symphotic Tii corporation

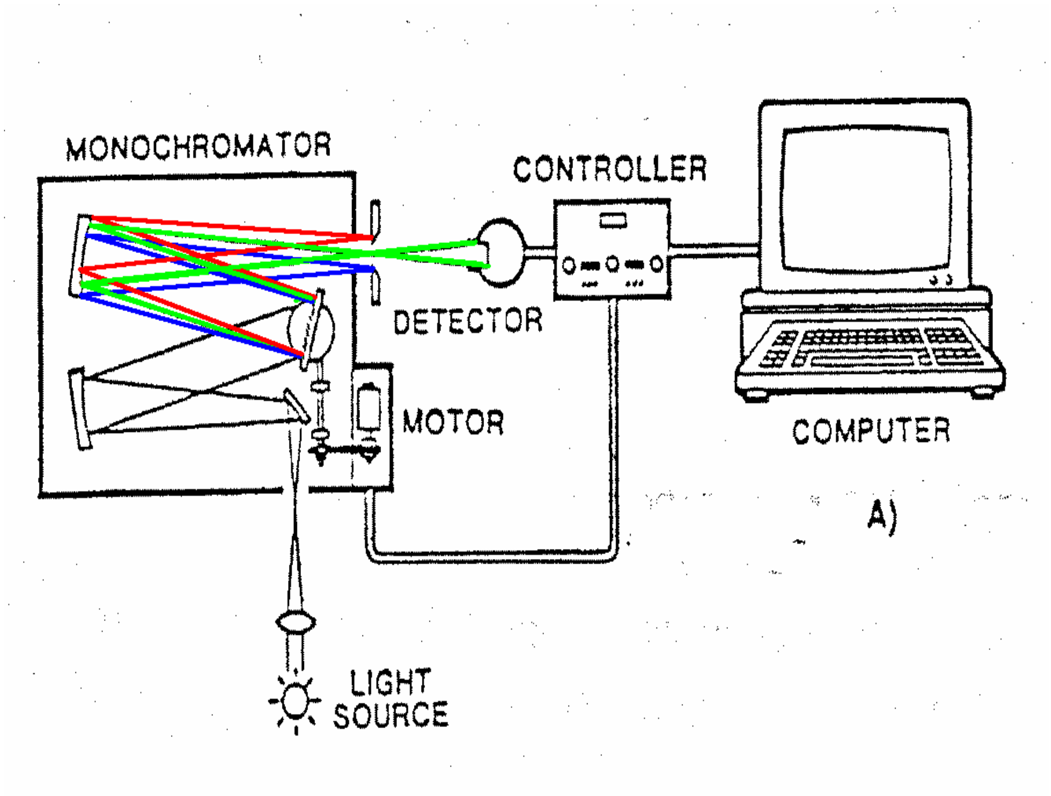
Monochromator Training

May, 2002

www.symphotic.com

Monochromator

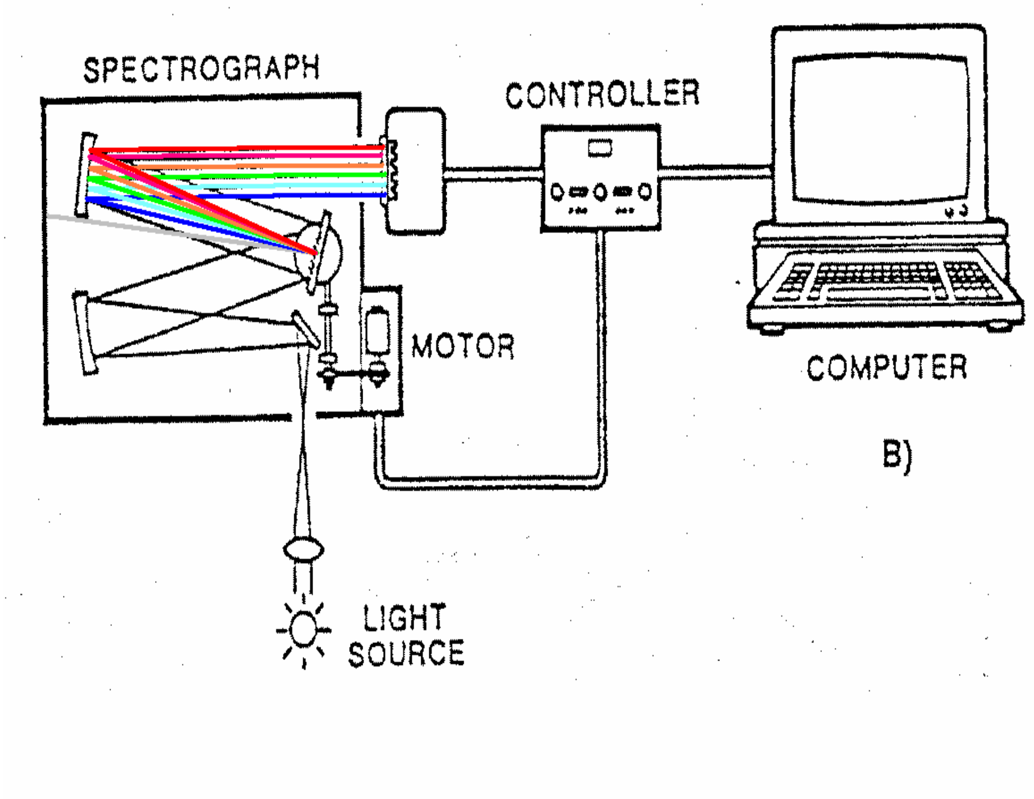
- Monochromators separate light into its component colors. The exit slit only allows a small amount of light through, usually one “color” or wavelength.



symphotic Tii corporation

Spectrograph

- Spectrographs separate light into its component colors. There is no exit slit: a large spectrum is seen by an imaging sensor

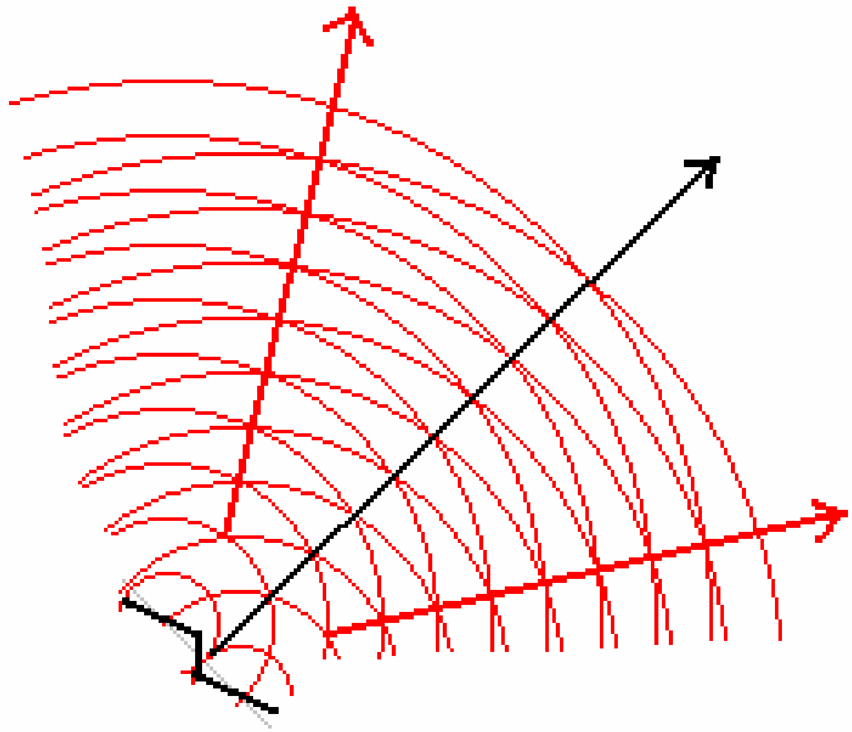


symphotic Tii corporation

Gratings

Gratings create interference patterns

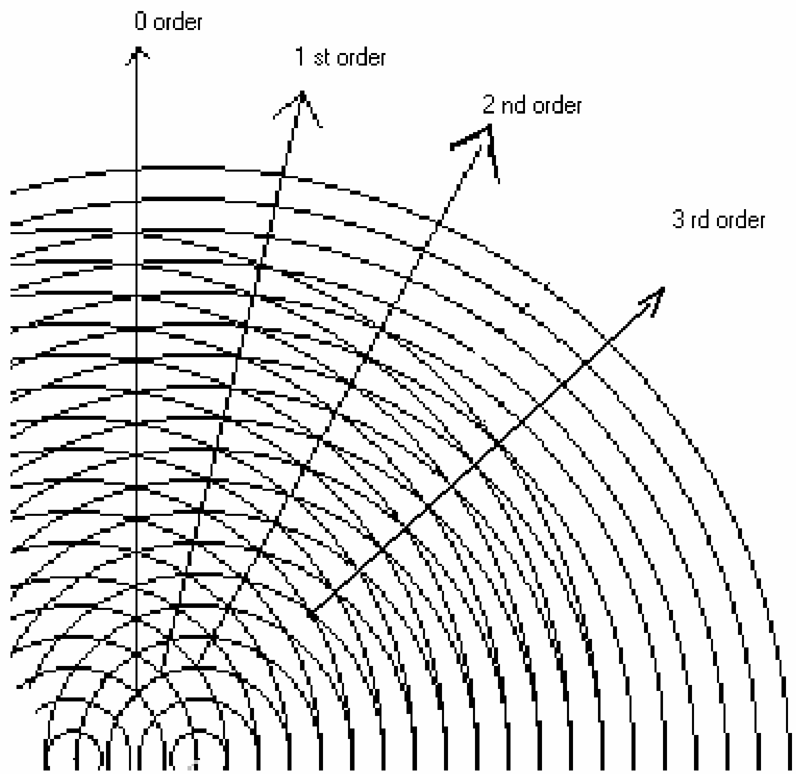
Different wavelengths interfere at different angles off the grating



symphotic Tii corporation

Grating orders

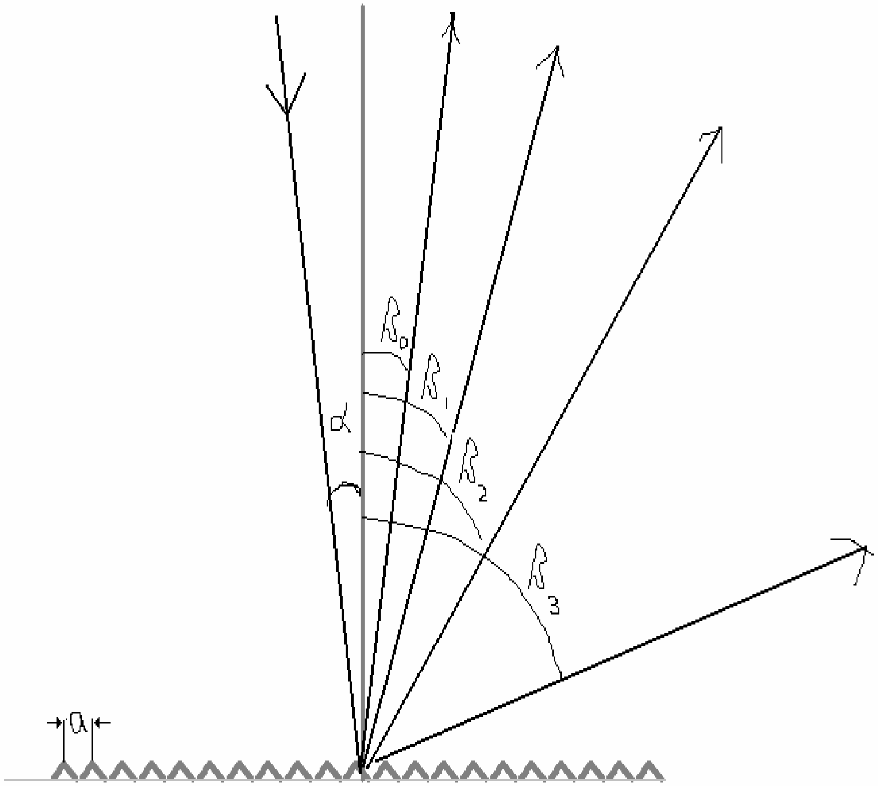
- Interference can happen more than once.
- All wavelengths interfere at one angle off the grating. This is called 0 order
- Each wavelength can interfere in more than one order



symphotic Tii corporation

The Grating Equation

- $m\lambda/a = \sin\alpha \pm \sin\beta_m$
- m = order numbera = groove spacing (nm)
- λ = wavelength (nm)α = angle of incident lightβ_m = angle of diffracted light of m order



Solving the grating equation

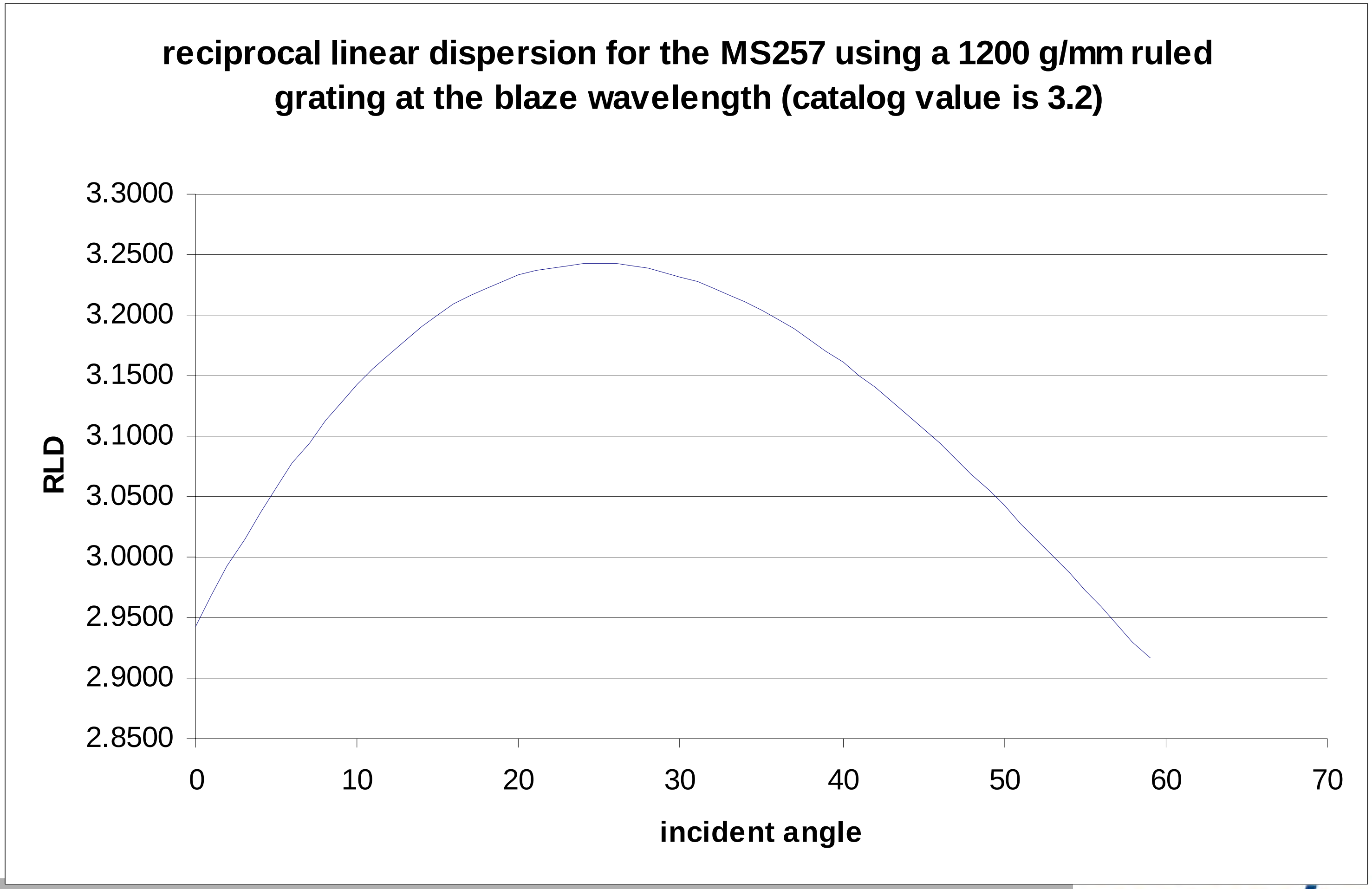
- $m\lambda/a = \sin a \pm \sin \beta_m$
- Note the order overlap highlighted in yellow:

g/mm	a	λ	α	m	β_m
2400	416.6667	200	0.00	0	0.00
2400	416.6667	200	0.00	1	28.69
2400	416.6667	200	0.00	2	73.74
2400	416.6667	400	0.00	0	0.00
2400	416.6667	400	0.00	1	73.74
1200	833.3333	600	0.00	0	0.00
1200	833.3333	600	0.00	1	46.05
60	16666.67	600	0.00	23	55.89
60	16666.67	600	0.00	24	59.77
60	16666.67	600	0.00	25	64.16

Dispersion

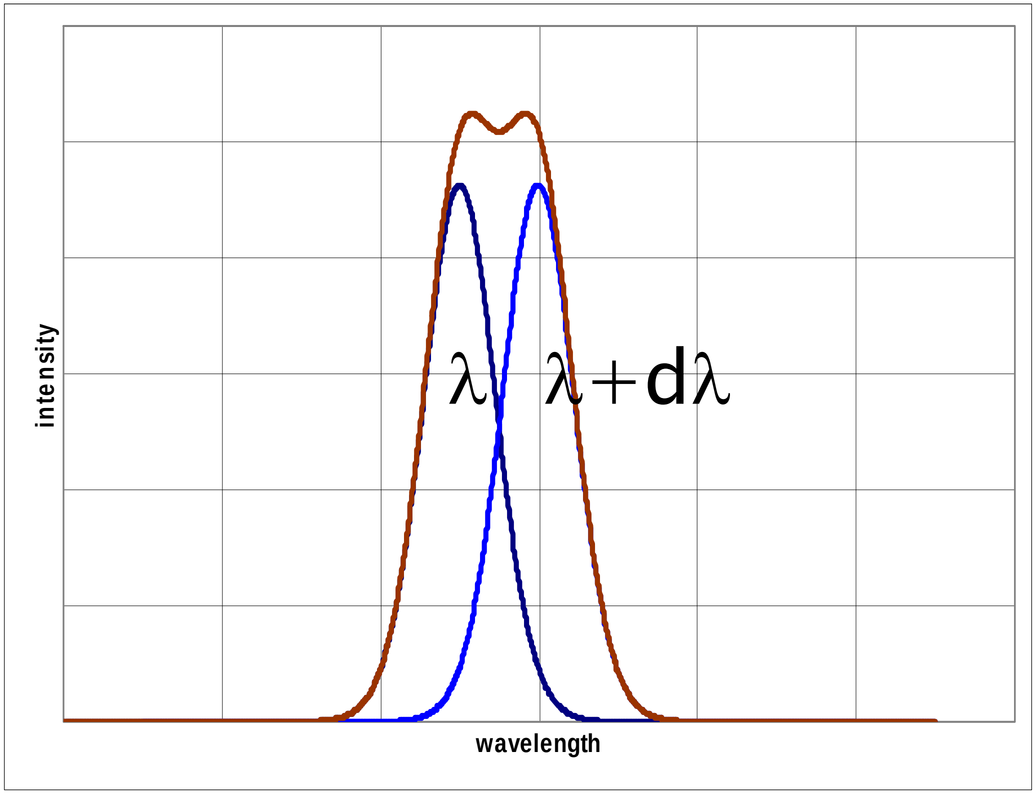
- Angular dispersion: D
  - $D = d\beta/d\lambda = m/a \cos\beta$ (the changed in the angle of diffraction per incremental change in wavelength is equal to the order number divided by the groove spacing times the cosine of the angle of diffraction)
  - By substitution: $D = (\sin a + \sin \beta)/\lambda(\cos \beta)$
- Linear Dispersion
  - $dL/d\lambda = f(d\beta/d\lambda) = f \times D$ (the change in distance [mm] per change in wavelength [nm] is equal to the focal length of the monochromator times the angular dispersion
  - Reciprocal Linear Dispersion = 1/linear dispersion
- Dispersion varies with wavelength and incident angles

Reciprocal linear dispersion in the MS257 monochromator



Resolving Power, R

- $R = \lambda / d\lambda$
  $= W(\sin\alpha + \sin\beta)/\lambda$
  - *W is the illuminated width of the grating*
- Two wavelengths, λ and $\lambda + d\lambda$ are resolved if they can be separated by the monochromator.

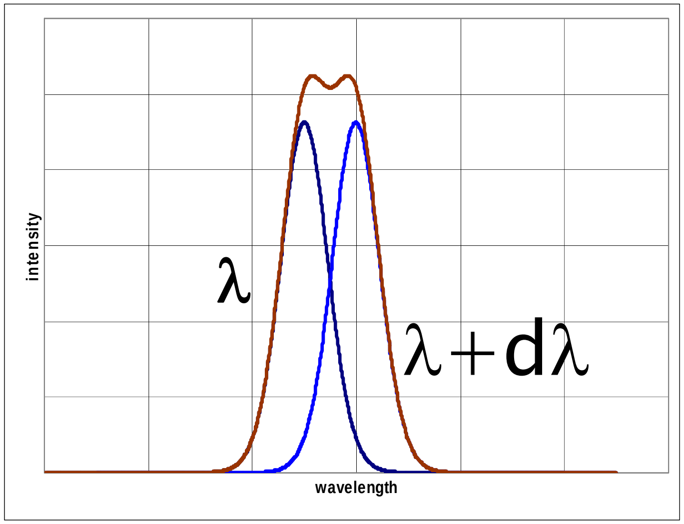


Resolving Power of a grating, R

- $R = \lambda / d\lambda$

  $= W(\sin\alpha + \sin\beta)/\lambda$

  - *W is the illuminated width of the grating*



- For a 1200 g/mm grating with a 350 nm blaze, at 350 nm:

$$R = \frac{50{,}000{,}000 * (\sin 0 + \sin 24.835)}{350\ \text{nm}}$$

$= 60{,}000$

$d\lambda = 350\text{nm}/60000 = 0.006\ \text{nm}$

(<u>however,</u> this is a mathematical calculation only: *Resolution depends on other factors*)

symphotic Tii corporation

Resolution

- Resolution is the ability to separate wavelengths. It is usually expressed in FWHM (full width at half max.)Resolution depends on the dispersion, slit width, and optical aberrations.Even though a grating may have resolving power, other factors limit resolution.

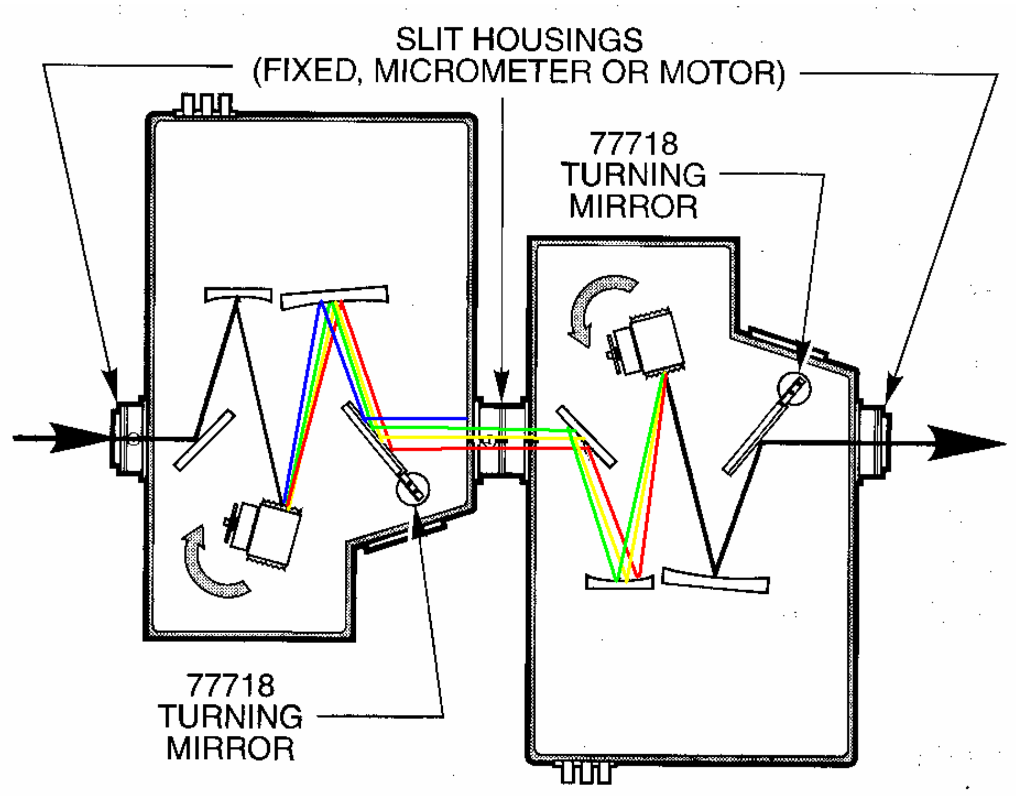
Factors affecting resolution:

- Monochromator focal length: greater focal length gives greater resolution.
- Slit width: Narrower slit width gives greater resolution
- Groove density: more lines/mm gives greater resolution, i.e. increased resolving power of the grating
- Grating order
- Pixel size in spectrograph detector: smaller pixel width gives better resolution (the limit for resolution is twice the detector pixel size)

symphotic Tii corporation

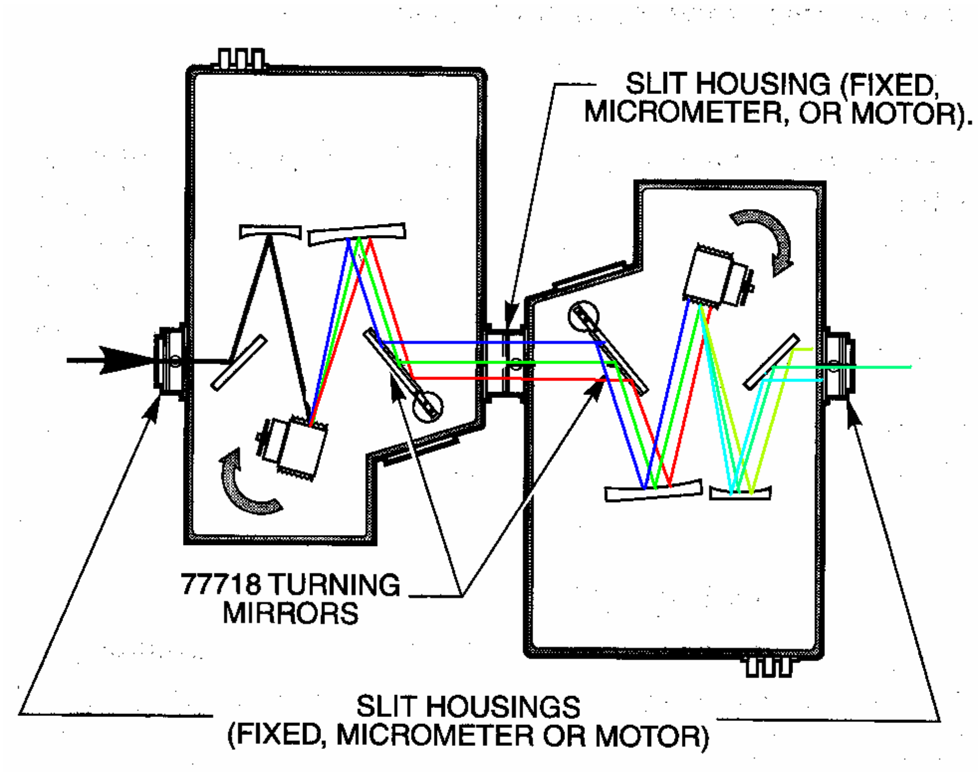
Double Monochromator: Subtractive

- Greatly reduces stray light, rejects unwanted orders or wavelengths
Performs like a bandpass filter



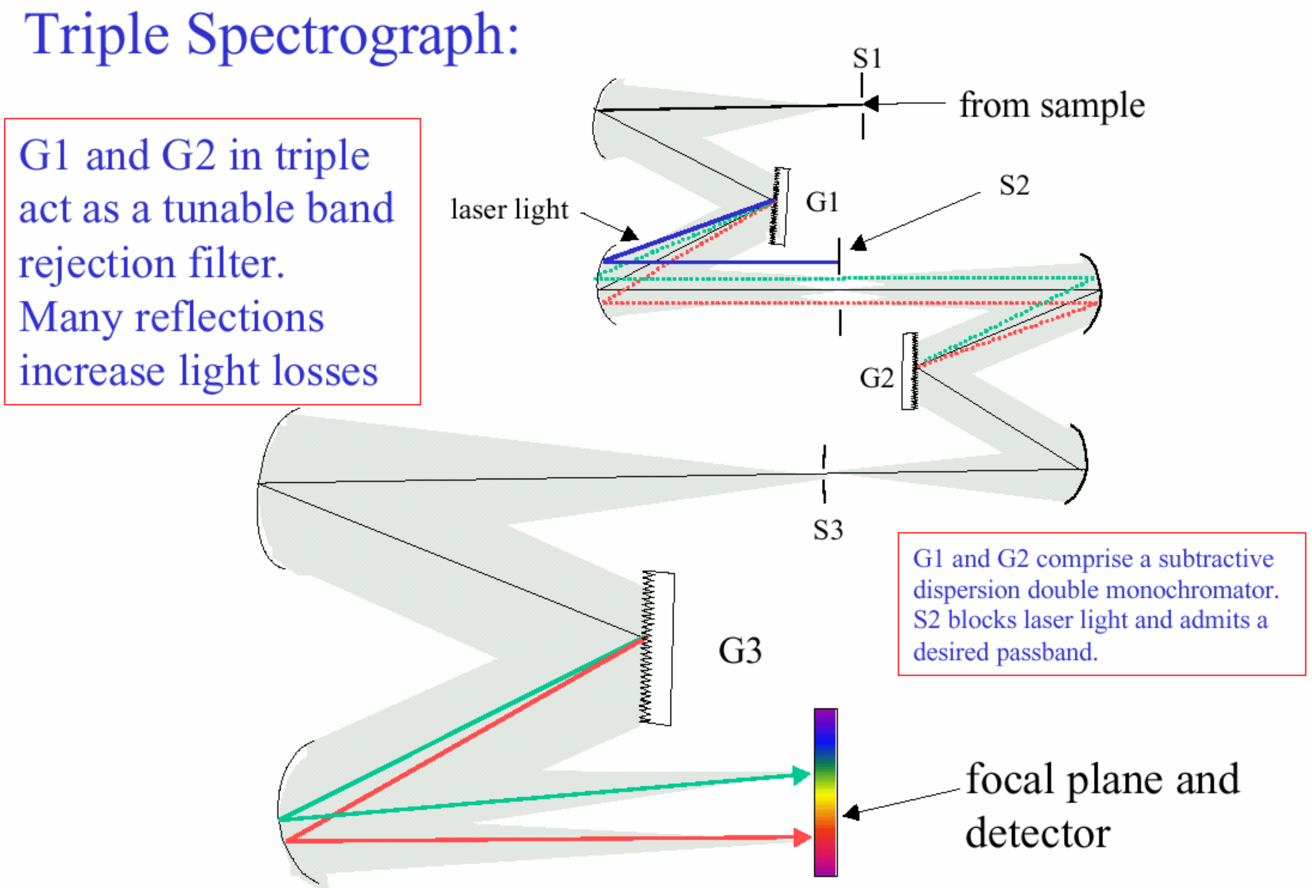
Double Monochromator: Additive

- Reduces stray light, rejects unwanted orders or wavelengthsIncreases resolution or increases throughput (but not both)



symphotic Tii corporation

Triple spectrograph using subtractive pre-monochromator



symphotic Tii corporation

Monochromator spectrograph types

- Ebert-Fastie. Uses one mirror to collimate incoming light and focus dispersed light.
  - *–77250 1/8 meter monochromator.*
- Czerny-Turner. Uses two separate mirrors for collimation and focusing.
  - *–MS257.*

Getting light into a monochromator

- Throughput
  - *–Also called geometric extent or etendue, is defined by this equation:*

$$G = A\Omega$$

Where G is the throughput, A is the image area of the entrance slit, and Ω is the solid angle of the grating area projected on the collimating mirror.

A is the height x width of the entrance slit.

Ω varies with the angle of the grating so it changes with wavelength.

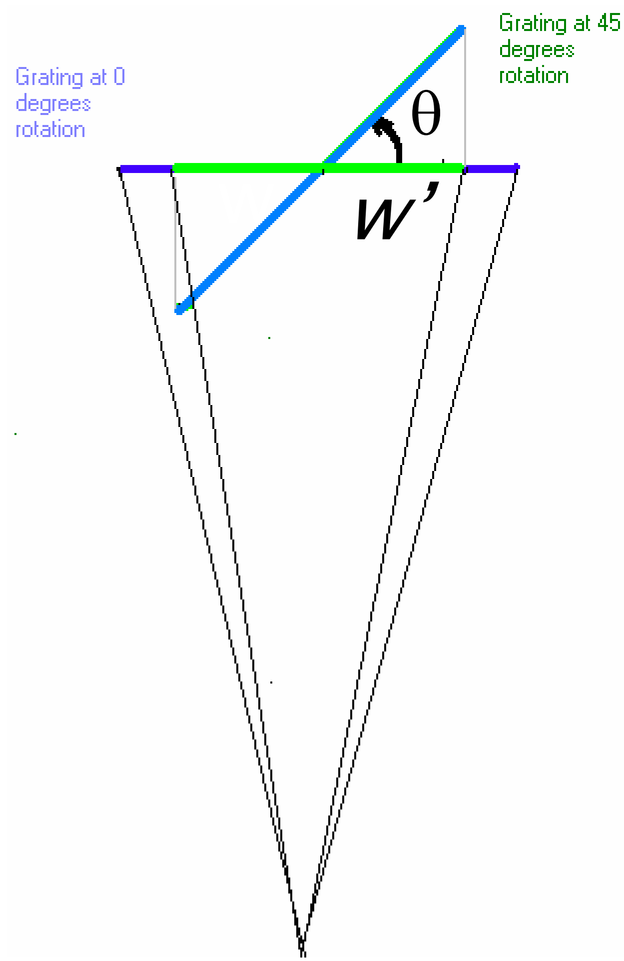
Ω depends on the inverse square of the focal length.

Getting light into a monochromator

- Ω is equal to a/f^2, the projected area of the grating divided by the square of the focal length of the mirror.
- Ω is unitless, but is referred to in units of steridians
- f is the focal length
- a = h x *w* where *w* is the projected width of the grating, equal to:

  $w = w' \times \cos\theta$

  where w' is the grating width and θ is the angle of rotation.



symphotic Tii corporation

Getting light into a monochromator

- Grating efficiency:
  - *–Varies with wavelength, design, and manufacture.*
    - 77742 is ruled
    - 77741 is holographic

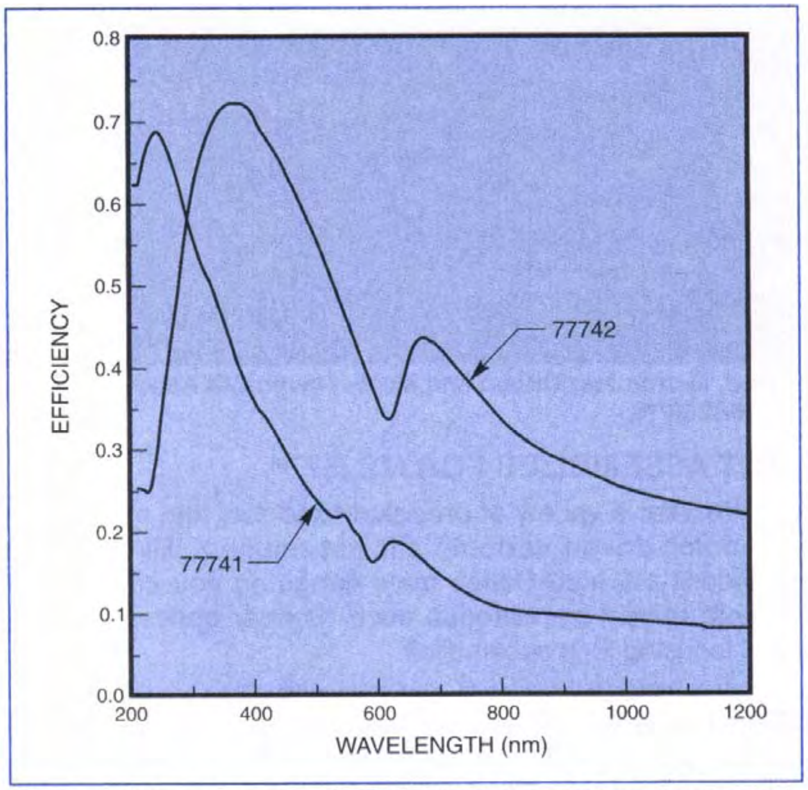


Fig. 5 Efficiency curves of 77741 1200 l/mm 250 nm blaze, and 77742 1200 l/mm 350 nm blaze gratings.

symphotic Tii corporation

Getting light into a monochromator

- More Throughput:
  - *Larger slits—select the largest slits for your application*
  - *Smaller grating angles—Select a grating that will cover your wavelength requirements at smaller angles*
  - *Work close to peak of the grating efficiency curve*
  - *Illuminate the full slit height*

Getting light into a monochromator

"Filling the acceptance cone"

- Light must be focused on the monochromator slit using a lens or mirror with the same F/#
  - *Source image should be the same size as the slit to reduce vignetting*
  - *F/# should match*
  - *Magnification may change:*

    $m=(F/\#)_2/(F/\#)_1$

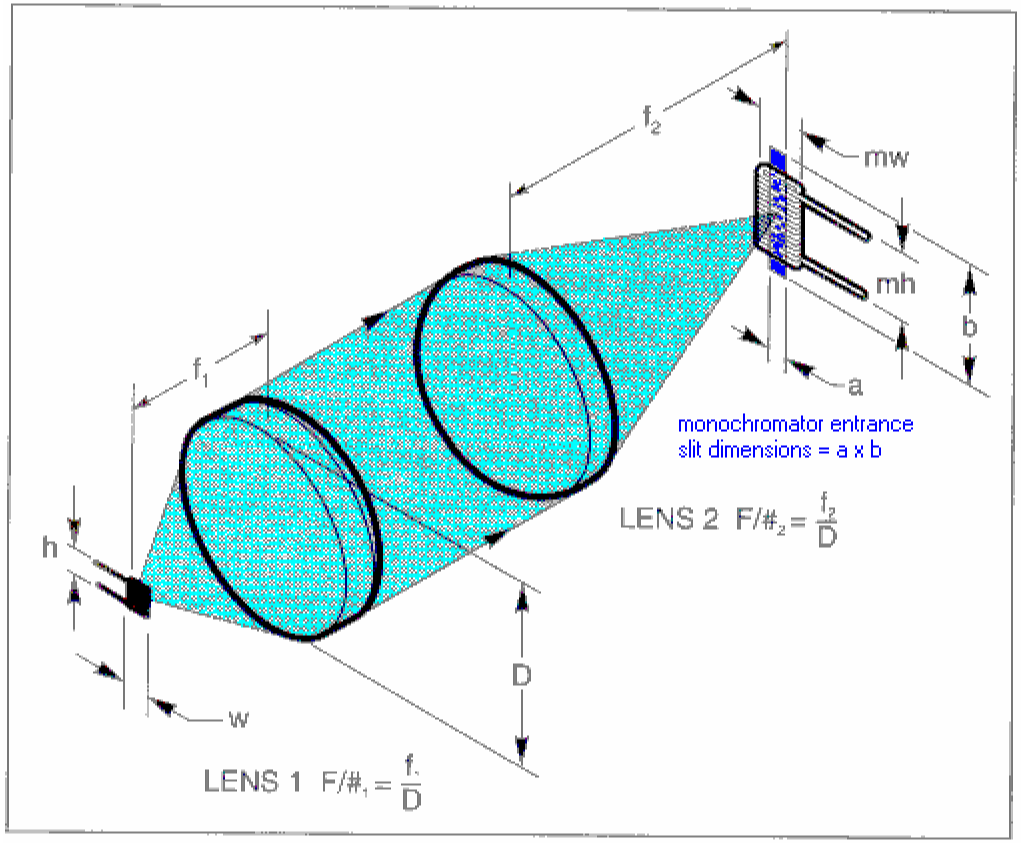
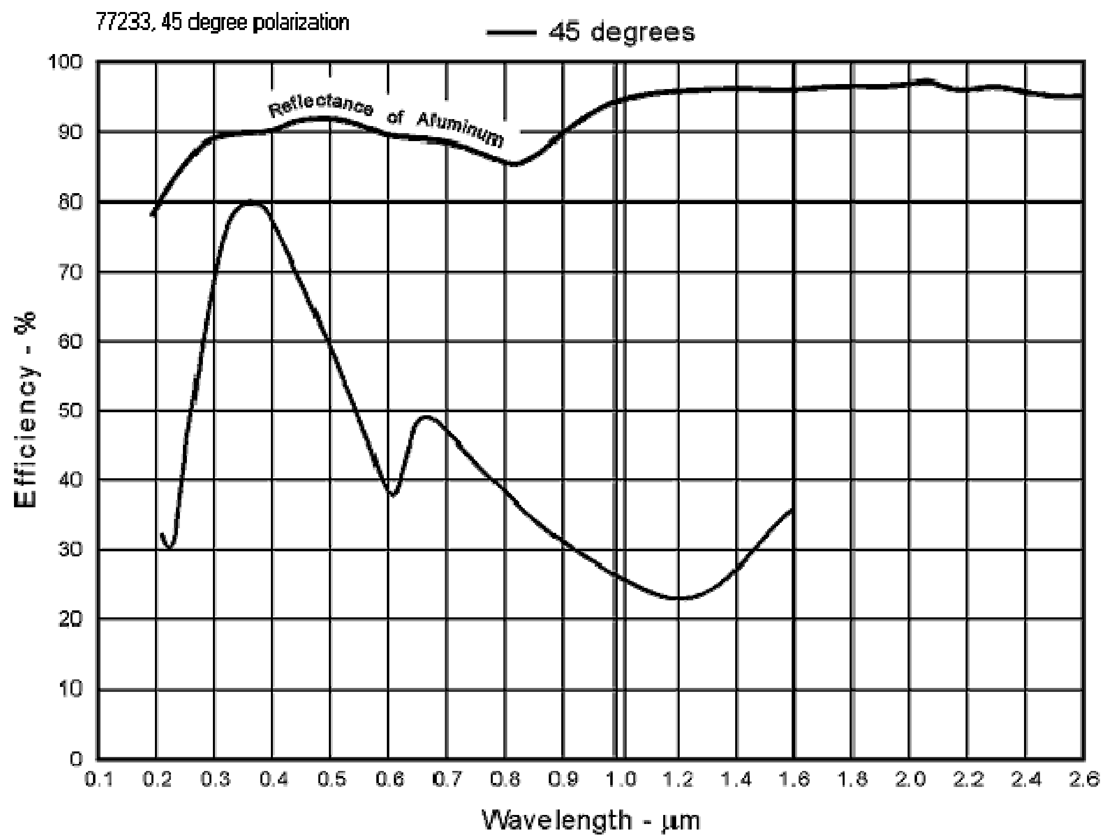


Fig. 5 A condenser and secondary focusing lens system.

symphotic Tii corporation

Example

- 2 nm bandwidth in visible range using 6253 150 W Xenon lamp and a 77200 ¼ meter F/4.4 monochromator with a 1200 g/mm grating with a 350 nm blaze (77233)



- 2 nm bandwidth requires a slit size of 0.6 mm, slit height is 18 mm (77216)

Slit Width(mm) = bandwidth (nm)/RLD (nm/mm) = 2/3 = .66

- Arc dimensions are 0.5 mm wide by 2.2 mm high.
- Focusing lens should be F/4.4 to match monochromator optics.

Table 2 Approximate Resolution of Fixed Slits

Slit Width (µm)	Slit Height (mm)	Monochromator Resolution* @ 500 nm (nm)	Slit Model No.
10	2	0.1**	77222
25	3	0.15**	77220
50	6	0.25**	77219
120	18	0.4	77218
280	18	1	77217
600	18	2	77216
760	18	2.5	77215
1240	18	4	77214
1560	18	5	77213
3160	18	10	77212
6320	18	20	77211

* For 1200 l/mm gratings; to obtain the resolution with other gratings multiply by the "Wavelength Counter Multiplier" in Table 1 on the previous page.

** Resolution with a diode array is limited by array element width.

symphotic Tii corporation

Getting light into a monochromator
page 1-71 for light source specs.

Table 1 Comparison of Condensers

Source Model No.	Condenser Type	Aperture inch (nm)	Lens Multiplication Factor*	Transmittance Range of Lens Material**	Size Series***
66906	F/1.5, single element fused silica	1.3 (33)	0.06	200 - 2500 nm	1.5 Inch
66907	F/1, two element fused silica	1.3 (33)	0.11	200 - 2500 nm	1.5 Inch
66919	F/0.85, single element molded Pyrex® Aspheric	1.3 (33)	0.13	350 - 2500 nm	1.5 Inch
66908	F/0.7, four element borosilicate crown Aspherab®	2.7 (69)	0.18	350 - 2500 nm	3 Inch
66909	F/0.7, four element fused silica Aspherab®	2.7 (69)	0.19	200 - 2500 nm	3 Inch

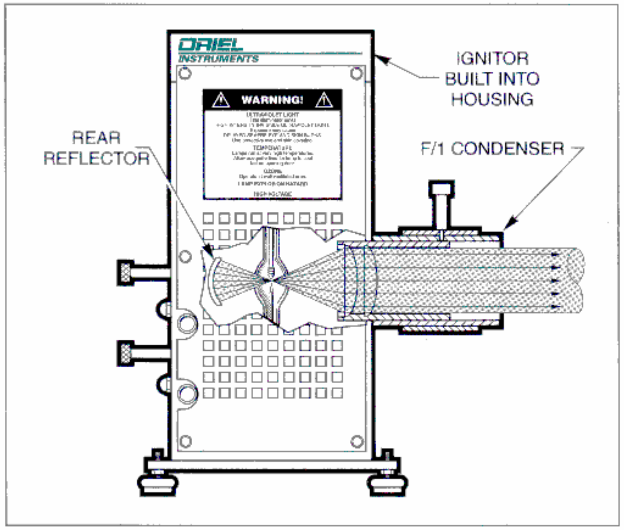


Fig. 1 The rear reflector collects the lamp's back radiation, adding up to 60% to the total source output.

Table 2 50 - 200 W Arc Lamps

Lamp Type	Effective Arc Size W x H (mm)	Lamp Model No.	Appropriate Socket Adapter Model No.
75 W Xe	0.4 x 0.8	6251	66150
75 W Xe (Ozone Free)	0.4 x 0.8	6263	66150
100 W Xe (Ozone Free)	0.4 x 0.8	6257	66150
150 W Xe	0.5 x 2.2	6253	66151
150 W Xe (UV Enhanced)	0.5 x 2.2	6254	66151
150 W Xe (Ozone Free)	0.5 x 2.2	6255	66151
150 W Xe	0.5 x 1.5	6256	66152
50 W Hg	0.2 x 0.35	6282	66158
100 W Hg	0.25 x 0.25	6281	66150
200 W Hg	0.6 x 2.2	6283	66144
200 W Hg(Xe)	0.5 x 1.5	6291	66152
200 W Hg(Xe) (Ozone Free)	0.5 x 1.5	6292	66152

symphotic Tii corporation

- Beam diameter is 33 mm, so focus of secondary lens should be about 150 mm

F/# = Focal Length/aperture,

Focal Length = (F/#)(Aperture)= 4.4 x 33mm = 145.2 mm ≈ 150 mmImage size options: (entrance slit is 0.6 mm x 18 mm)Using F/1.5 lens: (0.5mm x 2.2mm)x(4.4/1.5) ≈ 1.5 mm x 6.5 mmUsing F/1.0 lens: (0.5mm x 2.2 mm)x(4.4/1.0) ≈ 2.2 mm x 10 mmUsing F/0.85 lens: (0.5 mm x 2.2 mm)x(4.4/0.85) ≈ 2.6 mm x 11 mm

Getting light into a monochromator
Example

- Vignetting: The image is wider than the slit, so some power will be lost. The useful height of the slit is equal to the magnified height of the image.

$$V = (a \times b)/(mw \times mh).$$

$$b = ma, \text{ so } V = a/mw$$

- Relative power:

$$P \propto V \times (m^2)/(F/\#\text{of imaging lens})^2$$

With F/1.5 condenser, relative power=

$[(0.6)/(1.5)] x (4.4/1.5)^2/(4.4)^2 = 0.18$

With F/1.0 condenser, relative power=

$[(0.6)/(2.2)] x (4.4/1.0)^2/(4.4)^2 = 0.27$

With F/0.85 condenser, relative power=

$[(0.6)/(2.6)] x (4.4/0.85)^2/(4.4)^2 = 0.32$

- Highest relative power is with the F/0.85 condenser

Monochromator Power output

- $P_o = P_i V F E_m R^4$

- P_o = Power output in mWP_i = Power reaching the entrance slit plane in mWV = Vignetting factor due to slit smaller than image
- $F = (F/\#_{illuminator})^2 / (F/\#_{monochromator})^2$

(when F/# does not match.)

- E_m = Grating efficiency
- R^4 = Reflection efficiency (with 4 reflections)

Conclusions:

- Resolution depends upon focal length, slit widths, groove density, optical design and aberrations.
- Use a grating with a blaze angle closest to the lowest wavelength of the spectral range
- Use filters to remove unwanted wavelengths
- Match the Monochromators F/#
- Use low F/# imaging optics wherever practical
- Use slits that are completely filled by the image.
- Use smaller slits for better resolution, but light will be lost through vignetting.

symphotic Tii corporation

Acknowledgements

- Our thanks for the assistance of the staff of Thermo Oriel

symphotic Tii corporation