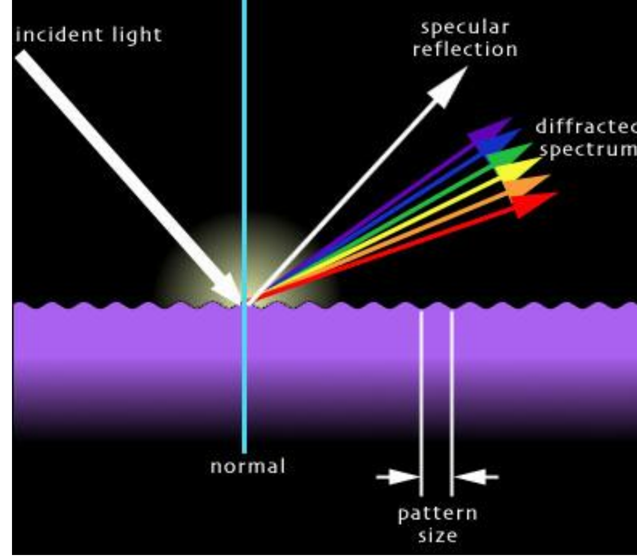
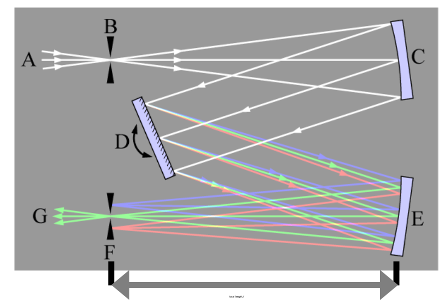
Grating Spectrometers, Thermopile Detectors, and Lock-In Detection



September 11, 2012



The University of Toledo
R. Ellingson and M. Heben

Where are We, Where we are Going? (the next three weeks and beyond)

- ✓ Igor (or comparable), LabView
- ✓ Properties of the Sun
- ❑ Understand Components in Optical Measurement System
  - ❑ Physics
  - ❑ Role in experiments
- ❑ Set Them Up!
  - ❑ Bread Board Layout
  - ❑ Interface to Computer
  - ❑ Develop software
- ❑ Characterize output of lamp/monochromator (three weeks)
- ❑ Onward to reflection, transmission, absorption, QE, J/V, and a host of other, potentially interesting measurements!

Lab Due Dates, and other Info

Previously – Due on Monday before the lab, noon.

Rationale – wanted students to look at lab report requirements/topics early, so we could help if needed

Now – Due on Tuesday, by Lab time

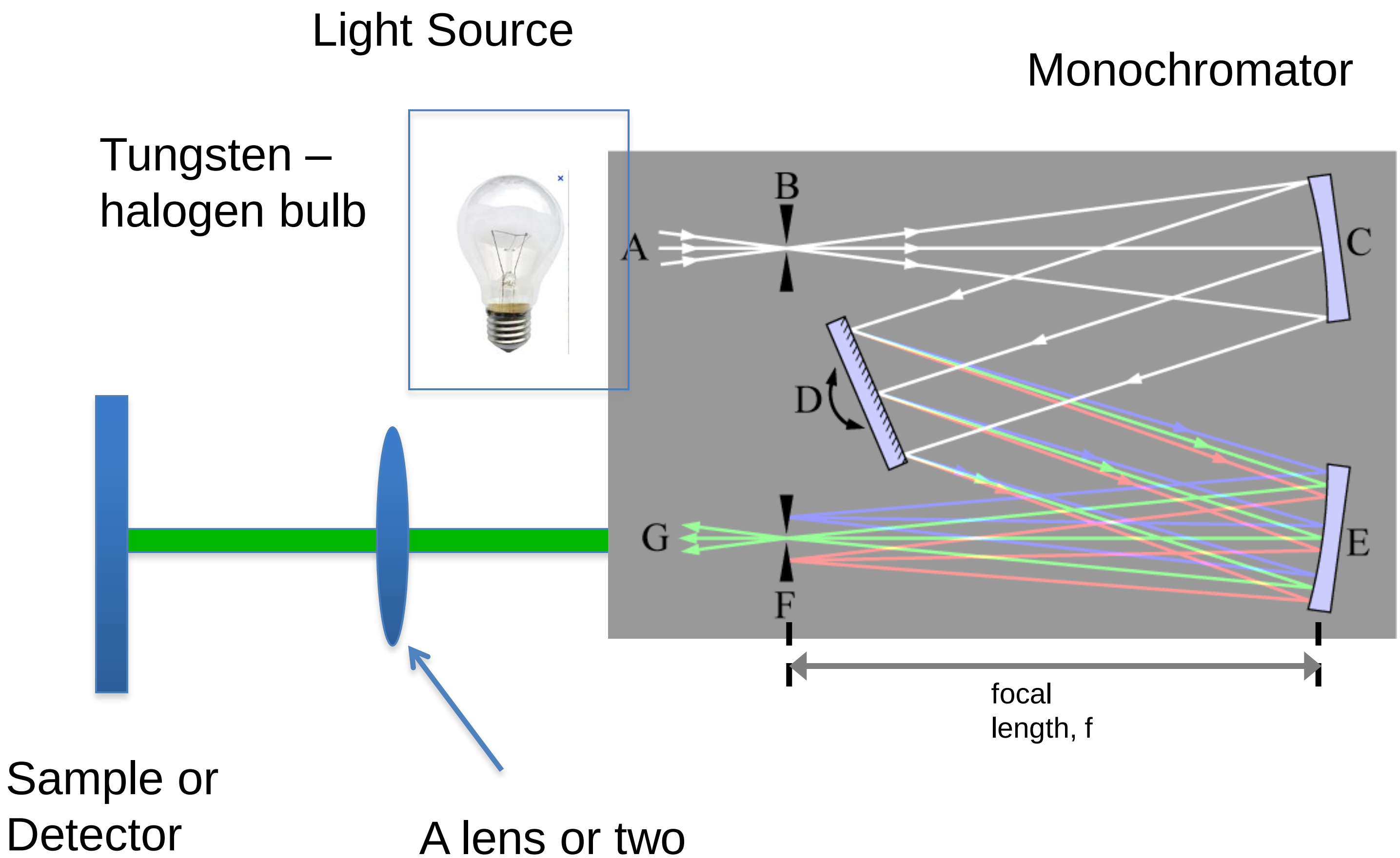
Think about your report and potential stumbling blocks early! Interface with group members early!

Late policy will be strictly enforced!

Next Lab Report Due October 3 – 1st day after Fall Break

First Quiz on September 25

The “Set-Up”

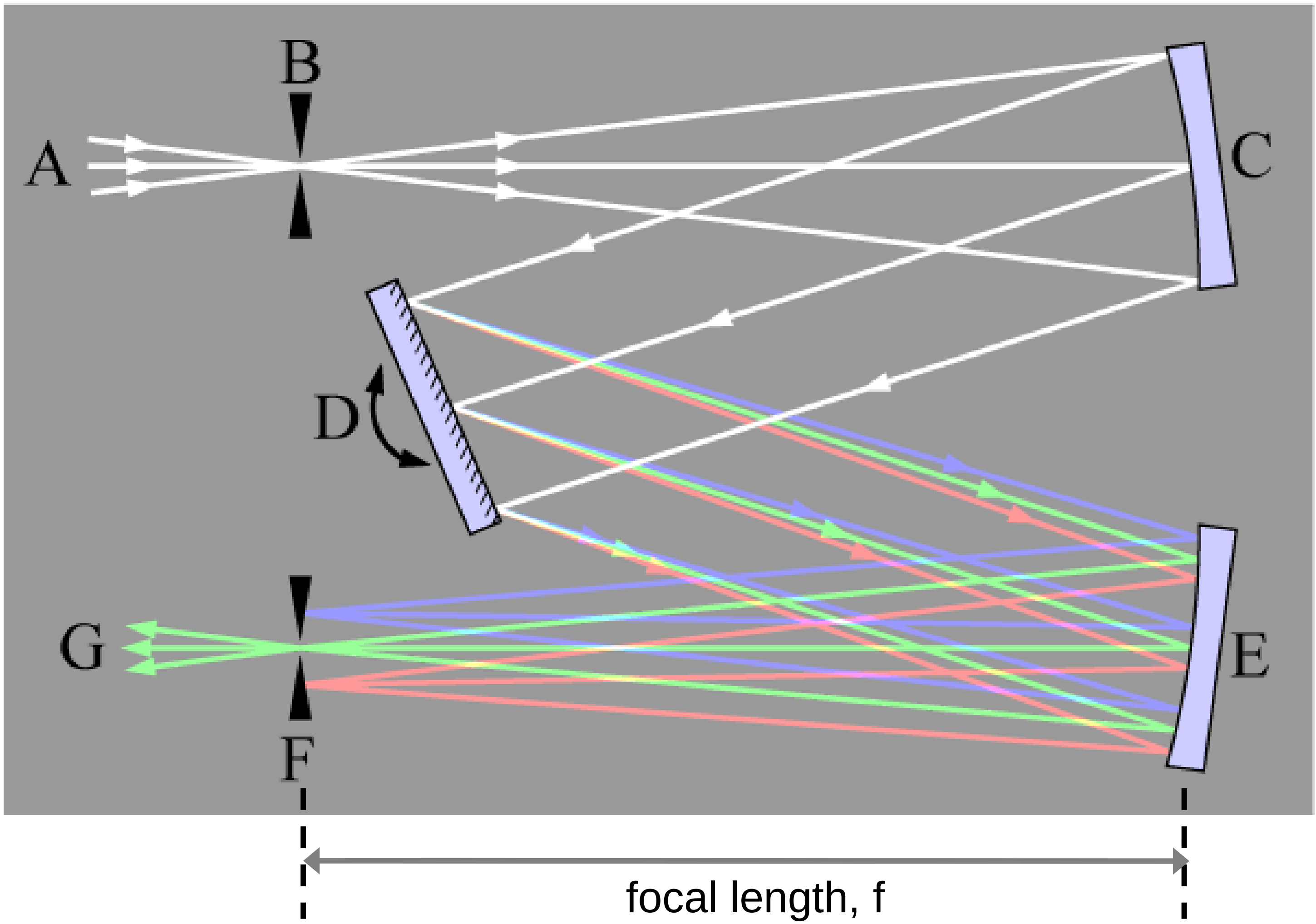


Samples – semiconductor layers, transparent conductive layers, PV devices
Detectors – calibrated thermopile, photodiode

Spectral Products, CM110 1/8th meter monochromator

Feature	Value
Design:	Czerny-Turner, dual-grating turrets
Focal Length:	110mm
f/#:	3.9
Beam Path:	Straight through standard, right angle provided on request.
Wavelength Drive:	Worm and wheel with microprocessor control and anti-backlash gearing. Bi-directional. Usable in positive or negative grating orders.
Wavelength Precision:	0.2nm
Wavelength Accuracy:	± 0.6nm
Slewing Speed:	>100nm/second
Stray Light:	$<10^{-5}$
Slits:	Standard Set includes; 0.125mm, 0.15mm, 0.30mm, 0.6mm, 1.2mm and 2.4mm x 4.0mm. For other sizes, consult SP.
Max Resolution:	<1nm w/1200G/mm grating and standard slits
Gratings:	One to two gratings. (30 x 30mm) must be purchased. See Appendix A for options
Software:	Demonstration control program and LabView driver included.
Power:	UL listed 110/220V power pack
Interface:	RS232 standard
Warranty:	One year
Options:	• Hand-held control module with function keys and display for local control • IEEE-488 interface • Interface cables • Gold optics See options and accessories

Czerny-Turner Monochromator



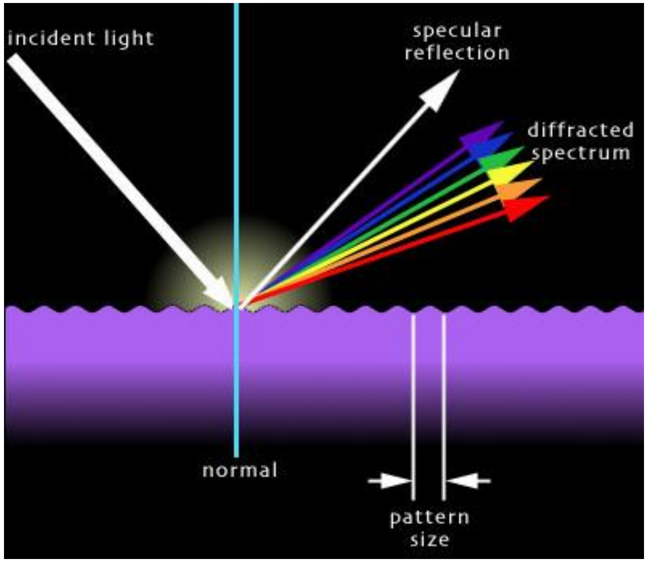
Diffraction
(not much different from Interference)

multiple sources >> Diffraction
Few source (e.g. Young's slits) >> Interference

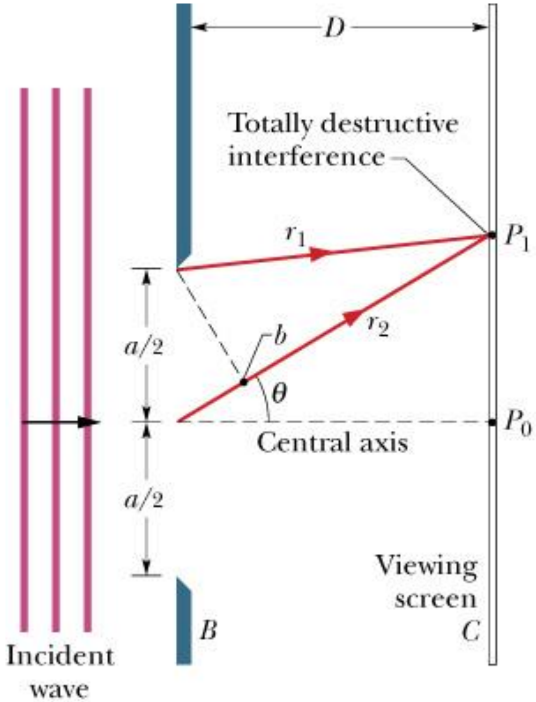
"no-one has ever been able to define the difference between interference and diffraction satisfactorily. It is just a question of usage, and there is no specific, important physical difference between them." – Richard Feynman

Occurs with all waves – Water, electromagnetic, matter waves

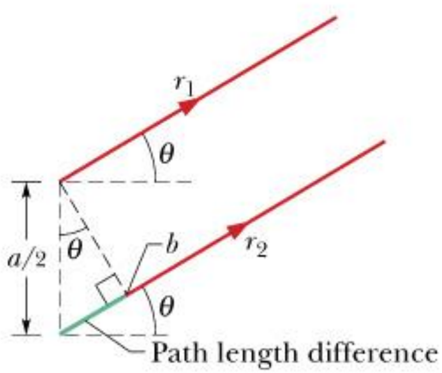
Classical and Quantum mechanic descriptions



Diffraction by a Single Slit: Locating the *Minima*



(a)

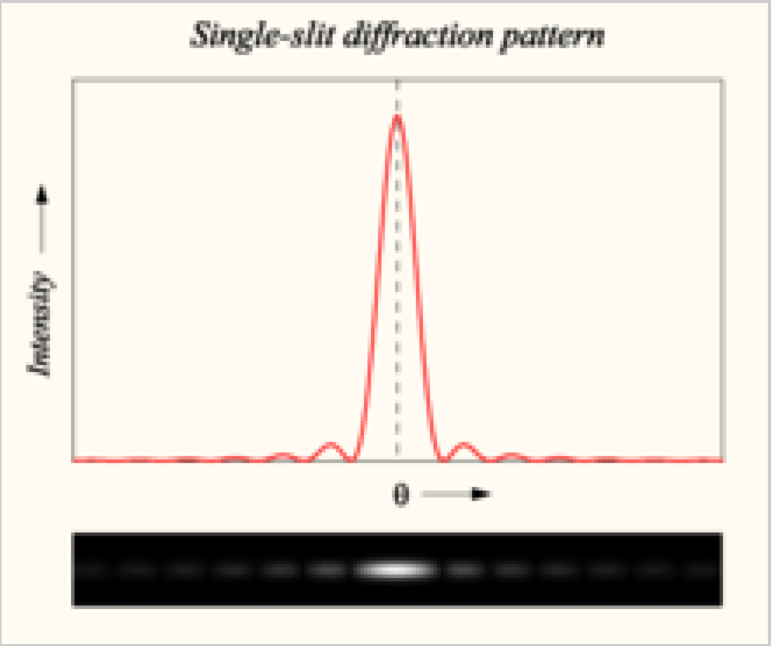


(b)

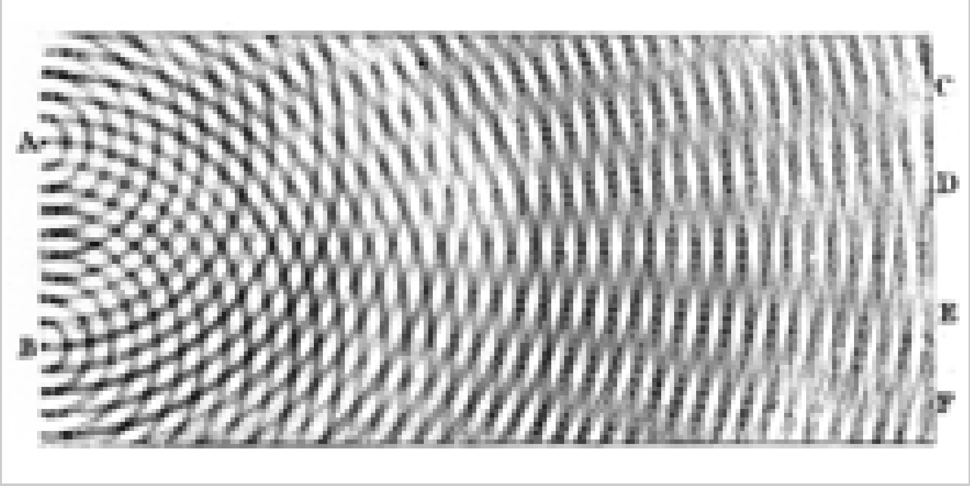
When the path length difference between rays r_1 and r_2 is $\lambda/2$, the two rays will be out of phase when they reach P_1 on the screen, resulting in destructive interference at P_1. The path length difference is the distance from the starting point of r_2 at the center of the slit to point *b*.

For *D*>>*a*, the path length difference between rays r_1 and r_2 is $(a/2)\sin\theta$.

Single- and double-slit diffraction patterns



Graph and image of single-slit diffraction



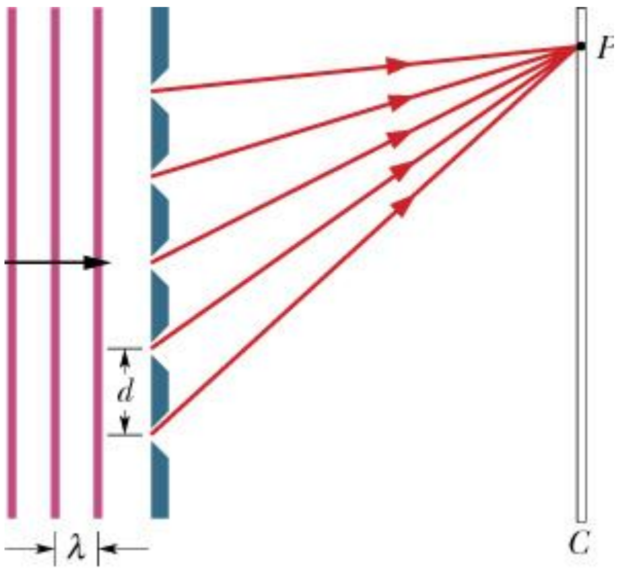
Thomas Young's sketch of two-slit diffraction, which he presented to the Royal Society in 1803

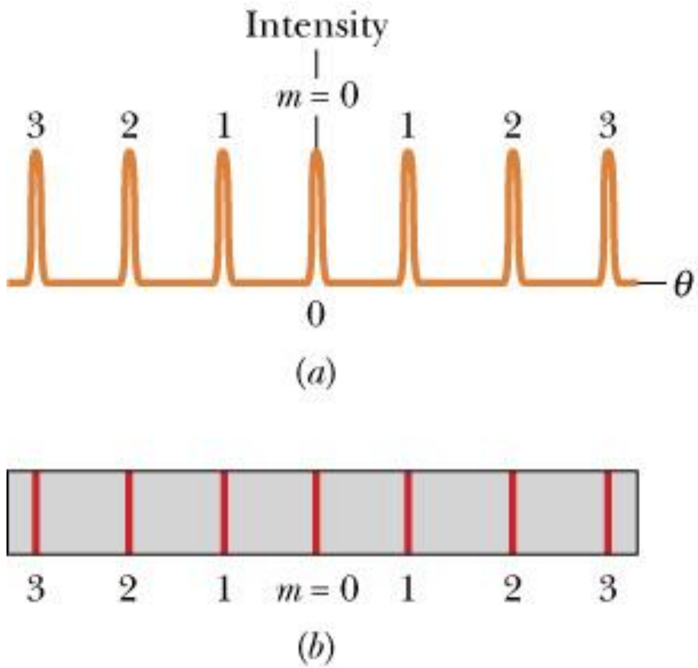
From *Wikipedia*

Diffraction Gratings (multiple "slits")

Device with N slits (rulings) can be used to separate different wavelengths of light that are contained in a single beam. How does a diffraction grating affect monochromatic light?

Here we consider a single wavelength



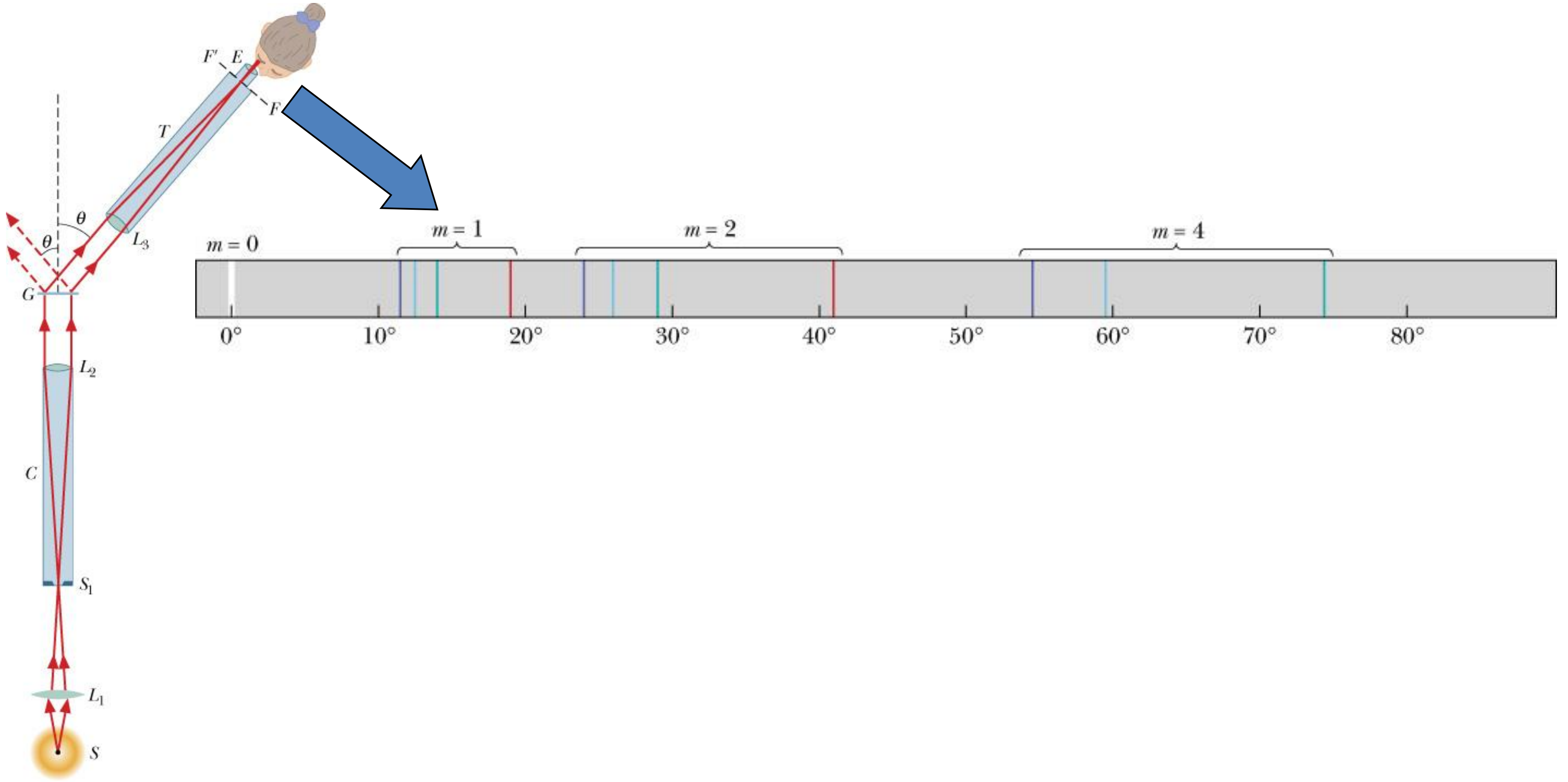


$$d \sin\theta = m\lambda \quad \text{for } m = 0, 1, 2\ldots \quad \text{(maxima-lines)}$$

Can operate in transmission or reflection

Grating Spectroscope (transmission diffraction grating)

Separates different wavelengths (colors) of light into distinct diffraction lines (this image shows a transmission diffraction grating, while most spectrometers use reflective diffraction gratings).



Developing the Grating equation

Reflective diffraction grating

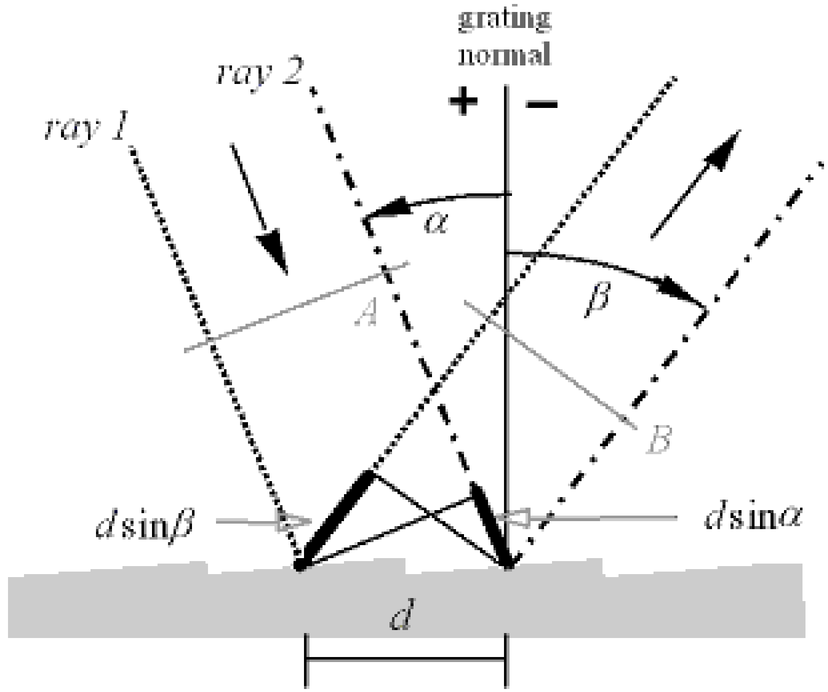
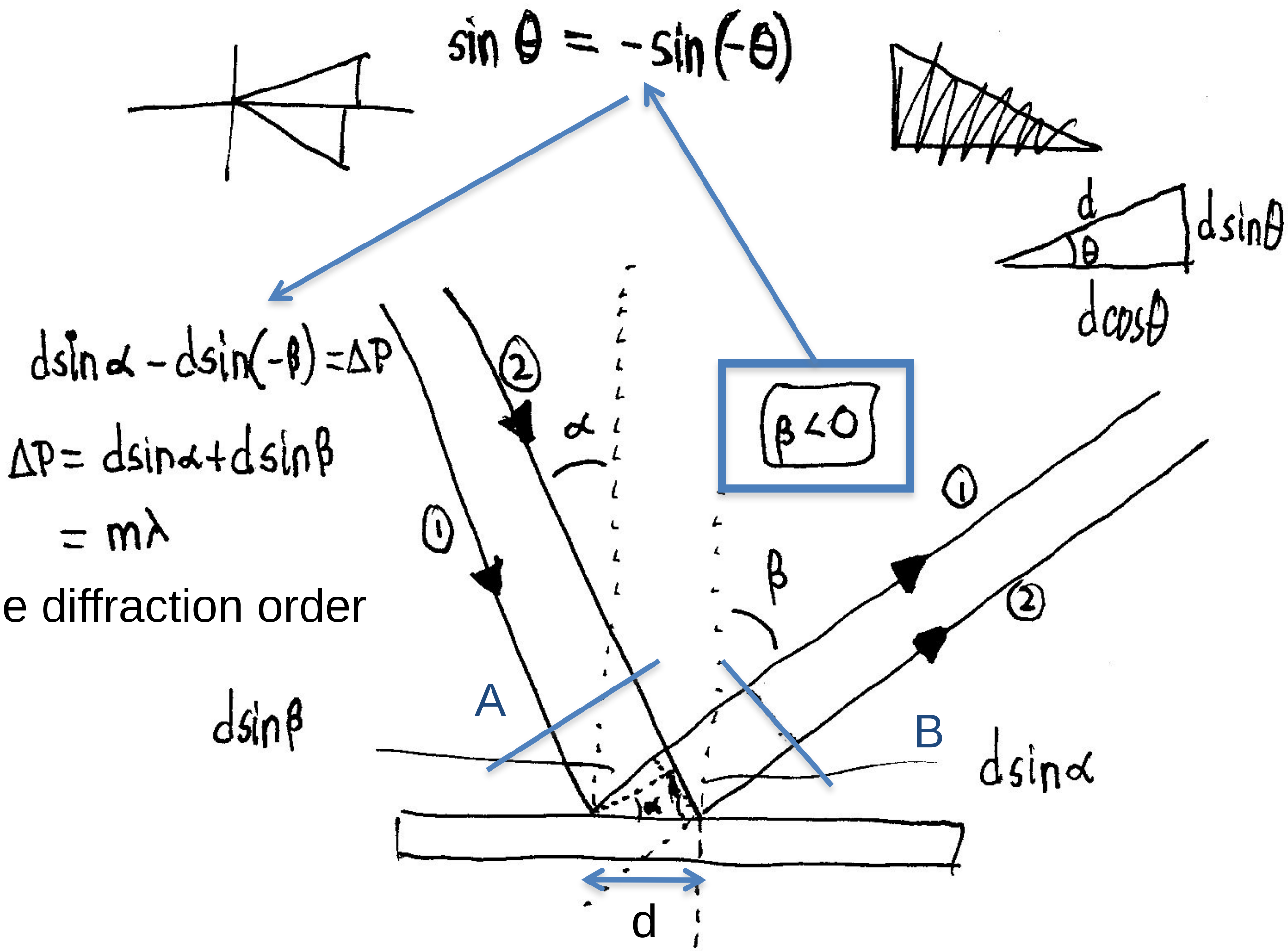


Figure 2-2. Geometry of diffraction, for planar wavefronts. Two parallel rays, labeled *1* and *2*, are incident on the grating one groove spacing *d* apart and are in phase with each other at wavefront *A*. Upon diffraction, the principle of constructive interference implies that these rays are in phase at diffracted wavefront *B* if the difference in their path lengths, $d\sin\alpha + d\sin\beta$, is an integral number of wavelengths; this in turn leads to the grating equation.

http://gratings.newport.com/information/handbook/chapter2.asp#2.2

Different path lengths for different wave fronts at A and B



m is the diffraction order

By convention, angles of incidence and diffraction are measured *from the grating normal to the beam. This is shown by arrows in the diagrams. In both diagrams, the sign convention for angles is shown by the plus and minus symbols located on either side of the grating normal. For either reflection or transmission gratings, the algebraic signs of two angles differ if they are measured from opposite sides of the grating normal. Other sign conventions exist, so care must be taken in calculations to ensure that results are self-consistent.*

http://gratings.newport.com/information/handbook/chapter2.asp#2.2

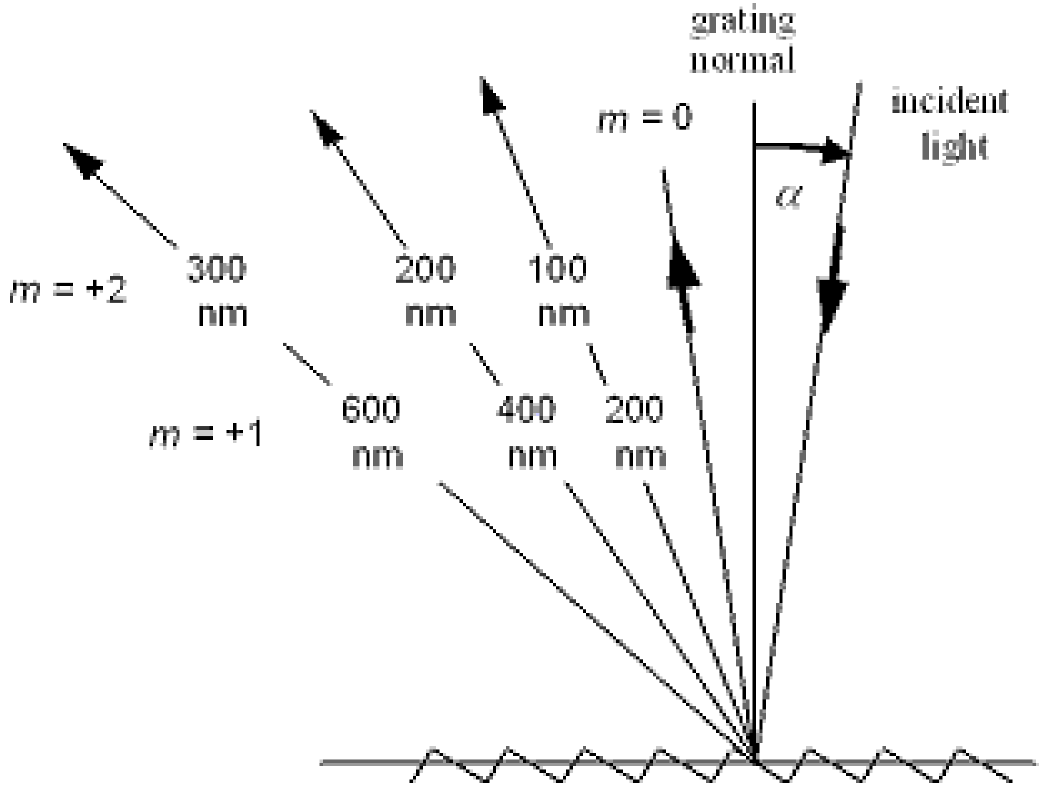
Different forms of the Grating equation

$$m\lambda = d\,(\sin\alpha + \sin\beta),$$

$$Gm\lambda = \sin\alpha + \sin\beta$$

$G = 1/d$ is the groove frequency or groove density

http://www.pariss-hyperspectral-imaging.com/GratingOrders_Movie/GratingOrders_Movie.html



It is evident from the grating equation that light of wavelength λ diffracted by a grating along direction β will be accompanied by integral fractions λ/2, λ/3, etc.; that is, for any grating instrument configuration, the light of wavelength λ diffracted in the m = 1 order will coincide with the light of wavelength λ/2 diffracted in the m = 2 order, etc. Above, red light (600 nm) in the first spectral order will overlap the ultraviolet light (300 nm) in the second order. A detector sensitive at both wavelengths would see both simultaneously. This superposition of wavelengths, which would lead to ambiguous spectroscopic data, is inherent in the grating equation itself and must be prevented by suitable filtering (called order sorting), since the detector cannot generally distinguish between light of different wavelengths.

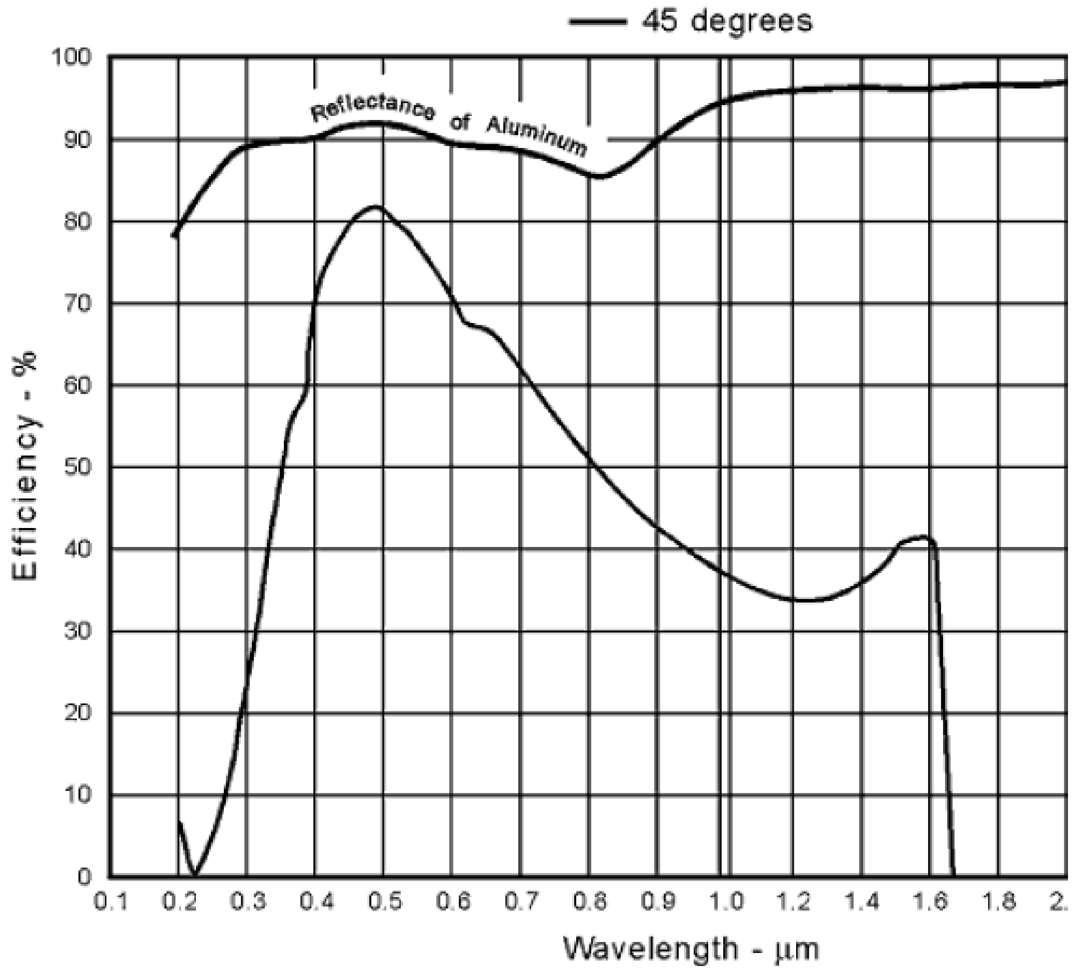
Spectral Products, CM110 1/8th meter monochromator

Feature	Value
Design:	Czerny-Turner, dual-grating turrets
Focal Length:	110mm
f/#:	3.9
Beam Path:	Straight through standard, right angle provided on request.
Wavelength Drive:	Worm and wheel with microprocessor control and anti-backlash gearing. Bi-directional. Usable in positive or negative grating orders.
Wavelength Precision:	0.2nm
Wavelength Accuracy:	± 0.6nm
Slewing Speed:	>100nm/second
Stray Light:	$<10^{-5}$
Slits:	Standard Set includes; 0.125mm, 0.15mm, 0.30mm, 0.6mm, 1.2mm and 2.4mm x 4.0mm. For other sizes, consult SP.
Max Resolution:	<1nm w/1200G/mm grating and standard slits
Gratings:	One to two gratings. (30 x 30mm) must be purchased. See Appendix A for options
Software:	Demonstration control program and LabView driver included.
Power:	UL listed 110/220V power pack
Interface:	RS232 standard
Warranty:	One year
Options:	• Hand-held control module with function keys and display for local control • IEEE-488 interface • Interface cables • Gold optics See options and accessories

Grating Efficiency

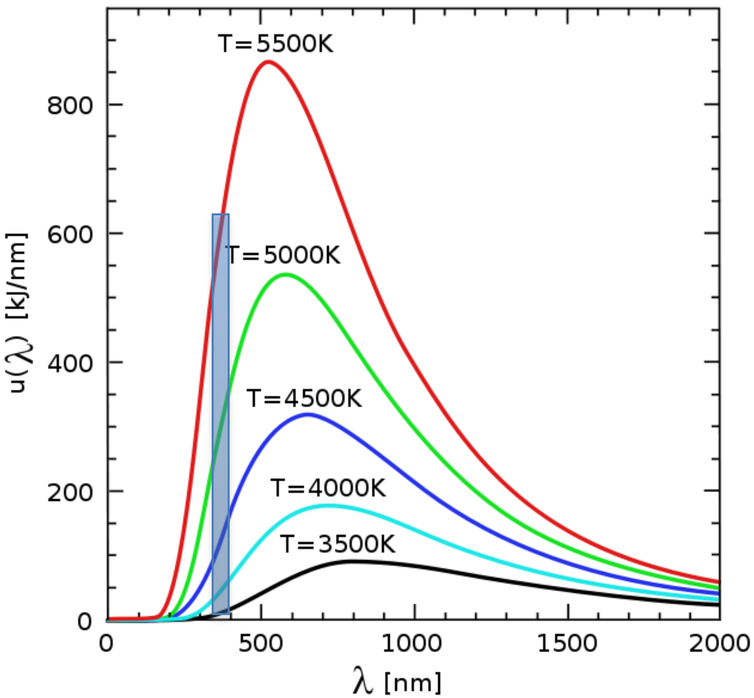
Catalog No. : 53-*-280R
Diffraction Order : 1
Master No. : 2687

Groove Frequency :
1200 g/mm
Grating Type :
Plane Ruled
Coating :
Aluminum
Nominal Blaze Angle :
17.5°
Blaze Wavelength :
500 nm
Maximum Ruled Area :
102 x 60 mm
Remarks :
Date 12/27/72



Maximum diffraction efficiency is produced from a given grating is produced at the "Blaze Wavelength"

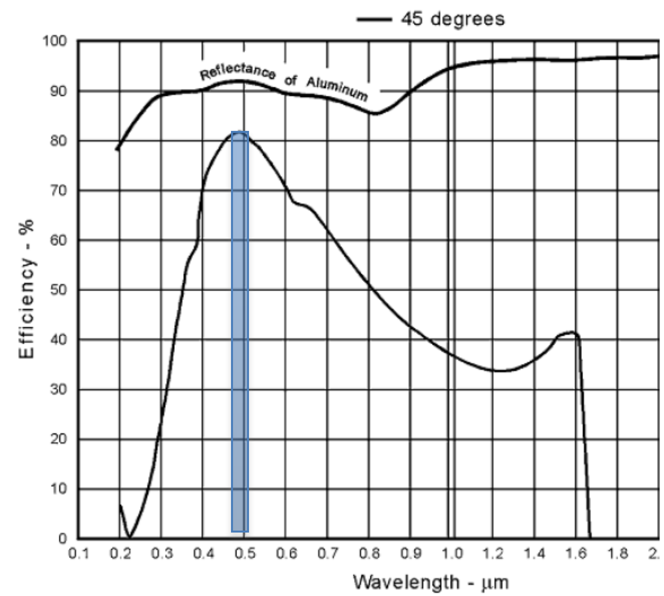
Characterize lamp/monochromator output (photon flux) at the sample plane (three week duration)



X

Catalog No. : 53-*-280R
Diffraction Order : 1
Master No. : 2687

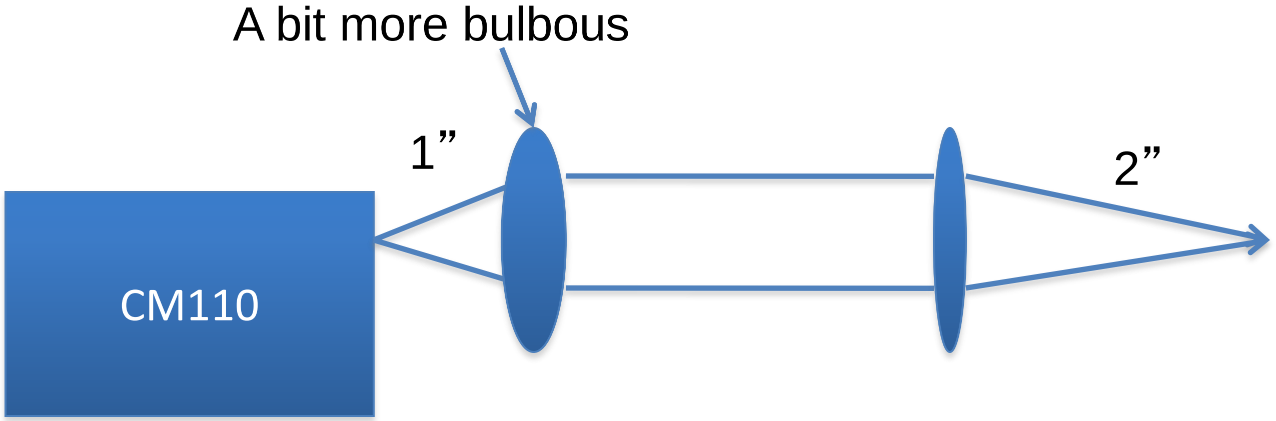
Groove Frequency :
1200 g/mm
Grating Type :
Plane Ruled
Coating :
Aluminum
Nominal Blaze Angle :
17.5°
Blaze Wavelength :
500 nm
Maximum Ruled Area :
102 x 60 mm
Remarks :
Date 12/27/72



How many Photons/s/nm are incident at the sample plane?

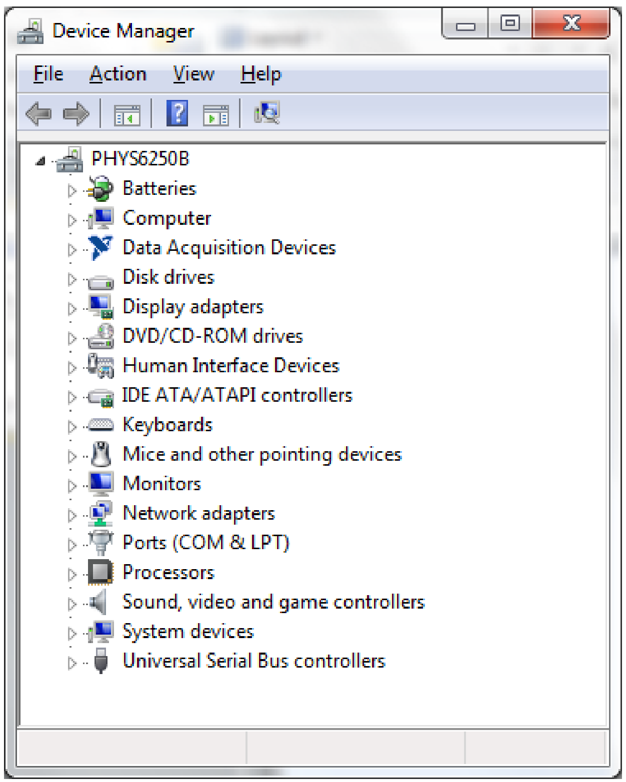
You have two lenses per set-up

1) Both 1’ diameter
2) One has a focal length of 1”
3) The other has a focal length of 2”



The nitty-gritty of communication with the CM110

Many of us had trouble getting the CM110 under proper computer control. Some troubleshooting last week with a Spectra Products employee led us to proper operation. The SP employee indicated that proper communication w/e CM110 requires that we be on COMx where $1 \leq x \leq 4$. To check the situation wrt our serial (RS-232) port assignments, one can go into the Device Manager. You can get there by going to Control, then Hardware and Sound, then Device Manager. It looks like this:



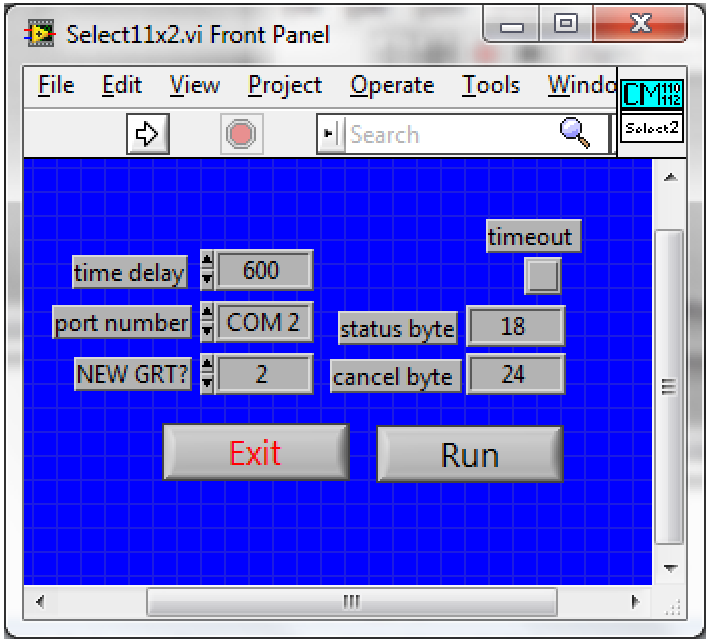
Expanding the Ports entry, one sees the COM ports listed with their assigned number (you'll see four ports listed most likely). If you encounter this problem again, check into this listing – if none of the COM ports refer to COM1-4, then right-click on one of these numbers and choose Properties. From there, go to Advanced. There you can reassign the COM port from, e.g., COM8 to COM2.

But Note: you shouldn't't (hopefully) need to do this, so please confirm that you have tried all COM ports on the USB to RS-232 hardware, and have tried all of COM1-4 on the LabView program. Then take a look at the Device Manager to see if indeed you lack at least one COM1-4.

Getting nominally monochromatic light out of the CM110

Once you have correct communication, you'll be able to read the wavelength using, e.g., getLambda.vi (if you have the port set correctly). When you first power up the CM110, the wavelength setting goes to 0. OK, then if you use goToLambda.vi to set the wavelength, and you don't see the color you set, then you likely need to change the grating selection. Note that the CM110 has a double-grating turret, as Mike described in an earlier email. One side has our 1200 g/mm grating (make sure you know what g/mm means); the other side has a flat aluminum mirror.

You can use the CM Series Demo vi (and set the COM port correctly, while ensuring that you are not running any potentially conflicting .vi's elsewhere that may simultaneously try to communicate with the CM110), to see which grating is selected. The number is in the upper right corner. If necessary, change the grating by: (a) exiting the Demo vi, (b) finding and running Select11x2.vi. This .vi is in the folder 'Desktop\CmC\8-0138-e'. You'll need to set the COM port correctly.



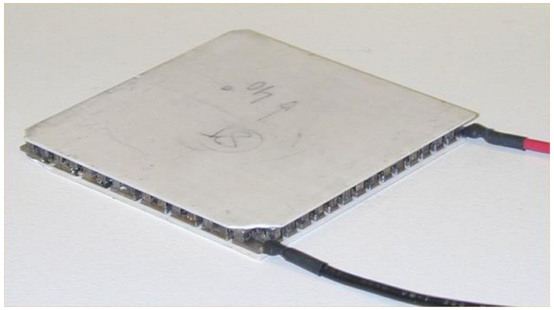
Thermopile Detector

Dexter 2M detector

A thermopile is an electronic device that converts thermal energy into electrical energy. It is composed of several thermocouples connected usually in series or, less commonly, in parallel.

Thermopiles do not respond to absolute temperature, but generate an output voltage proportional to a local temperature difference or temperature gradient.

Thermopiles are used to provide an output in response to temperature as part of a temperature measuring device, such as the infrared thermometers widely used by medical professionals to measure body temperature. They are also used widely in heat flux sensors. The output of a thermopile is usually in the range of tens or hundreds of millivolts.



After *Wikipedia and Dexter Research*

Goals of this Unit

1) Build an optical set-up to permit development of a LabView program to acquire (directly into the DAQ board), plot, and store signals from the thermopile detector. The detector is to be excited by the chopped output of the CM110 monochromator. Determine the time constant of the detector, and identify the gas used for packaging. Useful resources are under "Effects of Encapsulation Gas on Thermopile Detectors" and "Thermopile Time Constant Determination" at the http://www.dexterresearch.com/?module=Page&sID=technical-library

2) Acquire plot and store data from the thermopile using the lock-in technique. Compare to data from (1), and understand how the measured voltage relates to the thermopile's response.

3) Develop a program to measure, plot and store the output of the monochromator, in terms of # of photons/nm-cm2-s, as function of wavelength, for various lamp powers, and several slits widths. How does your measured spectrum compare to a Black Body spectrum? How does your measured spectrum compare to the AM 1.5 spectrum? Use Igor Pro to develop a correction file to convert measured spectrum into either BB or AM 1.5.

Additional guidance for Part 3

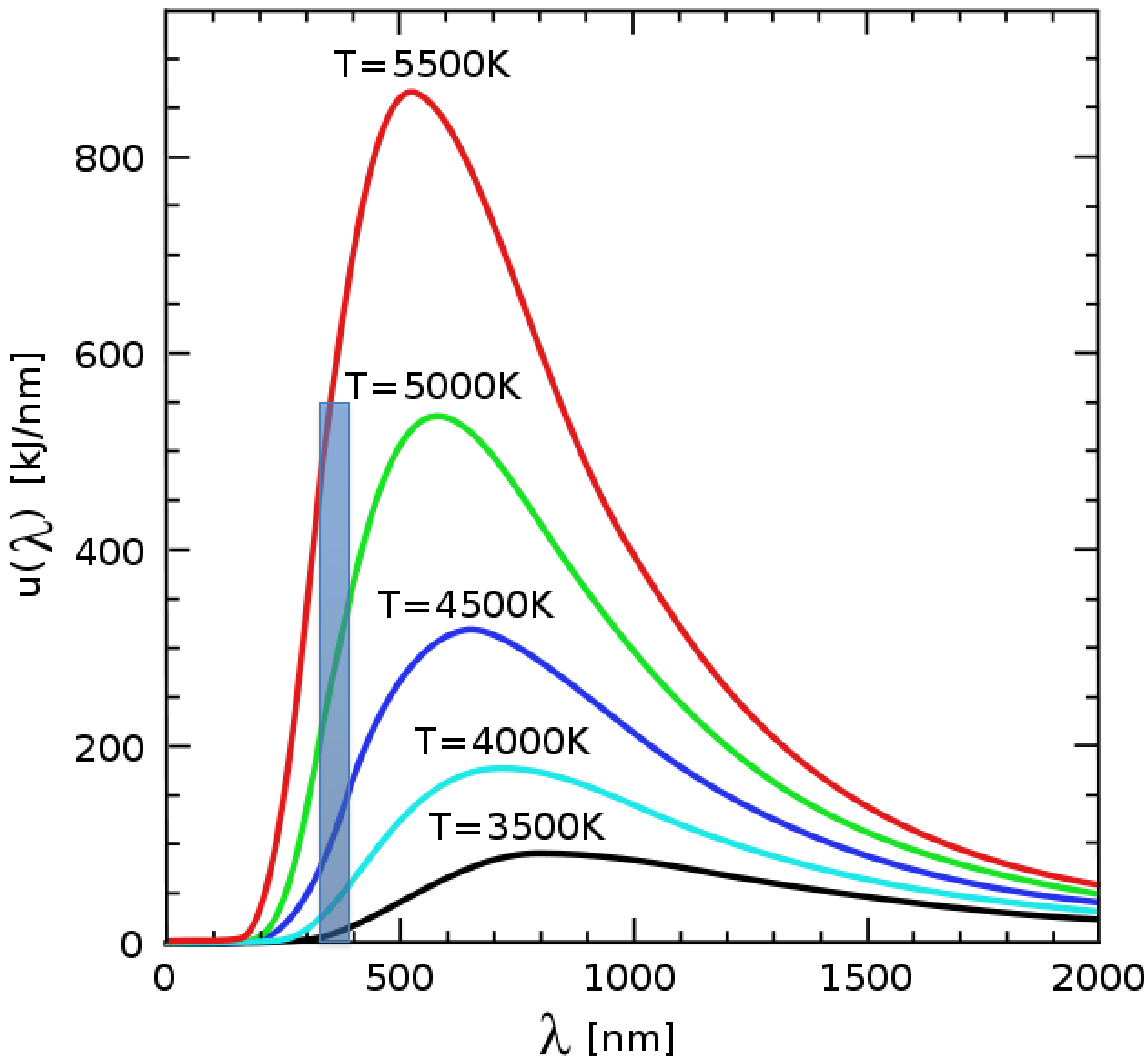
- Include information about calculations and assumptions (step by step).
- Include a comparison of measured data to the AM 1.5 and AM0 spectra in units of #photons/(s-cm^2-nm).
- Specify definition of correction files as AM X(λ)/measured spectra (λ).
- Plot (measured spectra x correction file) for each case versus AM X spectra.

Chopper height and CM110 exit port height

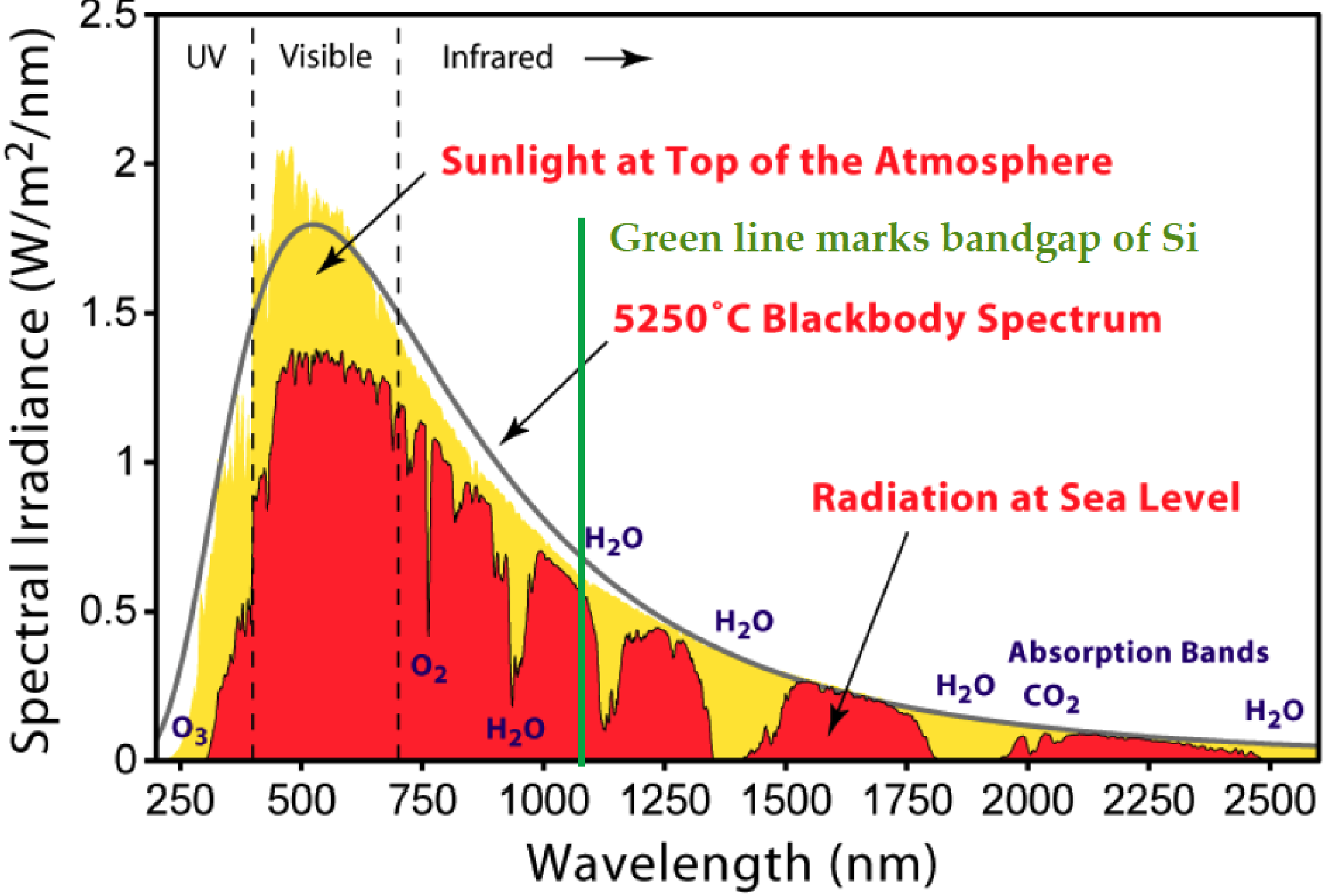
The chopper has a base plate and is conveniently mounted flat on this base plate – so it's height is less easily changed. If you set the CM110 up correctly, its height should be fine for use with the chopper without clipping the beam. Specifically, use the smallest post holder, and screw these directly into the optical breadboard (do not use a baseplate underneath the post holder) using the ¼-20 set screws we provided). Then, be certain you're using the 1.5" posts mounted on the bottom of the CM110.

More on lock-in amplifier next week

Spectrometer sensitivity calibration: black body radiation, grating efficiency, detector sensitivity



Solar Radiation Spectrum



Resources:

http://gratings.newport.com/information/handbook/toc.asp

http://www.thinksrs.com/products/SR510530.htm

http://www.dexterresearch.com/?module=Page&sID=technical-library

http://www.pariss-hyperspectral-imaging.com/GratingOrders_Movie/GratingOrders_Movie.html