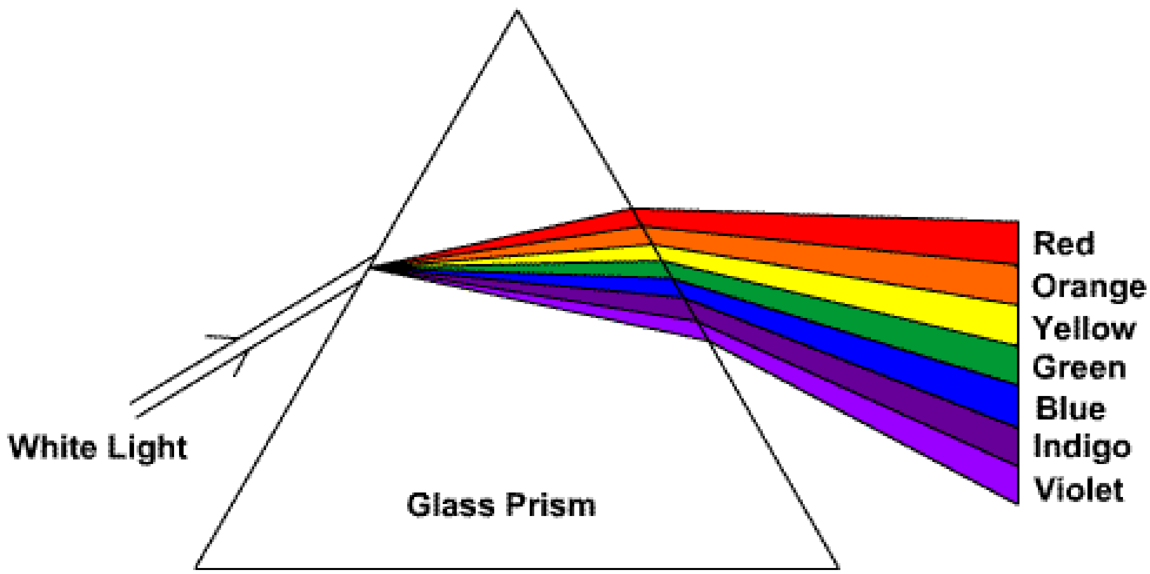
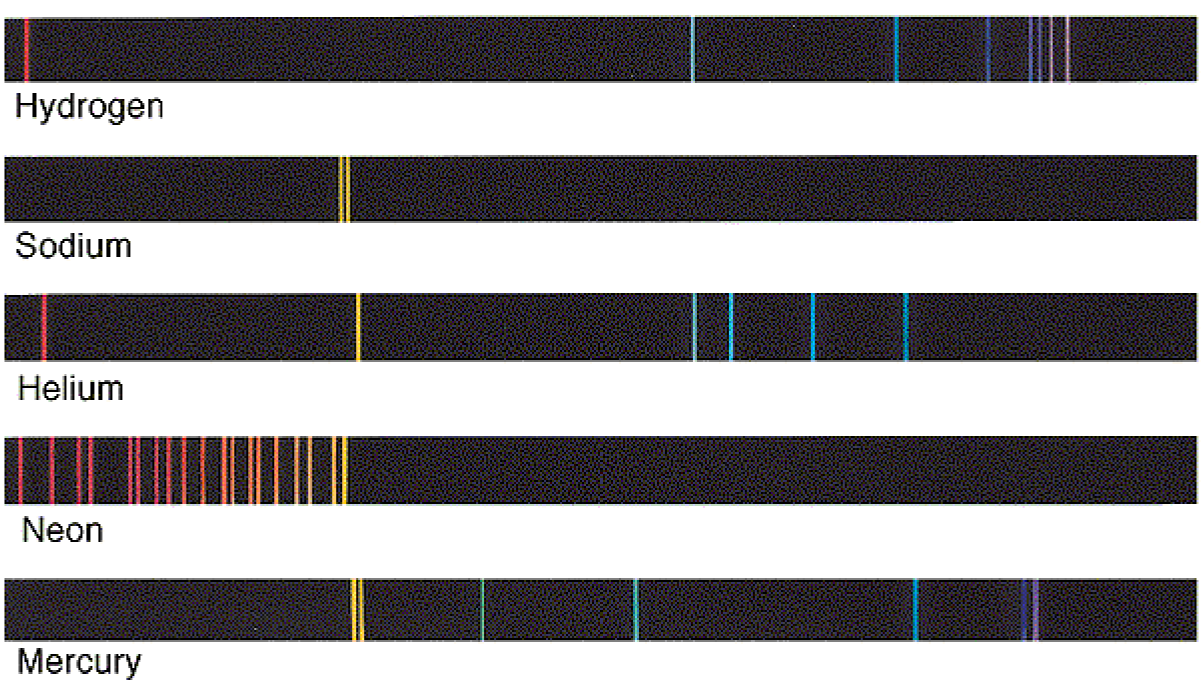
Spectrometry

- Want to see the spectral distribution of the light
- Used for detecting presence of elements based on spectrum
- Two ways – prism & diffraction gratings
- Mostly use diffraction gratings





Diffraction Gratings

- Diffraction gratings are periodic multiple slit devices
- Consider a diffraction grating: periodic distance a between slits
- Plane wave light hitting a diffraction grating at angle θ_i
- Then light gets bent to output angle of diffraction θ_m
- Light of second slit path is increased by

$$\Delta = \Delta_1 + \Delta_2 = a\left[\sin(\theta_i) + \sin(\theta_m)\right]$$

- Want the plane waves to be in phase for constructive interference
- Thus require path difference to be multiple of wavelength

$$\Delta = m\lambda$$

$$a\left[\sin(\theta_i) + \sin(\theta_m)\right] = m\lambda$$

- Where m is an integer (+ or -)
- Thus light will be spread out in colours at different angles

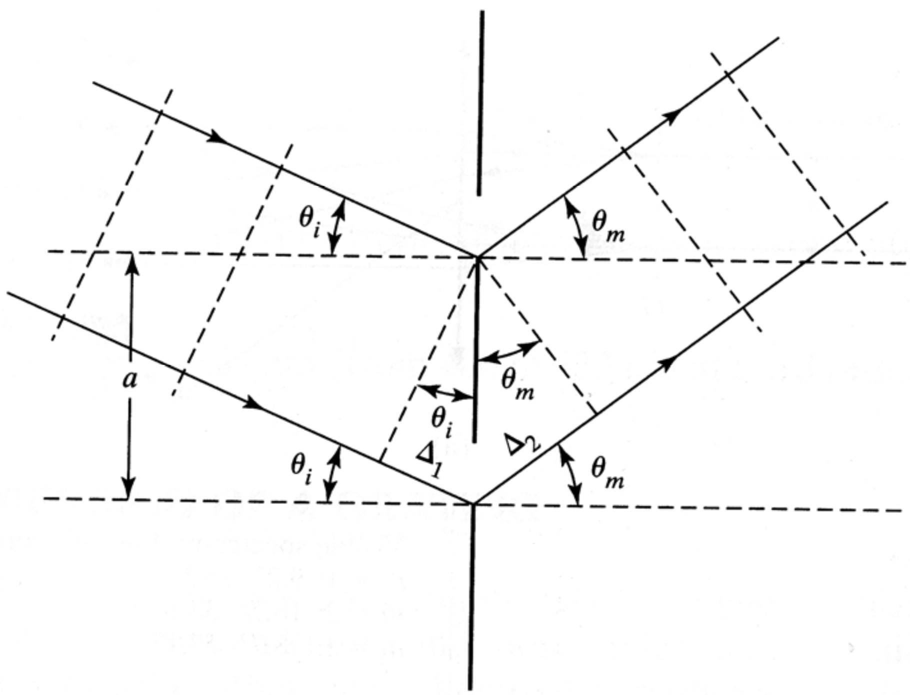


Figure 12-1 Neighboring grating slits illuminated by light incident at angle θ_i with the grating normal. For light diffracted in the direction θ_m, the net path difference from the two slits is $\Delta_1 + \Delta_2$.

Free Spectral Range

- One problem is that each wavelength has multiple orders of angles
- What is the spectral range before wavelengths overlap
- λ_1 is the shortest detectable wavelength
- λ_2 is the longest detectable wavelength
- Then for non-overlap require

$$m\lambda_2 = (m+1)\lambda_2$$

- Thus the free spectral range is

$$\lambda_{fsr} = \lambda_2 - \lambda_1 = \frac{\lambda_1}{m}$$

- Non overlap range smaller for higher order

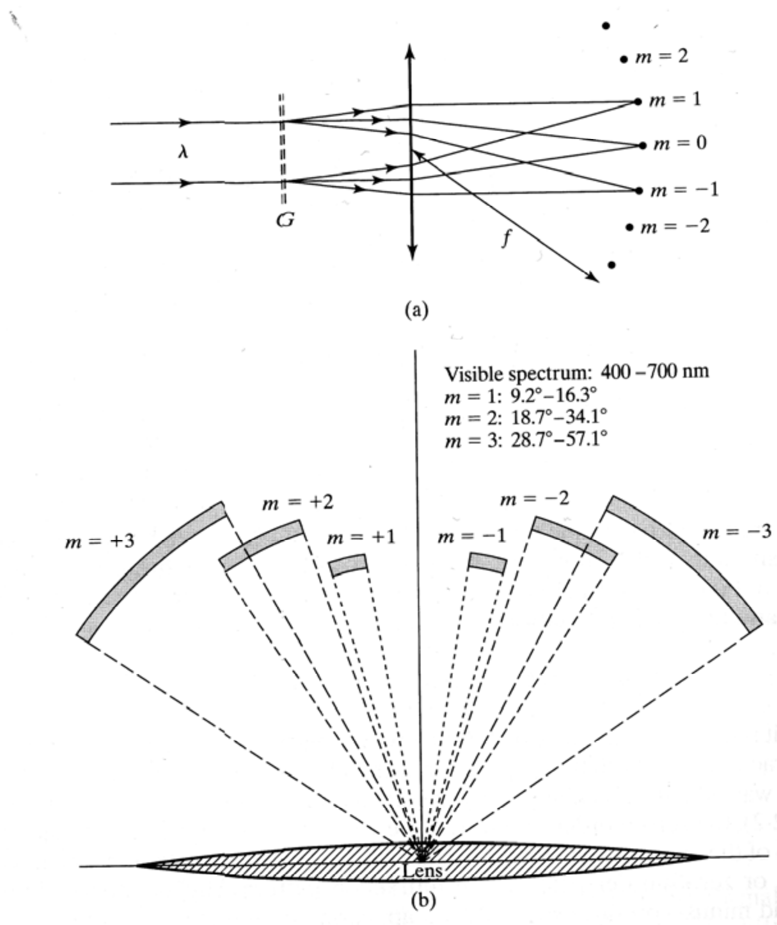


Figure 12-2 (a) Formation of the orders of principal maxima for monochromatic light incident normally on grating G. The grating can replace the prism in a spectroscope. Focused images have the shape of the collimator slit (not shown). (b) Angular spread of the first three orders of the visible spectrum for a diffraction grating with 400 grooves/mm. Orders are shown at different distances from the lens for clarity. In each order, the red end of the spectrum is deviated most. Normal incidence is assumed.

Dispersion of a Grating

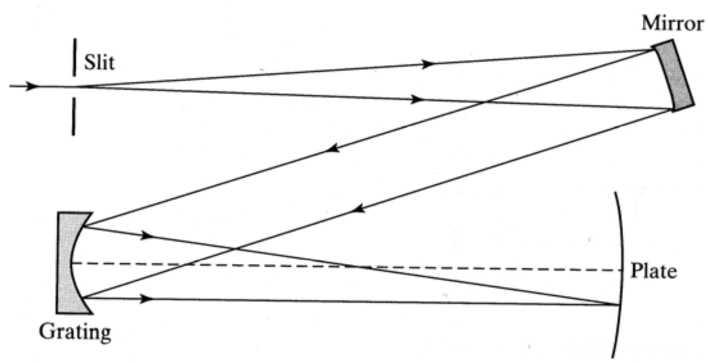
- Gratings measured by Angular Dispersion, *D*
- Measures the angular separation

$$D = \frac{d\theta_m}{d\lambda} = \frac{m}{a\,cos(\theta_m)}$$

- If a lens focuses the light to record the spectrum
- The want the linear dispersion

$$linear\ \ dispersion = \frac{dy}{d\lambda} = \frac{d\theta_m}{d\lambda} f\ =\ fD$$

- Reciprocal of linear dispersion is called the plate factor



Resolution of a Grating

Resolving power *R* is given by

$$R = \frac{\lambda}{\Delta\lambda_{min}}$$

Separation of two peaks set by Rayleigh's Criteria

$$d_{min} = \frac{1.22 f\lambda}{D}$$

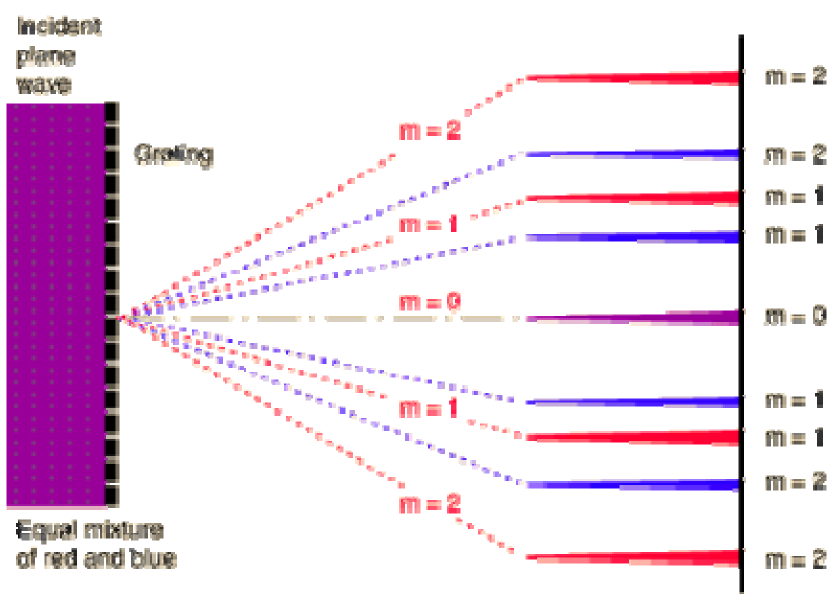
With a diffraction grating order m with N groves

$$a\,sin(\theta_m) = \left(m + \frac{1}{N}\right)\lambda$$

Resolving power related to the order of the peak
For grating of width W, spacing a then

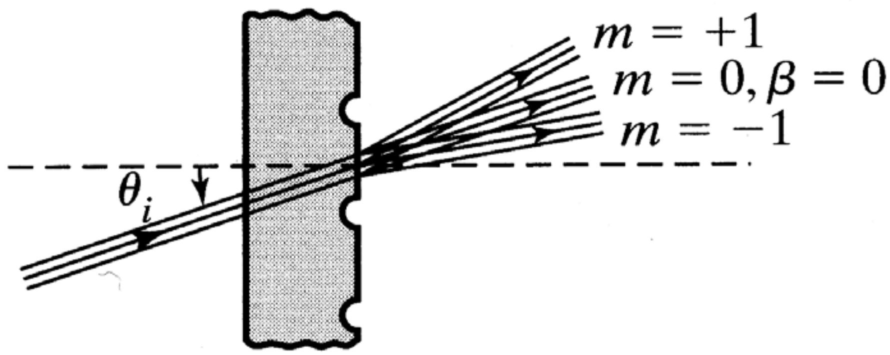
$$R = mN = \left(\frac{a\,sin(\theta_m)}{\lambda}\right)\left[\frac{W}{a}\right] = \frac{W\,sin(\theta_m)}{\lambda}$$

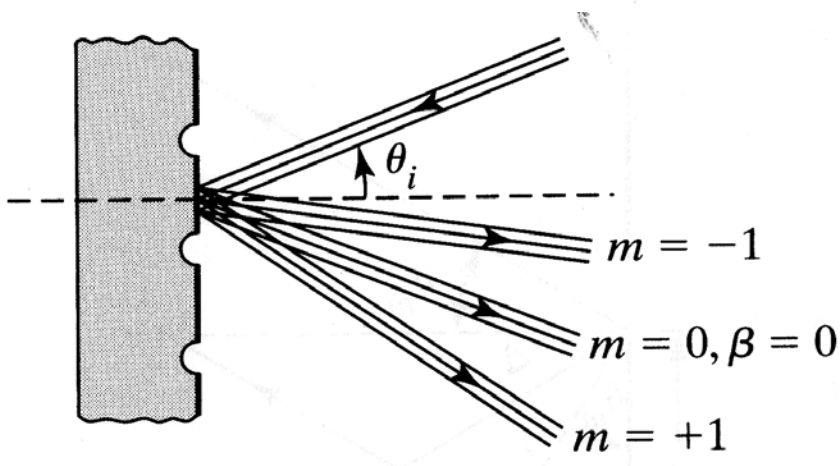
Actually does not just depend on width of grating
More fewer groves, wider grating means using larger order m

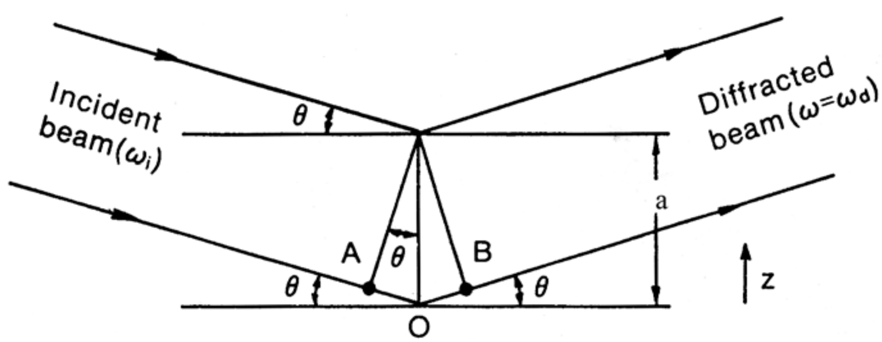


Types of Gratings

- Gratings can be of two types
- Transmission gratings: light comes from behind
- Reflection gratings: light reflects off surface
- Transmission common for small gratings





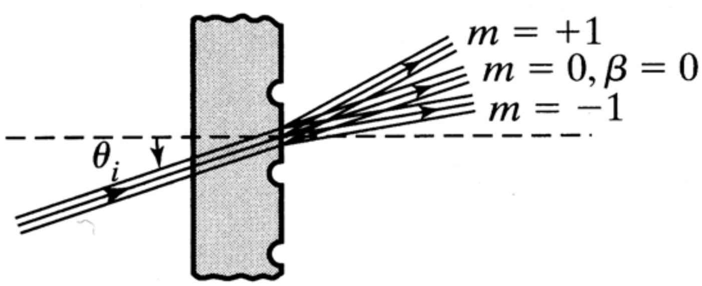


Blazing

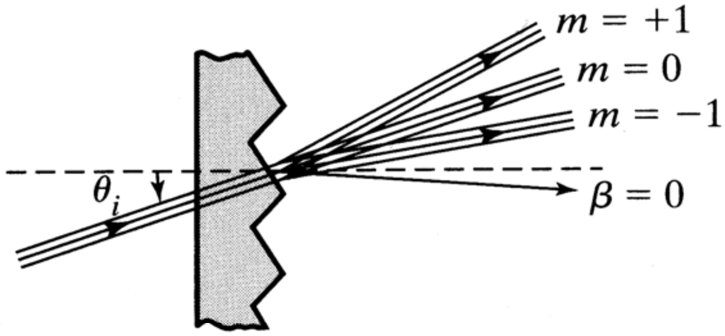
- Can angle gratings to change the angle light comes off at
- Plane gratings called "unblazed"
- Gratings with angle called Blazed
- For transmission do this by creating series of prisms
- Specified by the blazing angle

Brightest peak is a the zeroth order in diffraction
Blazing moves the brightest peak to another order m
Peak occurs when β=0
Then for the blaze and θ_b the equations change to

$$a\left[\sin(\theta_i)+\sin(2\theta_b-\theta_i)\right]=m\lambda$$



(a) Unblazed

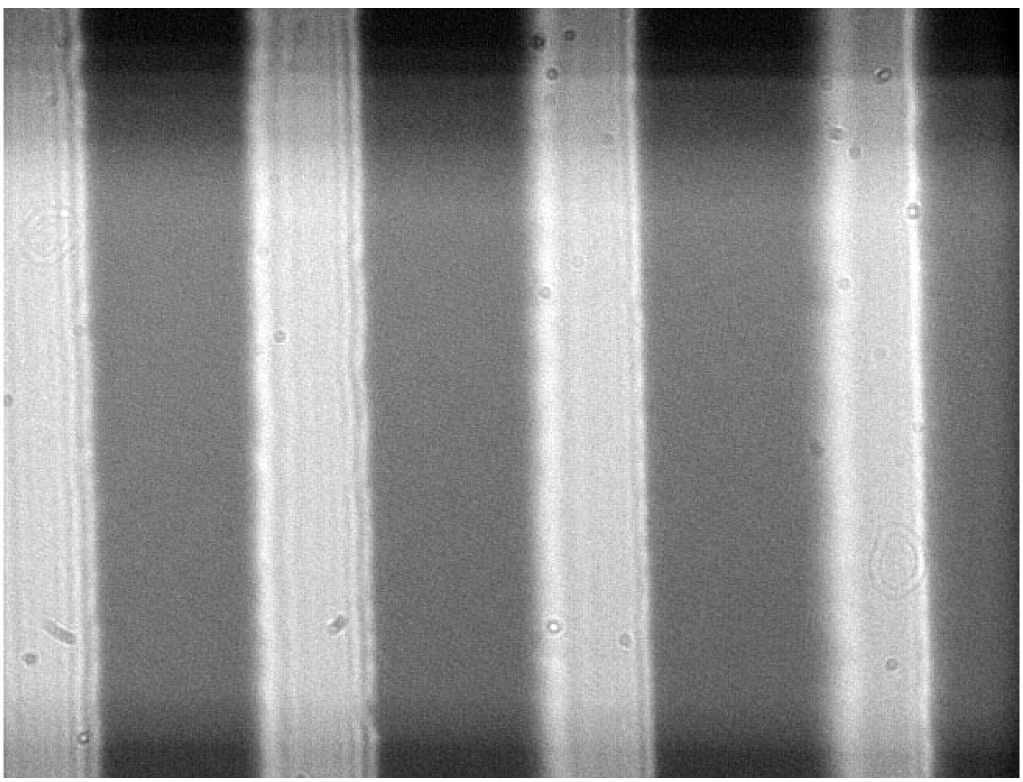


(b) Blazed

Figure 12-4 In an unblazed transmission grating (a), the diffraction envelope maximum at $\beta = 0$ coincides with the zeroth-order interference at $m = 0$. In the blazed grating (b), they are separated.

Creating Gratings

- Gratings created in 3 methods
- Machined – high accuracy machining with a milling grove
- Makes master gratings
- Commonly uses replicas – copy of grating masters
- Using microfabriction methods
- Deposit aluminium on plate & cover with photoresist
- Use grating patterings
- Alternatively use mask with grating pattern
- Expose resist, develop it and etch pattern
- etch aluminium film
-



Interference Gratings

Creating grating with interference methods
2 possibilities – wedge type interference
Take monochromatic beam (laser) split in 2
Combine two beams at plate
Lines on plate function of the very with angle of beams
Can get line/spaces below 100 nm

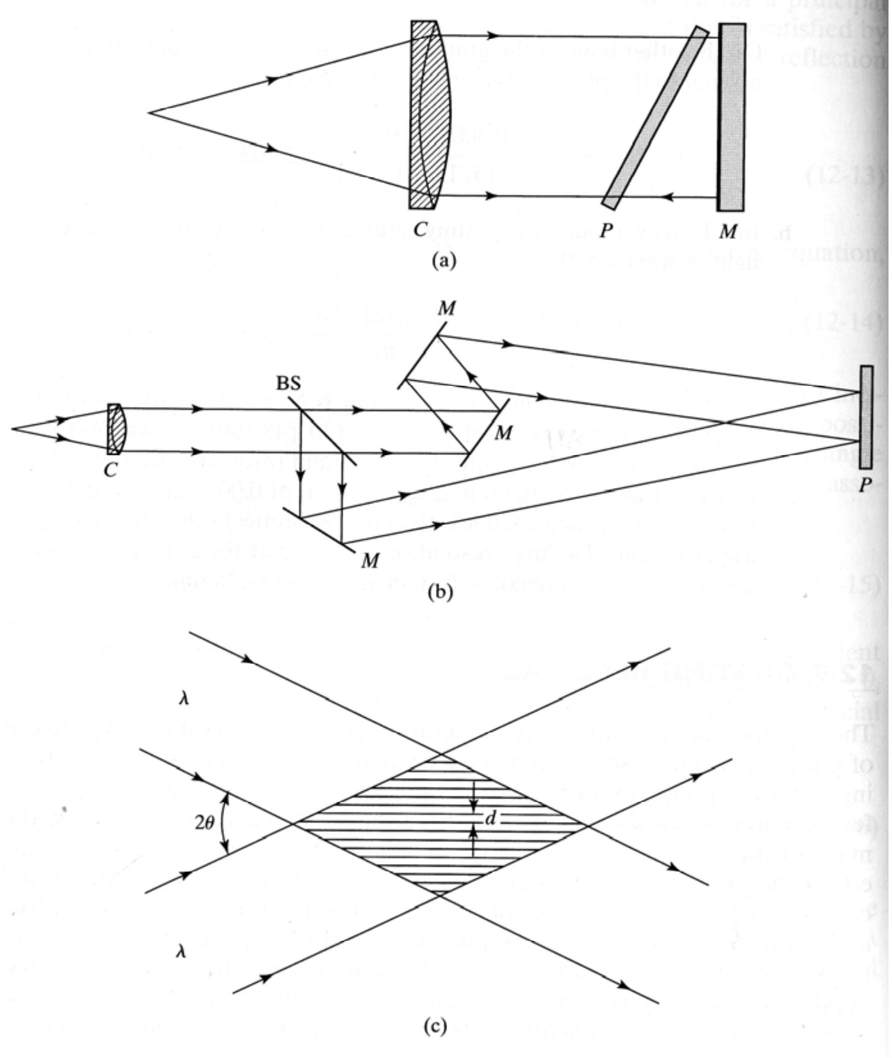


Figure 12-7 (a) Michelson system for producing interference gratings, including collimator C, mirror M, and photographic plate P. (b) Holographic system for producing interference fringes including collimator C, beam-splitter BS, mirrors M, and light-sensitive plate P. (c) Production of interference fringes in the region of superposition of two collimated and coherent beams intersecting at angle 2θ.

Spectrometers

- Usually start with a slit to give narrow source
- Add concave mirror to create parallel beam
- Reflect off grating to create spectrum
- Then another mirror to create focus light to detector
- Rotate grating to get different lines
- Often motorized to sweep spectrum – record the data with λ
- Use high sensitivity detector (photodetector)
- Common types Echelle two gratings
- Czerny-Turner – single grating
- These also call monochromoters
- Longer the length – higher the accuracy

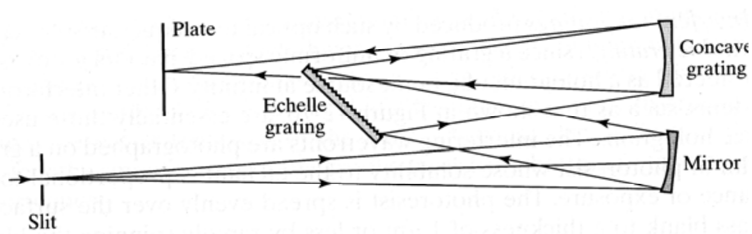


Figure 12-9 Side view of the echelle spectrograph. The echelle is positioned directly over the slit-to-mirror path, but the plate is offset in a horizontal direction.

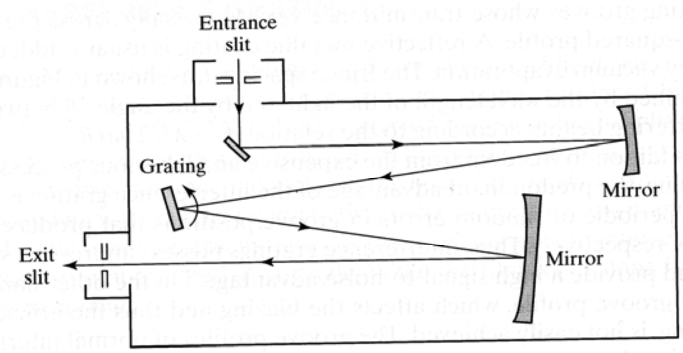
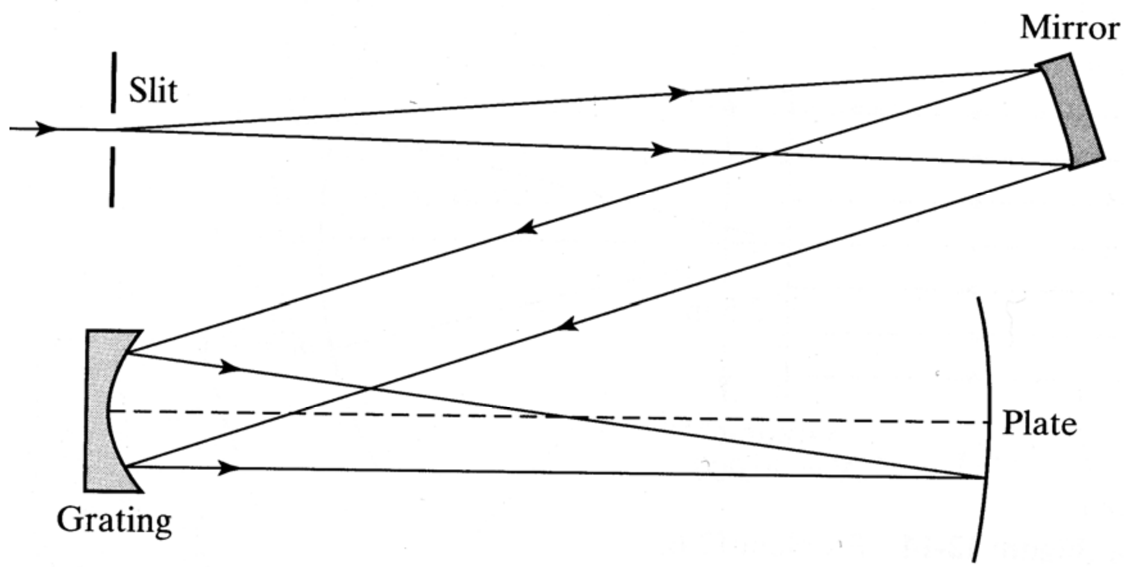


Figure 12-10 Czerny-Turner spectrometer.

Curved Mirror Gratings

- Can make the grating as a curved mirror
- Wadsworth spectrometer
- Less parts but harder to make the mirror
- This takes an full spectrum on a detector plate



CCD Spectrometers

- New spectrometers small, use CCD detector array
- Eg. from Ocean Optics
- Spectrometer input from fiber optics
- Connected to computer by USB cable
- Select the gratings to give line width, wavelength range
- Typical 200-1100 nm