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 $\rightarrow d\theta \quad \text{rad} \quad \frac{-----}{d\lambda} \quad \text{in} \quad \frac{-----}{\text{nm}}$
Linear Dispersion – distance $dx$ over which a waveband $d\lambda$ is spread in the focal plane of a monochromator $\rightarrow$ $dx$ mm

----- in  --------

$d\lambda$ nm

Linear Reciprocal Dispersion – range of $\lambda$’s spread over a unit distance in the plane of a monochromator $\rightarrow$ $d\lambda$ nm

----- in  --------

dx mm

Related terms spectral slit width or bandwidth or bandpass = range of $\lambda$’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 < Grating < Interferometer
Monochromator Monochromator

Relative power

Range of $\lambda$’s passing when set at $\lambda_o$

bandpass or bandwidth or spectral slit width

-20 -10 $\lambda_0$ +10 +20
Dispersion Devices

1) Prisms

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

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

Angle changes with $\lambda \Rightarrow$ 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 = \( d \sin \beta \)

For higher orders the distance gets longer
Reflection grating with non-normal incidence

$$m\lambda = d \left( \sin \alpha \pm \sin \beta \right)$$
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 = $\lambda_B = \lambda$ 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 possible
Mountings for Gratings – Czerny-Turner

Collimating mirror

Entrance

mirror

Scan $\lambda$ by rotating grating

$\phi$ is fixed relative to normal
$\alpha$ & $\beta$ change as grating moves

Focusing mirror

Exit
Mountings for Gratings – Ebert Mounting

Scan $\lambda$ by rotating grating.
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)

\[ R = \bar{m} \, N \]

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 \( \rightarrow \) radiation present at unwanted orders
3) order overlap \( \rightarrow \) multiples of \( \lambda \) 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
d₁ = distance to moving mirror
d₂ = distance to fixed mirror
Interferometers have no slits so a wide beam of radiation can be used

Assuming monochromatic radiation

\[ d_1 = d_2 + n\lambda \rightarrow \text{for constructive interference} \]

\[ d_1 = d_2 + n\lambda + \frac{1}{2}\lambda \rightarrow \text{destructive interference} \]
Michaelson Interferometer as commonly used in an FTIR

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d_1 = distance to moving mirror
d_2 = distance to fixed mirror

\[ d_1 = d_2 + n\lambda \]

\[ d_1 = d_2 + n\lambda + \frac{1}{2}\lambda \]
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 $\lambda$ 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 $\lambda$) 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 greater 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