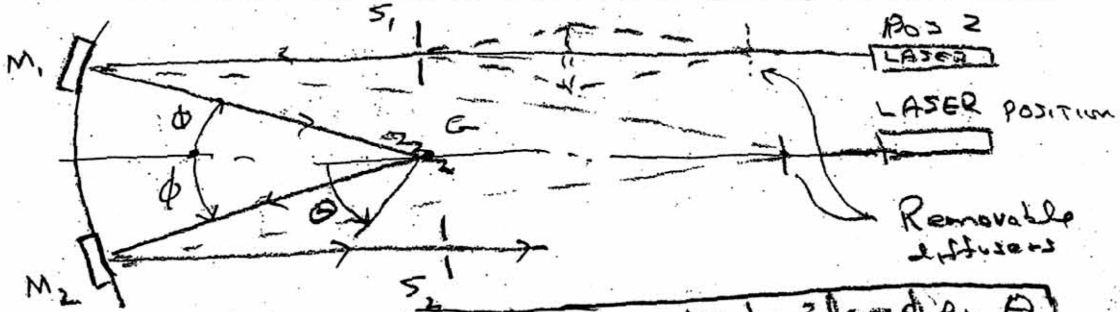
3/31/03

625-gratinglab.

In this lab we will build and test an Ebert-Fastie grating monochromator.



Grating eqn: $m\lambda = 2d\cos\phi\sin\theta$

1. Measure heights (h) between the centers of the grating and mirrors and the table. Mount a laser so its beam is parallel to the table and at the height of the grating center. A pinhole mounted to a rod in a magnetic stand will be very useful as a height gauge. Mount the laser near one end of the table and align the beam with a row of holes. A straight edge clamped to the table along which you can slide your pinhole height gauge might be useful for this. This beam will be used to determine the axis of our spectrometer.

2. Study all the mechanisms on the grating mount assembly until you understand them. Carefully mount the grating on the tip-tilt platform so the grating face can be adjusted ~~parallel~~ perpendicular to the axis of rotation by a tip adjustment, and the grooves parallel to the axis of rotation by the tilt mechanism (orthogonal to the tip). This will assure that the plane of dispersion can be made perpendicular to the rotation axis and (as a consequence) parallel to the table surface. (We assume the rotation axis is perpendicular to the table because of the way the holders are made.)

3. Slide the grating into the laser beam, and adjust the tilt mechanism so zero order from the grating goes directly back to the laser output; ie, specular reflection at normal incidence.

4. Find the +/- first (and second?) diffraction orders. (Can you tell which is nearest blaze?) Using the height gauge, adjust the grooves parallel to the rotation axis by adjusting the diffracted spots to the same height as the pinhole in the gauge. If this can't be done, the axis of rotation is not perpendicular to the table. We don't have an adjustment for this, and assume the mounts are ok. (Get as close as you can on the blaze side.)

5. Defining the instrument axis.

Mount the laser near one end of the table and align the beam with a row of holes near the center of the table. A straight edge clamped to the table along which you can slide your pinhole height gauge might be useful for this. This beam will be used to determine the axis of our spectrometer. Make sure the laser output will be a little beyond the radius of curvature of the mirrors where they will finally be positioned. This is easy for the 12in focal length mirrors, but marginal for the 20inch focal length mirrors. Just plan on putting the laser on one end, and the mirrors on the other.

6. Place the mirrors near the edge opposite the laser, and position them so their centers are equidistant from the axis. 10cm or so will do. Using a "Scotch tape" diffuser stuck to a rod in a mount you can slide around, diffuse the laser beam so light fills both mirrors. Locate the reflected spots from both mirrors. We want to adjust things (mirror pitch and yaw, and diffuser position along the axis) so the spots overlap the diffused spot when it is at the center of curvature of the mirrors. This makes the two mirrors part of the same spherical surface. This is similar to the auto collimation process you've used several times.

7. Place the slits the same distance off axis as the mirrors (about 10cm). Measure from the undiffused laser beam. The slits should be in the focal plane of the mirrors (f = R/2).

8. Slide the grating mount between the slits so the grating center is on axis. Also position the mount in rotation so you can easily read the angle. CAUTION!! There are two ways to rotate the grating, but only one rotates the angle scale. Be careful of this when you start making measurements. Lock the magnetic bases.

9. Reposition the laser without changing the height and tilt adjustments so the beam goes through the center of the slit and hits the center of the mirror, ~~grating~~. Try to make the beam parallel to the hole rows again (parallel to the axis) Move the slit laterally a bit if you need to. Keep the slit distance near R/2 from the mirror. The laser beam reflected from the mirror should also hit near the center of the grating. Slide the mount a little parallel to the axis if you think it's needed to get the beam near the center of the grating.

10. Rotate the grating so zero order goes through the exit slit. The beam should also hit near the center of the exit mirror. If it's quite a bit off, rotate the grating until the beam is centered on the mirror, and move the exit slit to pass the beam.

11. FOCUS.

We use the "knife edge" test over and over. Diffuse the laser beam again, and use a lens* to focus the diffused spot onto the entrance slit. Place a card over the entrance mirror. Do a knife edge focus by moving the lens laterally while sliding the lens parallel the axis until the signature of a focus is observed. Remove the card. The grating should now be (over) filled with collimated light if the entrance slit is close to the right distance from the mirror. If you think the beam is converging or diverging, move the slit along the axis and refocus. Check mirror focus by autocollimation using grating in zero order

Send zero order light to the <u>exit</u> slit by rotating the grating. Look at the light passing through the slit on a card, and move the slit laterally very slightly while moving it along the axis until the focus signature is achieved. (Knife edge test again.)

12. MEASUREMENTS:

Carefully read angles for 0, 1, 2 orders and calculate (d cos ϕ). How does this compare with the value you expect from the claimed groove spacing for the grating and the measurement (or estimate) for cos ϕ ? You can estimate ϕ from measurements with a ruler for the positions of components, or using the angle scale and rotating the grating appropriately. ($\lambda = 6328 Å$)

12. Hg spectrum.

Install the Hg lamp, and measure the wavelengths of the blue, green, and yellow lines. Avoid looking into the lamp and prolonged exposure to it because it emits lots of UV unless it's covered by the glass cover. Use foil or black cloth or paper to block unwanted light. How accurately can y measure angles, and what wavelength precision does this lea you to expect.

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* Before the laser beam is diffused, the lens should be adjusted in height so the laser beam remains parallel to the table (i.e., put the lens on axis.)

Edmund Scientific

INFORMATION AND INSTRUCTIONS

INSTRUMENT QUALITY PLANE REFLECTION GRATINGS
Nos. 41,013–41,048

		Grooves per inch Blaze wave length	15,240 (600/mm) 4,000A	15,240 (600/mm) 5,000A	30,480 (1200/mm) 2,400A	30,480 (1200/mm) 4,000A
Size	Groove lgth.	Ruled Width	Stock No.	Stock No.	Stock No.	Stock No.
½" x 1"	½"	1"	41,021	41,030	41,039	41,048
1" x 1"	1"	1"	41,019	41,028	41,037	41,046
2" x 2"	2"	2"	41,016	41,025	41,034	41,043
4" x 4"	4"	4"	41,013	41,022	41,031	41,040

Examination of the replica's surface may reveal small imperfections which will have little if any effect upon the spectrum. The grating should not be touched with your fingers, and if inadvertently the grating becomes soiled, DO NOT ATTEMPT to clean the ruled surface with lens tissue, or cotton swabs. In most cases dust and oil can be removed by flushing the ruled surface with laboratory grade ether and drying quickly with a jet of clean air.

These high-quality replicas were produced from precision-made, imported masters. The masters were made on an interferometrically-controlled ruling engine, which is the most modern and accurate method.

Basically, a replica grating consists of a series of closely-spaced lines impressed on the surface by the master. Because of the phenomena of diffraction and interference, these lines cause a dispersion of light according to wavelength. The result is a series of bright bands or spectra, each of which contains all visible wavelengths of the light source. These bands lie perpendicular to the grating lines.

Because of the regular distribution of the spectral bands and wavelengths in each band, replica gratings are extremely useful in spectrographic studies, such as determining the wavelengths of unknown color bands, analyzing the spectral characteristics of an unfamiliar light source and photographing spectra.

Fig. 1

Typical Light Paths

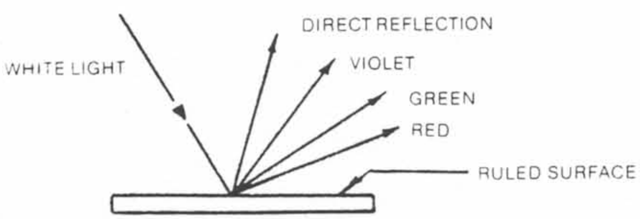
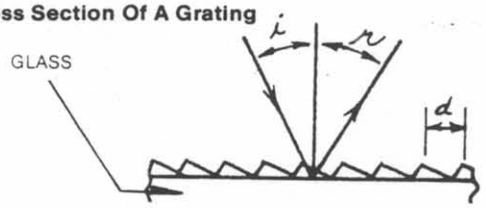


Figure 1 illustrates the dispersion effect of grating.

Fig. 2 Cross Section Of A Grating



If we could examine a grating in cross section we would see something like Figure 2. The normal is the line perpendicular to the face of the grating. All angles are measured from this line. "i" is the angle the incoming light makes with this line, "r" the angle of the reflected light. "d" is the distance between one ruled groove and the next. The dispersing action of the grating is determined by the following formula:

$$n\lambda = d(\sin i \pm \sin r)$$

where:

n = *Order (explained below)

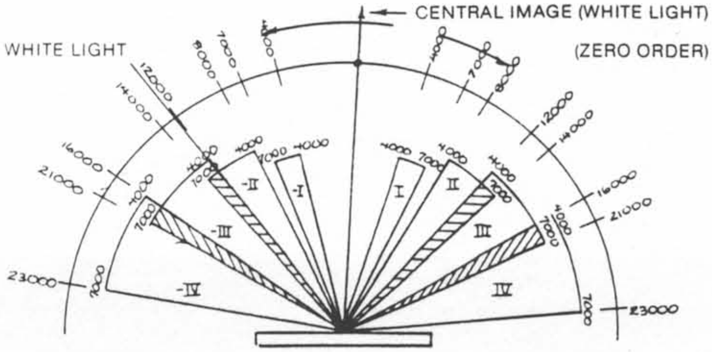
λ = Wavelength of light, measured in Angstroms units 1 A = 10^{-10} meters = 39.34×10^{-10} inches

d = Spacing, as explained above, also in Angstroms

i = Angle of incidence

r = Angle of reflection and the minus sign is used where i and r are on opposite sides of the grating normal.

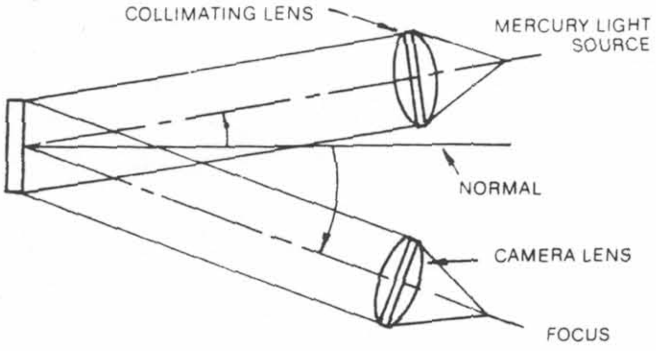
Fig. 3



* Since a grating forms not one, but rather a series of spectra, each is called an "order" as in Figure 3.

Overlapping of orders occurs as shown by the cross hatched areas. This drawing shows the spectra only for the visible wavelengths—in reality, each order extends into the U.V. and I.R. on each side of the visible. We can see that the direction, given by angle *r*, of light of a certain color (wavelength λ) in a certain order *n*, will be determined by the values we set for *i* and *d*. For example, if we have the set-up illustrated in Figure 4.

Fig. 4



Let us say we have a grating with 15,000 lines per inch.

$d = \frac{1}{15,000}$ inch or 16,930 Angstroms or in the metric system

$$d = \frac{2.54 \text{ cms}}{15,000} = .0001693 \text{ cms}$$

We set $i = 10°$, and wish to know at what angle V the green line of Mercury (λ =5460.7 A) will fall in the second order.

$$n = 2 \quad d = 16{,}930$$

$$n\lambda = d(\sin i + \sin r) \quad \lambda = 5460.7 \quad i = 10°$$

$$\sin i = .1739$$

$$n\lambda = d \sin i + d \sin r$$

$$\sin r = \frac{n\lambda - d\sin i}{d} = \frac{n\lambda}{d} - \sin i$$

$$= \frac{2 \times 5460.7}{16930} - .1739$$

$$= .6567 - .1739 = .4828 = \sin 28.86°$$

Note that two lenses are shown. A plane grating is almost always used in collimated light; either lenses and/or mirrors are needed to collimate and refocus the light. Typical set-up will be shown later.

In a spectrograph the "dispersion" corresponds to the magnification of a lens or microscope. The dispersion is a measure of the ability of the instrument to spread the spectral lines apart. The dispersion, or strictly speaking the "reciprocal linear dispersion" of a grating is given by:

$$\frac{D \text{ (in Angstroms)}}{\text{mm}} = \frac{d(\cos r)\ (\cos y)}{Rn}$$

where R is the distance from the camera lens to the focal curve, and y is the angle the curve makes with the light ray at the point.

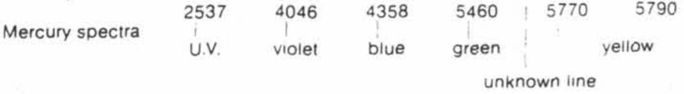
The quantity D becomes smaller as the effective magnification becomes larger (hence the designation "reciprocal".) We can see that D becomes smaller, (we spread wavelengths farther apart), by using long focal lengths, high orders, small ruling spacings, and large angles of reflection *r* and plate angle y.

An example, using the set-up as before:

$$\text{let } r = 28.86 \qquad \cos r = .8759 \qquad d = 16{,}930$$
$$R = 1000 \text{ mm} \qquad n = 2 \qquad y = 90° \qquad \cos y = 1$$

$$D = \frac{16{,}930 \times .8759 \times 1}{1000 \times 2} = 7.415 \text{ A/mm}$$

In a grating spectrograph the dispersion is usually fairly linear, at least over a short range. This means that it is possible to identify lines of unknown wavelengths by interpolating between lines of known wavelength. An example:



Let us say the distance between the 4358 line and the 5460 line is 2 inches. Then 2" = 1102A. Say the distance from the 4358 line to an unknown line = .423.

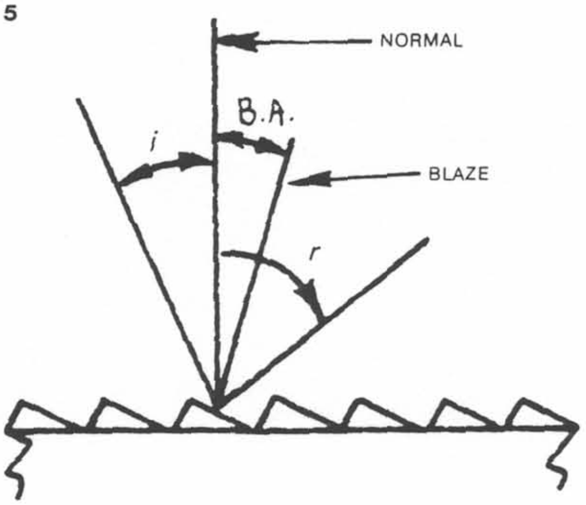
$$\lambda = 4358 + \left(\frac{.432}{2.0} \times 1102\right) = 4358 + 238 = 4596$$

$\lambda =$ 4596 Angstroms

The General Electric Company manufacturers a large variety of mercury lamps; the 4-watt germicidal lamp is fairly inexpensive.

Most diffraction gratings are blazed-that is, they reflect light most strongly in a certain direction. This is because the ruled grooves are shaped to present good flat reflecting surfaces at a certain angle. For optimum intensity, the angles " *i* " and " *r* " should be chosen to fall roughly on each side of the blaze angle at equal angles.

Fig. 5

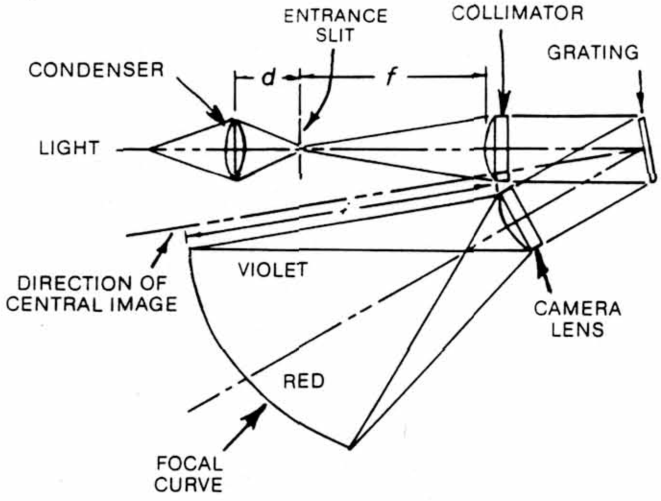


For example, when $i \approx r$, they should be set near the Blaze angle, see Figure 5.

let $i = 5°$ Blaze angle = 10° *r* should equal 25°

A grating may be used to form spectra of any optical wavelength, but it must be remembered that other materials used in the system may not transmit certain wavelengths. Glass, for instance, doesn't transmit much below 3300 A, quartz lenses must be used below this wavelength. In photographing spectra, attention must be given to the film sensitivity also. Any source of light may be used in conjunction with a spectrograph; some of the more common ones are tungsten filament, metallic and carbon arcs, Mercury, Neon, Argon, etc. glow tubes, flames with various salts introduced into them, & the sun. Following are sketches of 2 common mountings and comments concerning their use.

Fig. 6

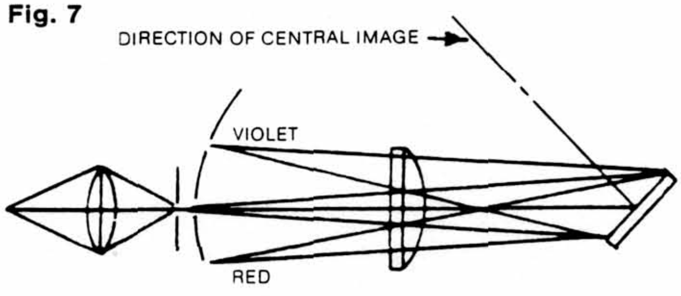


(1) Plane gratings:

The condenser of diameter "b" focuses the light on the slit. The collimator, and camera lens of focal length "f" and diameter "D", may be simple lenses or preferably achromats. "D" should be equal to the size of grating. See figure 6.

"b" should be at least $\frac{D}{f} \times a$.

Fig. 7



(2) Littrow

This is similar to (1) but uses. only one larger lens. The beam from the slit goes through a hole in the focal curve. Referred to as the Littrow Arrangement, see Figure 7.

It is strongly suggested that the interested experimenter consult the following references, as they give many more details than can be shown here:

1. Practical Spectroscopy, Harrison, Ford and Loofbourow. Prentice-Hall, New York, 1948. Good general spectrographic reference.
2. Experimental Spectroscopy, Sawyer, Prentice-Hall. Englewood Cliffs, New Jersey, 1951. Good treatment of mathematical design.
3. Experimental Physics, Strong, Prentice-Hall, Englewood Cliffs, New Jersey, 1938. Especially valuable for the general experimenter.

Advantages of reflection grating over transmission:

1. Less light loss by absorption.
2. Reflection grating can be blazed to put most of light at a given angle.
3. "Folded" layout can be used to reduce space.
4. Will transmit U.V.

Advantages of reflection grating over prism:

1. More speed per dollar.
2. More resolution per dollar.
3. Higher dispersion with a single grating (no need to use several as in prism systems) by using high orders and small grating spacings.