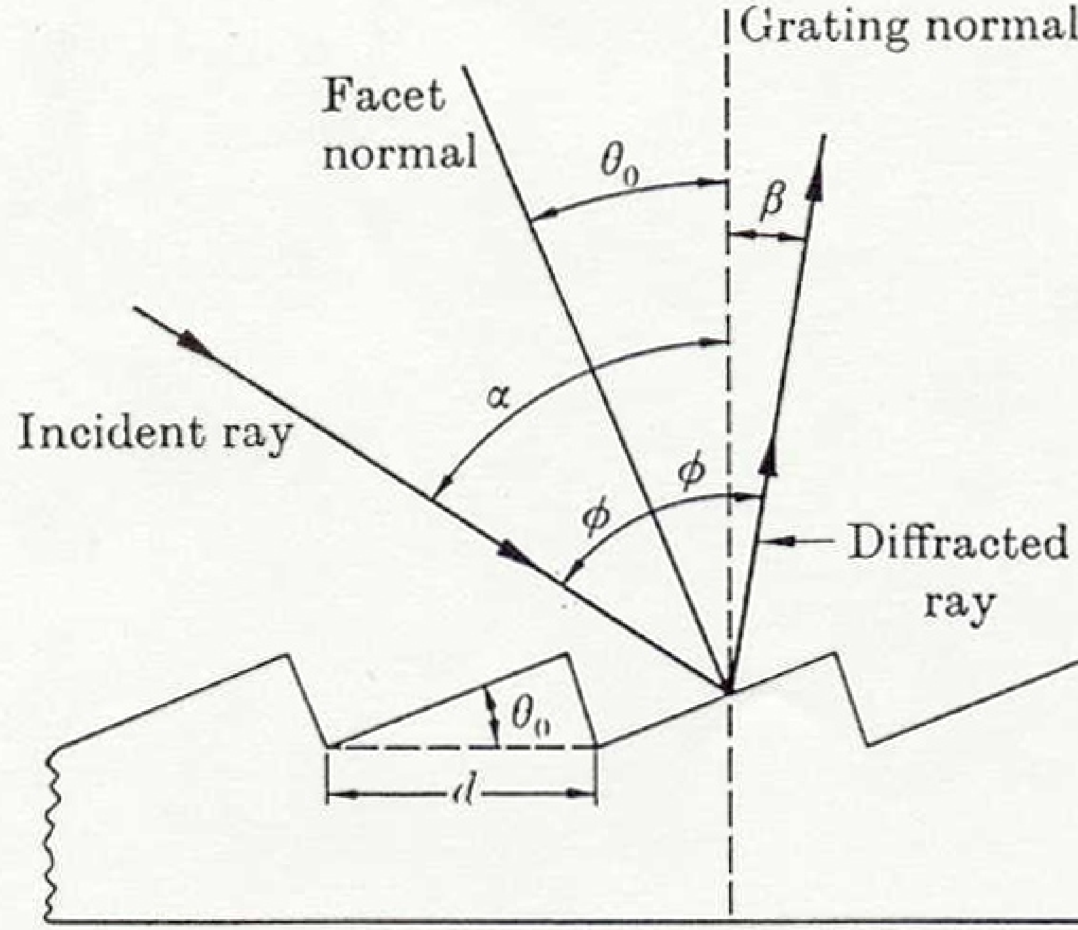
For higher orders the distance gets longer

Reflection grating with non-normal incidence



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

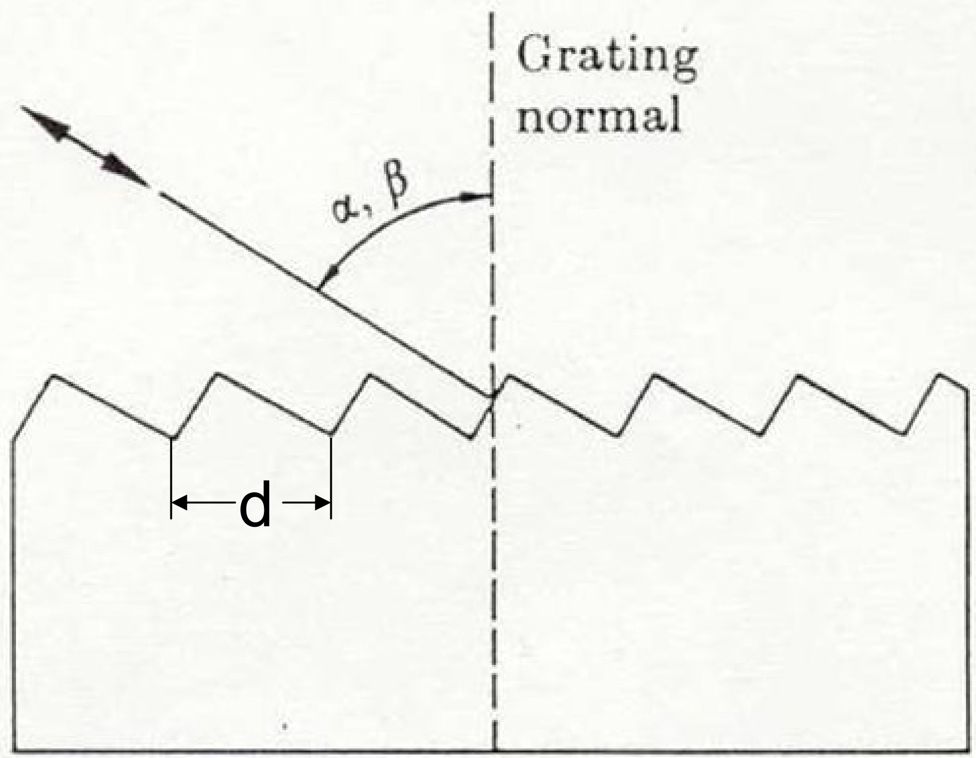
Reflection grating with non-normal incidence (another view)



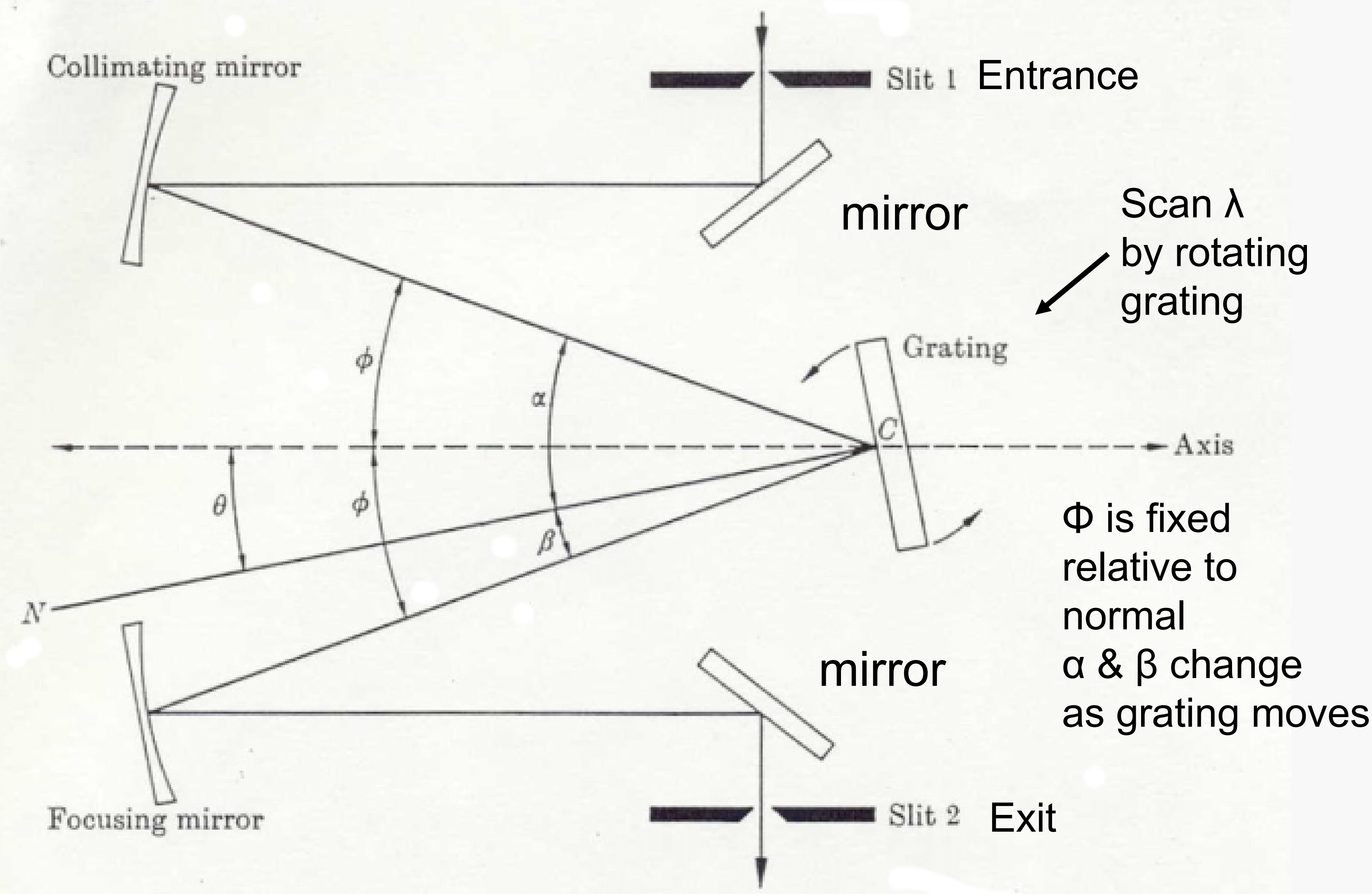
Φ is fixed relative to facet (or step) normal, α & β change depending on incident radiation relative to grating normal

Efficiency is maximum for situation where diffracted ray & specularly reflected ray coincide = blaze wavelength = λ_B = λ of maximum efficiency

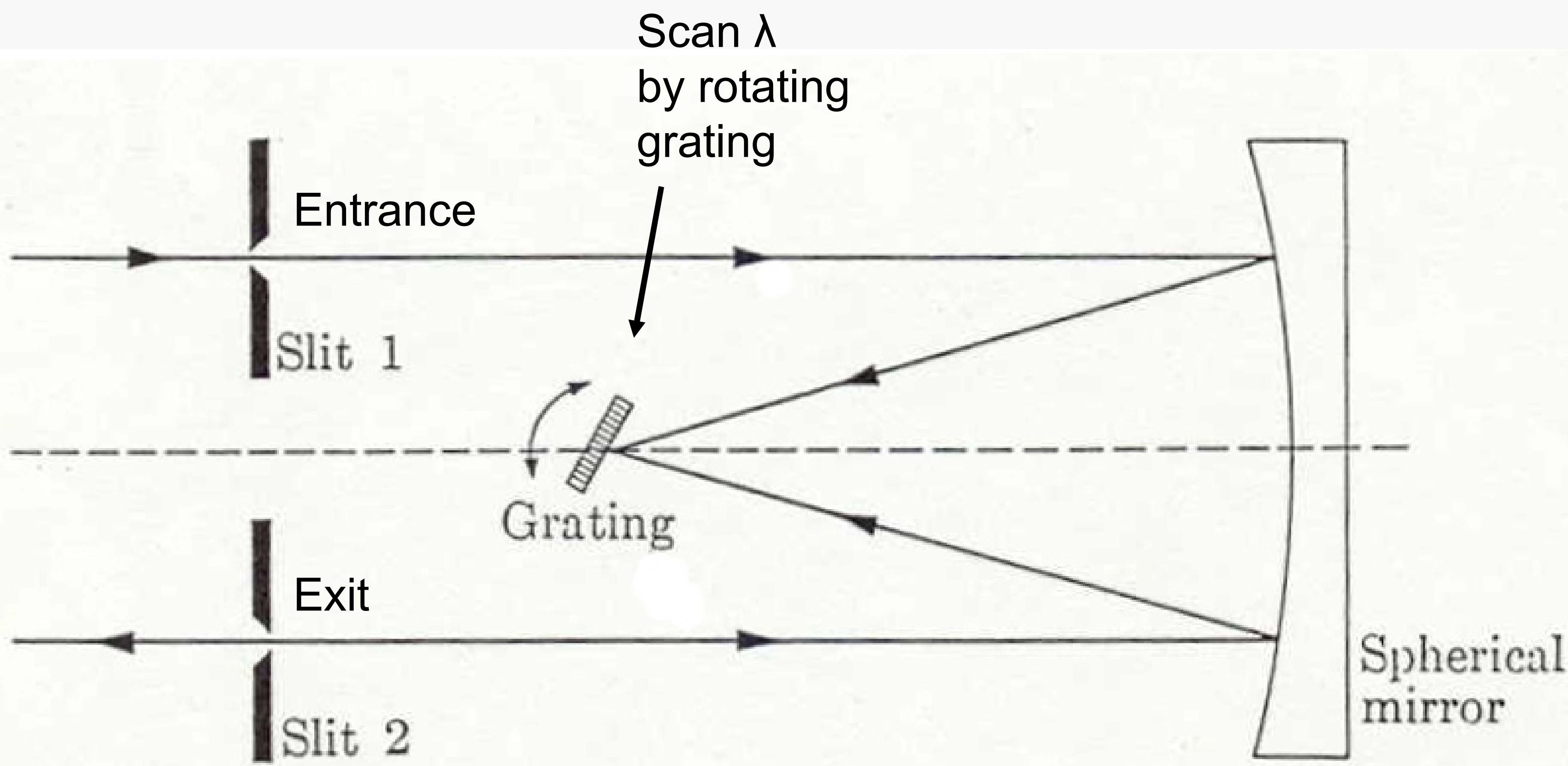
An Echelle type reflection grating has a coarse ruling (i.e. large d) and produces good spectral efficiency in higher orders making very high resolution posible



Mountings for Gratings – Czerny-Turner



Mountings for Gratings – Ebert Mounting



Littrow mounting is the same as for prism except use grating in place of prism

Grating Characteristics – Resolution & Dispersion are very high for a long, finely ruled grating

Resolution (theoretical)

order

number of rulings illuminated

$$R = m\,N$$

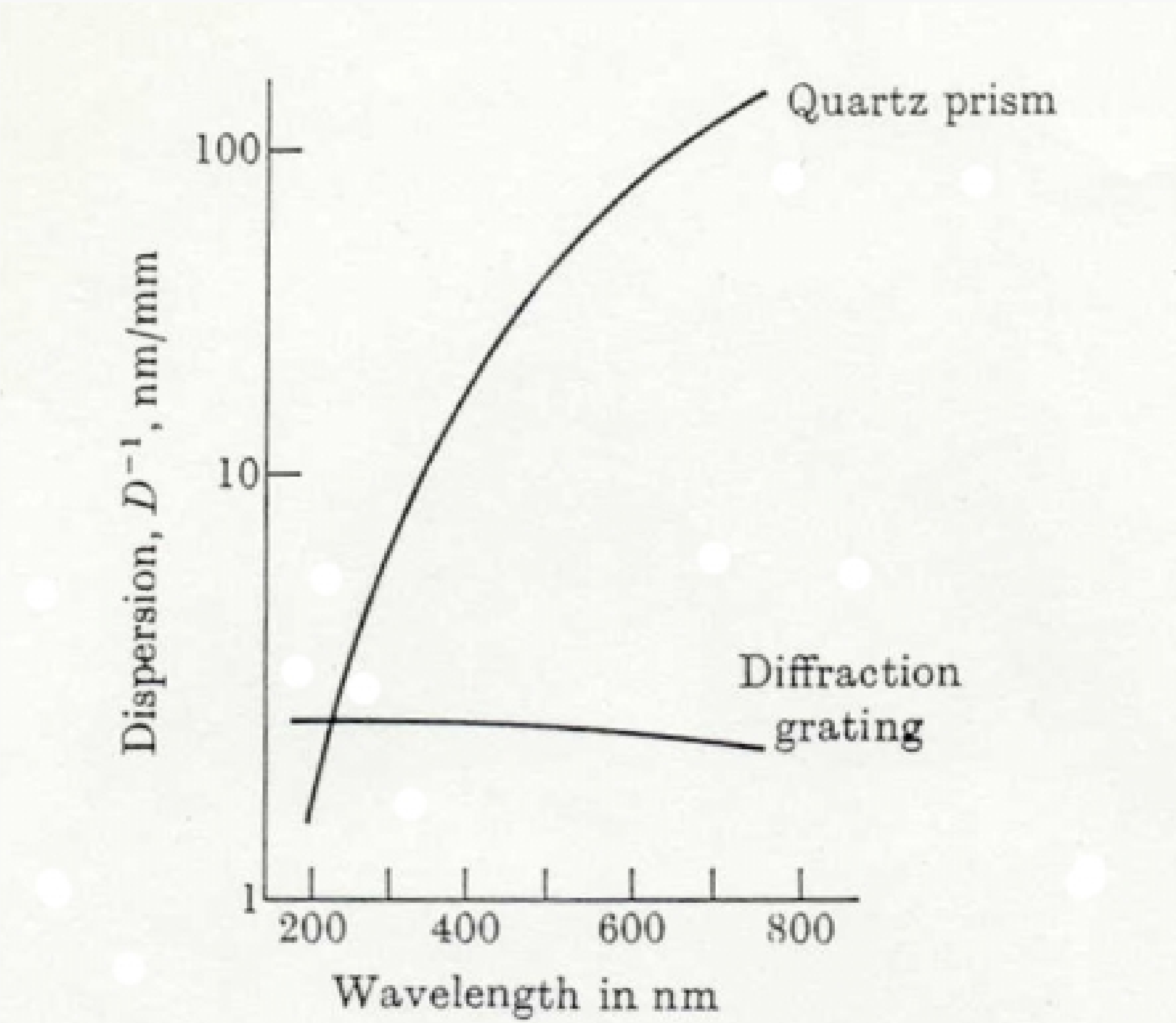
Combine with grating equation (given previously)

$$R = W\,(\sin \beta) / \lambda$$

where W (length of ruled area) = N d

The length of ruled area is important

Dispersion - almost constant with wavelength for grating (an advantage over prisms)



Don't have to change slits to get constant bandpass across spectrum

Disadvantages of gratings relative to prisms:

1) they are less rugged

2) they generate slightly more scattered light which is stray light → radiation present at unwanted orders

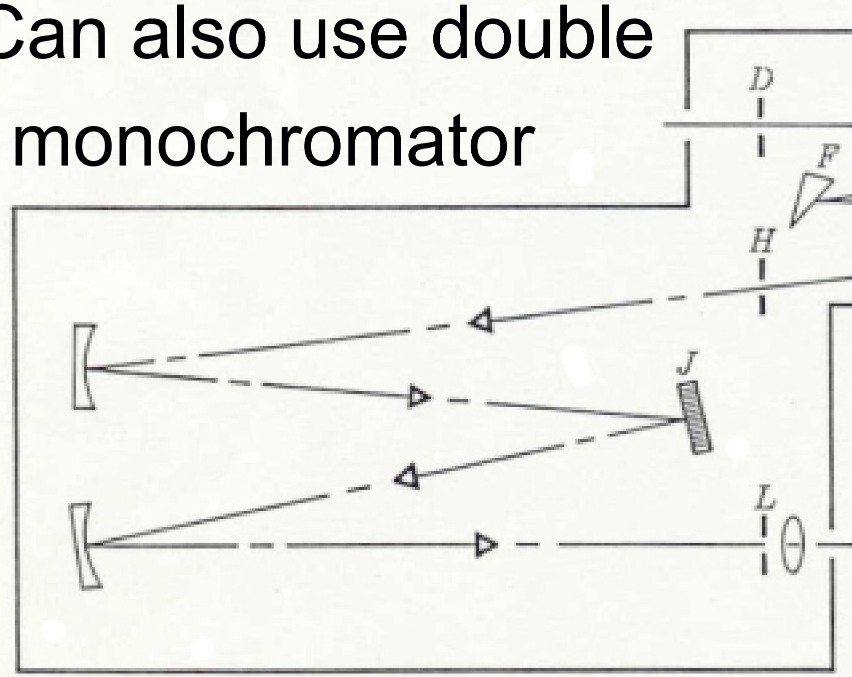
3) order overlap → multiples of λ present

Stray Radiation sources:

1) Diffracted from grating at unwanted angle
2) Diffracted from slit edges
3) Reflected from interior surfaces of filters, lenses, prisms & other components of system
4) Scattered by imperfections in optical components

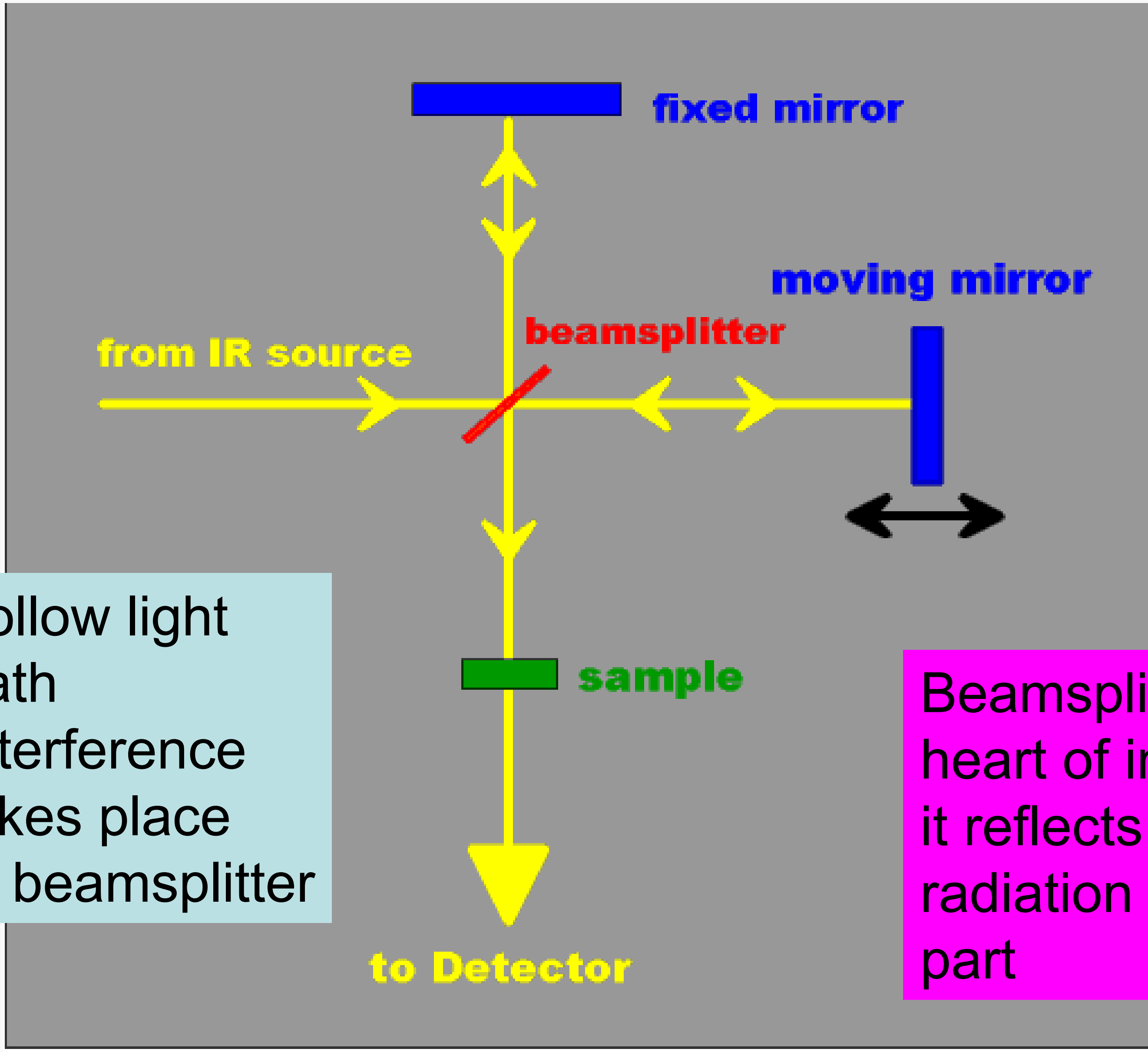
Methods of reducing stray light:

1) Paint interior black
2) Use baffles to obstruct stray radiation
3) Use high quality components
4) Keep out dust and fumes
5) Can also use double monochromator



Cary 14 & 17 UV-vis monochromator with very high stray light rejection

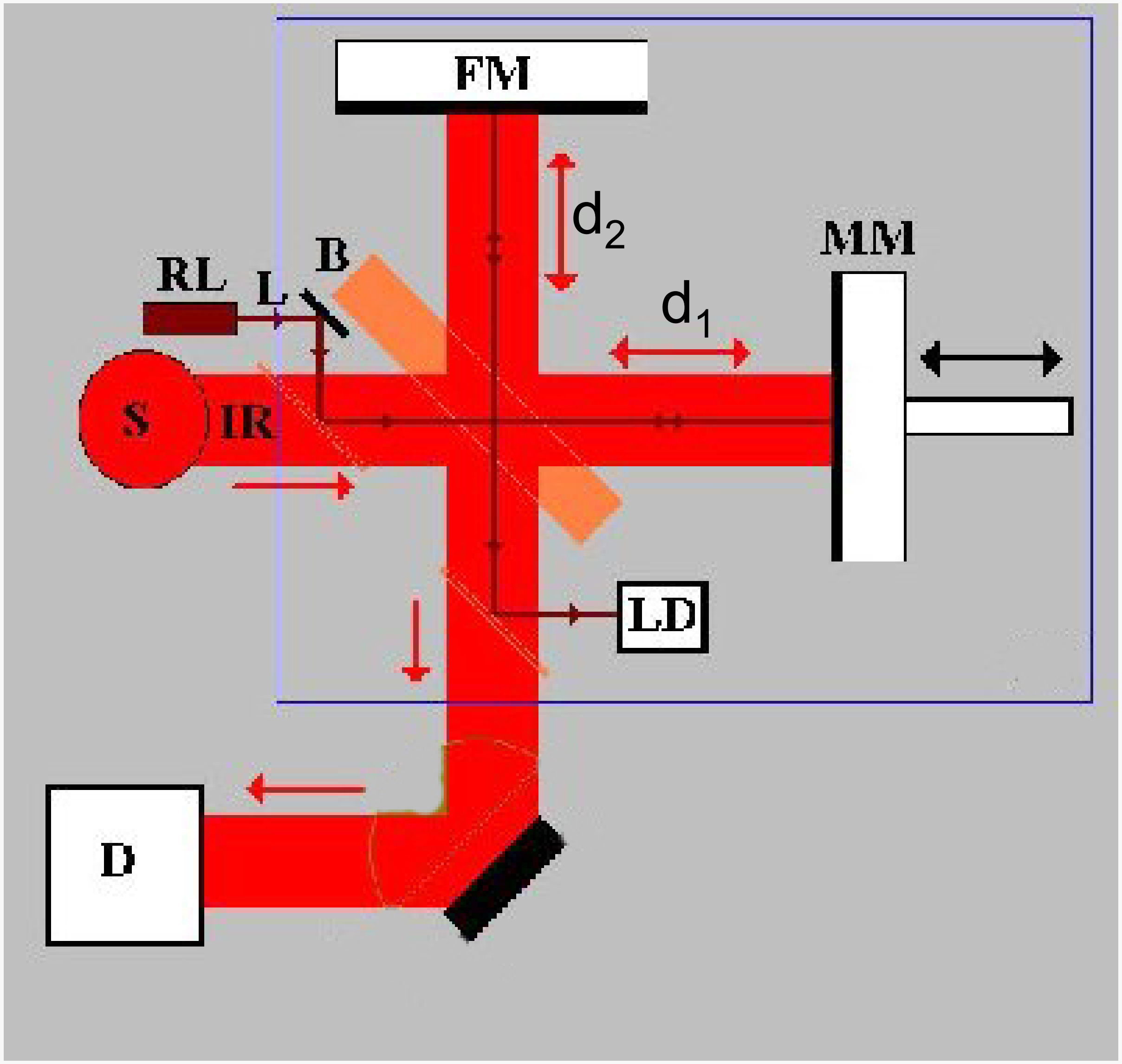
Basic diagram of a Michaelson Interferometer



Follow light path
Interference takes place at beamsplitter

Beamsplitter is at the heart of interferometer, it reflects part of the radiation & transmits part

Michaelson Interferometer as commonly used in an FTIR



Where:

S = IR source

IR = infrared beam

D = detector

B = beamsplitter

FM = fixed mirror

MM = moving mirror

RL = reference laser

L = laser beam

LD = laser detector

d_1 = distance to moving mirror

d_2 = distance to fixed mirror

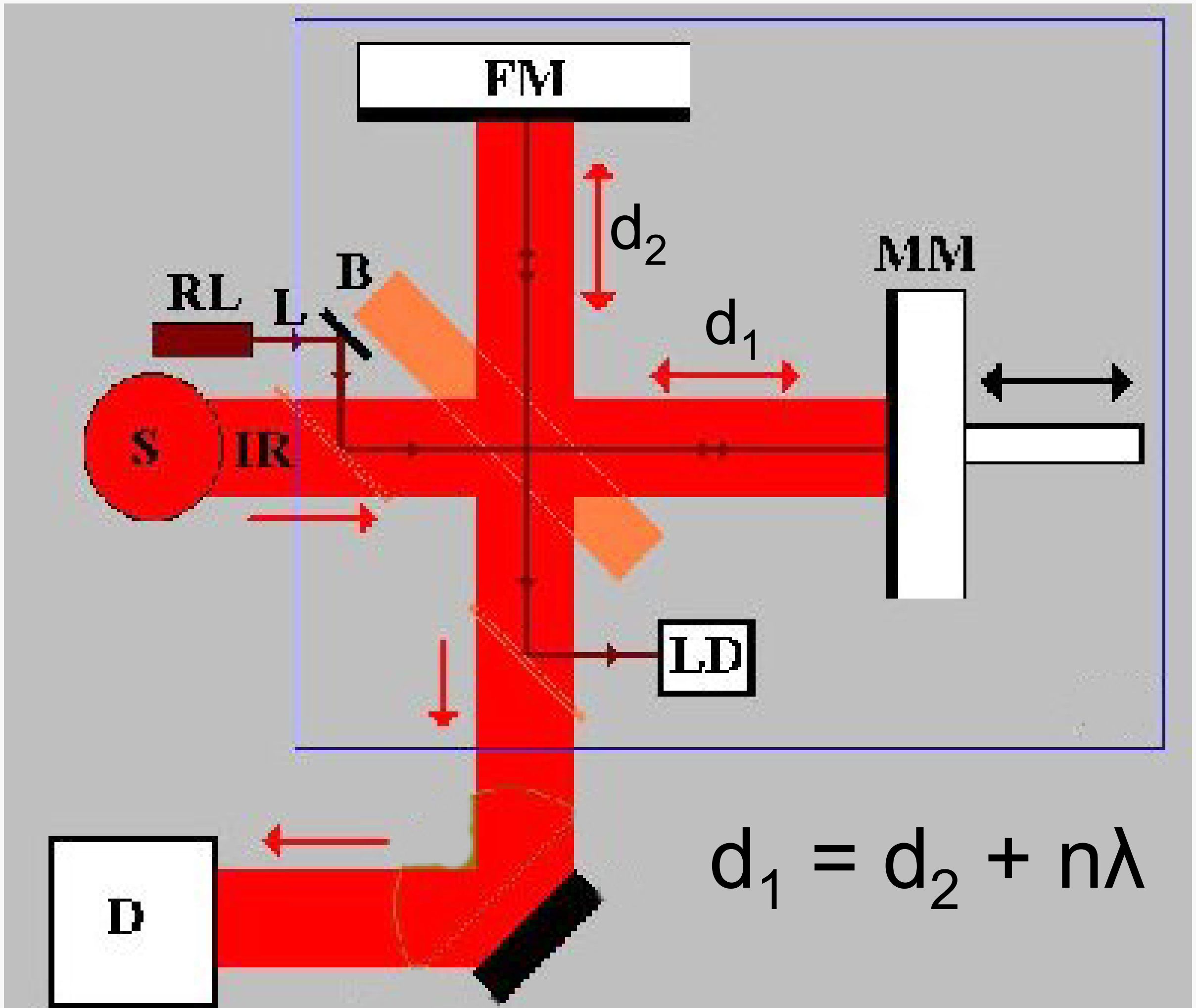
Interferometers have no slits so a wide beam of radiation can be used

Assuming monochromatic radiation

$d_1 = d_2 + n\lambda$ → for constructive interference

$d_1 = d_2 + n\lambda + ½\lambda$ → destructive interference

Michaelson Interferometer as commonly used in an FTIR



$$d_1 = d_2 + n\lambda$$

$$d_1 = d_2 + n\lambda + \tfrac{1}{2}\lambda$$

Where:

S = IR source

IR = infrared beam

D = detector

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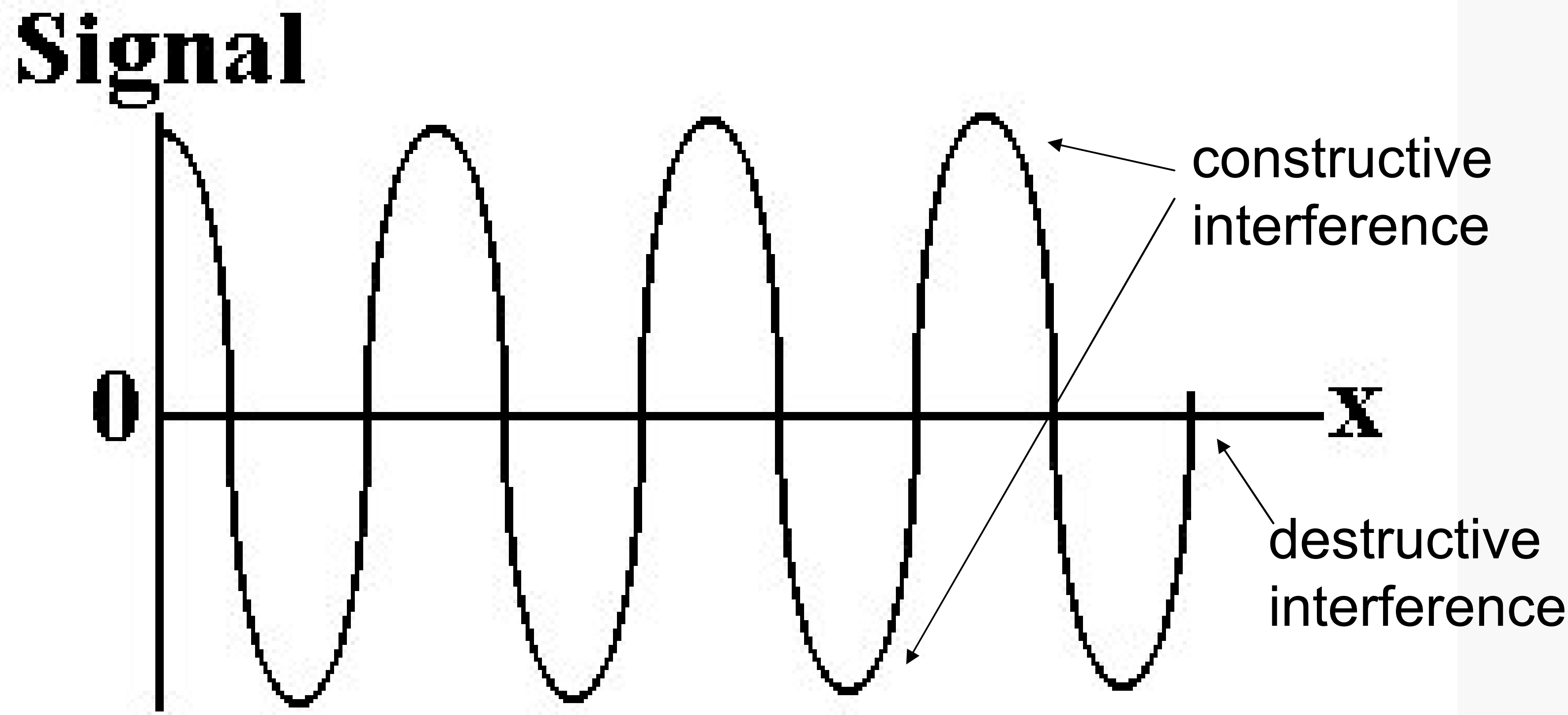
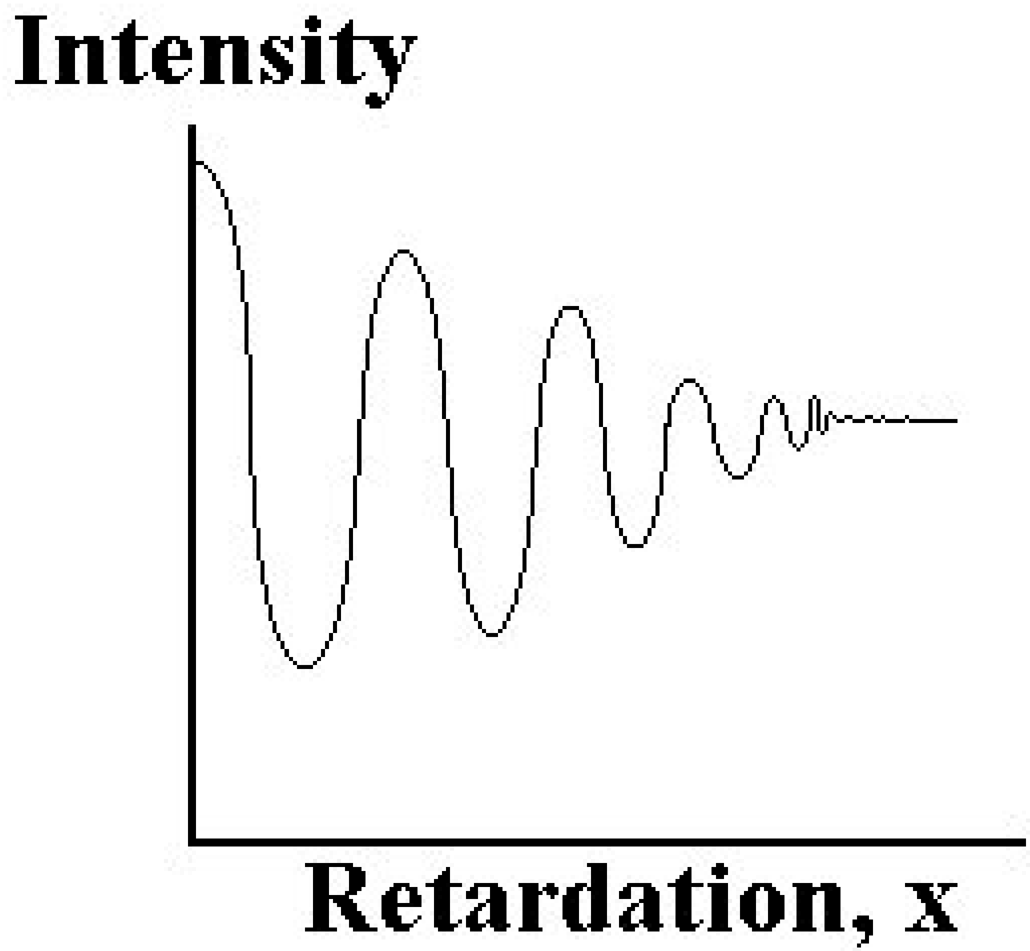
Reference laser signal as it passes through the interferometer



This allows the position of the moving mirror to be determined accurately

Interferogram is a plot of energy vs mirror displacement from zero (i.e. $d_1 = d_2$)



This is for polychromatic radiation

Mechanical specifications for mirror movement are very exacting → gets worse as λ gets shorter, therefore interferometers are used in the IR region but are not very feasible in the visible and UV regions

Extracting a conventional spectrum (i.e. I vs λ) from interferogram involves the complex mathematics of the Fourier integral also known as Fourier Transform → need computer to do calculations

Advantages of Interferometers:

1) Energy throughput is much grater than for monochromators → better signal to noise ratio because there are no slits – this is particularly important in IR where the sources are relatively weak
2) Multiplex Advantage – all signals are viewed simultaneously

Disadvantage: Mechanical tolerance for mirror movement is severe – can't do interferometry in the UV-vis region, λ too short

DETECTORS

Important characteristics:

1) Wavelength response
2) Quantum response – how light is detected
3) Sensitivity
4) Frequency of response (response time)
5) Stability
6) Cost
7) convenience