

# SOLAR SPECTROSCOPY

FOR THE AMATEUR

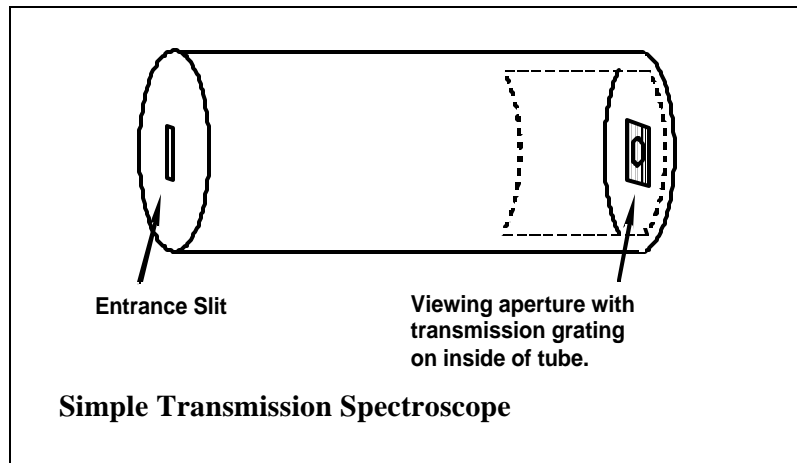
By David Lyon

With the increasing availability of commercially made telescopes, many new amateur astronomers are missing the optical basics of the hobby. The construction of a research capable spectroscope can provide a simple introduction to some of the basics, and reward the amateur with a capable instrument at a fraction of the cost of an equivalent commercial system. If a binocular lens (or small parabolic mirror) and a small first surface mirror are already available, a spectroscope can be built for not much more than the cost of a diffraction grating. The following article describes two designs that use mounts built from easily worked, modeling plywood that can be “breadboard” tested before being glued into place. The results of both designs are quite impressive, and their construction is well within the capabilities of most amateur astronomers.

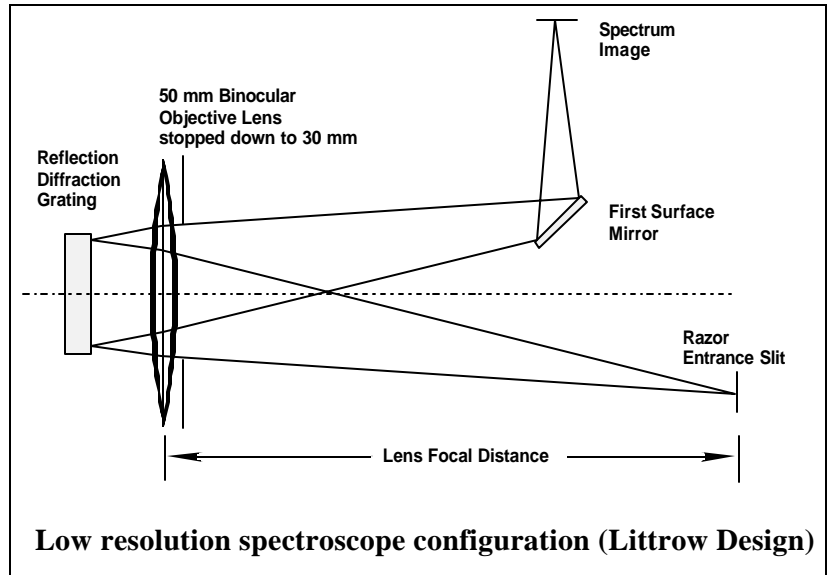
Many years ago when I was in grade school, I saved my allowance and purchased an inexpensive, transmission diffraction grating spectroscope to use with my chemistry set. I was intrigued by the colored, signature lines that could be used to identify chemicals when I vaporized them in the flame of an alcohol lamp. The spectroscope was very basic in design, with a dispersion (the amount the spectrum spreads out) low enough that the entire visible spectrum was displayed in the field-of-view. I desperately wanted to see the Fraunhofer lines in the solar spectrum, but because the resolution was limited to approximately 50 Angstroms, only a continuous rainbow of color was visible. I improved the spectral resolution by using a pair of razor blades to narrow the entrance aperture. I also introduced a lens at the viewing aperture to allow me to focus on the relatively near spectral image. Although these improvements allowed me to see just a hint of the most prominent Fraunhofer lines, attempts to photograph them were not worth the effort.

Recently, I decided to seriously research, design and construct an instrument that would allow me to see finer lines, and make photographs of the solar spectrum with sufficient resolution to split the yellow, sodium doublet.

It did not take very long to realize that as with everything in science, “trade-off” decisions had to be made. If I were to design for photographic resolution, then only a small portion of the spectrum would be visible in a 35mm camera frame. Higher resolution also meant a dimmer image and longer

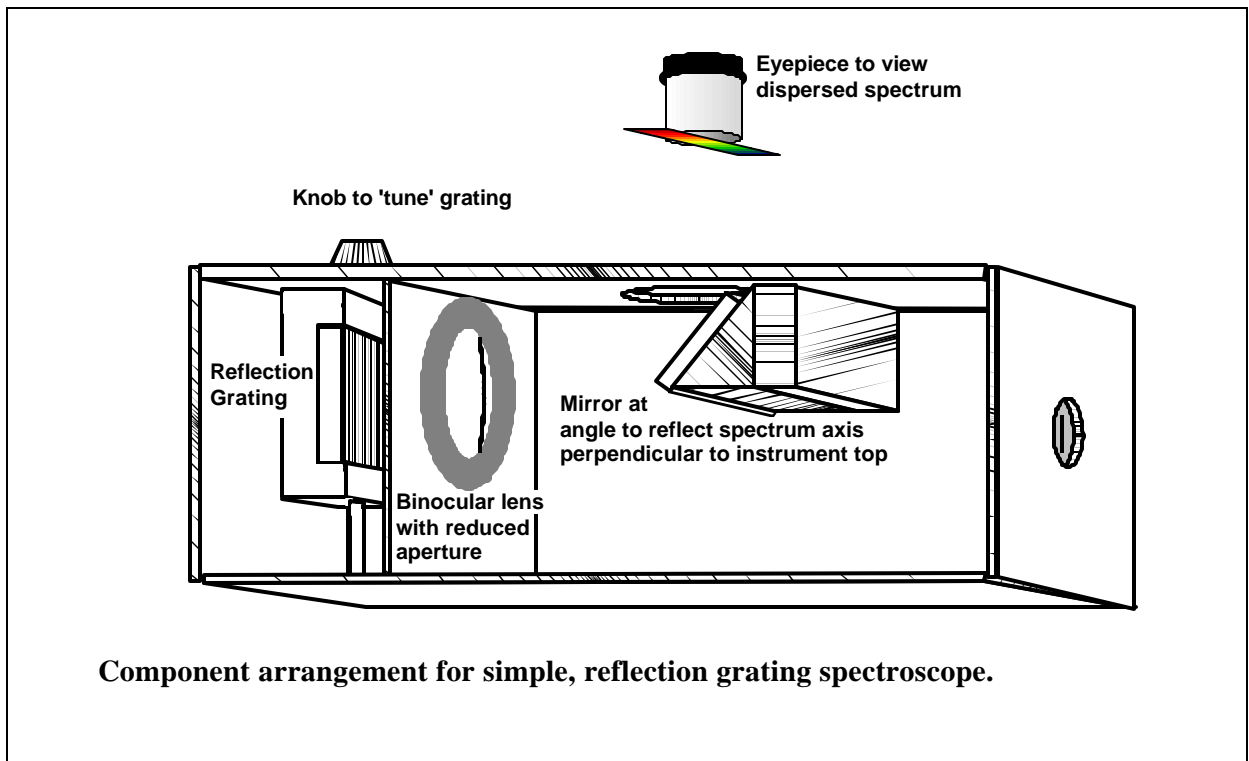


photographic exposure times. I put together a simple instrument using a binocular objective to collimate and then focus the light, and a 600 line/mm reflection grating to disperse the colors. The resulting visible spectrum was approximately 45mm long and could be photographed on two 35mm frames. Although the one Angstrom resolution was sufficient to easily separate the sodium doublet, it was still far less than the 1/15th Angstrom that was theoretically possible with the optical setup. To obtain a higher resolution, I increased the projection distance by exchanging the binocular objective with a 25 inch focal length, 4 1/4 inch parabolic mirror, and used a 25mm grating with 1200 lines/mm. These optics gave a photographic resolution of approximately 1/10th Angstrom, and dispersed the visible spectrum over five 35mm camera frames. Each 35mm film frame recorded approximately 600 Angstroms of the spectrum.

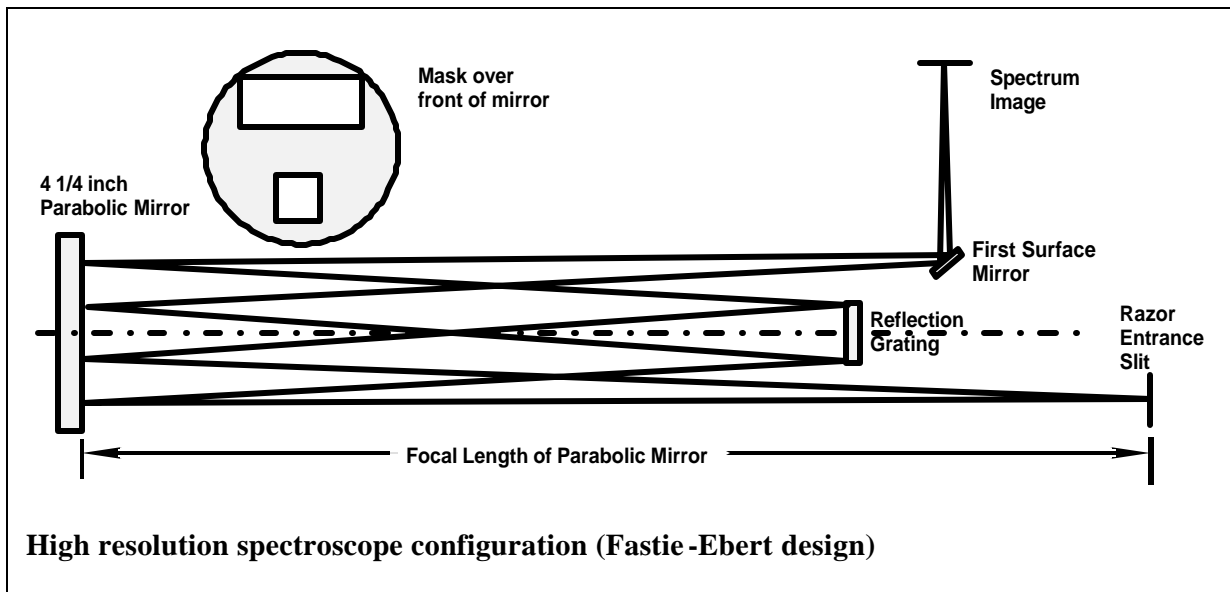


### Spectroscopy Construction

When designing and constructing each of my spectroscopes, I attempted to use materials that I had accumulated over the years. The only purchased component for each design was an experimental grade, diffraction grating, ordered from Edmond Scientific at a cost of \$13.50US for the 25mm size and \$25US for the 50mm size. Model aircraft plywood was used in the construction of adjustable optical mounts, and a spare Celestron cell thread mount



**Component arrangement for simple, reflection grating spectroscopy.**



and visual adapter allowed

me to use my telescope eyepieces and camera mounts. For the slit, I used two, new X-Acto razor blade sections carefully mounted with an even separation of approximately 1/40 mm. Rear lighting allowed me to adjust the blades to their minimum separation while they were secured using masking tape and glue. Their separation, once set in place, was accurately determined using an optical loupe with reticle. A second set of blades can be prepared to a wider separation for brighter images and shorter photographic exposures (but lower resolution). A 25mm eyepiece was used to view the spectrum image. A Barlow tube (with the lens removed) was required to extend the eyepiece position to the image plane of the camera. Anyone considering photography must also design in a method for camera focusing. I used an old helicord focuser (designed for close-up photography) for adjustment of the camera body into the position of best focus.

The diffraction grating was mounted to allow rotation about a vertical axis along the center of the grating surface. This allowed the resulting spectrum to be moved (or 'tuned') across the field of the viewing eyepiece or across the camera focal plane. Alignment of each component was important for maximum performance. If the entrance slit, grating rulings, and grating rotational axis are not parallel to each other, poor focus and skewed image will degrade the final resolution.

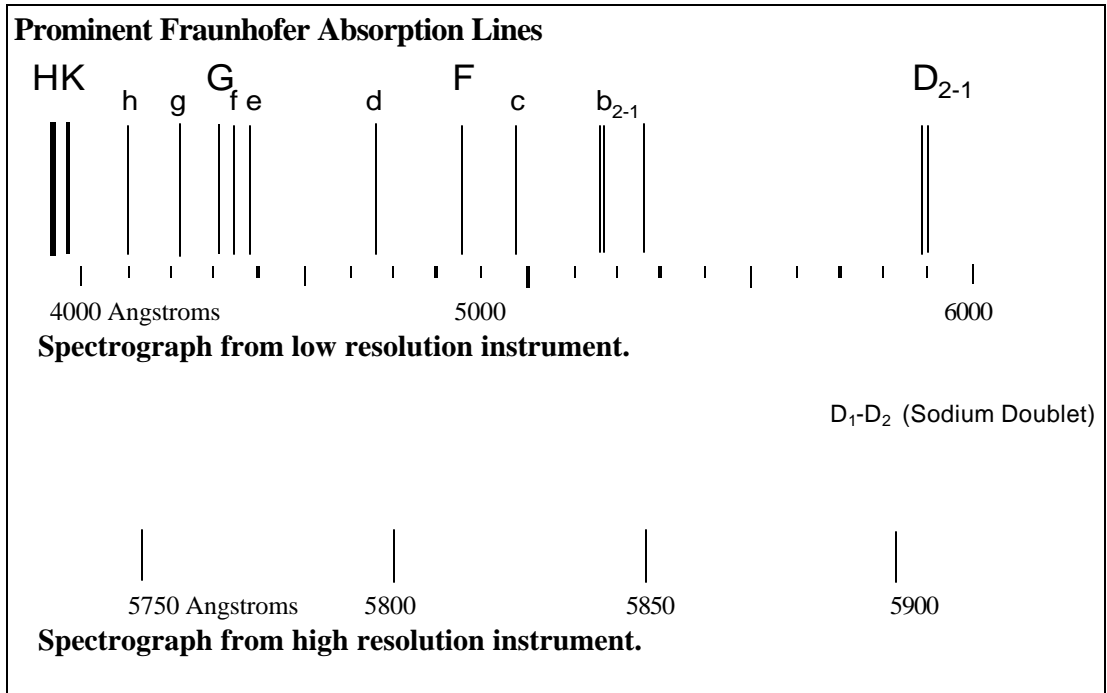
In the higher resolution instrument, I took advantage of a large Kodak, roll-paper box for the outer, light-tight covering. After optimizing the location of the optical mounts, and gluing them in their final locations, the inside of the instrument was sprayed with photo mounting adhesive (with the optical components removed), shaken with fine sawdust, and sprayed with matte black paint. The use of the sawdust contributed to a significant reduction in unwanted stray light.

A cylindrical lens with the same f-number as the diffraction optics can be used in front of the slit to maximize the light entering the spectroscopy. An old microscope mirror can be placed further in front to easily direct the light along the optical path without having to continually realign the whole instrument.

### Photography

The techniques used to make a photo record of the spectral image are much the same as those used in low light astrophotography. Color film can be used, but the relatively low contrast of the dark absorption lines compared to the bright spectral image prevents the making of a good record. Kodak Tech Pan, black and white film was used to advantage because of its high image contrast. The exposure time was found by trial and error, and was dependent on the slit width. At best resolution, my high resolution spectroscopy required exposure times of approximately one second.

### Applications



The most basic application of the solar spectroscope is the study and identification of elements in the sun's atmosphere. The effects of the earth's atmosphere (including terrestrial pollutants) can also be monitored by comparing the spectrum of the sun when overhead to the spectrum when looking through a longer atmospheric path just before sunset.

The following spectroscopy basics were encountered in the construction and use of my two instruments.

- Spectral resolution is limited by the size of the grating, and improves as the grating size increases. A 25mm (one inch) grating is capable of approximately 1/15th Angstrom resolution in the visible spectrum. A 50mm (two inch) grating is capable of approximately 1/30th Angstrom.
- Each wavelength in the dispersed spectrum is displayed as an image of the slit, with a width equal to the width of the undefracted slit image. If the slit is too wide, adjoining colors overlap in the spectrum image, and resolution is reduced below the theoretical best possible spectral resolution. This overlapping of spectral wavelengths also decreases the contrast between dark Fraunhofer lines and the adjoining spectrum.
- The spectrum must be sufficiently dispersed or magnified to allow the spectroscope to be used at full resolution.
- Dispersion of the spectrum is proportional to the grating line frequency. (A grating with 1200 lines/mm gives twice the dispersion as a grating with 600 lines/mm).
- Dispersion of the spectrum is proportional to the distance the spectrum is projected from the grating.

### **Advanced Applications**

Detection of the sun's rotation is possible by recording the Doppler shift in the solar Fraunhofer lines with the spectrograph slit located across the east-west direction of the sun's image. A resolution of at least 1/20th Angstrom is required to detect the difference in velocity between the edge of the solar disk approaching the Earth (a blue shift of the Fraunhofer line), and the edge receding from the Earth (a red shift). The difference will be seen as slanted, solar absorption lines compared to unslanted lines generated by absorption in the Earth's atmosphere. A spectrograph with a higher resolution will permit measurement of the sun's rate of rotation.

Detection of the rising and falling of individual cells on the solar photosphere is possible by recording the Doppler shift of Fraunhofer lines where a highly magnified image of the photosphere is placed across the slit. The effect creates a wobble in the lines where the slit has dispersed the light from cells that are rising toward (blue shift) the earth and cells that are falling away (red shift). The magnified image of the sun's surface is focused on the slit. Individual cells must be resolvable.

Splitting of Fraunhofer lines (Zeeman effect) due to the high magnetic fields around sun spots, can be observed by placing a magnified image of a large sun spot on the spectrograph slit. Once again sufficient spectral resolution will be a requirement.

For these advanced applications, sufficient spectroscope size (to provide the necessary spectral resolution) will preclude most amateurs from mounting the instrument directly onto their telescope. This problem can be circumvented by removing the telescope tube from its mount, and using the optics in a static mode. A coelostat mirror arrangement will be necessary to track the sun and project its light into the telescope optics. The spectroscope is then aligned along the optical path of the now static tube, with the slit placed on the focused image of the sun.

### **Other Applications**

Absorption characteristics of nebular filters can be determined by placing the filter in front of the slit, and observing (or photographing) the modified solar spectrum. The Fraunhofer lines provide a known reference to identify the wavelengths that are being blocked. Similarly, the effects of filtering on light pollution can be examined by observing the spectrum of street lighting, and the effects of the filtering.

The spectral sensitivity of selected black & white and color films can be evaluated by photographing the solar spectrum and using the Fraunhofer lines to identify the film's sensitivity by wavelength. The absorption characteristics of the optics used in the spectroscope will affect the results.

The spectral sensitivity limit of different observers can be determined by having them identify the Fraunhofer lines that are just visible in the far red and violet ends of the spectrum.

### **Summary**

Readers are encouraged to construct either of the simple instruments described in the article as an introduction to spectroscopy. Edmond Scientific, in Barrington, NJ, provides an excellent instruction sheet with their experimental gratings. Although it is not necessary for the construction of either spectroscope, the basic grating theory and mathematics that are covered will provide a better understanding of how your instrument works.

Probably the most notable experience that I gained in my construction and use of the two spectroscopes is an appreciation for professional astronomers who routinely make spectrographs of faint nebula, galaxies and quasars. At a magnitude of -26, the sun is an easy target. I can only imagine the difficulties that must be overcome collecting useful spectra of deep sky objects.

## **Sources of Further Information**

Experimental Spectroscopy

Sayer, R.A.,

Dover Publications, NYNY

The Optics of Spectroscopy V2.0

Publication # 22.900.075, 1988;

Lerner, F.M., and Thevenon, A.,

Jodin-Yvon Instruments SA, Edison, NJ

Diffraction Grating Handbook

Bausch & Lomb Labs, Rochester, NY

Reflection Grating Instruction Sheet

Publication # 711161-9/80

Edmond Scientific, Barrington, NJ

The New Observe and Understand the Sun

Hill, R.E.,

Astronomical League, 1990

Washington, DC

Secrets of the Sun

Giovanelli,

Cambridge University Press, 1984

The Sun - Our Star

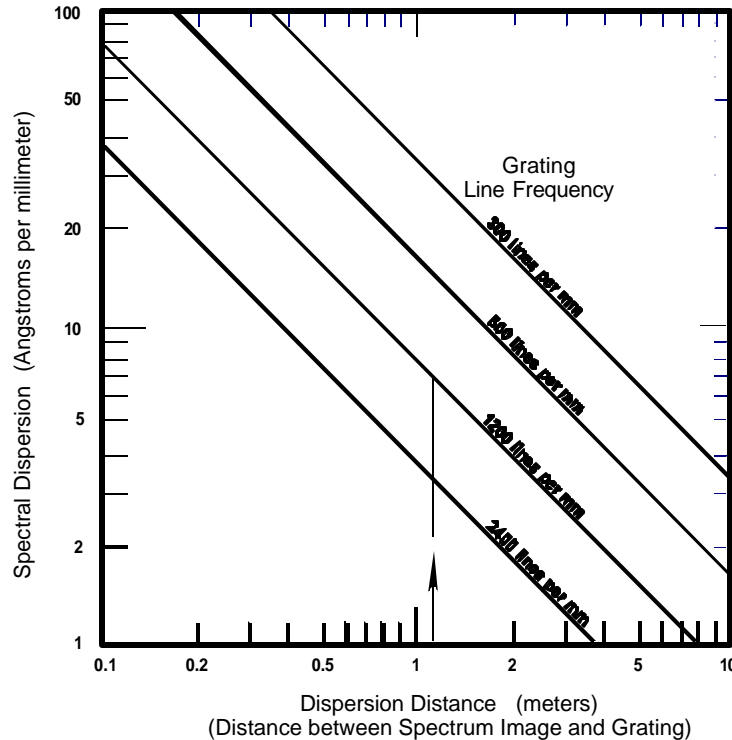
Noyes, R.W.,

Harvard University Press, 1982

## Instrument Resolution:

Although many factors can affect spectral resolution, the instruments described in the article are limited by the extent the spectral colors are dispersed, and by the size of the razor slit. The following graph and equation can provide a good indication of the theoretical spectral resolution for a home built spectroscope. Once the spectral dispersion has been found from the chart by applying the dispersion distance and the grating line frequency, the size of the razor slit is used to determine the instrument resolution. The slit can be narrowed until the limiting resolution of the grating is reached. At that point, the grating must be replaced with one of greater size if higher resolution is required.

Graph to Determine Spectral Dispersion



Example: My higher resolution spectroscope uses a 1200 line per mm grating, and has a dispersion distance of 1.2 meters (49 inches). On the graph, a vertical line is raised from the 1.2 m position on the Dispersion Distance axis to the 1200 Grating Line Frequency line. A horizontal line is then drawn to the Spectral Dispersion axis. For this example, the resulting spectral dispersion is 7 Angstroms per millimeter.

With the razor slit set to 1 mm, the instrument resolution will be 7 Angstroms.

With the razor slit set to 1/10 mm, the resolution will be approximately 0.7 Angstrom.

With the razor slit set to 1/40 mm, the resolution will be approximately 0.2 Angstrom.

The first order, best resolution (limited by grating size) is found using: **Limiting resolution** =  $\lambda^2/2w$

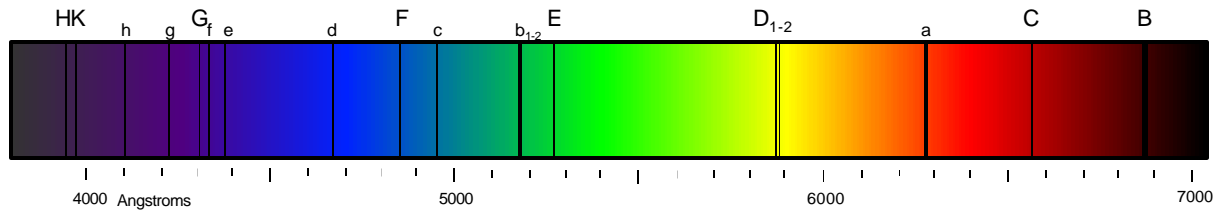
where:  $\lambda$  is the wavelength of light of interest;

$w$  is the width of the diffraction grating; and

**Limiting Resolution**,  $w$  and  $\lambda$  are all measured in Angstroms.

For a one inch grating, this limiting resolution of 0.07 Angstroms (for mid-visible wavelengths) is the best that could be reached with a combination of narrower slit width and longer dispersion distance.

## Location of Prominent Fraunhofer Lines in Solar Spectrum



| Lines                         | Element        | Wave Lengths | Lines | Element | Wave Lengths |
|-------------------------------|----------------|--------------|-------|---------|--------------|
| A band (not shown)            | O <sub>2</sub> | 7594 to 7621 | F     | H       | 4861         |
| B band                        | O <sub>2</sub> | 6867 to 6884 | d     | Fe      | 4668         |
| C (H $\gamma$ line)           | H              | 6563         | e     | Fe      | 4384         |
| a band                        | O <sub>2</sub> | 6276 to 6287 | f     | H       | 4340         |
| D <sub>1</sub> D <sub>2</sub> | Na             | 5896 & 5890  | G     | Fe & Ca | 4308         |
| E                             | Fe             | 5270         | g     | Ca      | 4227         |
| b <sub>1</sub> b <sub>2</sub> | Mg             | 5185 & 5173  | h     | H       | 4102         |
| c                             | Fe             | 4958         | H     | Ca      | 3968         |
|                               |                |              | K     | Ca      | 3934         |