

# Spectrometers and Spectra

Either the **Scanning Monochromator** or the **Photographic Spectrograph**

**Goals:** There are a number of different goals in this experiment. To some extent one can pick and choose amongst the goals listed below, although those marks with a \* **must** be done. All of this with the advise and consent of your instructor.

- 1.\* **Understand the optics**
2. Measure the performance of optics
  - Minimum line width
  - Observing faint lines
3. Understand detector
  - Film
    - \* **Exposure time vs slit width**
    - \* **Process for developing film**
    - Effect of “overexposing” film
    - Computer analysis of film
  - PMT (ASK ABOUT MAXIMUM VOLTAGE!)
    - Dark current vs bias voltage
    - Gain vs bias voltage
- 4.\* **Calibration**
  - \* **Wavelength vs position on film or wavelength indicator**
    - Detection efficiency using blackbody
    - How to correct for change in detection efficiency on scanning monochromator if data collected to PC
5. Sources & identifying unknowns ( How to use and understand how it works )
  - Blackbody
  - Discharge tubes
  - Carbon arc ( undoped / doped with unknown ), photographic only
  - Sun
6. Atomic physics
  - H, Na, & Hg
    - Energy level diagrams, See Melissinos: Chapter 2, p 31 for H, p.44-46 for Na; and p.50 for Hg.
    - ID transitions by upper and lower states
    - What not seen, selection rules
7. Molecular physics
  - N<sub>2</sub>, O<sub>2</sub>
    - Energy level diagram
    - ID transitions by upper and lower states
    - What not seen, selection rules
8. Solar physics
  - Identify the Fraunhofer lines, and identify associated elements and molecules

# Introduction to the Photographic Spectrometer

The photographic spectrometer is based on 1.5 meter radius Rowland grating. Thus the entrance slit, grating, and the film all lie on a circle with a diameter of 1.5 meters. The entrance slit can be slid vertically to select various slit widths ( the number appearing in the circular opening is in microns). In conjunction with the entrance slit is a horizontal slide called the Hartman slide. The Hartman slide consist of a diagonal opening and allows light from only part of the vertical entrance slit to pass into the instrument. A manual shutter completes the entrance slit assembly.

Between the slit assembly and the grating is an order sorter. This consists of a thin prism that disperse the light vertically. As an example of how this works consider a source that produce a line at 350nm and at 690 nm. The second order of the 350 nm line will be next to the 690 nm line in first order but will be displace slightly vertically.

The film holder is in the form of an arc such that the film is on the Rowland circle. A metal shutter covers the film when not in use. At the left side of the film opening is a slit with a small light bulb behind it. This is the film position marker light and is lit by pressing a white button. When this is done with the film in place the left end of the film is exposed which will help in calibration.

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See A.C.Melissinos, *Experiments in Modern Physics*, Chapter 2 and p.328-339.

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**Choose goals from the page of goals with the advise and consent of your instructor and complete these goals.**

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## Procedure

Because of the relatively long time needed to expose and develop film, **time management** is very important while doing this experiment. Consider how to order your work including the inspection of the equipment to insure that you expose and develop at least one and possibly several strips of film during your lab time.

Make a visual calibration of the spectrometer by matching position with color. Use the spectrometer with a blackbody source and your eye as the detector. To do this remove film holder, the Hartman slide and the entrance slit slide. Use an incandescent light bulb as a source and if needed control its brightness with a Variac (variable transform). Use the magnified crosshair assembly to view the resulting spectra. Make a crude calibration of color as a function of the distance from the film marker slit. That is make a figure the size of the film. On this figure indicate the position of the marker and the range for each color and an approximate ( $\pm 30$  nm) of the wavelengths. Use colors (pens, oil paints, crayons) to make this figure.

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Remove the top of the spectrometer and observe the optics, making measurements as needed. DO NOT TOUCH THE GRATING! Shine a laser through the entrance slit area ( slits removed) onto the grating and observe the path of the laser beam. DO NOT LOOK INTO LASER

Note the positions of red light in different orders.

Where is zeroth order? That is if the concave grating was replaced by a concave mirror where would the reflection be? ( Use a pair of two-meter sticks if it helps to visualize the angles and the normal.)

Which order is brightest?

Why are there black fins inside the spectrometer?

How does the order sorter work? Is red shifted up or down relative to blue?

How does the Hartman slide allow multiple exposures?

On the film, is the image of the entrance slit erect or inverted?

What part of the film will be illuminated by the different positions of the Hartman slide?

Replace the top of the spectrometer and tape the seam.

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### **Light source alignment**

The placement of the light source on the optical axis of the entrance assembly is critical. There is a small yellow wooden jig that fits onto the entrance slit housing. This jig is used to align discharge tubes to the optical axis. The right most surface of this jig corresponds to the optical axis so the center of the discharge tube should be aligned with this surface. If the light source is very bright, one can place a piece of frosted glass just in front of the slits. If the frosted glass is illuminated, some light will enter the spectrometer along its optical axis. (WHY?) If you are using the jig to align the light source to the optical axis, a quick test is worth the effort. The test is to remove the film holder and use the lens-crosshair assembly to view the spectra by eye. Try shifting the source slightly to optimize the brightness of the viewed line.

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### **Film information:**

See the inside of the film box for primary information on film use and developing. On roll of 36 exposures of 35 mm film is about 60 inches long, or enough for 5 strips 11 inches long for the spectrometer. Kodak provides great deal of technical information through the World Wide Web.

About the film used (Kodak TRI-X PAN 400 ):

<http://www.kodak.com/global/en/professional/support/techPubs/f9/f9.shtml>

Introduction to darkroom methods:

<http://www.kodak.com/global/en/consumer/education/lessonPlans/darkroom/index.shtml>

(Especially lessons # 1, 2, & 4)

Glossary of photographic terms:

<http://www.kodak.com/global/en/consumer/glossary/glossaryContents.shtml>

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### **Film handling and developing:**

- Film is approximately logarithmic in its response to light. That is to make the image noticeably darker one should double the exposure time.
- The film used in this experiment is Kodak TRI-X Pan 400, Black and White film.
- This film is very light sensitive and must be handled in **complete darkness** ( not even a safe light).
- Film should be developed on the day it is exposed.
  
- Before handling this film thoroughly wash your hands.
- Try to handle the film by its ends and edges.
- Before working with fresh film, practice with a previously exposed strip of film loading and unloading the film holder for the spectrometer. Practice loading film into developing tank spool (Note the film should spiral into it.).
- Identify the markings on the spectrometer film shutter so that you can know how far to pull it out to open it without completely removing it.
  
- After handling this film thoroughly wash your hands, and clean up your work area.

### Mixing and using developer and fixer

- Cleanliness is important. Be careful not to contaminate your chemicals. Clean everything, especially funnels, when changing chemicals.
- **Warning:** The developer will cause skin and eye irritation. Avoid direct contact and wash with soap after handling. See label for details
- When mixing the chemicals you may wish to use a dust mask, eye protection and gloves. A fan is available to improve ventilation.
- Please read the labels of the developer and fixer for detailed mixing instructions and safety precautions.
  
- Clean two 400 ml bottles for your chemicals. Label these bottles as yours and include the date that the chemicals were mixed
  - Clear bottle for fixer.
  - Brown bottle for developer
- Warm water is available from sink (with a wait) or one can use the hot plate.
- An electric stirrer is available.
  
- To mix the developer, add 50 g of Kodak MICRODAL-X to 400 ml of water at 90-100 °F (32-38 °C). Stir until the chemical is fully dissolved. Store in your dark bottle
- To mix the fixer, add 71 g of Kodak fixer to 400 ml of water at or below 80 °F (25°C). Stir until the chemical is fully dissolved. Store in your clear bottle.
  
- When in use the temperature of the developer and fixer should be between 65 ° and 75° F ( 18° and 24°C).
- Please report low supplies of the film, developer, or fixer
- Try to limit the light exposure that your chemicals receive by putting them in the cupboard between labs sessions.

### To load the film holder

- This must be done in **complete darkness** ( not even a safe light).
- Removed the shutter from the film holder of the spectrometer.
- From a canister of 35 mm film pull out **only** the amount of film needed using the special rule (about 11 inches long) as a length indicator. Leave about 1 cm out of the film canister so that more film can be pulled out.
- Identify the emulsion side of the film. (The emulsion side is lightly sticky smooth side, and on the inside of curve of the film.)
- Slide the film into the second or inner groove emulsion side out. The shutter goes into the outer groove. Slightly bending back the flexible end may help (practice this process!)
- Replace the shutter and cover the film holder in dark cloth for transport to the spectrometer.
- Keep the cloth over the end as you open and close the shutter. and use the cloth when returning to the dark room.

## Exposing the film

- Have developer and fixer mixed and setting out so that the temperature stabilizes.
- The light source must be carefully aligned on the optical axis of the spectrometer. ( see above)
- Exposure time must be determined experimentally. Films response to light is approximately logarithmic, so initially use exposure times that differ by a factors of 2. As a starting point, the exposure time for discharge tubes is a couple of minutes, so bracket around this exposure time.
- Pull out the film shutter to the indicated stop. (Keep sliding connection covered with dark cloth.)
- Control the exposure time with manual entrance shutter
- Use the Hartman slide to place multiple exposures on one strip of film
- Remember to push the button the mark the left end of the film.

## Developing the film

The developing process consist of two basic chemical processes. The first is done with developer and converted the exposed grains of silver halides on the film to grains of silver. The second process is done with the fixer and removes the unexposed silver halide grains so the film is no longer sensitive and will no longer darken when exposed to light. The fixer and developer are removed by thorough rinsing.

- Be sure that your chemicals are between 18°C and 24°C.
- Fill the clean developer tank with developer and note its temperature. This temperature allows you to determine the developing time.

Below is a developing time table when using Kodak TRI-X PAN 400 and Kodak MICRODOL-X developer:

18° C (65°F)	11 minutes;	20° C (68°F)	10 minutes;
21° C (70°F)	9.5 minutes;	24° C (75°F)	8 minutes.

- The next few parts of this process must be done in **complete darkness** ( not even a safe light).
- Load film into spool of the developing tank. Note the film should spiral into it, following grooves the top and bottom of the spool. ( Note ratchet effect. Practice in light Instructions on wall.).
- Place the insert back into the developing tank, cover with the lid and place thermometer into the center.
- Now the safelight can be turned on, but keep it off unless needed and be careful when handling developing tank not to expose the film to light until it is fixed.
- Agitate initially for 20 seconds. Do this by rotating the thermometer in the top of developing tank. Also tap the tank on the side of the sink to free any bubbles on the film. After the initial agitation, agitate and for 5 seconds every 30 seconds during developing.
- After developing pour your developer back into your bottle, but leave film in the spool.
- With water, rinse the film in the developing tank for a couple of minutes. Then drain off the water.
- Fill the developing tank with fixer and agitate for 4 minutes.
- Pour your fixer back into your bottle, but leave film in insert.
- Normal lights now OK.
- With water, rinse the film in the developing tank for 20 to 30 minutes.
- Remove film from insert, pat dry with towels, the hang up for a final drying ( weight the bottom of the film to keep it straight.) Use a hair drier or hot air gun if available.

## At the end of each lab session:

- Film holder ( cleaned and dry!) reinstalled on the spectrometer.
- Darkroom cleaned.
- Your bottles of developer and fixer stored in cupboard.
- Drying film labeled by ownership.
- Low supply of film, developer, or fixer reported
- Wash hands

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### Calibrate wavelengths

- Calibration can easily be within a few Ångstroms ( 0.1 nm) or better.
- Positions of lines on the film can be measured using the measuring light table, or the film can be scanned at the Academic Support Office and measured using a computer.
- One must put calibration spectra on each strip of film, but once an initial Hg spectra is identified and calibrated, repeating the process should be easy:

Make a figure the same size as the film with a “good” calibration of wavelength as a function of position from film mark. (Maybe on transparency?) This should let you read off values within a few nanometers the wavelengths of a other strip of film you make.

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### Notes:

Arc Safety: Electrical, high temperatures, very bright light, very bright UV light.

Sharpen carbon rods with pencil sharpener.

Use frosted glass just before entrance assembly.

Take spectra with and without unknown doped arc source.

To make doped source drill small ( 1/16" to 1/8" diameter, 3/8" to 1/2" deep ) hole in lower carbon rod and pack with powder.

Observe arc through viewing port so you can “see” when powder is burning

Do not need to ID lines in undoped “carbon” spectra (this spectra contains lines associated with carbon and molecules in atmosphere.) Just look for new lines in spectra from doped source.

### Solar

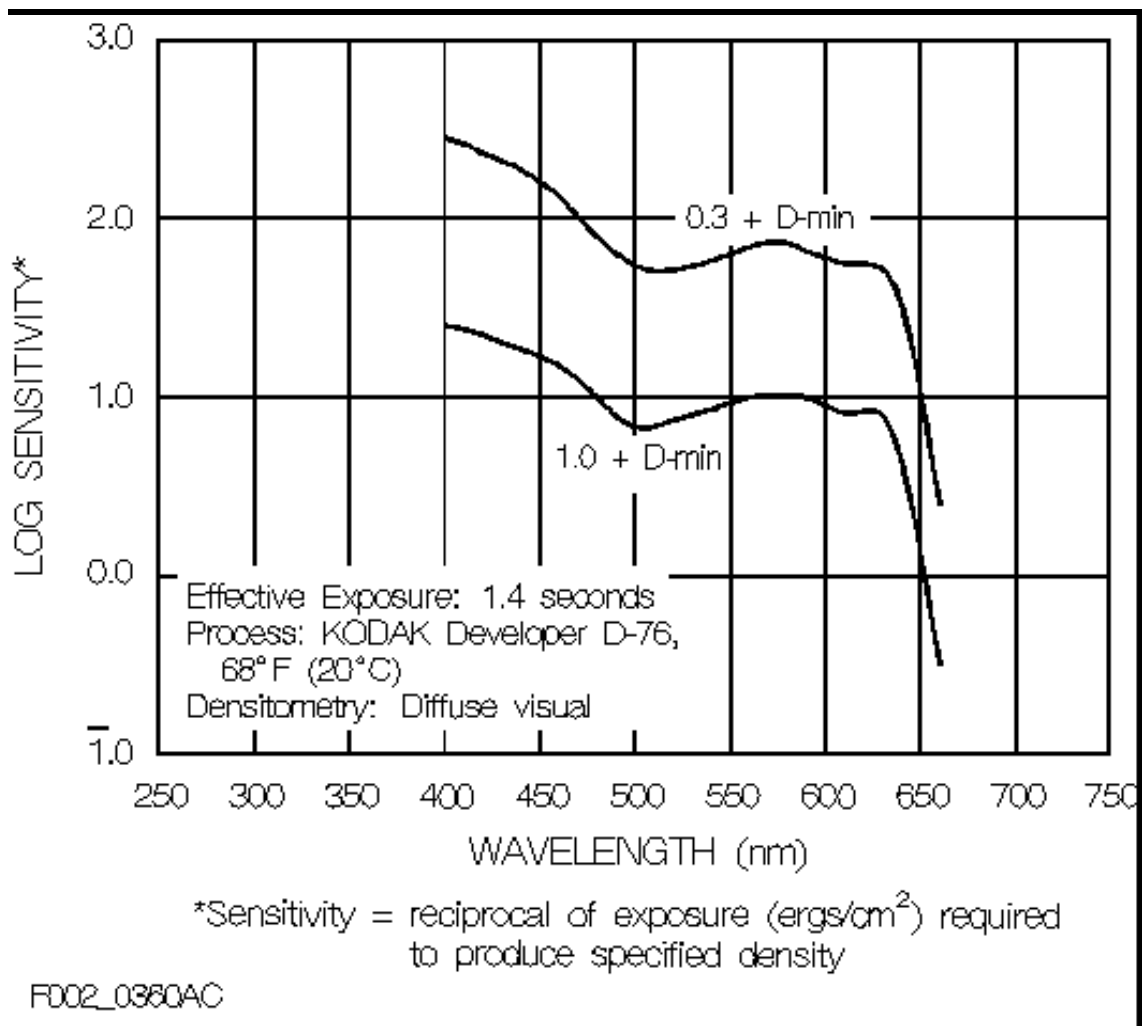
Use three mirrors:

Take mirror on tall stand out on roof below south windows. One person will need to constantly adjusting to the angle of this mirror. Use adjustments on mirror mount to make one axis parallel to Earth’s axis. (WHY?)

Place a second mirror on a stand several feet above the entrance slits of spectrometer to direct light from first mirror down.

Place third mirror to direct this light toward entrance slits.

Use frosted glass between third mirror and entrance slit (why?)



**Figure 1** Spectral Response curve for Kodak TRI-X PAN 400 film from:  
[http://www.kodak.com/global/en/professional/support/techPubs/f9/f002\\_0360ac.gif](http://www.kodak.com/global/en/professional/support/techPubs/f9/f002_0360ac.gif)