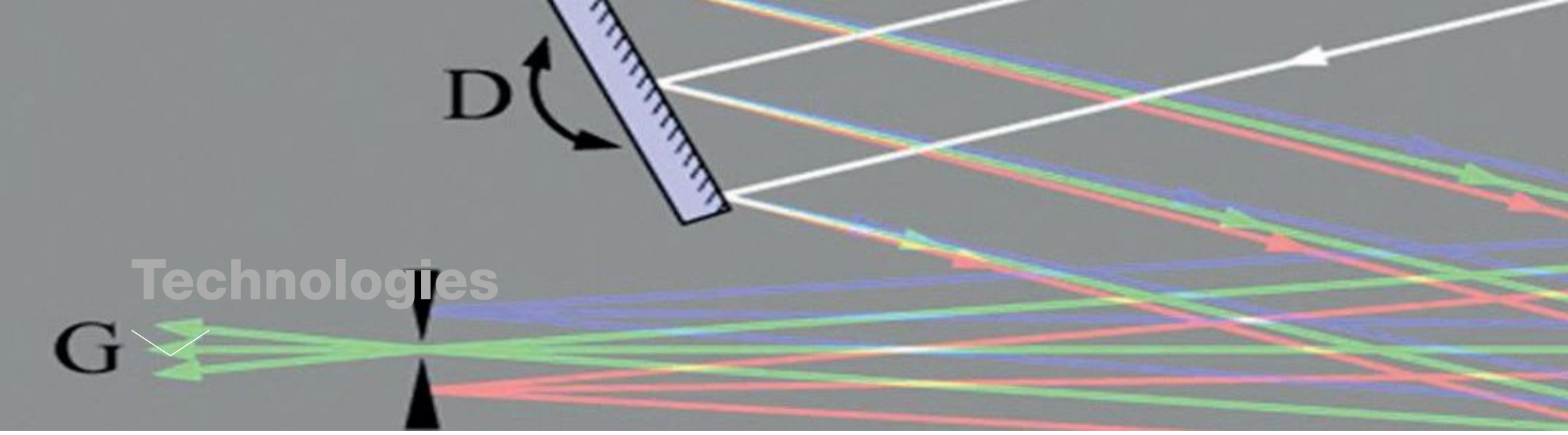
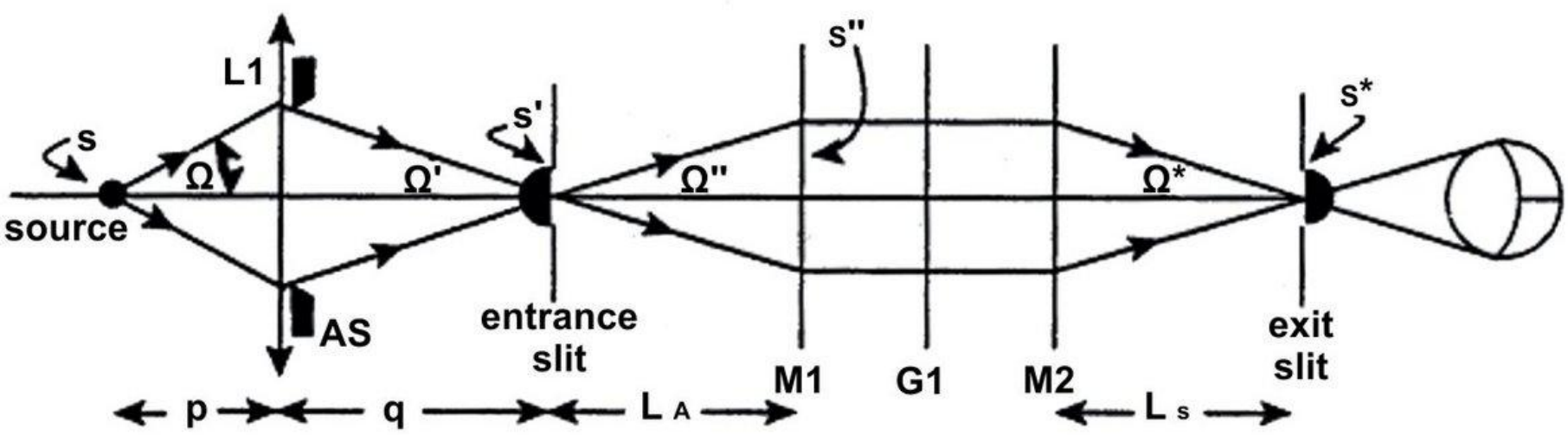


Entrance Optics

Choice of Entrance Optics

While lenses are used in the examples below, front surface concave mirrors coated for the spectral region of choice are preferred. A coating such as aluminum is highly reflective from 170 nm to the near IR, whereas crown and flint glasses start losing transmission efficiency rapidly below 400 nm. “Achromatic Doublets” are routinely cemented with UV absorbing resins and their anti-reflective coatings often discriminate against the UV below 425 nm (this is due to the fact that such lenses are often used in cameras where photographic film may be very UV sensitive).

If lenses must be used in the blue to UV, then choose uncoated quartz singlets or air spaced doublets.



A typical monochromator system with one fixed exit slit and one detector.

AS - aperture stop
L1 - lens 1
G1 - grating 1
M1 - mirror 1
M2 - mirror 2
p - object distance from lens L1
q - image distance from lens L1
F - focal length of lens L1
d - the clear aperture of the lens (L1 in diagram)

The above diagram shows a typical monochromator system with one fixed exit slit and one detector, however, all that follows is equally applicable to a spectrograph.

Review of Basic Equations

This lens equation:

$$(65)\quad \frac{1}{F}=\frac{1}{p}+\frac{1}{q}$$

Magnification (m):

$$(66)\quad \text{magnification}=\sqrt{\frac{S'}{S}}=\sqrt{\frac{f/\text{value}_{out}}{f/\text{value}_{in}}}=\frac{(NA)_{in}}{(NA)_{out}}=\frac{q}{p}$$

For simplicity, the diameter of an optic or that of its aperture stop (AS) (assuming it is very close to the optic itself) is used to determine the f/value. In which case Equations (4) and (23) simplify to:

$$(67)\quad f/\text{value}_{in}=\frac{q}{d}\ \text{object } f/\text{value}$$

$$(68)\quad f/\text{value}_{out}=\frac{q}{d}\ \text{image } f/\text{value}$$

Establishing the Optical Axis of the Monochromator System

Materials

- HeNe laser
- Lenses, mirrors, and other optical components as required for optimization
- Three pinhole apertures of fixed height above the table
- Precision positioning supports for above
- Optical bench, rail, or jig plate

Procedure

Assemble the above components so that the laser beam acts as the optical axis which passes first through two pinhole apertures, followed by the monochromator, and finally through the third pinhole aperture.

The external optics and source will eventually be placed on the optical axis defined by the pinhole apertures and laser beam. Position the pinhole apertures so that the lenses, etc. may be added without disturbing them.

Note: Reverse illumination may sometimes be preferred where the laser passes first through the exit slit and proceeds through all the optics until it illuminates the light source itself. Alignment of the components is an iterative process. The goal is for the laser beam to pass through each slit centerand to strike the center of each optical element. The following steps achieve this:

- If a monochromator has a sine drive, then set the monochromator to zero order.
- Aim the laser beam through the center of the entrance slit.
- Center the beam on the first optic.
- Center the beam on the next optic, and so on until it passes through the center of the exit slit.
- If the laser does not strike the center of the optic following the grating, then rotate the grating until it does. Many spectrometers are not accurately calibrated at zero order, therefore, some offset is to be expected.

Illuminating a Spectrometer

If a light source such as a sample or a calibration lamp is to be focused into the entrance slit of a spectrometer, then:

- Ensure that the first active optic is homogeneously illuminated (plane mirrors are passive).
- Place a white screen between the entrance slit and the first active optic (in a CZ monochromator the collimating mirror, and in an aberration corrected concave grating, the grating itself).
- Check for “images,” if there is a uniform homogeneously illuminated area, all is well. If not, adjust the entrance optics until there is.

Entrance Optics Examples

Aperture Matching a Small Source.

The emitting source is smaller in width than the width of the entrance slit for a required bandpass.

The majority of commercial spectrometers operate between f/3 and f/15, but the diagrams that follow use drawings consistent with f/3 and all the calculations assume f/6.

In the examples which follow, the lens (L1) used is a single thin lens of 100 mm focal length (for an object at infinity) and 60 mm in diameter.

The f/value$_{out}$ of the entrance optics must be equal to the f/value$_{in}$ of the monochromator.

If necessary, an aperture stop should be used to adjust the diameter of the entrance optics.

Remember when calculating the diameter of aperture stops, to slightly underfill the spectrometer optics to prevent stray reflections inside the spectrometer housing.

Aperture Matching a Small Source

Example 1 (Fig. 36)

The emitting source is smaller in width than the width of the entrance slit for a required bandpass.

Calculate the entrance slit width for appropriate bandpass (Equation 3-9). For this example, let the slit width be 0.25 mm.

Example Object: a fiber of 0.05 mm core diameter and NA of 0.25.

Object emits light at f/2 (NA = 0.25). Spectrometer = f/6.

Projected image size of fiber that would be accommodated by the system (given by entrance slit width) = 0.25 mm.

Calculate magnification to fill entrance slit.

m = image size/object size = 0.25/0.05 = 5.0.

Therefore, q/p = 5, q = 5p.

Substituting into the lens Equation 3-16 gives p = 120 mm, and q = 600 mm.

To calculate d, light must be collected at f/2 and be projected at f/6 to perfectly fill the grating.

Therefore, p/d = 2, d = 120/2 = 60 mm.

Therefore, aperture stop = full diameter of L1.

Projection f/value = 600/60 = 10.

In other words, the grating of the monochromator, even though receiving light collected at f/2, is underfilled by the projected cone at f/10. All the light that could have been collected has been collected and no further improvement is possible.

Example 2

If, however, the fiber emitted light at f /1, light collection could be further improved by using a lens in the same configuration, but 120 mm in diameter. This would, however, produce an output f /value of

600/120 = f /5

Because this exceeds the f /6 of the spectrometer, maximum system light collection would be produced by a lens with diameter:

$$d = \frac{q}{f/\text{value}} = \frac{600}{6} = 100 \text{ m}$$

thereby matching the light collection etendue to the limiting etendue of the spectrometer.

The collection f/value is, therefore,

$$f/\text{value}_{in} = \frac{p}{d} = \frac{120}{100} = 1.2$$

Since etendue is proportional to the square of the (f/value)-1, about 70% of the available emitted light would be collected at f/1.2 (see Section 3).

If the user had simply placed the fiber at the entrance slit with no entrance optics, only 3% of the available light would have been collected. (Light in this case was collected at the spectrometer's f/6 rather than the f/1.2 with etendue matching entrance optics.)

Aperture Matching an Extended Source


Aperture Matching an Extended Source.

The object width is equal to or greater than the entrance slit width. Aperture stops should be used to match etendue of the entrance optics to the monochromator. Because the object is larger than the slit width, it is the monochromator etendue that will limit light collection.

The object width is equal to or greater than the entrance slit width (see Fig. 37).

The $f/value_{out}$ of the entrance optics must be equal to the $f/value_{in}$ of the monochromator. The object distance should be equal to the image distance (absolute magnification, m, equals 1).

Aperture stops should be used to match etendue of the entrance optics to the monochromator. Because the object is larger than the slit width, it is the monochromator etendue that will limit light collection.

In this case, image 1:1 at unit magnification.

Taking lens L1

So for F = 100 mm, p = 200 mm, q = 200 mm (2F).
f/value of the monochromator = q/d = p/d = 6.

Then

$$d = \frac{q}{f/value} = \frac{200}{6} = 33.3$$

Therefore, aperture stop = 33.33 mm to fill the diffraction grating perfectly.

Demagnifying a Source


Demagnifying a Source.

Tthe f/value of the source is numerically larger than that of the spectrometer. In this case etendue matching is achieved by the demagnification of the source.

In this case the f/value of the source is numerically larger than that of the spectrometer. This is often seen with a telescope which may project at f/30 but is to be monitored by a spectrometer at f/6. In this case etendue matching is achieved by the demagnification of the source (see Fig. 38).

Calculate the entrance slit width for the appropriate bandpass (Equation (37)). Take, for example,

1.0 mm = final image size = entrance slit width.

Image projected by telescope = 5 mm and forms the object for the spectrometer.
m = 1/5 = 0.2,

then from Equation (58).

Taking lens L1 with F = 100 mm (given),
p = 600 mm, q = 120 mm.

Calculate d knowing the monochromator f/value = 6, q/d = 6, d = 120/6 = 20 mm.

The aperture stop will be 20 mm diameter.

Light is gathered at either the aperture of the projected image or 600/20 = f/30, whichever is numerically greater.

Use of Field Lenses

The concepts given in this section have not included the use of field lenses. Extended sources often require each pupil in the train to be imaged onto the next pupil downstream to prevent light loss due to overfilling the optics, vignetting

- Used when entrance slit height is large and the light source is extended.
- A field lens images one pupil onto another. In Figure 26, AS is imaged onto G1.

Field lenses ensure that for an extended source and finite slit height, all light reaches the grating without vignetting. In Fig. 39 and Fig. 40, the height of the slit is in the plane of the paper.


Use of Field Lenses.

Field lenses ensure that for an extended source and finite slit height, all light reaches the grating without vignetting.


Use of Field Lenses.

Field lenses ensure that for an extended source and finite slit height, all light reaches the grating without vignetting.

Pinhole Camera Effect

When entrance optics are absent, it is possible for the entrance slit to project an image of just about everything before the slit into the spectrometer. This may include the lamp, the sample, rims of lenses, even distant windows. Previous part describes how to correctly illuminate a spectrometer for highest throughput. Following this procedure will eliminate the pinhole camera effect.

Multiple imaging may severely degrade exit image quality and throughput. On the other hand, the pinhole camera effect is very useful in the VUV when refractive lenses are not available and mirrors would be inefficient.

Spatial Filters


Spatial Filters.

Aperture and field stops may be used to reduce or even eliminate structure in a light source, and block the unwanted portions of the light. In this capacity, aperture stops are called spatial filters.

Aperture and field stops may be used to reduce or even eliminate structure in a light source, and block the unwanted portions of the light (e.g., the cladding around an optical fiber). In this capacity, aperture stops are called spatial filters (see Fig. 41).

The light source image is focused onto the plane of the spatial filter. which then becomes the light source for the system.

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