THE

SPECTROHELIOSCOPE

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FOREWORD

This book first came out in 1972. The author corresponds with many amateurs of the world. He learned of new ideas which are in this book.

There are new solar image synthesizers by Brian G. Manning and M. V. Gavin, both of England. Jeffery Young started the knodding mirror synthesizer; lives in the U.S.A. Spacek synthesizer related to the author by M. M. Maner of Florida, U.S.A. also. A new coelostat design is from Heinrich W. Beeker of the Federal Republic of Germany. Gõte Flodqvist of Sweden uses two separate knodding mirrors connected with a rod. Toshio Ohnishi of Japan, folded up oscillating slits for an advantage.

The spectroheliosope is perfectly safe to observe with. Only a narrow section of the sun passes through the entrance slit. And that bright, narrow section is spread out into a long solar spectrum, further greatly reducing the intensity of the sun light. Finally only a thin section goes through the exit slit and into the eye at a comfortable brightness.

The author has tried Tuthill Mylar screen and Thousand Oaks solar glass filters. Both work very good. Both are totally safe to the eyes.

Prisms and 600 gr/mm gratings were used decades ago. That was all available. High quality reflection gratings were copied as replicas in the mid-fifties, greatly reducing the price. Now gratings of 1200 gr/mm and 1800 gr/mm are available for about $300 to $600. They have excellent resolving power.

Do not copy the gratings of 70 years ago for a spectrohelioscope. Use new products to an advantage. Large professional solar observatories use 600 gr/mm gratings of large size for various reasons. Do not copy them exactly. Use 1200 gr/mm and 1800 gr/mm gratings for an amateur spectrohelioscope.

The author wishes to thank the editors of Sky and Telescope for the information on sunspot polarity work by NOAA, Colorado. This lead was important. The scientists there showed that a visual polarity instrument works. Not need a hu ge instrument. In other words, amateurs can enter the field too. Also my thanks for the lead on Jeffery Young and his knodding synthesizer. The author thanks editors of the Journal of the British Astronomical Association for the address of Brian G. Manning and his new synthesizer. Also thanks to other amateurs and their contributions. This book becomes all the more richer for amateur solar astronomers.

The author was born July 24, 1930, California. Graduated from the University of California, 1957, with a B.A. in bacteriology. Astronomy has been a hobby since 16.

FNV, 1999

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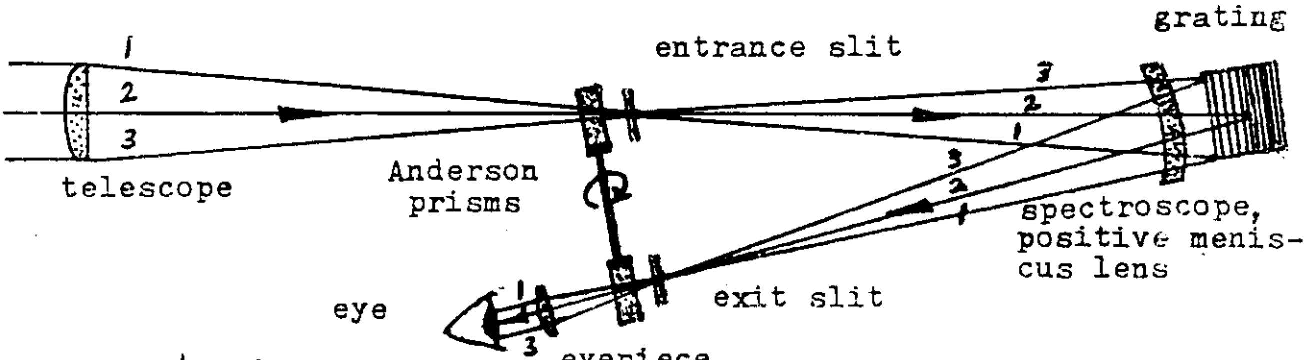
Warning. Do not buy a grating with 3600 gr/mm. It is for the deep violet.
A grating with 2100 gr/mm or 2400 gr/mm can be used only in the first order.
A grating with 1800 gr/mm can be used in first order and in blue and green of second order.
A grating with 1200 gr/mm can be used in first and second orders to best advantage.

OBSERVATIONS WITH A SPECTROHELIOSCOPE

Instrumental designs for H-alpha work. A spectrohelioscope is a solar spectroscope and a telescope stuck end to end. Add a solar image synthesizer near the prime focus of the telescope, and you have a complete instrument. Use it for just photography, it is a spectroheliograph. The prints are spectroheliograms. A mirror system reflects sunlight into the telescope. Halfbandwidths (HBW) from 0.5Å to 0.1Å are easy to adjust for the solar disk in order to see filaments, plage, flares and prominences.



Passband and halfbandwidth are used equally.

A Zeiss 0.5Å HBW birefringence filter is complex and difficult to produce. Basically it consists of four quartz and three calcite plates of various thicknesses. A red filter and many Polaroids are included. Also several ¼ wave and ½ wave retardation plates are for shimming and tuning the wavelength to H-alpha light. A precision oven is necessary for temperature control. The filter is very expensive.

A DayStar filter of 0.5Å HBW is one calcite plate partially aluminized on both sides, called a Fabry-Pérot étalon, invented about one hundred years ago. There is a 10Å HBW blocking filter. An oven is needed. The filter is medium expensive.

For solar prominences, the bandwidth can be somewhat wider. A 4.0Å HBW quartz prominence filter consists of seven plates, eight Polaroids, and a red filter. An oven is required too but temperature control is not as critical as previous filters. The filter is medium expensive. A cheaper method is to employ a 4.0Å HBW interference filter for about $200 or more. It is a piece of glass coated with various layers of di-electric materials. It will last a few years or so. An oven usually is not needed.

The two main solar image synthesizers that are emphasized in this book are Anderson prisms and the rotating glass disk. Both have no vibration problems. Other synthesizers are discussed.

<u>Spectroheliloscope resolution</u>. How much detail that can be seen on the solar disk in H-alpha light with a spectrohelioscope depends upon two factors. First, the size of the solar image on the entrance slit. Second, the width of the slits. The following table shows resolution on a day of good seeing. Assume 0.006" slits (150 microns).

Sun dia.	Telescope f.l.	Slit res.	Truer res.
2" (50mm)	18' (5.4 m)	6 arc/sec	3 arc/sec
1" (25mm)	9' (2.7 m)	12	6
½" (13mm)	4½' (1.3 m)	24	12

With a 9' f.l. telescope lens giving a one inch (25mm) sun image with a 0.006" slit width, then the calculation is:

$$R = \frac{0.006\text{" slit}}{\text{one inch sun}} \times \frac{\text{2000 arc/sec sun diameter}}{\text{in the sky}} = \text{12 arc/sec slit resolution}$$

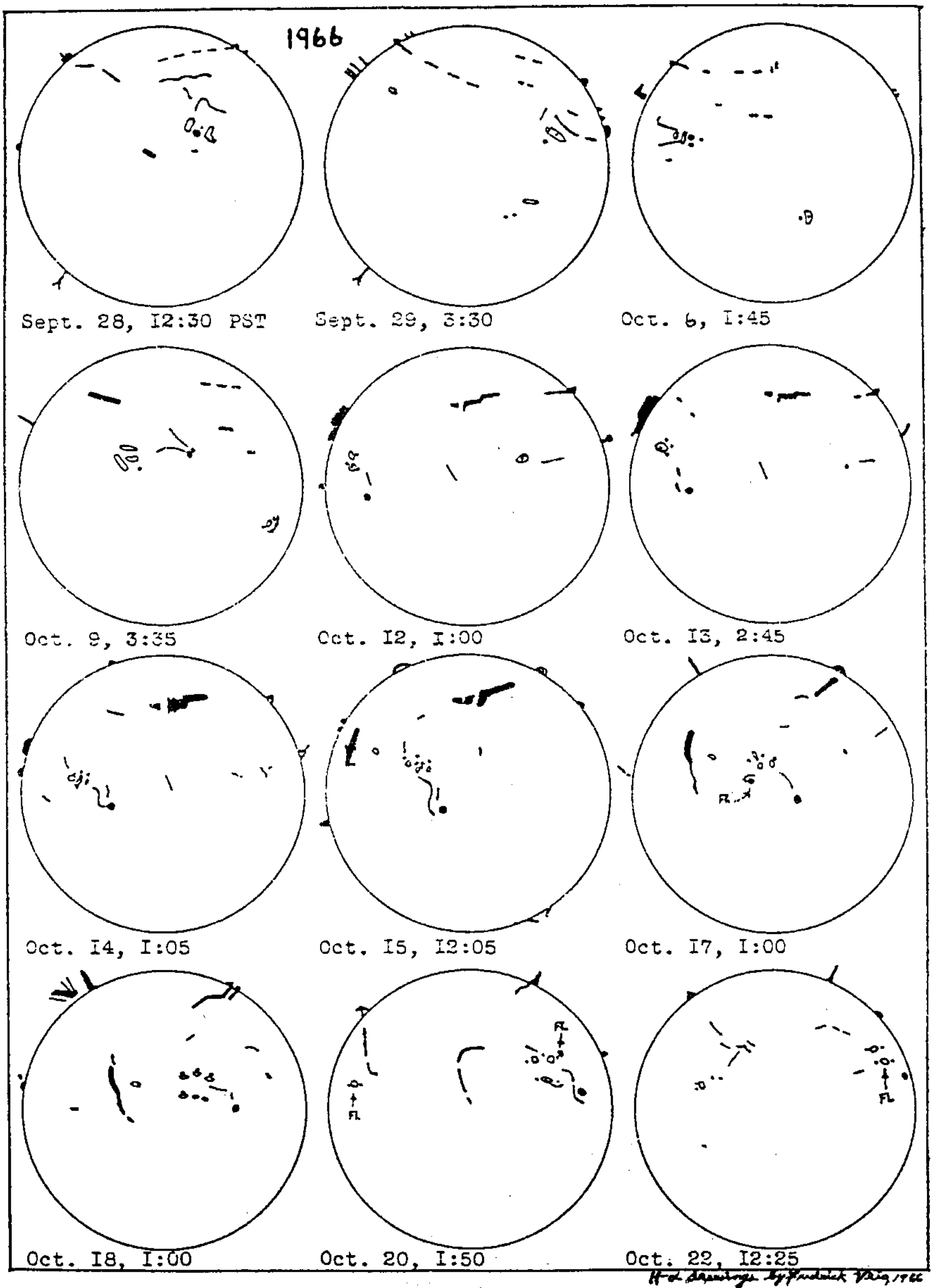
The shape and brightness or darkness of the solar detail determines the actual minimum resolution. For a 9' f.l. telescope with 0.006" slit width, examples of visible solar details will be a faint flare or faint plage about 12 arc/sec, a bright flare or a bright plage about 6 arc/sec, a faint filament about12 x 60 arc/sec, a dark filament about 6 x 30 arc/sec, and prominence 6 arc/sec.

The author's spectrohelioscope has a 9 ' f.l. telescope and a 6' f.l. spectroscope. The diffraction grating is 32mm x 30mm ruled area, 1200 gr./mm, 5000Å blazed wave length, giving 4.0Å/mm in the first order. The solar image synthesizer is the rotating glass disk with 0.006" slit widths, passing 0.6Å band width. This medium sized instrument gives good visual views of the solar disk because all the main features on the disk are about 5 arc/sec or larger. Plages are seen as a mass of brightnesses, from very faint to somewhat bright. Filaments usually have a vague shape with varying darkness from deep black to a very faint grey. Prominences are from bright to faint red. A bright flare is much more intense than the brightest plage, but most flares have a similar brightness to plages. All the solar features have detail as fine as 1 arc/sec, but this detail is observable only with a longer focal length telescope.

There are three kinds of instruments to observe the sun in H-alpha light: a DayStar Fabry-Pérot interference device, a costly quartz-calcite birefringence filter, and a professional spectrohelioscope. A shelter will add several thousands of dollars. The narrower the bandwidth, the higher the price. The only economical way to observe the sun is to build a spectrohelioscope yourself.

For acceptable contrast for the detail on the solar disk in H-alpha light, the bandwidth must be 0.8Å. For excellent contrast, the bandwidth should be 0.6Å. A narrower bandwidth is not necessary, but it is desirable. With a spectrohelioscope, you just work with narrower slits to get 0.2Å or less. There is no added expence.

Pacific Standard Time + 8 hrs = UT



FL = flare

A bandwidth wider than 1.0Å displays prominences and bright flares with associated off-band surge filaments and prominences, but the plage and on-band filaments will not be seen.

Drawing technique. It is quite possible to draw the various solar events with speed if a definite technique is adopted. The fastest events are surge prominences, surge filaments and flares. Surges usually spread out in a given area and are a little more difficult to outline. Flares are confined moreso in an area and are somewhat easier to record. But large flares are spread out.

A surge often starts as an active filament or prominence. Then suddenly and unexpectedly it develops high sight line (S. L.) velocities. It quickly scatters itself to pieces and disappears within 30 to 60 minutes. A flare develop from nothing to maximum brightness in about ten minutes or more. This peak intensity lasts several minutes. Then there is a gradual decline which may last about 20 minutes or less. Consequently there are about 30 minutes for the main changes of the average flare or a surge. Plages do not change very quickly but variations in brightness and in shape do occur from day to day. This is for about 5 arc/sec resolution.

Use a notebook 8½" x 11" (200 x 250mm). It would be wise to have ruled lines half an inch (about 10mm) apart, for they serve as references to draw enlarged square sections of part ofthe solar disk apart from the main drawing. Buy an inexpensive compass. A 6" (150mm) diameter circle is used by the British Astronomical Association as a standard, and this is the size we will select. Best of all is to buy special paper marked with ¼" x ¼"squares (6mm x 6mm). With a 6" circle for the sun, then each ¼"square will cover 75 x 75 arc/sec. The sun diameter varies a bit throughout the year, but it is not necessary to be that exacting. Most solar events will occupy an area about 75 x 75 arc/sec.

One ¼" square can be enlarged to four ¼" squares for a linear magnification of two times, or an area increase offour times. More detail can be drawn without crowding. If square paper is difficult to obtain or becomes a bit expensive, just plain or lined paper will be adequate. You will need a 6" circle because a certain amount of convenient drawing space is necessary. Circles of 2" to 3" (50 to 75mm) diameter are too small and require much greater care to draw in. A circle larger than 6" is not necessary.

There is a considerable amount of solar disk detail at the 5 arc/sec resolution level, much more than can be drawn. Only the main solar features need be drawn. Use short or long, narrow or wide black lines for the filaments. Make closed lines for the plages and the flares. Have a black outline for the prominences on the solar limb. The umbrae will be small or large round black dots. The penumbrae are omitted.

Brightness or darkness system. After all the solar features are drawn on the circle, the relative brightness and darkness should be noted in a simple manner. The reason is because a filament may be changing, either appearing or disappearing, or a plage actually is a flare in progress, either increasing or decreasing in brightness. A number system will be employed. For the filaments, 4 is deep black, 3 is medium black, 2 is faint grey, and 1 is a very faint shade of grey (barely detectable). For the plage and flares, 5 is very bright, 4 is bright, 3 is medium bright, 2 is faint, and 1 is very faint (barely seen). One through 5 is for flares, and 1 through 4 is for the plages. No plage will ever be as bright as a number 5. But often a plage of 4 will look the same brightness as a flare of 4, and so forth for the other numbers. For the prominences, use 1 to 4 in a similar manner. Put the proper number by the solar feature on the drawing. It is impossible to remember the brightness or darkness of all the various features. The number system acts as a memory check, quite invaluable at times too.

When a description of an event is written on a separate page, filament darkness is abbreviated as FD, flare brightness as FB, and prominence and plage brightness as PB. This short hand method of letters and numbers will allow an event to be accurately and quickly followed in detail. Here is an example: a bright flare near a faint plage with nearby dark filament. Abbreviated: FB4 flare near PB2 plage with FD4 filament. Much precious time is saved.

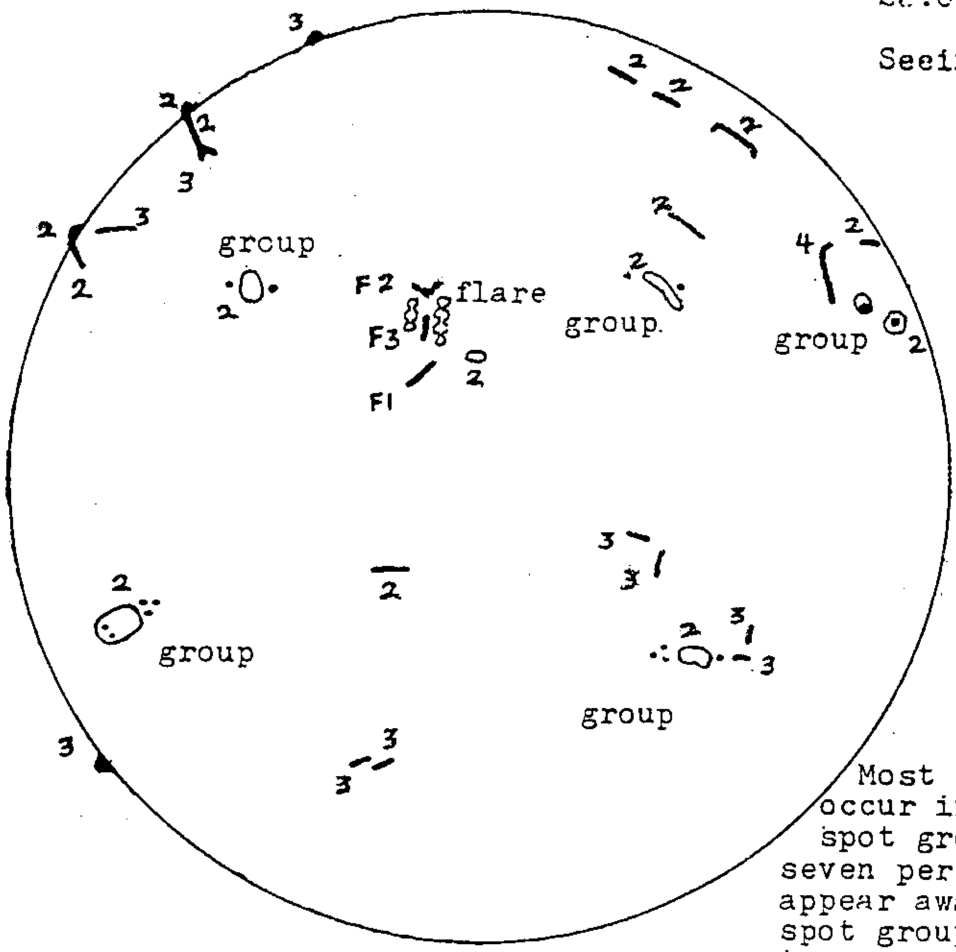
Scanning method. Sometimes a flare, a surge filament, or a surge prominence will be developing when you are setting up the spectrohelioscope. You must draw the location of events with a certain amount of accuracy on the 6" circle. Using the spectroheliosocope to draw the main umbrae of the sun spots on the circle is not very fast because the umbrae are not easily seen in H-alpha light. With slit widths of 0.006" passing 12 arc/sec, umbrae less than this value will not be detected, unless a small group of about 5 arc/sec umbrae are close together. In the H-alpha line, about 18 arc/sec umbrae or larger will be discerned, but out of the H-alpha line about 12 arc/sec umbra comes into view. The field of view of the instrument is somewhat limited, usually about 30 x 15 arc/min of the 32 arc/min solar disk. It is best to use a small 40mm to 60mm refractor for the placement of the main umbrae on the 6" circle. The author uses a 2" (50mm) refractor with an Optron solar filter in front of the lens. A 50X eyepiece works best. Even a 1" (25mm) refractor of 25X is useful. About five minutes are needed for a quick white light observation. With average or large size sun spot groups, mark a few of the main large umbrae. Forget about the penumbrae and most of the tiny spots. For a small spot group of 10 arc/sec umbrae or less, mark a few umbrae on the circle. Now set up the spectrohelioscope. Make a complete white light drawing later in the day.

Quickly look at the solar disk in H-alpha light by turning the line shifter. Any surge activity or flares will be easily seen off-band (out of the H-alpha line, or out of the core) due to Doppler shift of the surge and to the wide emission of the flare. Other solar disk details will not be seen off-band. Now on-band (in the H-alpha line, or in the core), the flare will appear brightest, but the surge will only be partly viewed. The reason is different parts

H-α EXAMPLE

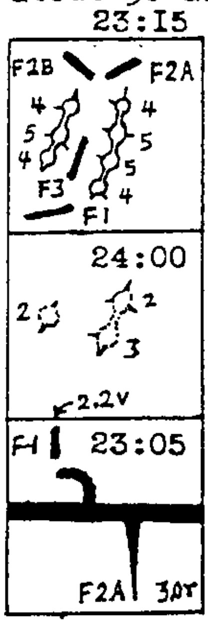
March 6, 1967
23:00 to 24:20 UT

Seeing: good



Most flares occur in a sun spot group. But seven per cent appear away from spot groups. This is an example.

Each flare bead is about 30 arc/sec.



Flare observed from 23:00 UT to 24:20 UT. Class 2B. This is a composite drawing of the three surge filaments F-I, F-2, and F-3. They appeared and disappeared as the flare progressed. F-2 actually was an arch filament as seen in two sections. F-2A was seen first in the violet. Minutes later it disappeared and F-2B was seen in the red. F- I and F-3 were viewed in the red. The drawing shows maximun develcpment of the flare.It was two bright to very bright parallel regions looking like two short lengths of beads. The beads had a sharp outline at maximun intensity about 23:I5 UT. The regions waned with a diffuse cutline minutes later. Only three beads with a faint shape were seen at 24:00 UT. The spectroscopic study at 23:05 UT of surge filaments F-I and F-2A showed S. L. velocities of 2.2Å v and 3.0Å r respectively. Estimated time of initial development of the flare, about 22:40 UT, although it was not observed.

of the surge will have various S. L. velocities. The high velocity sections will only be seen off-band,and the low velocity sections will be observed on-band. Using the line shifter, a surge filament or surge prominence will be noticed piece by piece as the shifter is turned. Plages are seen in the H-alpha line (core). Plages and flares of unequal brightness can be separated by the line shifter. Now faint flares will not be so easy to descriminate because they will have a similar brightness as faint plages.Only continuous observing for several minutes or longer will detect the flare by a change in brightness.

A full scan implies a spectroscopic and a spectrohelioscopic observation. Therefore, change the rotating 24 slit disk for the spectroscope disk, and back to the 24 slit spectrohelioscopic disk again. There is a reason. Very faint surge filaments and prominences are easier to detect with the spectroscopic disk due to the Doppler shift than with the 24 slit disk, which can easily miss a very faint surge, whether the surge is large or small in size. But usually surge filaments are dark and easy to see either with the stationary spectroscopic disk or the rotating 24 slit disk. Flares are easy to detect with the 24 slit disk and line shifter.

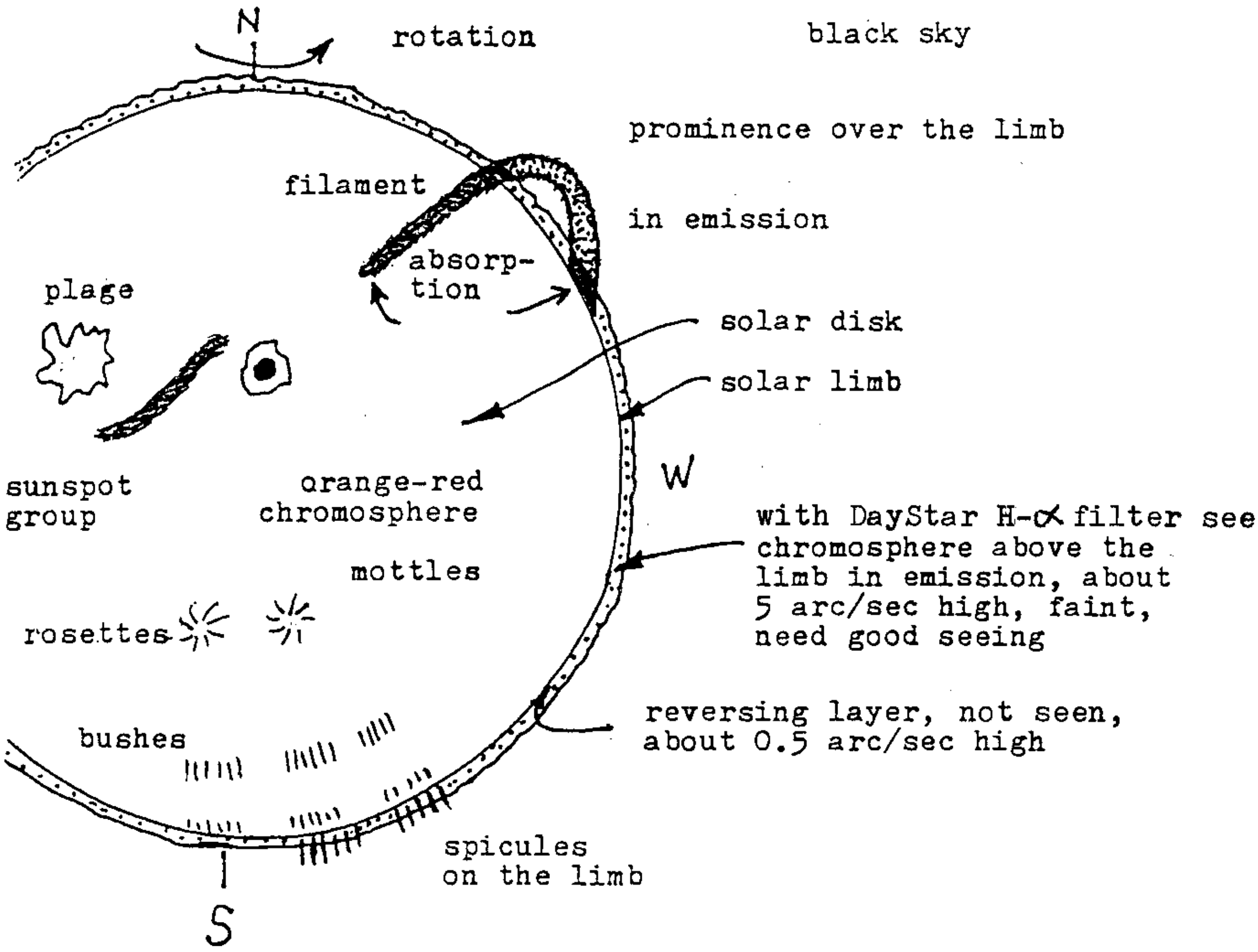
Assume the solar disk has had a five minute preliminary scan, and there are no surges or flares in development. Now start to draw some of the filaments and plages near the sun spot groups on the 6" circle, using the umbrae as guides. Do not draw a lot of detail yet. After drawing for five minutes, again scan the whole sun. Check against the numbered plages whether any flare has changed in brightness. Now draw some more, putting in other filaments and plages and prominences. Do not forget the proper numbers. From start to finish should take about 20 to 30 minutes for a good drawing. Hereafter perform a scan about every ten minutes. This completes the routime of observing the sun in H-alpha light.

Perhaps you will see some movies on TV or at an astronomical convention of the rapidity of surges and flares. These events are sped up and give the impression of great quickness. Actually most flares and surges can be easily and nicely observed and the suddenness of the events is lacking. Rather there is a steady growth of most of the events. So good drawings of them are possible.

Chromospheric network. Solar detail in H-alpha light may be divided into two groups: (1) the main disk features, and (2) the chromospheric network. The main features are flares, prominences, filaments and plages. The chromospheric network is the mottles, fibrilles, rosettes and bushes. Filaments and prominences are above the chromosphere about 30 arc/sec or more. Fibrilles are in the chromosphere.

In the H-alpha line with a 9' (2.7 m) f.l. telescope, network shows a patchy appearance of dark and light areas called mottles. They are somewhat faint in the center of the solar disk and more conspicuous towards the solar limb. Average size is 10 arc/sec

H-α SOLAR DISK AND LIMB FEATURES



relative intensity compared to the solar continuum of 100% photosphere :

bright flare	150%	or more
photosphere	100	
faint plage	25	
faint flare	25	
H-alpha core	16	chromosphere
faint filament	14	
dark filament	2	
faint prominence	2	

The chromosphere is visible in the H-alpha line. The photosphere is visible outside of the H-alpha line about one ångstrom, showing the sunspots, umbrae and penumbrae much better and sharper.

<u>Basic solar disk. details.</u> The general bibliography will give many excellent b ooks for quick information on the sun. But here are a few basics.

Patterns on the surface
1. hypergranulation, or magnetic continents, large areas
2. supergranulation, medium areas, 40 arc/sec
3. granulation , small, 2 arc/sec
4. areal vertical oscillation, small areas, 10 arc/sec

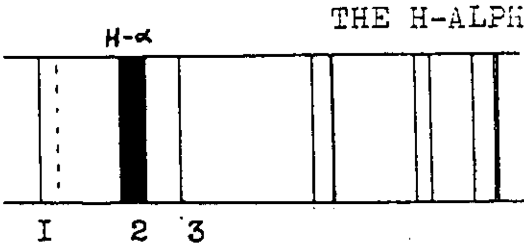
Sunspots
1. velocity inversion level, net motion of zero
2. Evershed velocity, small, 2 km/sec
3. umbral oscillations, small, 0.5 km/sec
4. umbral flashes, few minutes of time
5. penumbral running waves, 10 km/sec
6. moustaches, not flares , few minutes of time
7. penumbral filaments, dark, 1 arc/sec wide

Magnetic fields
1. magnetic continents, large area, weak field
2. polar regions, weak, one gauss
3. nonspot fields, small area, 200 gauss
4. single spot umbra, 800 gauss
5. sunspot groups, very strong, 2500 gauss
6. classification
   a. Mt. Wilson: alpha, unipolar; beta, bipolar; beta-gamma, little mixed polarities; gamma, mixed completely; delta, umbrae in the same penumbra
   b. Modified Zurich, 1966: A, B, C, D, E, F, H (P. McIntosh)

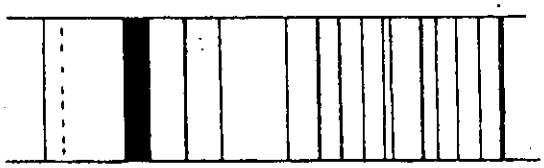
Filaments and promiences, higher than 30 arc/sec above limb
1. quiescent, very slow motions, 2 km/sec.
2. active, medium velocity, 20 km/sec.
3. eruptive from an active, fast, 200 km/sec.
4. surge, very fast, 60 minutes of time, 4Å Doppler shift or more
5. spray, extremely fast, 20Å Doppler shift
6. activation by Alfvén waves, large and very fast (Moreton)

Solar features
1. chromosphere, height above photosphere, visible 5 arc/sec.
2. reversing layer, height 0.5 arc/sec.
3. photosphere
4. flare cycle: pre-flash phase(sometimes), flash, maximum, decay
5. most flares, less than 10 km/sec motion
6. proton flare, rare, 200 km/sec motion
7. spicules in emission on the solar limb, 1 arc/sec. wide
8. bushes and rosettes (spicules in absorption) on solar disk
9. plage and plagette, last days, slow changes
10. chromospheric thread, low in the chromosphere, consists of many fibrilles (spicules bent over in absorption)
11. chromospheric brightening, last hours, are not flares which can wax and wane in minutes
12. H-α mottles, dark and light patches
13. filaments and prominences

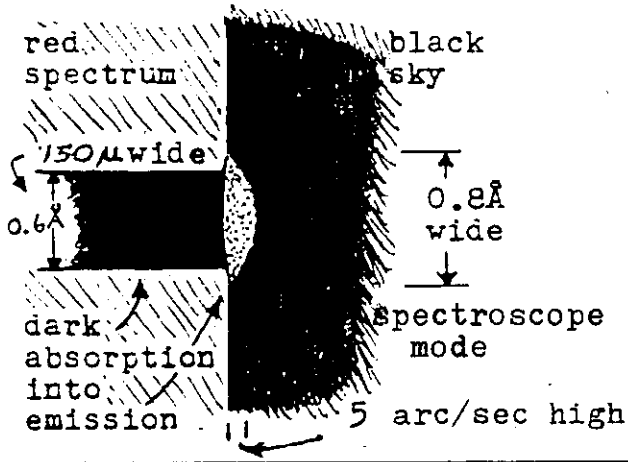
THE H-ALPHA LINE AND ENVIRONS



The region of the H-alpha line with the sun high in the sky. The spectral lines 6560.6Å (1) and 6564.2Å (3) wave length on the sidesof the H-alpha line 6562.8Å (2) are used to measure the Doppler shift of a prominence or a filament. The two lines can be used to calibrate the line shifter.

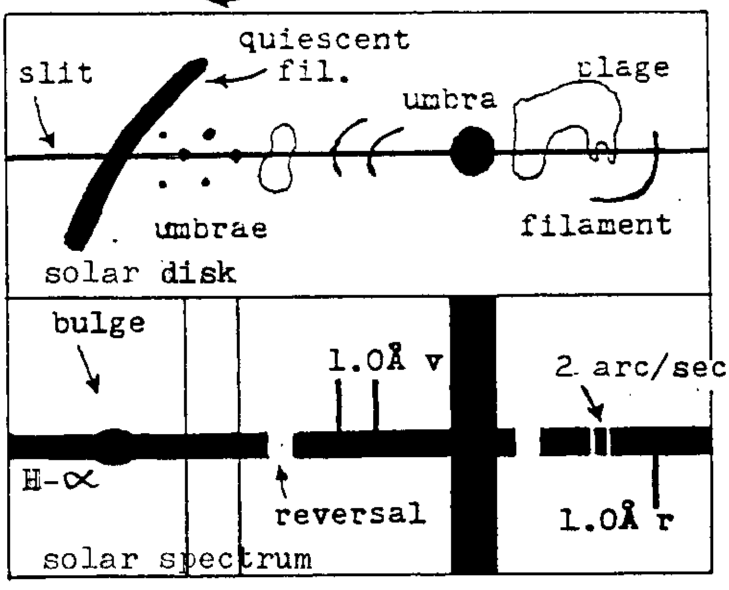


The region of the H- alpha line with the sun low above the horizon. The water vapor lines become very numerous.



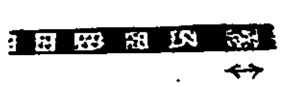
The H-alpha line at 4Å/mm is 0.6Å wide. At the edge of the solar limb, the H-alpha line reverses itself (into emission) and is 0.8Å wide and 5 arc/sec high.

Measured faint spectral lines are 0.02Å (5 micron);medium lines, 0.05Å; strong lines, 0.1Å; violet H and K lines, 2 Å and 3Å wide; using 2" (50mm) f.l. eyepiece.



This is a typical sun spot area in H-alpha light. The dense quiescent filament causes an absorption bulge in the H-alpha line. Umbrae give a lengthwise line along the full length of the spectrum. Plages around spots produce reversals. Loop prominences (here as filaments) show Doppler shifts of 1.0Å in the red and violet. A 0.001" (25 μ) slit give 2 arc/sec detail.

r, red Doppler shift; v, violet.



The H-alpha line slowly moves and wiggles like a snake as sun goes slowly along the slit.

Assume 9' f.l. tele-lens. Delicate dark and light patterns in H-alpha line. Slightly moving sun on entrance slit reveals them better. Lin. disp. 4Å/mm.

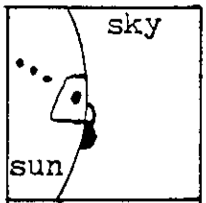
diameter. Out of the H-alpha line about 0.3Å, towards the red or the violet side of the line, the network changes to an appearance of dark elongated structures called fibrilles. They look like narrow filaments, but are not filaments. Average 3 x 20 arc/sec. Out of the H-alpha line by 0.5Å, either to the red or the violet, the network changes to another kind of area detail called rosettes. These areas are forshortened near the limb where they are called bushes. The rosettes and bushes on the solar disk appear as if black pepper was scattered over the solar disk and almost to the limb. Black peppery areas average 5 to 10 arc/sec. The rosettes overlay the supergranulation network. With a much longer focal length telescope, the coarse detail resolves into 1 arc/sec. The rosettes and bushes are spicules in absorption onthe disk.

You should be aware of the chromospheric network because at times the spectrohelioscope willdisplay it. You will wonder what you are seeing if not properly informed. Mottles, fibrilles, bushes and rosettes are not included in the 6" drawing because it would be impossible to draw it all. And it is not necessary to include it. A 9' f.l. telescope will show coarse chromospheric network detail. Also slight air currents in the spectro-box might cause a slight smearing effect of the bandwidth. Use baffles.

Seeing. The atmospheric seeing and ground heating will vary from day to day and will smear the solar disk detail. A spectrohelioscope with an average of 6 arc/sec resolution will not be seriously affected by average seeing conditions because thelatter will be about 1 arc/sec. Only on a poor day of seeing of about 10 arc/sec or worse will the latter influence the instrumental seeing. For spectroscopic study of the solar disk with a narrow slit passing 1 arc/sec detail, then the atmospheric seeing will alter the fineness of the spectroscopic detail, for the 1 arc/sec detail will be about the same as the seeing conditions.

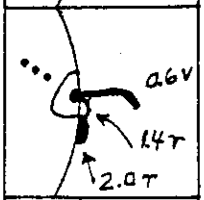
Chromosphere. Books and magazines sometimes show photographs of the chromospheric network but often brief comments are mentioned. What is happening is that various solar disk details are seen at different heights of the chromosphere. In the center (core) of the H-alpha line, the top of the chromosphere is viewed. At plus or minus 0.3Å from the H-alpha core, the middle of the chromosphere is studied. At plus or minue 0.5Å, near the bottom of the chromosphere. At plus or minus 1.0Å, the photosphere is in view. A 9' f.l. telescope gives a 25mm sun image, or coarse detail. An 18' to 27' f.l. produces 50mm to 75mm sun image for finer detail.

Tabulation of events. The solar events should be tabulated at the end of the month. The following table is sufficient. Note the beginning of a flare to the nearest minute in the "Begin" column. If you cannot observe the flare to its ending, just put the time of last observation inthe "End" column, and have as asterisk before the time. If the exact time to one minute of appearance is detected, then underline the time. If the maximum flare brightness is not obvious, leave the "Time at Max." column blank. If the time at maxi-

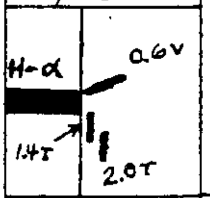


March 4, 1967
28N 90W
21:30 UT
Two very active prominences.

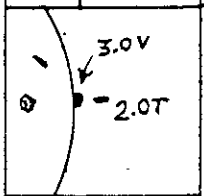
22:00 UT
New prominence appears.
Plage is shown around umbra.



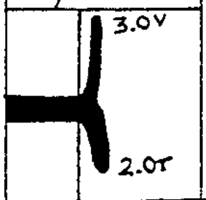
22:20 UT
New active prominence, 0.6Å v.



23:00 UT
Spectroscopic view of all 3 prominences.



March 5, 1967
28N 90W
23:24 UT
Two active prominences.



23:25 UT
Spectroscopic view.

PROMINENCES

The sky around the solar disk is black. To draw black sky for the drawings is time consuming. Just have a white background, implying black sky. The prominences are outlined as black, but in reality they are shades of red.

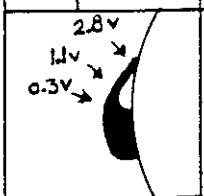
To make spectroscopic study of the limb or solar disk, open the top cover at the front of the spectroscope box and put the hand inside. Move the spectroscope disk with the forefinger. Thus, sections of the sun can be precisely studied.

A number system is employed for plage brightness (PB) and prominence brightness (PB):

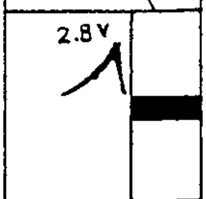
PB 4 is bright;
PB 3 is medium bright;
PB 2 is faint;
PB 1 is very faint.

Filament darkness (FD) is:

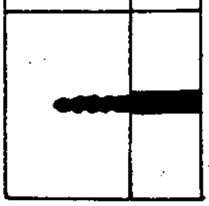
FD 4 is deep black , 2%;
FD 3 is medium black, 4%;
FD 2 is faint grey , 8%;
FD I is very faint grey,14%.
H-alpha core is 16%.



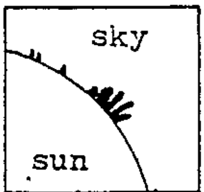
March 24, 1967
30S 90E
21:25 UT
Surge prominence.



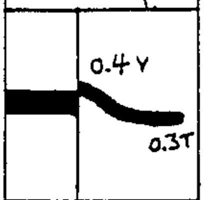
21:26 UT
Spectroscopic view. Most of it in the violet.



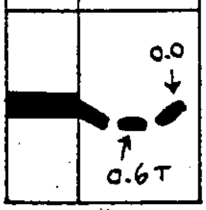
21:30 UT
Surging gone. Now have rattle snake appearance emission for prom.



Sept. 27, 1966
22N 90W
20:50 UT
Active prominence over sun spot on the limb.



Two different positions of the entrance slit. Emissions of 0.4Å to 0.6Å width are common for a prominence.



The H-alpha line itself is 0.6Å wide and is used as a reference to measure widths of emissions. The 0.3 r to 0.6 r are S. L. velocities.

mum can be estimated to a few minutes, then put a time value in. Some flares brighten up unevenly. Use Universal Time (UT).

Date	Begin	End	Time Max.	Position Lat. Long.	Imp.	Max. Area *	Remarks
9-19	20 31	20 50	20 40	14S 09E	S	40	flare
9-19	21 15	22 15	21 35	04N 03E	--		SF

* millionths

Filament and prominence abbreviated: SF, surge filaments; SP, surge prominence; AF, active filament; AP, active prominence. The difference between a surge filament and an active filament is that a surge will dissipate itself within an hour whereas an active filament will remain in view for a few hours. The same can be stated for a surge prominence and an active prominence.

Area units. A convenient unit to express the area of a flare is in millionths of the solar hemisphere. For example, a subflare (Class S) of one millionth is equal to 6 square arc/sec. This is an area 2 x 3 arc/sec, or other equivalent total area. Most flares average 100 millionths, or abbreviate it 100 units. This is equal to an area 15 x 40 arc/sec, or 20 x 30 arc/sec, or otherwise. The sun is almost 2000 arc/sec at maximum diameter.

The derivation of area units is quite simple. The circumference of a circle is 360 arc/degrees, or 115 arc/degrees in diameter. The area of a sphere is equal to 4 pi radius squared. Thus a solar sphere is:

115 arc/deg. diameter = 43,000 sq. arc/deg.
2000 arc/deg. diameter = 12,000,000 sq. arc/sec

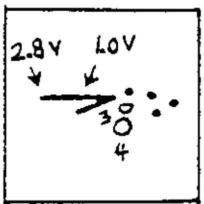
Only half of the sun is visible. For a solar hemisphere, divide by two and have:

= 21,000 sq. arc/deg.
= 6,000,000 sq. arc/sec

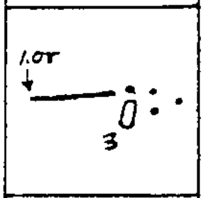
The previous solar hemisphere units are awkward to use. The term millionth of a solar hemisphere is easier. Just divide the above values by one million, giving:

1 millionth solar hemisphere = 0.02 sq. arc/deg.
= 6.0 sq. arc/ sec

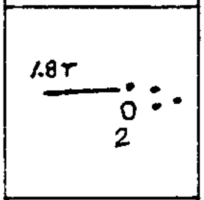
These two unit values are used to express the total area of a flare at maximum growth. Measure the area of the flare on the drawing. For example, a flare 10 arc/sec wide by 20 arc/sec long. Now 10 x 20 = 200 sq. arc/sec. Divide 6 sq. arc/sec (1 millionth) into 200 gives 33 millionths, or 33 units. Surges are not expressed in area units. A 1 arc/sec diameter flare is equal to 450 miles (730 kilometers). Such a tiny flare is big when compared to earthly values, being equal to several H-bombs exploding at the same time.



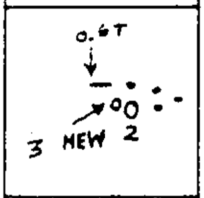
Aug. 22, 1967
18N 42E
22:03 UT
10 and 20 arc/SEC
flares plus surge.



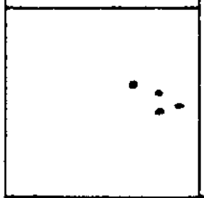
22:15 UT
Surge was moving out fast but now going in along same path.



22:25 UT



22:30 UT
New small flare. Surge filament almost gone.



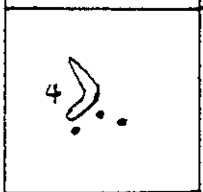
22:45 UT
Flare and surge filament gone.

FLARES

Plages are omitted to keep drawings simple and easier to complete. Only main umbrae put in the drawing in order to locate events. Penumbra is not included. Not always but sometimes a surge filament accompanies a flare.

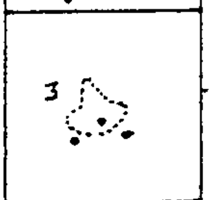
To save time in order to make good drawings, a number system for brightness of the flare:

FB 5 is very bright, 150-300%;
FB 4 is bright, 80-150%;
FB 3 is medium bright, 45-80%;
FB 2 is faint, 25 to 45%;
FB I is very faint, less 25%.
H-alpha core, 16% of continuum.
Photosphere represents 100%.

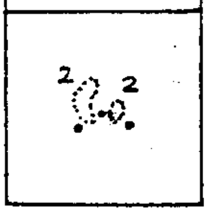


Oct. 20, 1966
14N 58E
20:35 UT
Bright and sharp outline.

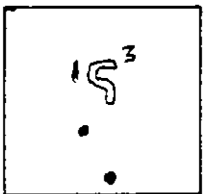
20:40 UT
Flare still growing; bright and sharp. Surge appears.



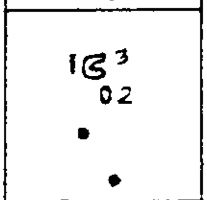
20:55 UT
Less bright and fuzzy (diffuse) outline. Surge gone.



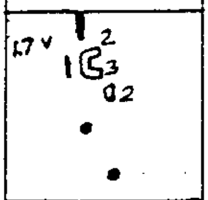
21:05 UT
Less bright and diffused into 2 separate areas.



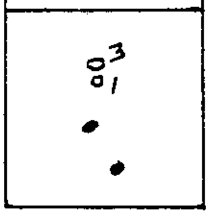
Nov. 12, 1966
15N 05E
22:15 UT
This flare never exhibited diffuseness.



22:20 UT
Flare divides into 2 unequal medium bright areas.



22:25 UT
Flare still decreases in brightness. Surge filament appears 1.7 v.



22:30 UT
Surge gone. Flare becomes smaller.

23:00 UT. Flare gone.

Flares. Flares are classified by the total area at maximum growth, not by time or brightness. A reticle with 1mm squares is used to estimate maximum area in millionths of the solar hemisphere. With a one inch sun image on the entrance slit, 1mm equals 80 arc/sec. Location of a flare in a sun spot group with many plage is found by using the line shifter. Most flares are irregular patches. The smallest flares, Class S, are often tiny oval or round points (actually a tiny area) of light. S is subflare.

In the initial stages of an average flare, the bright areas are narrow and sharply outlined. Once past maximum intensity, there usually is observed a broadening and outward diffusion of the flare, but sometimes there is no broadening or diffusion. Then the flare wanes in brightness. Surges are frequently observed with flares. The letters f, n, and b are faint, normal and bright for a flare at maximum growth.

Class	Maximum total area (corrected)		
I.A.U. 1966	millionths	square deg.	sq. arc/sec.
Sf, Sn, Sb	<100	<2	<600
1f, 1n, 1b	100-250	2-5	600-1500
2f, 2n, 2b	250-600	5-12	1500-3500
3f, 3n, 3b	600-1200	12-25	3500-7200
4f, 4n, 4b	>1200	>25	>7200

Surge filaments. Surge filaments may occur in one of three ways. First, it can develop in the form of an arch, ascending rapidly and then descending just as fast. Second, the filament moves outward along one path; then suddenly returns along the same path. Third, the filament moves outward and scatters itself out of sight. Velocities start about 40 km/second and increase in a matter of minutes to about 100 km/second or more. Surge activity may or may not be associated with flare activity.

There are some kinds of solar detail that can not be seen with a medium sized spectroheliscope, namely Ellerman H-bombs (or moustaches) on the solar disk.

The relationship of sight line velocity (S. L. V.) and associated filament or prominence is as follows:

Filament or prominence	Average sight line velocity	Doppler shift
Quiescent	1.2 mi./sec. (4,300 mi./hr.); 2 km./sec.	0.04Å
Active	12 mi./sec.(43,000 mi./hr.); 20 km./sec.	0.42Å
Surge	120 mi./sec.(430,000mi./hr.); 200 km./sec.	4.20Å

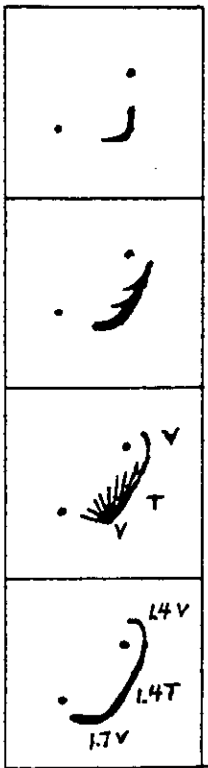
Solar spectrum atlases. A good inexpensive spectrum atlas is in the book "The Sun" by G. Abetti. Excellent set of 15 slides of solar spectrum by Tersch Enterprises, P.O. Box 1059, Colorado Springs, CO 80901.

SURGE FILAMENTS

The term radial velocity is for stars. For the sun it is best to use sight line velocity, S. L. velocity, or line-of- light velocity.

Most surge filaments move at an angle to the observer. The S. L. velocity is not the true velocity. Sometimes a filament moves along the surface of the solar disk. This is a tangential velocity.

An active filament with above average S. L. velocity will last a few hours. A surge filament will come and go within about 60 minutes. Some active filaments remain such for a period and then suddenly and unexpectedly develop into a surge.



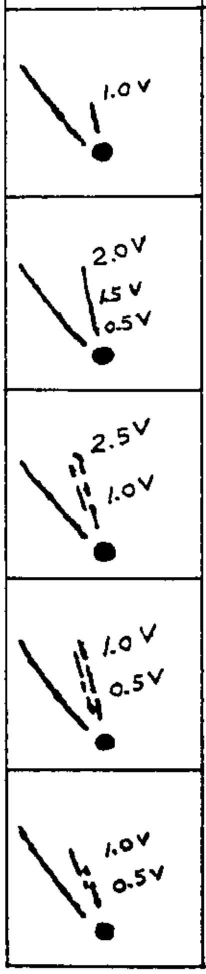
Oct. 9, 1966
20S 60W
23:00 UT
Active filament.

23:10 UT
Surge development.

23:20 UT
Surge filament in rapid change, fanning out fast.

23:35 UT
Maximun spread of the surge filament.

24:00 UT. Gone.



Sept. 19, 1966
04N 03E
20:45 UT
Active filament.

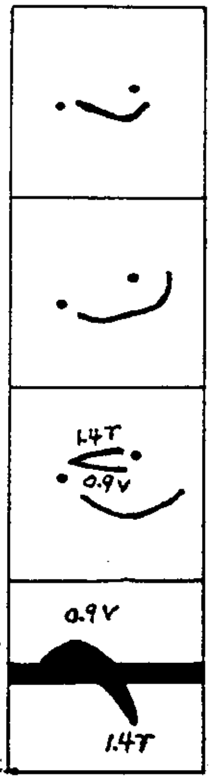
21:25 UT
Surge filament in progress. About 200 arc/sec long.

21:35 UT
Surge is fragmenting itself to pieces.

21:40 UT
Surge moving straight outward towards the earth (in the violet).

21:45 UT
Surge almost gone. Much less active.

22:30 UT. Gone.



Oct. 20, 1966
10N 35W
20:35 UT
Tangential filament moving along the solar surface.
21:50 UT

22:45 UT
Two active filaments appear. One in violet and one in red.

23:00 UT
Spectroscopic view of the two active filaments.

Observation in the spectroscope mode. Unique experiences seen on the solar surface. High linear dispersion required.

1. Atmospheric lines. The red A and red B (7594Åλ oxygen, 6867Åλ oxygen respectively) and water in the atmosphere of the earth cause many dark lines in the spectrum, especially when the sun is near the horizon.

2. H-alpha line at solar limb. With the slit radial on the limb, view the spectrum for the bulge in emission of the H-alpha line and the blue H-beta line (4861Åλ).

3. Solar disk. Place the slit across a chromospheric plage, and see the plage in emission (reversal of the H-alpha line). Violet calcium H and K lines (3968Åλ and 3934Åλ respectively) also show plage in emission. To see the solar disk in violet light with a spectroheliosope, the instrument must be designed differently. Also a young adult's eyes are better.

4. Emerging magnetic regions. Magnetic flux ropes slowly emerge from the photosphere and push through the chromosphere. Hot gaseous material moving along the flux ropes gives a zig-zag appearance to the H-alpha line, about 0.5Å Doppler shift in the red and in the violet. The zig-zag itself has slow changes of about 0.1Å shift per hour, or less usually.

5. Light bridges. The bridge forms across a large umbra-penumbra of a sunspot, giving an upward violet Doppler shift of H-alpha.

6. Rotational velocity. They occur in surge prominences and in surge filaments (Ellison, 1968). Use a Dove prism to rotate the solar image so that the spectroscope slit lies across the base of the prominence or filament. There will be seen an opposite tilt of the parts of the H-alpha line in emission or absorption.

7. Yellow helium (5876Åλ). With the entrance slit tangentially placed on the solar limb, the helium line will be in emission.

8. The solar spectrum. It has very fine detail, particularly in the second order of the grating, giving equal, visual detail as compared to professional work by photography with large scopes.

Observation in the spectrohelioscope mode.

1. Temperature map of flares. A flare in emission in H-alpha is about 10,000°K. Some parts are hotter and seen in absorption in yellow helium at 15,000°K. Hottest parts in emission in yellow helium at 20,000°K.

2. Height structure of a flare. A flare in H-alpha and in yellow helium is in the upper chromosphere, about 5 arc/sec above the solar disk. A flare in sodium and in magnesium light is in the lower chromosphere, about 1 arc/sec above the solar disk.

3. Hot and cold prominences and filaments. Hot parts have a temperature more than 10,000°K, giving strong hydrogen Balmer lines (H-alpha, H-beta, etc.), strong in helium, weak metal lines (Fe, Mg, Na, etc.). The cold parts have a temperature less than 10,000°K, showing strong Balmer lines, weak helium, and strong metal lines.

4. Polarity work. Visual polarity determination of sunspot groups need 0.05Å bandwidth with Mg b_4 (5167Å λ, green). It is best to use Anderson prisms to avoid H-alpha lag effects. Set exit slit on the blue wing for maximum contrast, off-set 0.05Å.

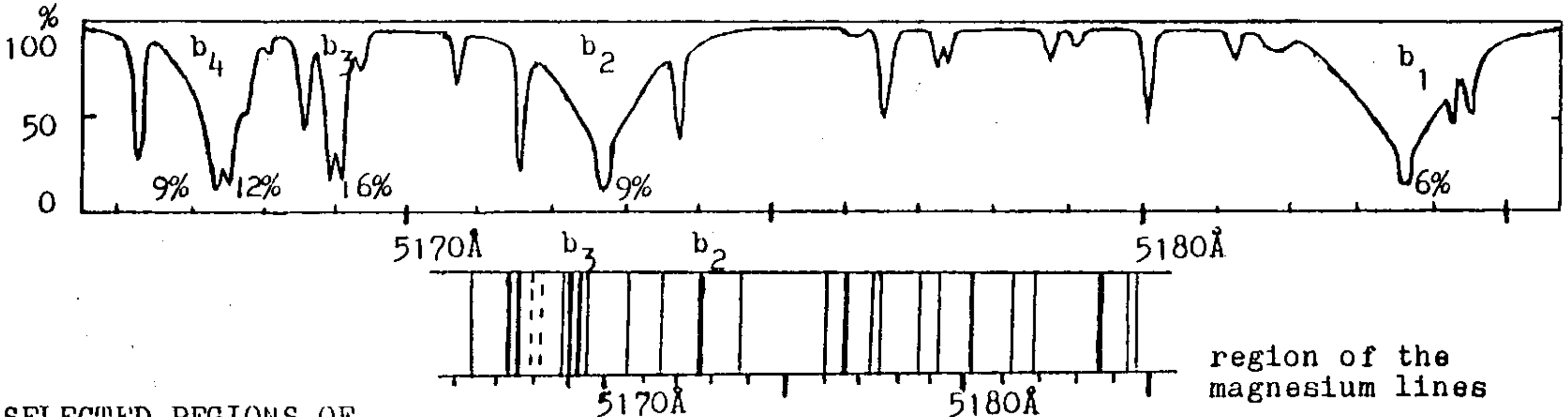
5. H-alpha details. No occulting disk needed for solar disk and solar limb. Both seen together. Best contrast in the H-alpha center core of the line. Spectroscopic work useful.

6. Useful spectral lines. Main visual lines, also by photography, are: red H-alpha, 0.6Å bandwidth or less; blue H-beta, 0.4Å or less; yellow sodium line, 0.1Å; yellow helium in emission, 0.1Å; yellow helium in absorption, 0.1Å; green magnesium 5173Å λ, 0.1Å; green magnesium 5167Åλ, 0.05Å. For the violet H and K lines about 3.0Å bandwidth or less for good contrast.

7. Explosive flares. Most flares have slow expansion, about 10 to 20 km/sec. Some flares have an explosive phase that last about 30 seconds of time, best observed by time lapse photography. On occasion a rare, large proton flare will exhibit the explosive phase. The single flare ribbon in emission will split into two separate ribbons with a tangential velocity of about 100 km/sec or more for about 15 minutes or more. Such splitting of the flare ribbons near the solar limb will have a Doppler shift of the bright moving parts such that most of the flare will not be seen in H-alpha, only out of the H-alpha core with a fast adjusting line shifter. If the splitting occurs away from the solar limb and towards the solar center, the moving ribbons will be observed in the H-alpha core.

The previous modes of usage of a spectrohelioscope will give you a quick idea of the versatility of the instrument. These two pages are to teach you <u>now</u>. Making observations and slowly learning yourself, you will miss certain types of solar events. These events are discussed in hard-to-get technical journals, but it takes time to peruse the literature.

The human eye varies in sensitivity with age. At age 30 one will see the spectrum from the violet to the red with high dispersion. But the eye yellows with age. So about 50 years or so, the eye will not see the violet part of the spectrum very good. At low dispersion as with a hand spectroscope, the spectrum is greatly compressed. Now the violet will be seen. At age 60 the violet H and K lines are not seen at high dispersion, but a hand spectroscope will barely show the H line but not the K line.

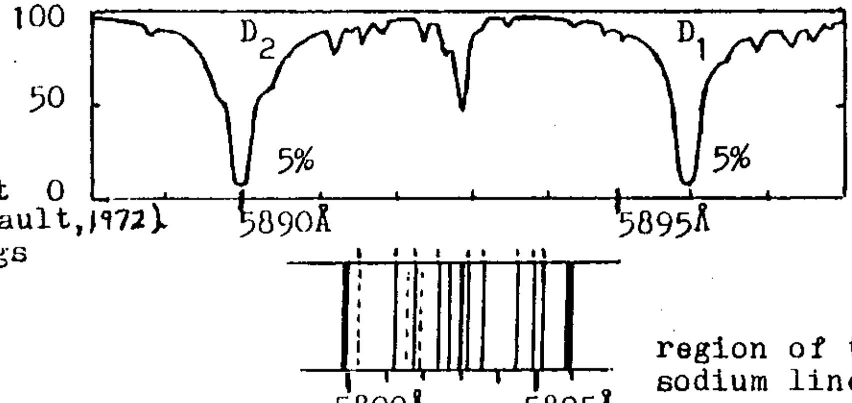


region of the
magnesium lines

SELECTED REGIONS OF

THE SOLAR SPECTRUM

The smoothed out
PEP curves are from
the Preliminary Kitt
Peak Solar Atlas (Brault, 1972).
The spectral drawings
are by F. N. Veio.

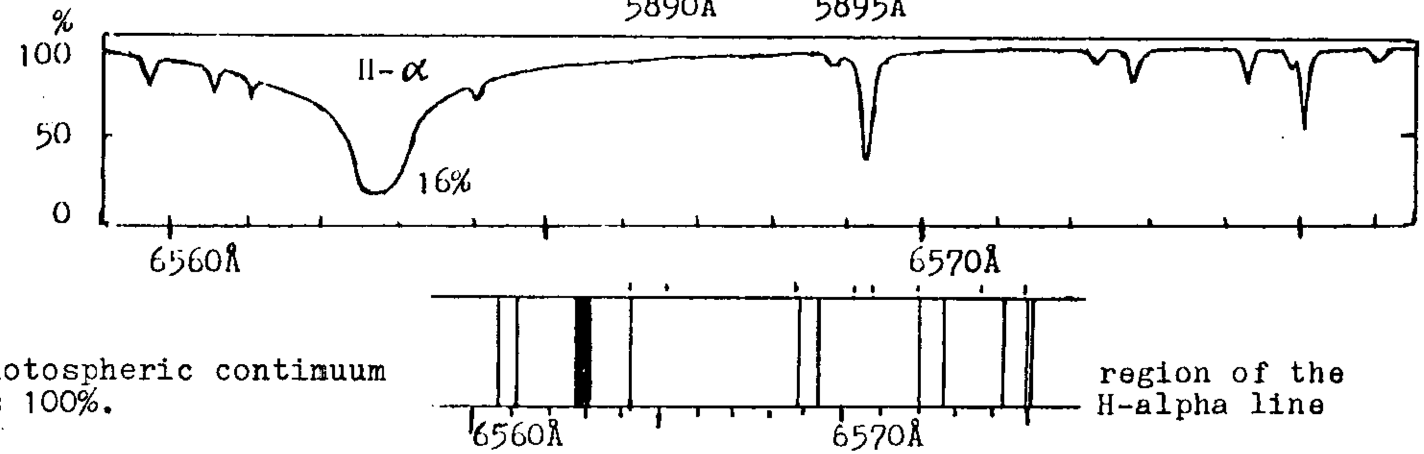


region of the
sodium lines

Ticks marks are
atmospheric lines.

30x32mm grating
1200 gr/mm
first order
4Å/mm lin. disp.

The sun high in
the sky, no haze.



region of the
H-alpha line

Photospheric continuum
is 100%.

The solar spectrum. The following wavelengths are from The National Bureau of Standards, Monograph 61, by C.E. Moore. These three regions are easy to find in order to use the wavelengths for grating resolution. Units are in ängstroms, Å.

Green magnesium region

5166.28	Fe		5176.14	Co	
5167.33	Mg	> b_4	5176.57	Ni	
5167.51	Fe		5177.24	Fe	
5167.72	Fe		5177.41	Cr	
5168.19	Fe		5178.80	Fe	
5168.66	Ni		5179.13	Ni	
5168.91	Fe	> b_3	5180.07	Fe	
5169.05	Fe		5181.33	Fe	
5169.30	Fe		5181.84	--	
5170.77	Fe		5183.62	Mg	b_1
5171.61	Fe		5184.27	Fe	
5172.70	Mg	b_2	5184.56	Cr	
5173.75	Ti				

About 93% of the lines are neutral atoms.

Yellow sodium region

5889.97	Na	D_2	5892.88	Ni	
5890.20	H_2O		5893.05	H_2O	
5891.18	H_2O		5893.51	H_2O	
5891.50	atm.		5894.39	H_2O	
5891.66	H_2O		5894.94	H_2O	
5891.89	Fe		5895.14	H_2O	
5892.40	H_2O		5895.94	Na	D_1
5892.70	Fe				

Orange-red hydrogen region

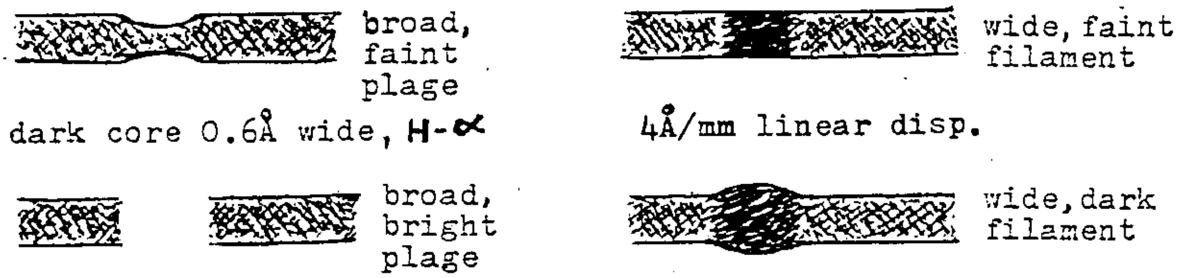
6560.56	H_2O	6570.63	H_2O
6561.10	H_2O	6571.18	Fe
6562.81	H-alpha	6572.09	H_2O
6563.52	H_2O	6572.80	Ca
6564.21	H_2O	6573.53	H_2O
6565.55	H_2O	6574.25	Fe
6567.85	atm.	6574.85	H_2O
6568.81	H_2O	6575.04	Fe
6569.22	Fe		
6570.05	H_2O		

Extreme UV, 1000 to 2000Åλ. Ultra violet, 2000 to 3000Åλ. Deep violet is 3000 to 4000Åλ.

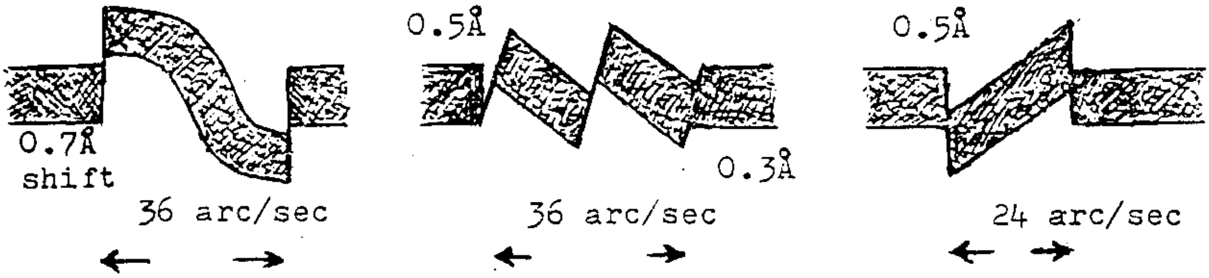
3800 to 4200Åλ visible violet.
4200 to 4500Åλ deep blue.
4500 to 5000Åλ light blue.
5000 to 5500Åλ green.
5500 to 6000Åλ yellow.
6000 to 6600Åλ orange-red.
6600 to 7600Åλ red.

There are about 4,000 spectral lines between the orange-red and the violet (6600Å to 3900Åλ) of the spectrum. About 3,000 are very faint to faint lines. The rest are strong to medium strong.

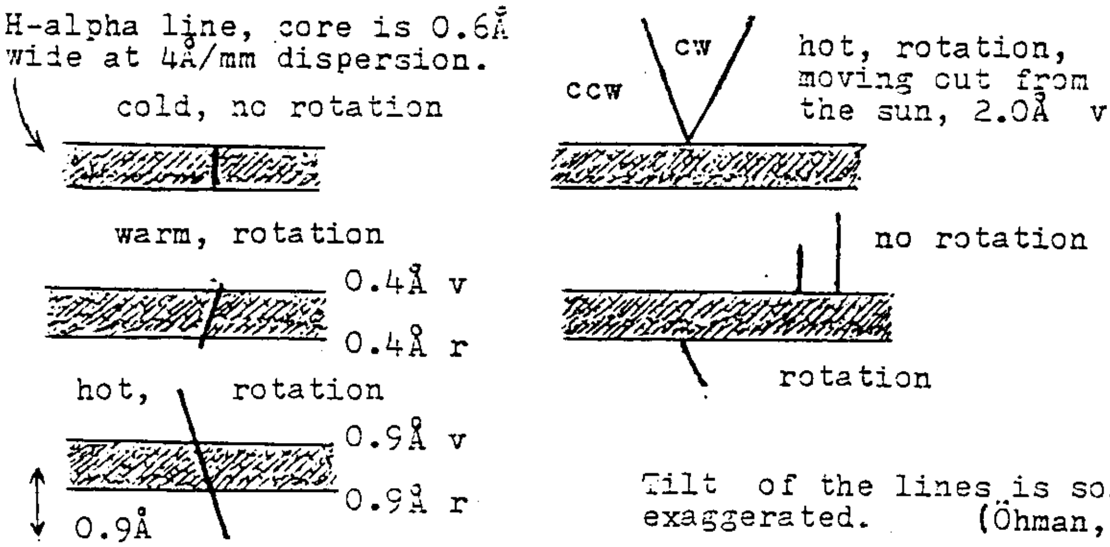
<u>Zig-zags and tilting of the H-alpha line.</u> Careful spectroscopic observations can reveal many interesting events on the solar disk. Slowly move a faint plage over the entrance slit. The H-alpha line will appear pinched due to the slight filling in of the bottom of the H-alpha line. A medium bright plage will show a complete reversal. The H-alpha line itself is not completely black, rather a grey black. With the entrance slit over a faint, grey filament, the H-alpha line becomes slightly darker due to a filling in of the bottom of the profile of the line. With a dark filament, the H-alpha line will bulge outward a bit because of the filling in of the bottom and the wings of the line.



On occasion magnetic flux tubes will slowly push out of the photosphere and through the chromosphere. Gaseous material moving along the flux tubes causes a rigid zig-zag shift of the H-alpha line. If the gaseous material is rotating, the end of the zig-zag of the H-alpha line will be tilted. The zig-zag usually shows no change in shape after an hour of time. Observed summer of 1966.



Carefully move an active sunspot group with loop prominences (filaments) over the entrance slit. If there is a narrow, cold quiescent filament, a dark streak will appear in the H-alpha line. If there is rotation of material in the filament, the dark streak will be tilted slightly. If the filament is not moving towards or away from the observer, the dark streak will be centered over the H-alpha line, which is 0.6Å wide at 4Å/mm dispersion. If the narrow filament is hot and rotating but not moving outward or inward, the dark streak will be conspicuously extended about 0.9Å out from the H-alpha line on both sides and also be tilted slightly. If material is strongly moving along the filament, also hot and rotating, a dark streak will appear away from the H-alpha line and be tilted to the left or right, indicating clockwise or counterclockwise rotation of the material.



Tilt of the lines is somewhat exaggerated. (Öhman, 1968)

With a narrow entrance slit of 0.001" (25 microns), small, narrow 2 arc/sec detail in a loop prominence (filament) is about the same size as the slit. A Dove prism is not needed to rotate the solar detail perpendicular to the slit. But for wider prominences and filaments about 10 arc/sec or more, a Dove prism is required because the detail is definitely larger than the entrance slit.

Observing a prominence will show the parts in emission with a straight shift away from the H-alpha line if there is only sight line velocity and no rotational velocity. If there is rotation of the prominence, the parts will be in emission and tilted relative to the H-alpha line. If viewing a filament, sections will be tilted in absorption in the H-alpha line.

Sometimes seeing a prominence or a filament without a Dove prism for orientation will show an apparent tilting of some of the parts. But you do not know for a certainty whether the tilting of the H-alpha line is real or apparent.

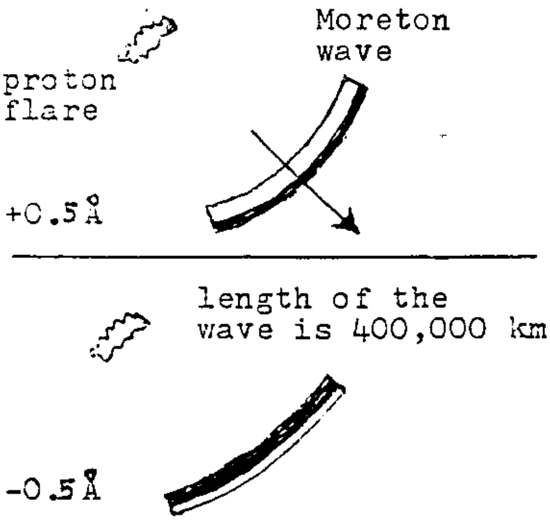
Observing a medium large quiescent prominence on the limb will often show sections 0.4Å to 0.6Å wide as an average emission value. If there is little or much sight line velocity, the 0.6Å width still holds true to a certain extent. If the gaseous material is tenuous, sections in emission as narrow as 0.2Å will be seen. An active prominence or filament can be small, say 15 arc/sec, but the slight line velocity might be 2Å or more in the red or violet, or both. Straight visual examination reveals little or nothing at first glance. Spectroscopic study will exhibit sudden surprises in activity by watching shifting of the H-alpha line.

A 9' f.l. telescope is limited in analyzing small 2 arc/sec detail. The above examples are border line visible. Much longer focal length is desirable for more critical work. But a 9' f.l. works fine for flares and filaments because they are larger, about 5 arc/sec or more.

<u>Wave disturbances.</u> Evidence now indicates that a flare originates in the lower corona with highly energetic particles moving out into space towards the earth and downward onto the chromosphere, allowing the flare to be seen in H-alpha light andhelium light, 5876Å wavelength. Moments later some of the flare energy passes further downward into the lower chromosphere and the reversing layer, which is just above the photosphere, showing the flare in sodium, magnesium, iron and other wavelengths.

When the flare begins in the corona, an outward and downward wave disturbance occurs, sometimes called <u>Moreton waves</u>, pressing upon the chromosphere, first causing about 0.2Å Doppler shift to the red for the front of the wave. As the wave moves along and over the chromosphere, the rear of the wave comes upward, presenting a slight Doppler shift to the violet. This is obvious in time lapse movies. It is thought that these huge waves are magnetic transverse waves, called Alfvén waves, in contrast to sound waves which are longitudinal. The waves travel over the solar disk about700km/sec.(1,300,000 miles/hour) up to about 1,500 km/second of time.

The wave disturbance can activate a filament, shoving it downward, giving a Doppler shift to the red. A few minutes later the rear of the wave rises upward and up comes the activated filament, now shifted to the violet wing of the H -alpha line. Eventually the filament returns to its normal viewing position in the center of the H-alpha line. This "winking" in and out was observed by Greeves in 1930 with a spectroheliscope.



If a large flare occurs, it is best to take spectroheliograms not only in the center of H-alpha but also on the red and violet wings. The large proton flare of August 23, 1966 is an excellent example. In the drawings the reason for the dark and light appearance of the front and rear of the wave is as follows, taking the offset of +0.5Å for discussion. The exit slit is almost out of the H-alpha core. The downward moving front of the wave shifts the H-alpha line to the red. Now the exit slit isin the dark core, passing to the eye or film that area of the wave as dark. The moving upward rear of the wave shifts to the violet, away from the dark core, onto the brighter side of the wing of the line. Exit slit transmits that area of the wave as somewhat brighter. A big proton flare may occur on the non-visible side of the solar disk. In which case the huge wave will move around the solar disk and still cause the "winking" of the filaments. Above with a spectroheliograph to capture the flare. Bandwidth about 0.1Å. (Dodson, 1968).

AN IMPORTANT CONCEPT TO UNDERSTAND IN SPECTROHELIOSCOPES

Linear dispersion. Telescope is 9 ft. focal length as a bare minimum. The spectroscope must produce a solar spectrum about 3.3 feet long (one meter) in order to widen the spectral lines, notably the H-alpha line. The term used is linear dispersion. A 75 inch f.l. (1.9 meters) spectroscope lens with a 1200 gr/mm grating used in the first order will be excellent. From the violet to the red is 4000Å, and the latter divided by 4Å/mm = one meter long spectrum.

75" f.l. spec-lens (1.9 m), 1200 gr/mm grating, 1st order, spectrum is one meter long, 4Å/mm linear dispersion, good

→ 1.9 meter lens, 600 gr/mm, 1st order, 0.5 meter spectrum, 8Å/mm disp.

→ 1.9 meter lens, 600 gr/mm, 2nd order, one meter spectrum, 4Å/mm disp.

↓ 19 meter lens, 600 gr/mm, 2nd order, 10 meter spectrum, 0.4Å/mm disp.

↓ 19 meter lens, 600 gr/mm, 4th order, 20 meter spectrum, 0.2Å/mm disp., or 5mm/Å disp.

↓ 108" f.l. lens (2.7 m), 1200 gr/mm, 1st order, 1.4 meter spectrum, 2.8Å/mm disp., very good

↓ 1.9 meter lens, 1800 gr/mm, 1st order, 1.7 meter spectrum, 2.4Å/mm disp., better

↓ 2.7 meter lens, 1800 gr/mm, 1st order, 2.2 meter spectrum, 1.8Å/mm disp., best

→ 2.7 meter lens, 1800 gr/mm, 2nd order, 10 meter spectrum (equivalently), 0.4Å/mm disp.

Warning. If you use a grating blazed for 5000Å wavelength (green) in 1st order, the blaze shifts to 2500Å wavelength (violet) in 2nd order.

Most of the time pick a 5000Å blaze (green) or 6000Å blaze wavelength in first order.

If you want to do sunspot polarity work, buy a grating at 10,000Å blaze(red) wavelength, 1st order. The blaze shifts to 5000Å wavelength in the second order.

The dispersion is not linear at high grooves/mm and higher orders.

Grating formulae. There are three formulae in "Amateur Astronomer's Handbook" by J. B. Sidgwick. The chapter on spectroscopes discusses prisms and gratings for the solar spectrum. There are two types of gratings: transmission and reflection. Transmission gratings are limited to about 600 gr/mm because of the index of refraction of the glass in visible light. Reflection gratings are preferred because the grooves/mm can be much higher, allowing greater linear dispersion for longer solar spectrum from one meter up to ten meters or more.

The first formula is resolution of a grating,

100% resolution = wavelength/ grating width x grooves/mm x order

With 32x30mm ruled area of 1200 gr/mm,
R = 5200Å/32mm x 1200 gr/mm x 1st = 0.14Å
R = 6563Å/32mm x 1200 gr/mm x 1st = 0.20Å

With 58x58mm ruled area of 1800 gr/mm,
R = 5200Å/58mm x 1800 gr/mm x 1st = 0.05Å
R = 5200Å/58mm x 1800 gr/mm x 2nd = 0.025Å
R = 6563Å/58mm x 1800 gr/mm x 1st = 0.06Å

A 600 gr/mm grating has orders from one up to 8 in the violet. A 1200 gr/mm grating has orders from one up to 4 in the violet. An 1800 gr/mm grating has orders in the first up to green in the second order. Up in higher orders the grating is tilted about 80 degrees to the incoming light.

The formula for angular dispersion for transmission grating,

sin alpha = wavelength/grating constant (space)

For a reflection grating,

sin alpha = 1/2 x wavelength/grating constant.

One millimeter is 1000 microns, or 10,000,000 angstroms. With a 1200 gr/mm grating the grating constant (spacing) is 8333Å between the grooves. At H-alpha with such a grating,

sin alpha = 1/2 x 6563Å/8333Å = 0.3938, or 23 deg. 11 min.

The last formula is linear dispersion,

$$\text{lin. disp.} = \frac{\text{spec. f.l.} \times \text{order} \times 1\text{Å}}{\text{grating constant} \times \cos\alpha} = \text{mm/Å}$$

With 75" f.l. (1.9 m) spectroscope, cosine of 23 deg. 11 min. =0.91925,

$$\text{lin. disp} = \frac{1900\text{mm} \times 1 \times 1\text{Å}}{8333\text{Å} \times 0.91925} = 0.25\text{mm/Å, or } 4\text{Å/mm}$$

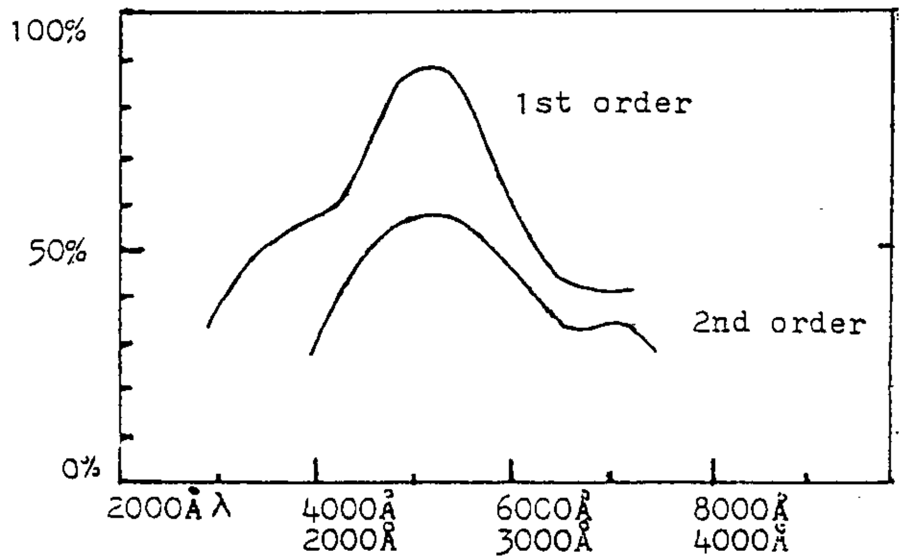
Inverting from mm/Å to Å/mm is termed reciprocal linear dispersion. The three formulae explain the mystery of gratings.

<u>More grating details.</u> A performance table for good and average quality gratings for the first order (Jarrell, 1964).

specs.	minimum			good		
grooves/mm	300	600	1200	300	600	1200
resolution, % theo.	50%	40%	30%	95%	90%	85%
efficiency at blaze λ , %	50	35	20	90	80	70

High quality replica gratings came on the commercial market in the mid-1950's. An original grating would cost about ten times as much. That is why a rare amateur constructed a spectrohelioscope. About 20 years ago holographic gratings appeared. Both classical ruled and holographic gratings have high resolution.

The following chart by Jarrell and Stroke gives the light curve of a well blazed grating of 1200 gr/mm, 5000Å blazed wavelength.



In the first order the grating is 90% efficient at 5000Å wavelength and about 40% at H-alpha.

Or the grating is 90% efficient at 5000Å wavelength in first order but 55% efficient at 2500Å wavelength in the second order.

Spectrum length, violet to red			
spec. f.l.	grating 1200 gr./mm	grating 600 gr./mm	one 60° prism
75" (1.9m)	40" long	20" long	6" long
7.5" (190mm)	4" (100mm)	2" (50mm)	0.6" (16mm)

For a small spectroscope of short focal lengths, an Edmund grating of 12 x25mm ruled area will work fine. For long focal length, use a high quality replica grating.

MAIN BASICS FOR A SPECTROHELIOSCOPE

Comparison of designs. The author used the rotating glass disk as the solar image synthesizer in his first instrument. For just the H-alpha line, the rotating glass disk functions fine. But as the years passed by, it was realized that observations in the metal lines and helium were also useful. The Young synthesizer easy will allow usage of the latter, narrow lines with fixed slits, or Anderson prisms and fixed slits.

There are several spectrohelioscope designs in this and following chapters. It may seem a little confusing. So a brief comparison of the designs herewith. It is important to keep in mind that a long solar spectrum is desired, about three feet (one meter). The reason is to keep the H-alpha line wide.

A. Basic design. Rotating glass disk or Young synthesizer. A six ft.f.l. spectroscope, nine-foot focal length telescope, grating 32x30mm ruled area with 1200 gr./mm. Spectrum will be about one meter long. An 1800 gr./mm grating is better, giving about 1.5 meter long spectrum.

B. Advanced design. Young synthesizer. About nine-foot f.l. spectroscope, about nine-foot f.l. telescope. Grating 52 x 52mm or larger, 1200 gr./mm is good. Spectrum about 4.5 feet long (1.5 meters). Good for H-alpha, also metal and He lines.

C. W-spectroscope design. Anderson prisms only. A six- to nine-foot f.l. spectroscope. Grating 32 x 30mm or larger, 1200 gr./mm. Attach it to the end of a medium large refractor to make a solar spectroscope, or conversion into a spectroheliosCope. Spectrum three feet long. An 1800 gr/mm grating better.

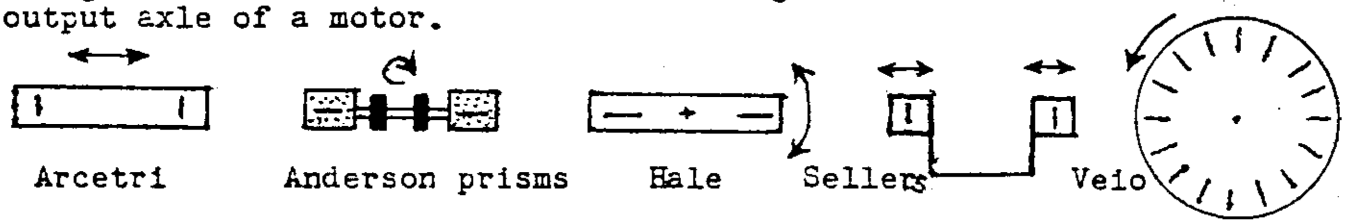
D. Commercial design. Convert an F:15 refractor of 3 inch (76mm) aperture to a spectroheliosCope. Add a 2X Barlow (-10" f.l.), 100" e.f.l. Use the Arcetri spectroscope design with 36" f.l. (900mm) achromats. Grating 32 x 30mm, 1200 gr./mm is good. But 1800 gr./mm is better, giving about 2.3 feet long spectrum.

Warning about using a Barlow lens. It must be adjusted correctly so no aberrations are introduced to harm the solar image. It is best and less critical for adjustment to use about -10" f.l. (-250mm). About 1.5 to 1.7X is best, less critical. If in doubt, use a long focal length single lens or a concave mirror, slightly off-axis.

All the larger designs above require a high qualitygrating. Gratings of 600 gr./mm were used in the literature of 60 years ago because only that ruling was available then. Now high quality replicas came on the market in the mid-50's. Thus buy a 1200 gr./mm grating; the spectrum is longer. If you have extra money, buy an 1800 gr./mm grating, giving a longer spectrum even more so for the same focal length. Good quality lenses and mirrors are a must, 1/10λ. Test your optics for quality. Take nothing for granted.

Solar image synthesizers. There are five main types of image synthesizers: Anderson prisms, Arcetri slits, Hale's oscillating slits, Sellers' vibrating slits (like a musical tuning fork), and Veio's simplified rotating glass disk. Not any type of synthesizer can be used with any spectroscope design, which includes the Arcetri, Ebert, off-axis Ebert, grating-Ebert, Hale and Littrow design.

Anderson prisms are two separate square prisms about 4" apart mounted on the ends of an axle which rotates in front of two slits. The fixed slits are in line with each other. The Arcetri slits are about 4" apart. They are parallel to each other, using a sideways motion. Hale's oscillating slits are on a metal bar about 5" (125 mm) long. The slits are fixed and in line with each other on the bar. Sellers' slits are on a mechanical spring mechanism. The slits are about 4" apart and parallel to each other. The Veio 4¼" diameter rotating glass disk has 2 4 slits cut in the paint on the surface. The glass disk is bolted on a metal flange which is mounted on the output axle of a motor.



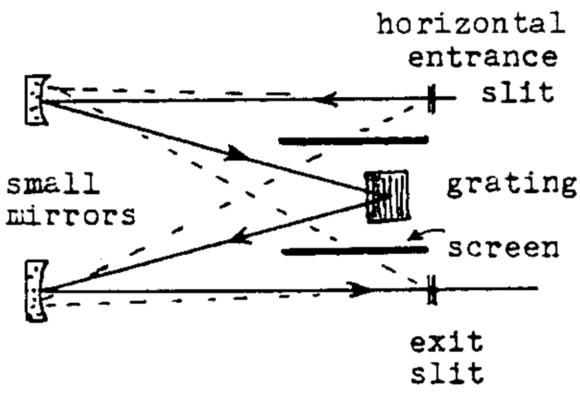
Arcetri spectroscope design. The Arcetri design consists of 2 almost identical focal length lenses, one optical flat, and a reflecting grating all arranged in the form of a U-shape. The light from the entrance slit passes through one lens, off the optical flat and off the grating, and passes through the other lens to the exit slit. There is an even number of reflections, namely two. The Arcetri design can not be used with the rotating glass disk , for the spectrum is tilted at a 45 degree angle at the exit slit. Rotating the grating does not correct the situation. The Arcetri design only works with sideways moving slits. An interesting design. Remove any vibration problem. Instead of a reflecting grating, a transmission grating can be used, but it presents no particular design advantage. A transmission grating exists up to only 600 grooves per mm for visible light. A reflecting grating up to 1200 lines/mm can be used to achieve higher linear dispersion and resolution. Instead of moving slits, use the Pettit system of fixed slits with separately mounted Anderson prisms on separate motors.

Ebert, Hale, Littrow designs. All the following designs have an odd number of reflections. The Ebert design is one large mirror. The off-axis Ebert consists of two small mirrors cut from one large mirror. The grating-Ebert is the ruled area of the grating on a concave mirror. Such gratings cost about $800 or more. The Ebert design has tilting of the spectral lines. Thus the H-alpha line can not line up exactly with the fixed slits of the rotating glass disk. But other synthesizers have adjustable exit slits and can be used to better design advantage.

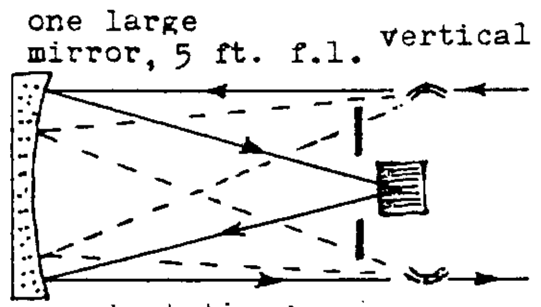
SPECTROSCOPE DESIGNS

These are some common spectroscope designs, particularly the Littrow. Crossing over of extraneous light is blocked out by a screen placed along the optical axis. Or the screen with holes can be located across the optical axis. Dotted lines are the light crossing over. For the Littrow (Veio) design, the positive meniscus lens shape is best because the two lens reflections are more easily blocked out than with a plano-convex lens or related shape.

Hale design
(Hay-l)

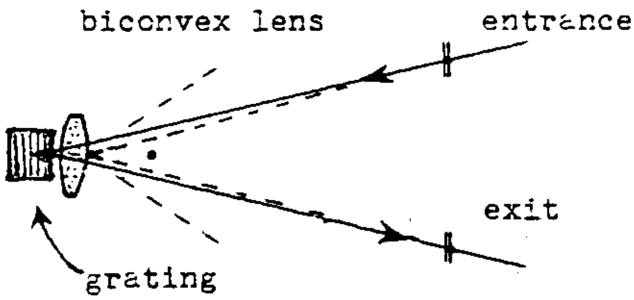


Ebert design
(Ee-bert)

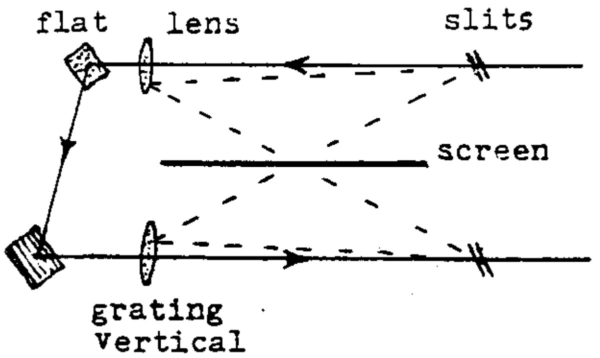


orientation:
10' f.l., horizontal slits or vertical slits
5' f.l., vertical slits

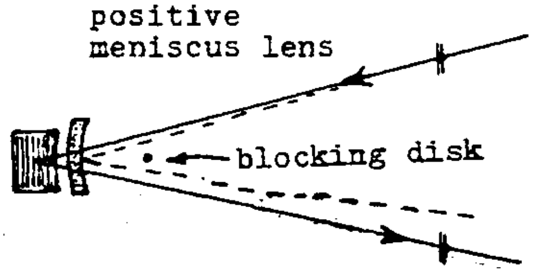
Littrow design



Arcetri design
(Ar-chet-tree)



Veio design
(Vee-oh)



The Hale design is two spherical mirrors made separately and the same focal length within 4" inch. There is some tilting of the spectral lines at the exit slit. The Littrow design has one lens of biconvex, plano-convex or positive meniscus shape. Or an achromatic lens is usable. With the biconvex, plano-convex and achromatic shape, there are two sun reflections off the surfaces of the lens. They must be removed. One small black piece of tape placed on the rear surface of the lens and another small disk on a wire about a foot from the lens will remove the two reflections.

The positive mensicus lens has two lens reflections, but they can be conveniently blocked out. The rear surface of the lens is about the same radius of curvature as the equivalent focal length of the lens. The light from the entrance slit bounces off the rear surface and focuses near the exit slit, assuming the optical axis of the lens does not coincide with the output axle of the motor. The second small but very bright reflection is blocked out with a small I/8" (3mm) disk mounted about one foot behind the lens. This small reflection moves as the rotating glass disk revolves, but the reflection movement is very slight and the disk is more than big enough to block it out. Hale's slits, Sellers' slits, and the rotating glass disk all have moving slits and would work best with a positive meniscus spectroscope lens shape. The reason is the extraneous reflecting light can be completely removed.

The rotating glass disk can not be used with a biconvex, plano-convex or achromatic lens shape because the extraneous light from the entrance slit reflects off the convex rear surface of the lens and back to the exit slit. What happens is as the rotating glass disk turns around, the light off the Littrow lens also moves. This results in a large part of the sun in H-alpha light that can not be studied because there is a whitish haze on that part of the solar disk. Blocking out the two reflections from the biconvex lens (and other related shapes) is impractical because the blocking disk must be too large in order to cover the area through which the reflections shift due to the movingslits. A synthesizer that can be used with any lens shape for the Littrow design is Anderson prisms because the slits are fixed and the necessary blocking disk need only be small. The HYLOV synthesizer is all right.

The Ebert and Hale spectroscope designs have harmful extraneous sun light from the entrance slit which crosses over and reflects off the mirror(s) and back to the exit slit. The light can be eliminated by having a screen placed along and parallel to the optical pathways so that no crossing over occurs. Or have the screen across the optical pathways and holes in the screen in the proper places.

The importance of adjustable slits, particularly the exit slit, is if the spectroscope optics are of relatively short focal length, about 3 feet (one meter), the spectral lines will be tilted relative to the exit slit. The tilted H-alpha line will not coincide exactly with a fixed exit slit. The result is that part of the spectral light through the exit slit is H-alpha light and the neighboring tilted part of the H-alpha line misses the rest of the exit slit.

When observing the sun in H-alpha light,narrow part of the sun is H-alpha,and the rest will be a different wave length, plus or minus about one angstrom. With a Littrow design (any lens shape) about 6 feet (1.9m) focal length, there will be no significant tilting of the spectral lines. With the Hale or Ebert designs, there is tilting of the spectral lines, depending upon the focal length of the optics. About 12 feet (3.8m) focal length is preferred with the latter two designs. Keep slits close together, about four inches.

Synthesizers versus spectroscopes. For a portable spectrohelioscope, Arcetri's slits, Hale's slits, and Sellers' slits present a minor vibration problem. Therefore, only Anderson prisms and the rotating glass disk are workable. Anderson prisms will cost about $500 mounted and the rotating glass disk about $200 or more by an optical company. From the economic point, the rotating glass disk is preferred. Making the rotating glass disk is very delicate. The tolerances for a pair of Anderson prisms are semi-critical.

A summary of some of the solar image synthesizers which can be used only with certain spectroscope designs:

Synthesizer	Slit motion	Spectroscope optics			
		Arcetri	Hale	Littrow*	Veio**
Arcetri slits	sideways	yes	no	no	no
Anderson prisms	fixed	no	yes	yes	yes
Hale's slits	oscillating	no	R	R	yes
Sellers' slits	vibrating	no	R	R	yes
Veio disk	rotating	no	R	R	yes

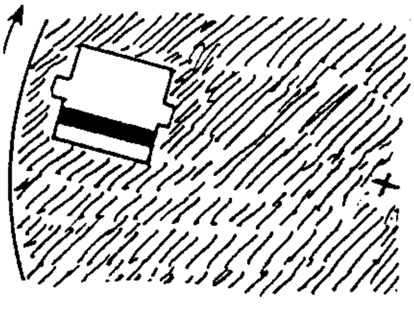
* Lens shape is achromat, plano-convex, biconvex; long f.l. best.
** Lens shape is positive meniscus only; about 6' f.l.(1.9m).
R Recommended only with long focal lengths; about 12 feet f.l.

Professional spectrohelioscopes have very long focal lengths. The telescope is about 18 feet f.l.,and the spectroscope is about 13 feet f.l. The amateur does not in most cases need such lengthy optics. About half such dimensions will serve most excellently.

The rotating glass disk was invented in 1912 by F.Stanley. Hale and Mitchell had worked with it. Mitchell's glass disk was 8"(200mm) diameter and cut with 150 slits. His optical-mechanical mounting was very involved. The author reduced the size of the disk to 4¼" (108mm) and cut only 24 slits in the paint. Decreasing the separation of the slits from 8" to 4¼"reduced the off-axis effects of the spectroscope lens upon tilting the spectral lines to nothing. Thus one degree prisms, as employed by Mitchell, were not needed. The overall simplification and smaller costs of rotating glass disk were considerable.

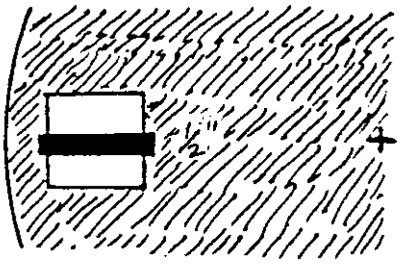
Diffraction gratings. The resolution of a grating is calculated in a simple manner. With a 32mm x 30mm ruled area of 1200 gr per mm, then 32mm x 1200 totals 38,400grooves.This total number of lines divided into the interested wave length gives the resolution in the first order. Thus, for the H-alpha line:6563Å/38,400 grooves =

SPECTROSCOPE CONSIDERATIONS



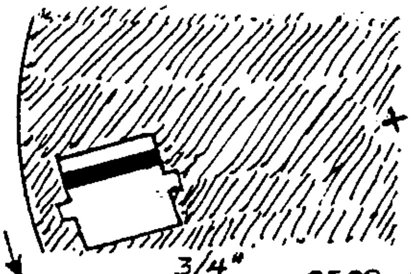
The three diagrams at the left depict the ½" x ½" clear window on the spectroscope disk. The H-alpha line is in the window.

With a 6 feet f.l. spectroscope lens, the tilting of the spectral lines can not be detected. If the spectroscope disk is rotated by the finger up and down, the H-alpha line will lag behind the side reference marks about 0.4Å as seen in the top and bottom diagrams.



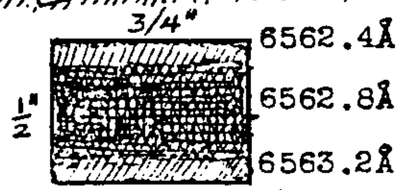
spectroscope disk

When the 24 slit disk is exchanged for the spectroscope disk and the motor turned on, the field of view of the solar disk is not all 100% H-alpha light. Rather the top and bottom of the field is a little brighter than the dark middle, which is pure H-alpha light.



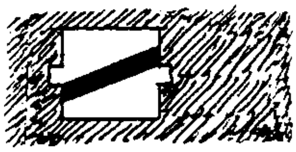
The 0.4Å lag of the H-alpha line is caused by the slight bending of the sun light through the spectroscope lens in an off axis position.

Exit port (window) 3/4" by 1/2" (18mm x 12mm).

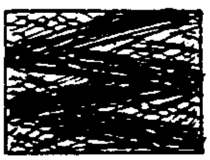


24 slit disk

The rotating spectroheliosccope disk. Drawing at left shows the H-alpha view of the solar disk. The top is about 6562.4Å wave length. The middle is 6562.8Å, or H-alpha. The bottom is about 6563.2Å wave-length. The air current wall is used.



With a 3 feet f.l. spectroscope lens, the H-alpha line will be tilted about 2Å. Fixed slits and Anderson prisms are all right. Rotating disk will not work.



If the air current wall is not used, the field of view of the solar disk in H-alpha light results in various zig-zagged patterns of uneven H-alpha light. Solar detail is not as easy to discern.

There must be no serious sources of vibration on the spectroheliosccope or in the environs. The H-alpha line would be badly shakened, giving a very irregular appearance to the field of view.

0.17Å resolution. This is 100% resolution which seldom happens. About 90% resolution is a better value which is 0.19Å with the preceeding example. For excellent contrast to solar disk detail in H-alpha light, a bandwidth of 0.6Å is selected. The grating must have a resolution of at least 1/2 of 0.6Å, namely 0.3Å resolution, although 0.2Å resolution is best. This is why a small grating will give fine contrasty views of the solar disk. A small grating of about 40% resolution yields about 0.4Å. Such a fair quality grating will show conspicuous detail on the solar disk, such as bright flares and bright plages and dark filaments, but much fainter disk detail will not be discerned, which includes faint flares, faint plages and faint grey filaments. There is much more faint detail on the solar disk than obvious detail.

The efficiency of a grating is the amount (Jarrell, 1964) of light concentrated (blazed) in a particular region of the spectrum. An 85% efficiency at 5000Å (green) blazed wave length means that 85% of the green light is located at 5000Å wave length. The best compromise grating to buy is one with a blazed wave length of 5000Å. The full visible spectrum from the violet to the red can be used. There is a fantastic amount of spectral detail in the green and blue regions of the spectrum and much less in the yellow, orange and red regions. With a top quality 32mm x 30mm grating of 1200 gr/mm, about 4000 spectral lines will be resolved in the first order by the eye. This is almost as good as by photography by a large professional solar observatory. With higher orders, much more lines will be discerned. Higher orders also produce finer resolution and greater linear dispersion. The second order has twice as much resolution.

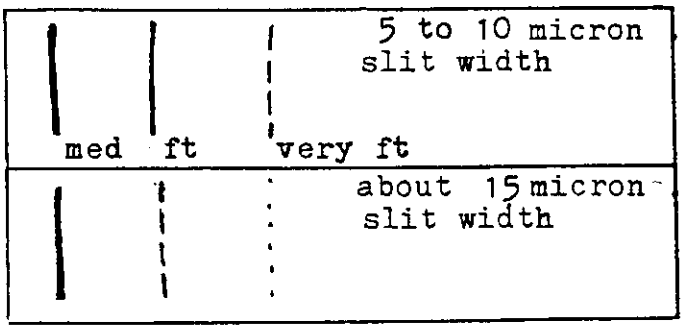
To observe a higher order, it is necessary to use filters (glass or gelatin) to eliminate overlapping orders. A deep red filter is for the red end of the spectrum, and a blue filter is for the violet end of the spectrum. In the red part of the spectrum of the first order, a red filter is needed in order to view further than about 7200Å wave length. Otherwise the Fraunhofer A line can not be observed. In the blue-violet region of the second order, a blue filter is used to view the H and K lines. For the green region, no filter is required in the second order.

<u>Spectroscope limitations.</u> It is best to have somewhat lengthy focal lengths for the spectroscope because adjustments are more convenient, and full grating resolution is much easier to achieve. The eyepiece for fine spectroscopic detail is not the same as required for spectroheliosccpe work by the 24 slit disk. Long spectroscope focal lengths permit wider entrance slit widths so that critical adjustment is not necessary. The following table has grating empirical (actually observed) resolution of 90% in the first order. For comparison the bottom examples have 45% resolution. Notice how the eyepiece focal lengths and slit widths change as the spectroscope focal lengths vary. The 12 feet and 6 feet f.l. designs are for a spectroheliosccpe. Of course, they can be used for a high powered spectroscope. The 3 feet designs are comparisons. Grating 32x30mm ruled area, 1200 gr/mm.

Definition of Res' width (resolved width) in the table is the width of the resolved lineson the spectrum. For example, 0.2Å resolution is 0.004" (100 microns) width onthe spectrum with a 12' (3.8 m) f.l. spectroscope. The desired slit width should be about one-third. Changing the spectroscope f.l. and/or grating resolution will alter the contrast of the faintest resolved spectral lines. To compensate one must change the slit width and/or the eyepiece f.l. in order to maintain the same contrast of resolved lines as before.

Theo. res.	Lin. disp.	Spec. f.l.	Emp. res.	Res'd width	Slit width	Eyepiece f.l.
90%	2Å/mm	12' (3.8 m)	0.2Å	0.004"	0.0013"	4" (100mm)
	4Å/mm	6'	0.2Å	0.002"	0.0007"	2"
	8Å/mm	3'	0.2Å	0.001"	0.0003"	1"
45%	2Å/mm	12'	0.4Å	0.008"	0.0027"	8"
	4Å/mm	6'	0.4Å	0.004"	0.0013"	4"
	8Å/mm	3'	0.4Å	0.002"	0.0007"	2"

For the very faintest spectral detail possible by the grating, use about 5 to 10 microns (0.0005") for the entrance slit. For good detail, about 15 microns (0.001") is quite acceptable.



A medium strong line is easily seen. A medium faint line is visible. A very faint line is barely seen.

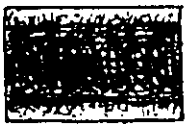
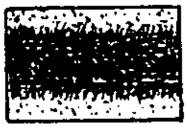
A medium strong line remains the same. A medium faint line becomes a fuzzy faint line . Very faint line may or may not be seen.

Tilting of the H-alpha line. At the exit slit the tilt depends upon the optical design of the spectroscope system.

separation of slits:	3"(150mm)			6"(300mm)		
shape f.l.:	12'	6'	3'	12'	6'	3'
biconvex lens	none	none	trace	none	trace	more
pos. men. lens	none	none	little	none	little	too much
two mirrors (Hale)	trace	little	more	little	more	too much

Try to keep the slits relatively close together, particularly for moving slits (rotating glass disk) that can not be adjusted. Slits that can be adjusted are an advantage, whether the slits are fixed or moving.

Moving slit synthesizers. They have a peculiar problem. As the slits move, the H-alpha line at the exit slit lags behind a slight amount. For a 6' f.l. (1.9 m) spectroscope lens as an example, if the entrance slit moves up ¼" (6mm), the H-alpha line does not move down exactly ¼" with the exit slit. Instead, the H-alpha line lags about 0.004" (100 microns) and shifts out of the exit slit. The field of view is not all H-alpha light. The top and bottom are a slightly different wavelength. Remember the H-alpha line is 0.006" wide (150 microns). Examples below.

0.6Å bandwidth	0.2Å bandwidth	0.3Å bandwidth
1/2"  80% H-alpha 3/4"	 40% H-alpha	 100% H-alpha
slit 0.006" (150μ) 6' f.l. (1.9m) 1200 gr/mm grating	slit 0.002" (50μ) 6' f.l. (1.9m) 1200 gr/mm grating	slit 0.006" (150μ) 9' f.l. (2.7m) 1800 gr/mm grating

If you use about 9' f.l. spec. lens and an 1800 gr/mm grating, the H-alpha line becomes much wider, and the field of view becomes almost all H-alpha light. The H-alpha lag effect is minimized. With moving slits, only the H-alpha line is useful with a 6' f.l. spec. lens. Exit port 3/4" by 1/2" (18mm x 12mm).

Other spectral lines (He, Na, Mg, Fe) are narrow, about 0.001" (25 microns) with a dark core of 0.1Å. The spectral line lag effect is serious. Only a 10% narrow central part of the field of view is one wavelength, or practically nothing. It is possible to tilt the grating to the second order. The spectrum is stretched about two times longer, making the narrow lines a bit wider. But the spectral lines become slightly tilted at higher orders. Then the tilted spectral lines do not coincide with the exit slit. The very narrow field of view is useless.

The best way to use both H-alpha and metal lines is with fixed slits. There is no spectral line lag effect, and the exit slit can be tilted to coincide with the tilted spectral lines. Anderson prisms are a good solution. There is one wavelength over the full field of view. The H-alpha line can be used only in the first order, not in the second order which has overlapping orders. The He and metal lines can be used in the first and second orders, easier and best in the second order because the spectral lines are wider, less critical to adjust the slits. The strong green metal lines and yellow helium have no overlapping orders. Blocking filters are unnecessary. So the lines can be used to pass the maximum amount of light for a reasonable, bright solar image. Going from 0.6Å bandwidth to 0.1Å means less light into the eye. But changing from the red H-alpha line to the green region of the spectrum means a brighter sun image because the eye is several times more sensitive to green than red light.

Anderson prisms. The adjustment (Hale, 1929) of the prisms is as follows. Each prism is mounted in a cell at the end of a steel shaft, which is mounted on analuminum base plate. The prisms with base plate are placed in direct sunlight. Rotate the steel shaft slowly. View the rectangular areas of sunlight as reflected from the four faces of one prism on a wall about ten feet (three meters) distant. Mark on the wall the end of one of these rectangular reflections. Adjust the prism in its cell until the ends of the four rectangular reflections are in the same position. This means the a xis of the prism coincides with the axis of the shaft. Repeat for the second prism. The two prisms may not lie in the same plane. Rotate one of the prisms until the faces are together.

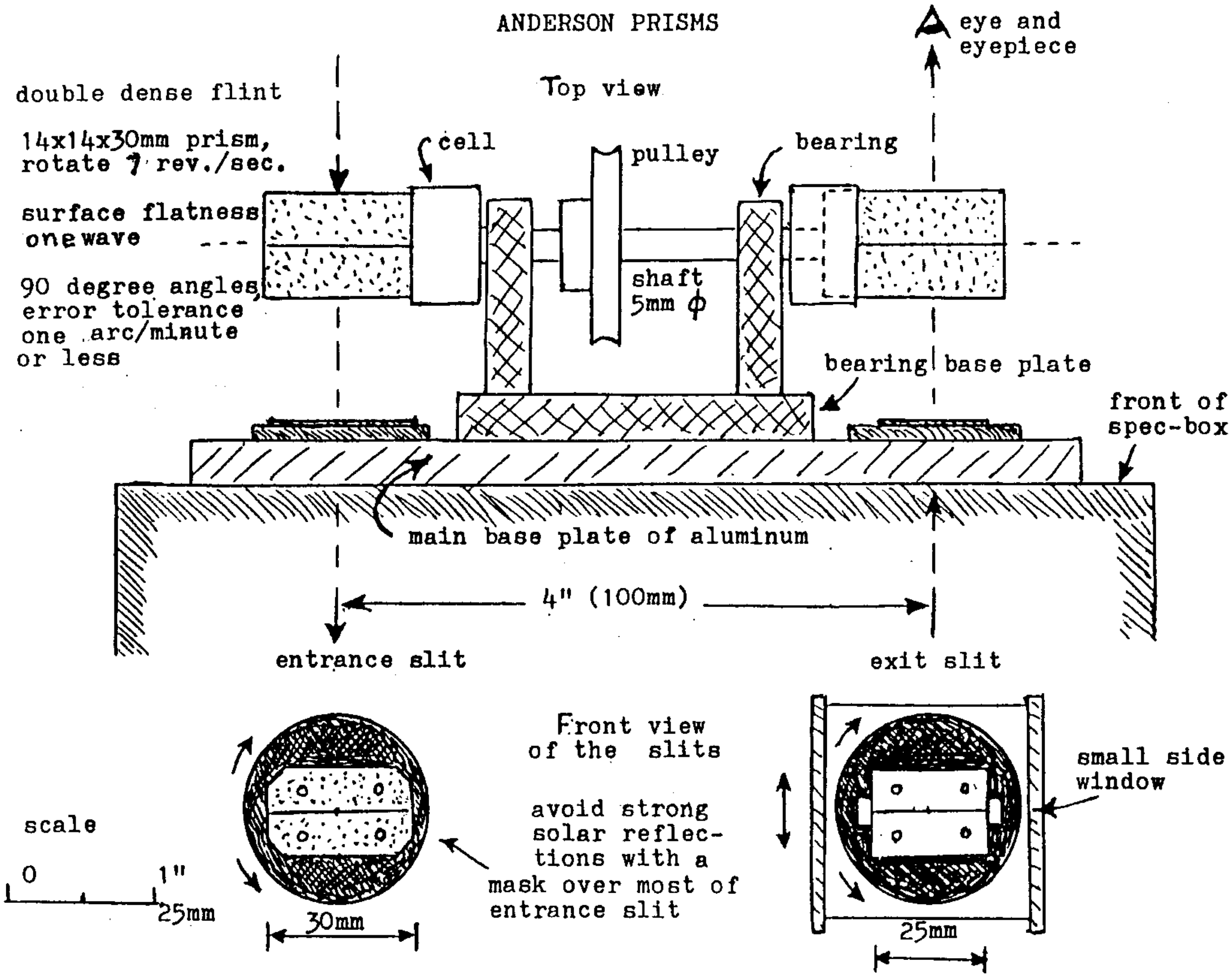
Entrance and exit slits are supported by a main base plate. Each slit rotates on a small, round base. The slit can be rotated about its center. The exit slit is provided with another motion for lateral adjustment. Set both slits in a horizontal line on the main base plate. Fasten the main base plate carrying the slits, shaft and prisms to the front of the spectroscope box. One prism in front of each fixed slit. Put the spectroscope box in front of a window, but not in direct sunlight, with the prisms facing the window. If the prisms and spec-box are mounted on a pier, skylight may be reflected through the prisms with one or two large mirrors.

Open the slits to a width of about 0.003" (75microns). Open the top front cover of the spec-box. With a small hand mirror, look at the entrance prism through the entrance slit from the rear of the main base plate. As the prisms are slowly rotated, their horizontal corners can be seen as dark lines, cutting off part of the light as they pass the slits. If these lines are not exactly parallel to the entrance slit, rotate this slit as described above until the light is cut off throughout its whole length at the same instant. Leave the prism in this position. Look through the exit slit, and see the dark line due to the corners of the exit prism through the small windows above and below the exit slit. If the coincidence is not perfect, move the exit slit laterally, or rotate it slightly until the light is cut off from both slits at the same instant when the prisms are turned.

Bring the solar image on to the entrance slit. Observe a narrow absorption line near the H-alpha line. Notice if the line makes a small angle (tilt) with the exit slit. If so, remove half of this angle by rotating the entrance slit and the rest by rotating the exit slit. Set H-alpha line on the exit slit by tilting the grating. Observe the sun in H-alpha light.

Two Anderson prisms do not have to be exactly the same squareness. One prism can be about 0.002" (50 microns) larger or smaller that the second prism. The 90 degree angles can be about 40 to 60 arc/seconds tolerance. The pyramidial tolerance can be about 5 arc/minutes. The surface flatness may be about one wave. The double dense flint glass should be grade A quality always.

ANDERSON PRISMS



Using the Anderson prisms. With the rotating glass disk synthesizer, there is a second, stationary spectroscope disk with a ½ x ½ inch (12 x 12mm) clear window. The latter is for observing the solar spectrum and also to mutually aligh the optical axes of the telescope and spectroscope lenses. See step two in the chapter on Setting up a Spectroheliosope. The front door of the spectroscope box has an entrance port of 1" x ½" (25 x 12mm).

With mounted Anderson prisms the opening behind the entrance slit must be about 1" x ½" high in order to fully use the clear aperture of the Anderson prism. A mask must be used to reduce down the opening to about ½"x ½" for optical alignment. The entrance slit mount must slide sideways about one inch. The Anderson prisms are stationary. Now moving the rear of the spectroscope box sideways slowly, align the telescope and spectroscope optical axes. This procedure is for a portable instrument.

To make observa_tions of the spectrum at the exit slit, the exit slit mount must slide sideways about an inch. The Anderson prisms do not revolve. The top and bottom small windows on the exit slit mount are too small for a large section of the spectrum. The small windows are mainly for centering the H-alpha line at the exit slit for spectroheliosope work. For the spectrum slowly turn prism cell with a finger. The solar image at the entrance slit will shift up or down a bit. Thus sections of the sun can be studied spectroscopically.

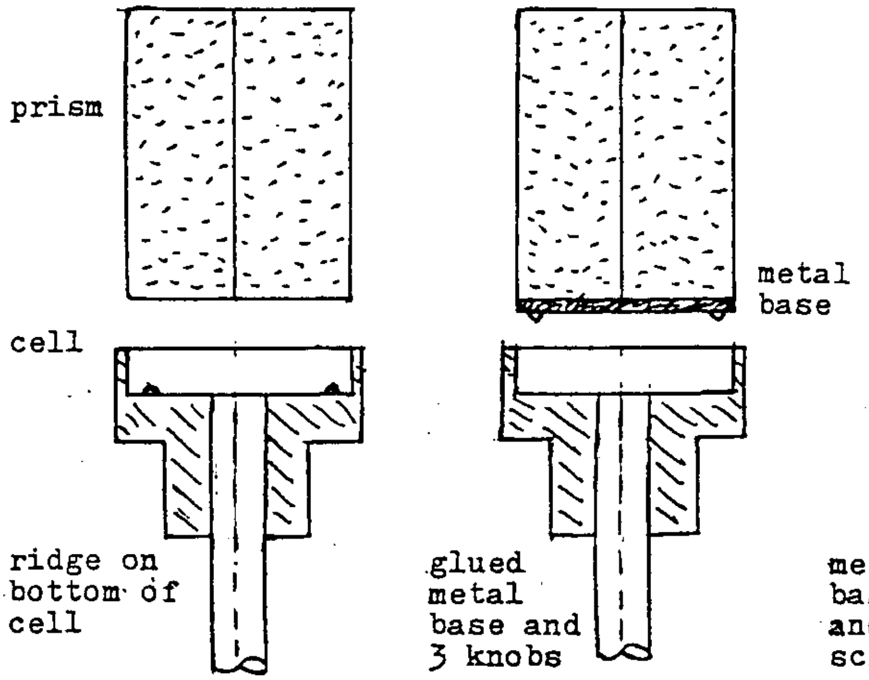
To change back to a spectroheliosope, slide back in position the exit slit mount. Now turn on the motor so the pulley can rotate the Anderson prisms. Now the solar disk is seen.

With Anderson prisms 14 x 14 x 30mm, about 5mm is to mount the prism in its cell. The index of refraction of glass limits the actual working area to about 2/3rds of 14mm, or 10mm high by 25mm long. Thus about half of the sun can be observed at one time. To prevent strong reflections of sun light off the entrance slit, have a dull mask cover over about 95% of the slit jaws.

Mount an Anderson prism. Fix in metal cell is preferred always . Calculate the diagonal of the prism. With a 14 x 14mm (0.55 x 0.55 inch) prism, the diagonal is 19.799mm. So make a cell with an inside diameter of 25 microns (0.001") more than the diagonal. The prism will automatically be centered in the cell. A rubber band temporarily holds the prism in place. Now the prism must be tilted slightly in the cell so that the prism axis and the cell axis coincide.

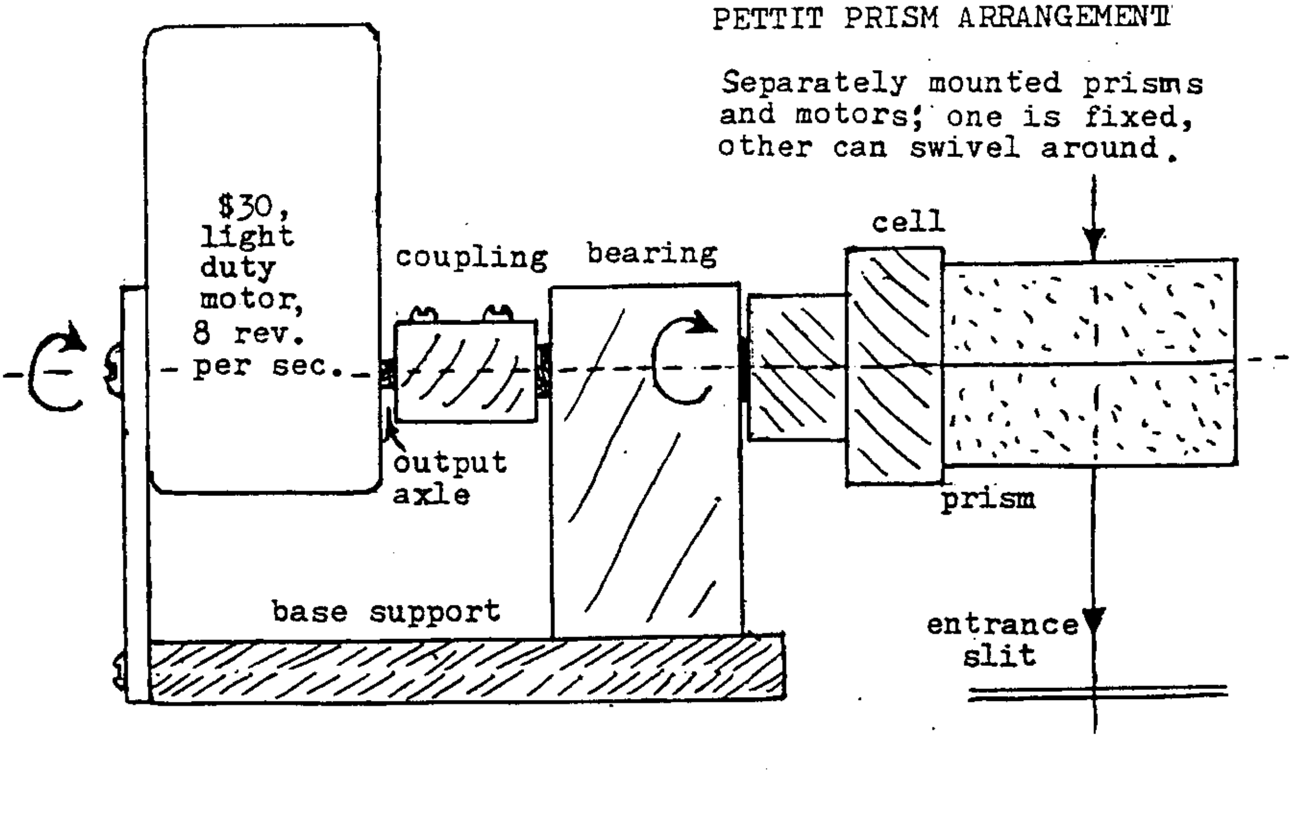
A simple way is to have a raised ridge on the bottom of the cell. File a little here and there to tilt the prism. Then set permanently in place with epoxy. A second way is to glue a round flat piece of metal on the bottom of the prism. Have three small epoxy knobs about 120 degrees apart on the bottom of the metal. Put the prism and the attached metal in the cell. Tilt the prism by filing down the knobs; perhaps 0.001" might be enough. A third way is to have the aforementioned metal with no epoxy knobs. Just put the prism and metal in the cell. Three very fine threaded screws are 120 degrees apart on the bottom of the cell. Adjust slightly one or more screws to tilt the prism.

ANDERSON PRISM MOUNTING



PETTIT PRISM ARRANGEMENT

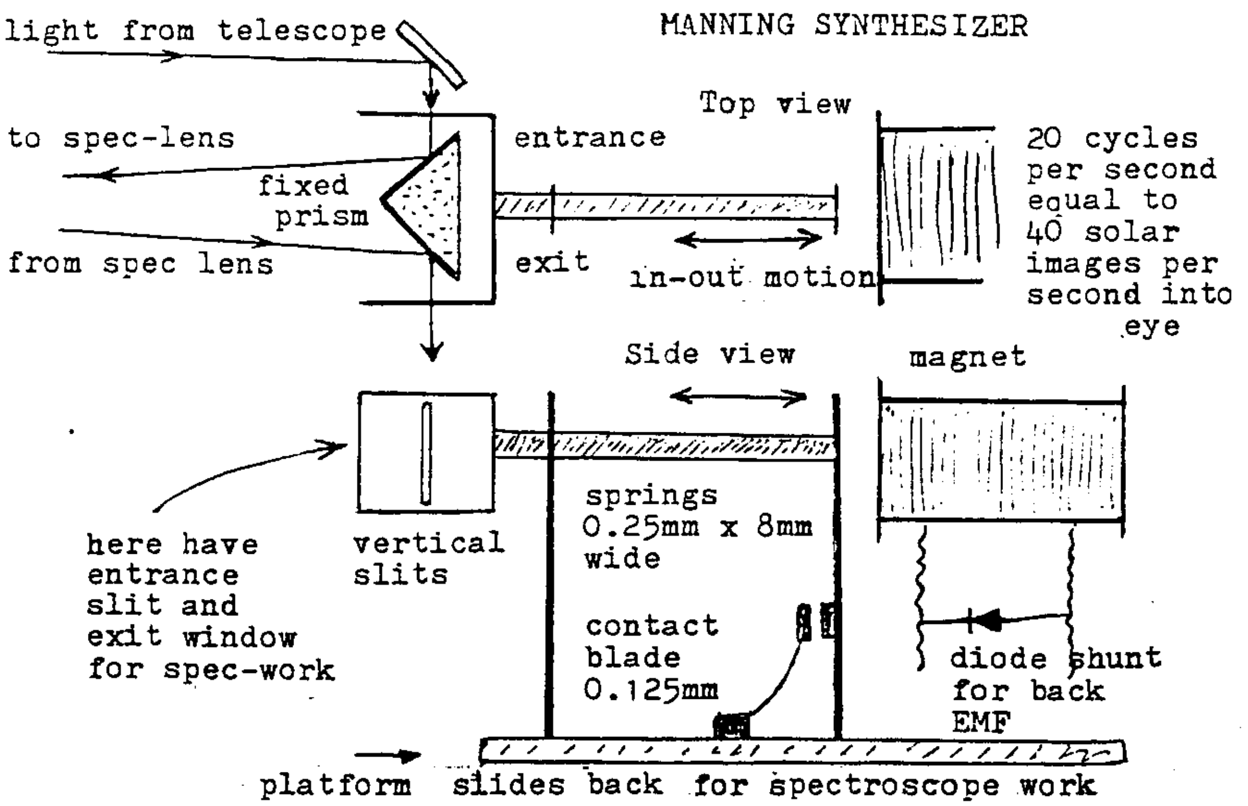
Separately mounted prisms and motors; one is fixed, other can swivel around.



MORE DETAILS FOR A SPECTROHELIOSCOPE

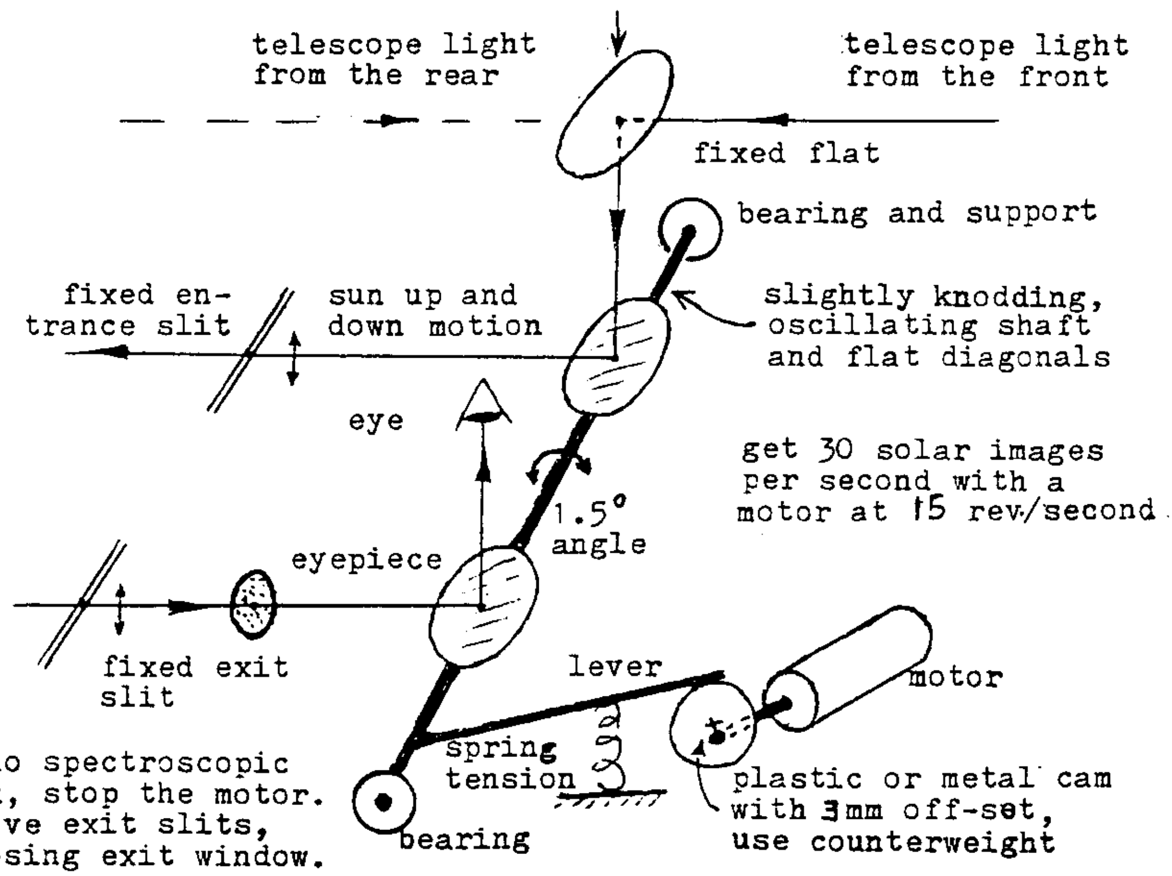
Other solar image synthesizers. Hale used an oscillating aluminum bar with slits mounted near the ends. The output axle of a motor had an eccentric knob that slammed the aluminum bar back and forth. Vibration limited the maximum amplitude to about 5/16" (7mm). It is suggested to minimize the vibration by employing a magnet and spring mechanism similar to Sellers' slits or Manning's slits. To change from solar disk work to spectroscopic detail, stop the oscillating slits. Move it to the side. Replace with a stationary entrance slit and an exit window for the spectrum.

B.G. Manning (private communication, and 1982) invented a synthesizer with fixed aluminized right angle prism. But two small diagonals would be all right. The folded up slits move in and out by a spring mechanism and a magnet. The magnet can be 34 to 36 guage enameled copper wire. Have four layers with about 170 turns total. Use 4.5 to 6 volts battery current. Keep the total mass of the slits down to about 16 grams or less in order to avoid overheating of the coil. Frequency will be about 20 cycles per second. Use slightly thicker springs in order to increase the frequency. So 0.25mm thick by 8mm wide beryllium copper is good. Spring steel is also good. Brass is not recommended because it is too flexible, and the springs tend to float. Amplitude of the slits will be six to nine millimeters. Do not try to see the whole diameter of the solar disk. To keep down the vibration, make a compromise. Have the Manning synthesizer on a movable small platform. To do spectroscopic work, stop the synthesizer. Move the platform back so that an entrance slit and exit window replace the platform.



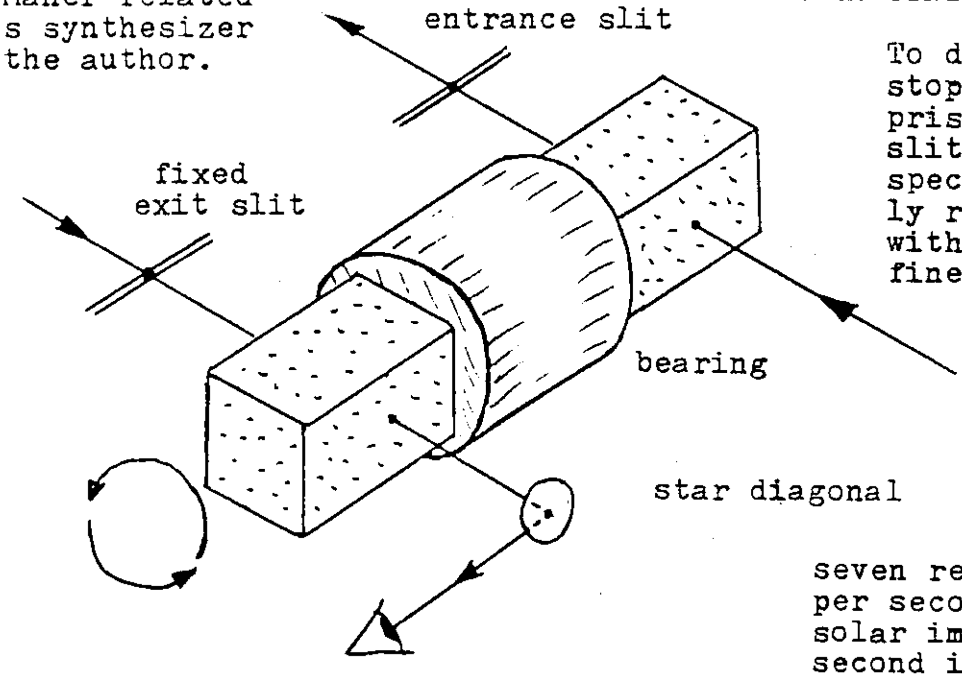
Do not limit yourself to traditional synthesizers. Jeffery Young (private communication) was first to mount two small flat diagonals, 1/10 wave, on a shaft and bearing mount. An eccentric cam on the axle of a motor oscillates shaft back and forth. The technique was suggested by Sinclair Smith (Hale, 1929). The solar image is moved over the fixed slits. Instead of a cam and motor, considera spring mechanism and magnet be used too. Keep the mounted flats from the slits by about 5 inches (125mm). Only a small angular tilt of the flats is needed to move the solar image. If the distance is less than 5 inches, the angular tilt must be greater, maybe introducing a vibration problem. The two flats must be mounted so that the axis of motion is along the surface. The flats and shaft mount must be balenced to eliminate a source of vibration. The off-set of the cam can be about 3mm from the axle of the motor. The sun light can come from three directions.

HYLOV-YOUNG SYNTHESIZER

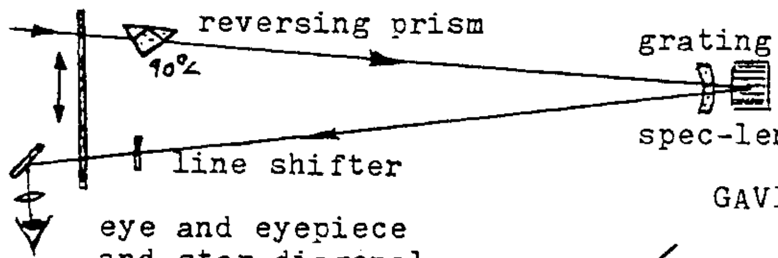


To do spectroscopic work, stop the motor. Remove exit slits, exposing exit window.

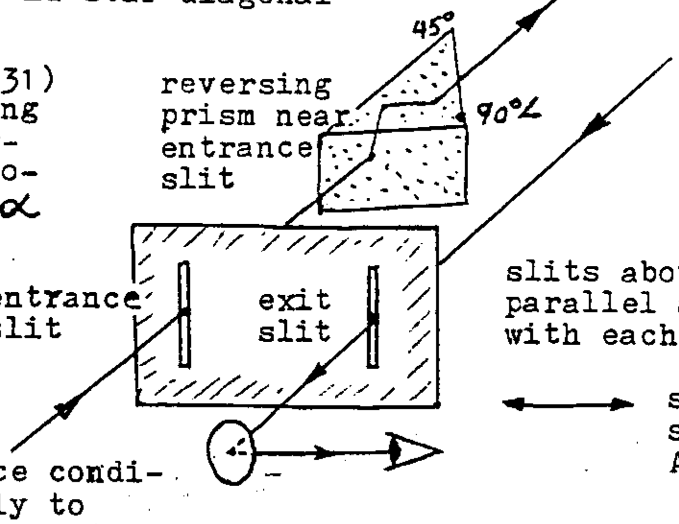
Spacek Company tried a single long prism mounted in a bearing. A motor rotates the assembly. To have a somewhat short prism, bring the slits close together, say three inches (76mm) center to center. The prism now can be about four inches long (100mm). Use a star diagonal so that the side of the face does not block the sun light focused upon the entrance slit.



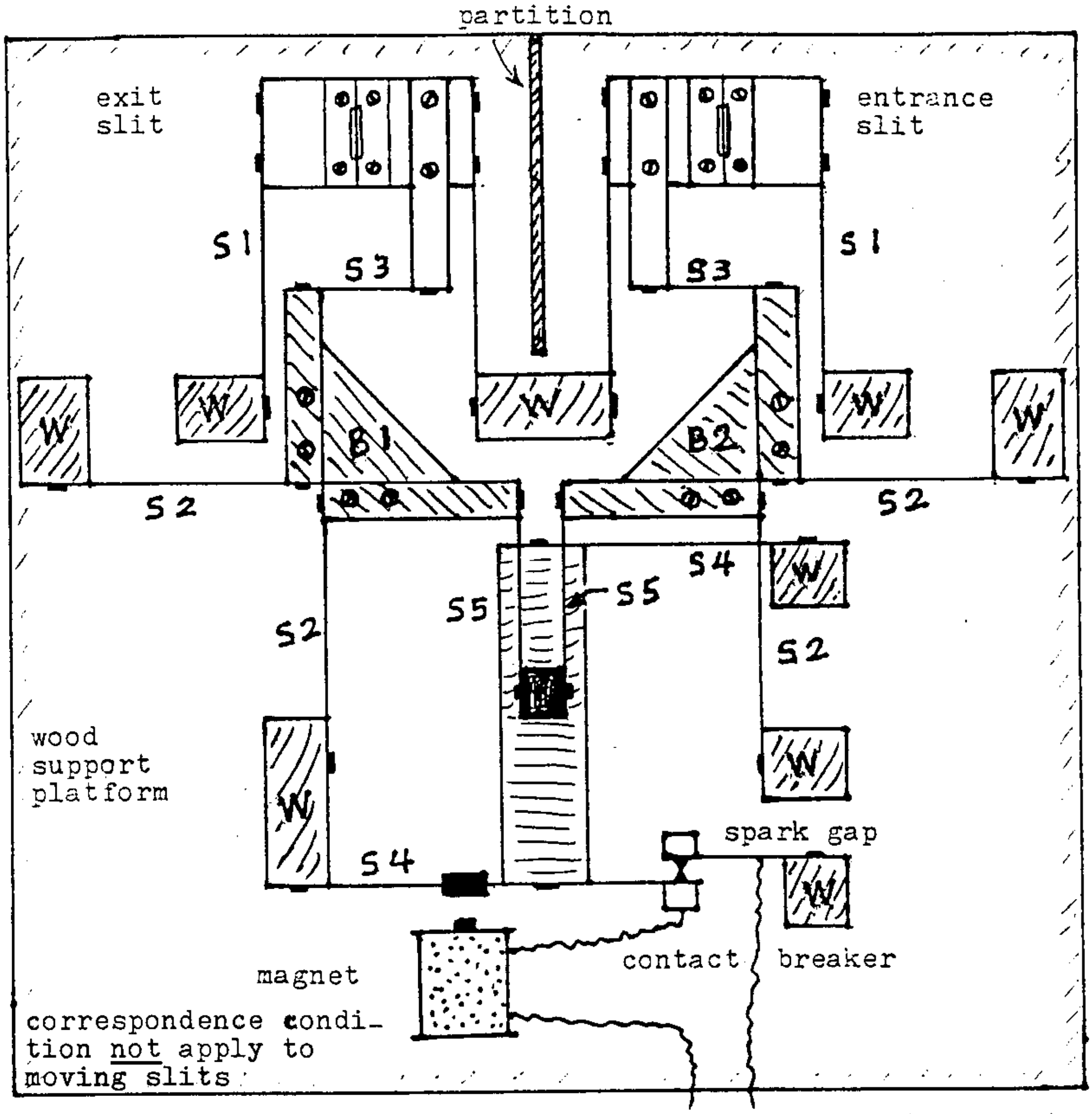
Maurice V. Gavin (private communication, England) has a modification of the sideways moving slits in the Arcetri spectroscope design. He uses a single lens spectroscope combined with a reversing prism (90-45-45 degrees) which yields mutual slit motion.



GAVIN SYNTHESIZER



<u>Sellers' vibrating slits.</u> The principle is similar to a

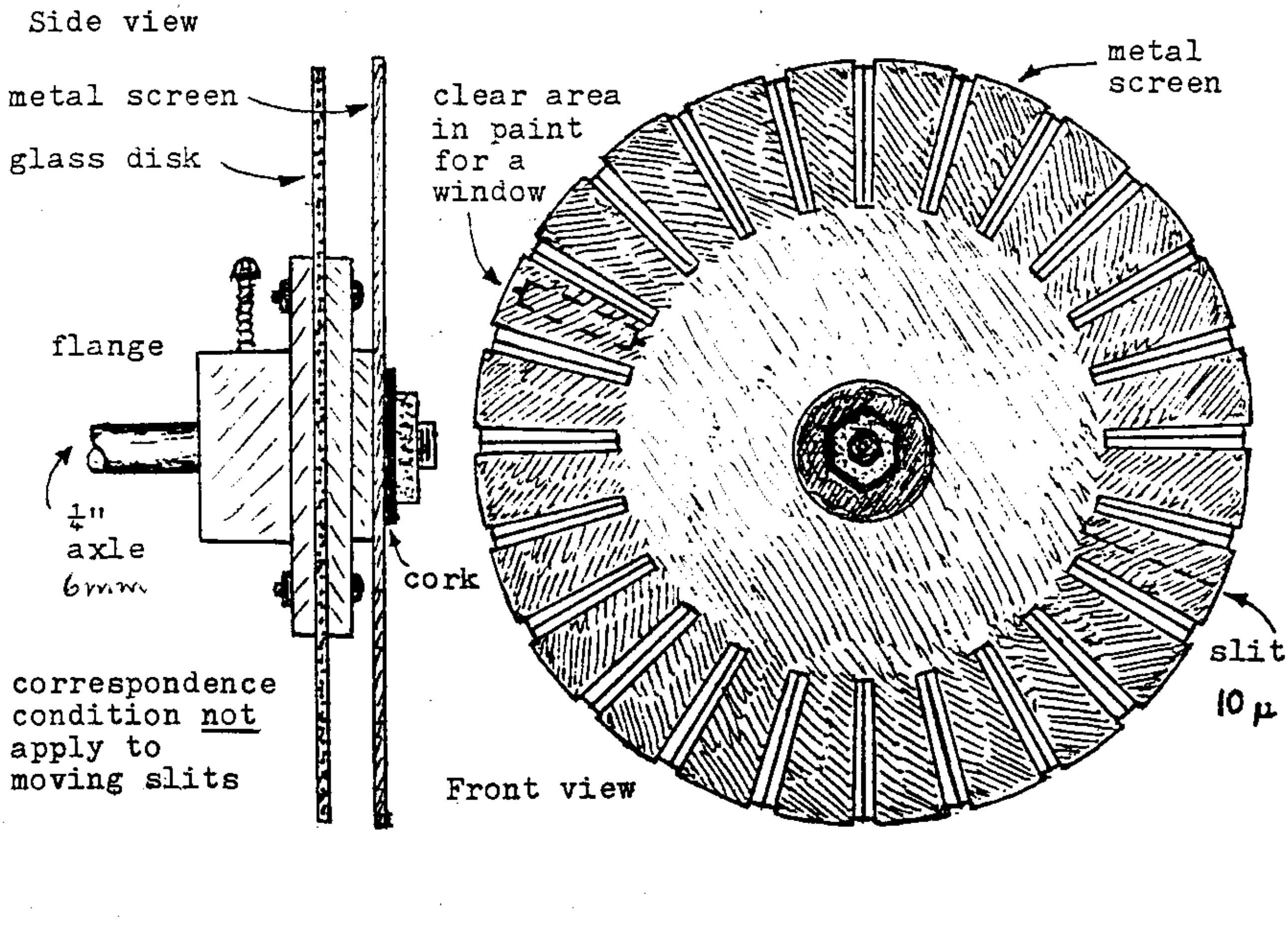


tuning fork. Sheet aluminum of two thicknesses (1/16" and 1/32") is used. Spring steel is good. Wood blocks (W) support the spring(S) mechanism. Two bell-crank levers (B 1 and B 2) move the slits exactly parallel. A trace of lost motion, about 0.0005 inch (12 microns), is acceptable because the H-alpha line is about 0.006 inch wide (150 microns). Natural period of oscillation is about 45 per second. But about 30 per second is quite good too. The magnet is operated by six dry cell batteries, giving an amplitude of 3/16 inch (5mm). The slit mechanism is mounted on a pier and separate from the rest of the instrument. To avoid excessive sparking, use a two microfarad condenser across the spark gap. Increase the thickness of the sheet aluminum will descrease thefrequency. For S 1, S 2, S 3, S 4 and S 5, use 1/32 inch sheet.

Veio combination glass disk. The stationary spectroscope glass disk and the rotating 24 slit glass disk can be combined into one glass disk. One can use a 5" diameter glass disk as a maximum. Pick 24 slits as a minimum. Cut 24 slits about 0.005" (125 microns) wide, giving 0.5Å bandwidth for H-alpha work. Between two of the slits, a clear area is cut to serve as the spectroscope window for the spectrum. On the other side by 180 degrees is cut a single slit of 0.0004"(10 microns) for the entrance slit. A second flange is mounted on the front of the painted glass surface. A metal screen with 24 wide slots is mounted on the second flange. The whole combination disk is stationary for spectroscopic work. The screen is moved with the thumb and forefinger so that the clear area is seen in one of the wide slots. For spectrohelioscopic work, the screen is moved so that the 24 slits are in the 24 slots. Then turn on the motor. Do not use the H-alpha line to focus on. It is too wide. Use a nearby narrow line.

For setting up the spectrohelioscope, first use the simple spectroscope disk because the clear window of ½" x ½" is used to mutually align both the telescope and spectroscope lenses. Next put on the combination glass disk. Flicker varies from person to person in low light conditions. The author needs 24 sun images per second into the eye for H-alpha work. Out of the core of H-alpha a trace of flicker is detected.

VEIO ROTATING DISK SYNTHESIZER (metal or glass)



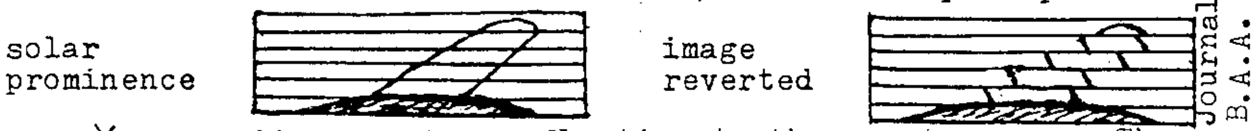
SUMMARY OF SOLAR IMAGE SYNTHESIZERS

Synthesizers	Slit motion, orientation	Spectroscope optics
fixed slits	one meter = 39.4"	6' f.l.= 6 ft f.l.(1.9 m)
Anderson prisms	rotation on same axle, horizontal	lenses or mirrors, as you wish it f.l.
Pettit prisms	two separate axles, vertical or horizontal	ditto
Spacek prism	rotation, horizontal	ditto
Flodqvist	mirrors with connecting axle, horizontal	two achromats, one meter f.l. or longer
HYLOV-Arcetri	mirrors on separate axles, rotate same, vertical	one flat and 2 achromats, one meter f.l.
HYLOV-Littrow	mirrors on separate axles, rotate opposite, vertical	ditto, one meter f.l. or longer better
HYLOV – Young	mirrors on same axle, horizontal	pos. men. lens, 2 concave mirrors, f.l. as you wish it
moving slits		
Arcetri	sideways, vertical	one flat, 2 lenses or achromats, meter f.l.
Gavin-Sellers	sideways, vertical, reversing prism	ditto, long f.l. bette
Gavin-Manning	sideways, vertical, reversing prism	ditto
Gavin	sideways, vertical, reversing prism	positive mensicus lens, 6 ft. f.l. minimum
Hale	up-down, horizontal	pos. men.lens 6ft f.l.; 2 concave mirrors 12 ft.
Sellers	in-out, vertical	pos.men.lens 6 ft. f.l.; 2 concave mirrors 12 ft.
Veio	rotation, radial slits	pos.men.lens 6 ft. f.l., straight pathway
Manning	forward-backward, vertical	folded pathway, pos. men.lens, 4 ft. minimum
Ohnishi	up-down, horizontal	folded pathway, pos. men.lens, 4 ft. minimum
Veio-Manning	rotation, horizontal	folded pathway, pos. men. lens, 4 ft f.l., longer better

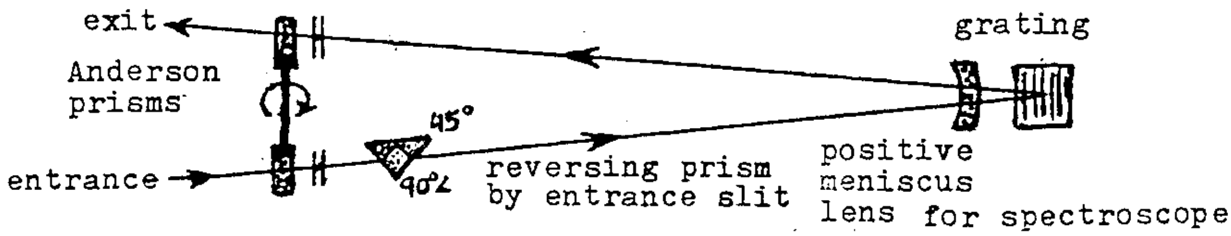
Spectrohelioscope variations:

A. Telescope 9' f.l., spectroscope 6' f.l., grating 32x30mm, H-alpha.
B. Telescope 9' f.l., spectroscope 9' f.l., grat. 52x52mm, H-α,He, metals
C. Telescope 9' f.l., spectroscope 9' f.l., grat. 52x52mm or larger, blazed 10,000Å λ (red), used second order, polarity work.

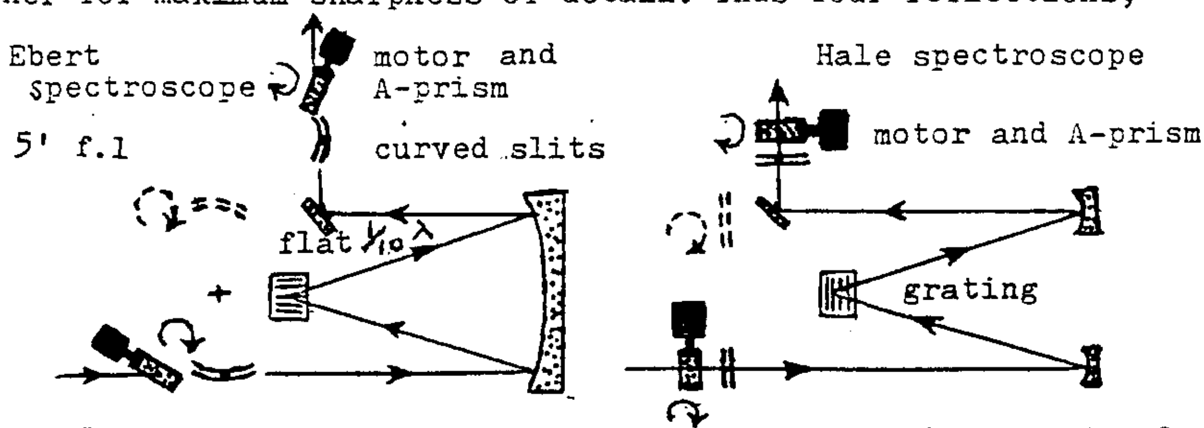
Correspondence condition. When you look in a mirror, you see a reverted image due to the odd number of reflections, namely one. If you had two mirrors properly set up and looked at yourself, you observe a true image. The same can be stated for the spectroscope section of a spectroheliscope. The solar image is seen section by section. For example, Anderson prisms with fixed slits and one lens Littrow design, there is one reflection. The solar image passing through the entrance slit comes out at the exit slit reverted. For somewhat wide slits, about 0.020" (0.5 mm), the combined sections will be smeared, not as sharp as possible.



You add an extra reflection to the spectroscope. There is an even number of reflections, and the sun inH-alpha light will be sharper detail.



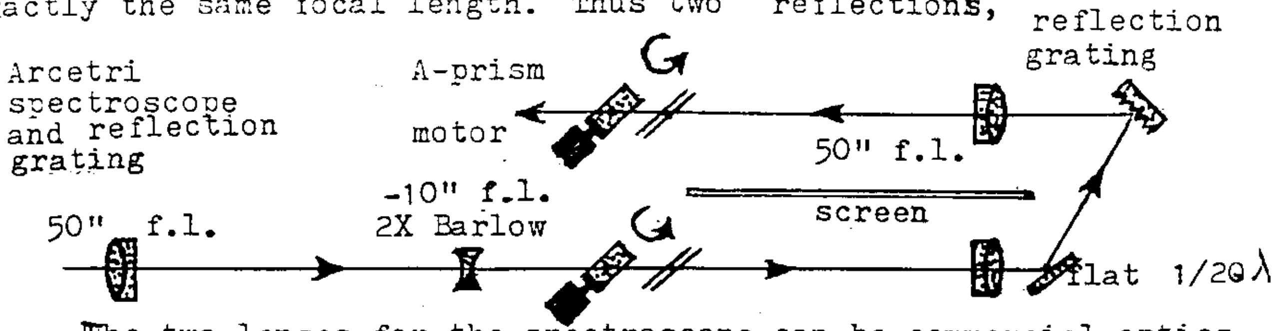
With very narrow slits, about 0.002" (50 microns) or less, the smearing effect is minimized or eliminated. For the one mirror Ebert or the two small mirror Hale design, there is an odd number of reflections, namely threeincluding the grating. Add an extra reflection again solves the reverting problem. For the Ebert design, have the Anderson prisms mounted parallel to each other for maximum sharpness of detail. Thus four reflections,



Pettit had each Anderson prism mounted on the output axle of a motor-bearing combination. No wobbling of the prism occured. One of the two motors could be rotated about its own axis in order to have both Anderson prisms in relative synchronity.

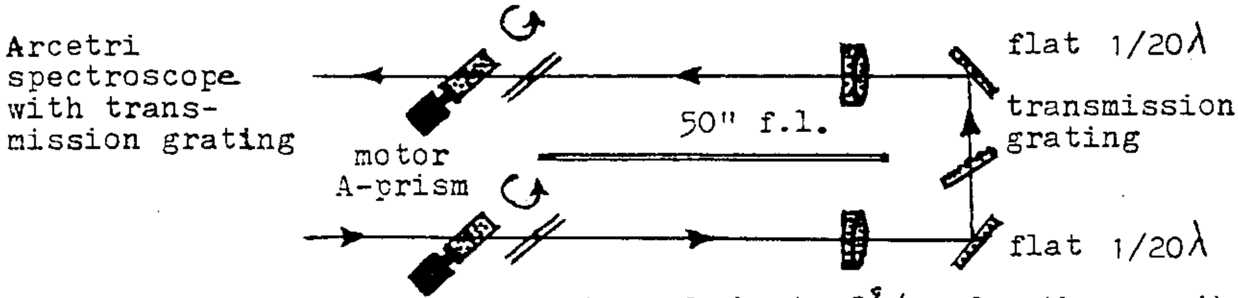
For the Arcetri spectroscope with sideways moving slits, the focal lengths of the two lenses must be almost the same in order to minimize the H-alpha lag effect. With fixed slits and separate

Anderson prisms on two motors, the two lenses do not have to be exactly the same focal length. Thus two reflections,



The two lenses for the spectroscope can be commercial optics. Edmund sells 50" f.l. achromats of 3 inch diameter for about $150 each. The telescope can be another Edmund achromat of 50" f.l. with a 2X Barlow, giving a minimum desirable 100" e.f.l. Instead, use two guide scopes of 60mm diameter, 900mm f.l., and 1800 gr/mm grating.

Have high linear dispersion, 4Å/mm, to detect small and large Doppler shifts. With 50" f.l. one can use an 1800 gr/mm grating of 32x30mm ruled area. For average high dispersion of about 6Å/mm in the first order, use a 1200 gr/mm of 32x30mm area. Both gratings produce high resolution of 0.2Å or better. A large refractor can have an Arcetri spectroscope attached to the end, converting it to a spectroheliosope. The long focal length of the refractor is an advantage to study very fine solar detail. The refractor must be diaphragmed down to match its F:ratio with the spectroscope.



For minimum linear dispersion of about 12Å/mm for the sun in H-alpha light, select a transmission grating of 600 gr/mm, 32x30mm ruled area. Grating resolution will be about 0.4Å. A better grating would be 50x50mm ruled area. They are about twice the price of a reflection grating of similar ruled area. The 50x50mm transmission grating will yield about 0.2Å. Following table compares transmission versus reflection grating at 0.6Å bandwidth. Notice how narrow the slits must become for short focal lengths of 24".

spec. f.l.	linear dispersion, first order, 0.6Å bandwidth H-α			
	transmission 600 gr/mm	grating slit	reflection 1200 gr/mm	grating slit
75" (1.9m)	8Å/mm	0.003"	4Å/mm	0.006" (150μ)
48"	12Å/mm	0.002"	6Å/mm	0.004" (100μ)
24"	24Å/mm NR	0.001"	12Å/mm	0.002" (50μ)

NR, not recommended.

A transmission grating is not particularly recommended with a 50" f.l. spectroscope. Detection of fast Doppler shifts is limited. In the literature of about 50 years ago, workers discuss gratings of 600 gr/mm because only that was available. Now 1200 gr/mm gratings are on the market, so take advantage of them. The Arcetri design with a reflection grating of 1200 gr/mm or 1800 gr/mm is a much better design than working with a transmission grating. Comparison of transmission versus reflection grating is to make you aware of the limitation of a transmission grating. Narrow slits of 0.001" (25microns) are not easy to work with. Also high linear dispersion has to be seen in order to be fully appreciated.

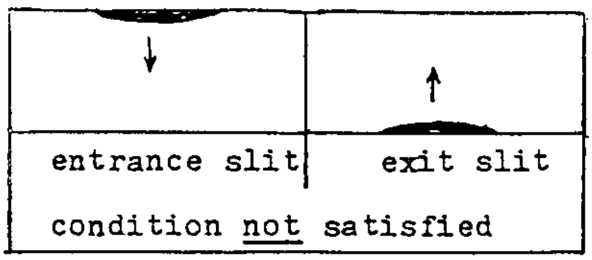
Summary of the correspondence condition with two spectroscope designs and number of reflections.

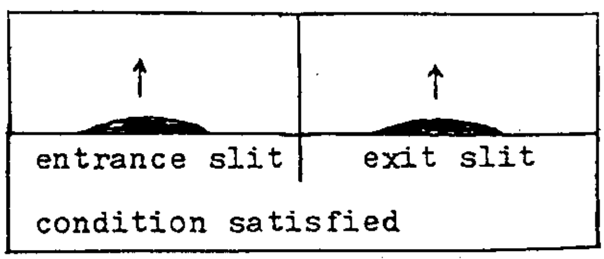
synthesizer	Hale, odd	Littrow, odd	
oscillating slits	—	—	For synthesizer with moving slits, the correspondence condition does not apply. Only with fixed slits will the condition be considered or not.
rotating disk	—	—	
Anderson prisms	no	no	With very narrow slits, the condition is minimal or eliminated, no problem at all. So disregard the small prism.
Anderson prisms + small prism	yes	yes	

yes, condition satisfied; no, condition not satisfied.

Due to the index of refraction of glass, a transmission grating can not be used with more that about 600 gr/mm for a spectroscope. A transmission grating costs more than a reflection grating of the same ruled area.

A test of the correspondence condition is possible as follows. With a stationary Anderson prism or other mechanism, open the fixed exit slit wide and center the H-alpha within it. Next open the fixed entrance slit somewhat. Bring the solar limb into it. Note how the limb enters the H-alpha line. If the limb is convex in the same direction in both the openings of the entrance and exit slits, the correspondence condition is satisfied. If the curvature of the two images is opposite, the condition is not satisfied.





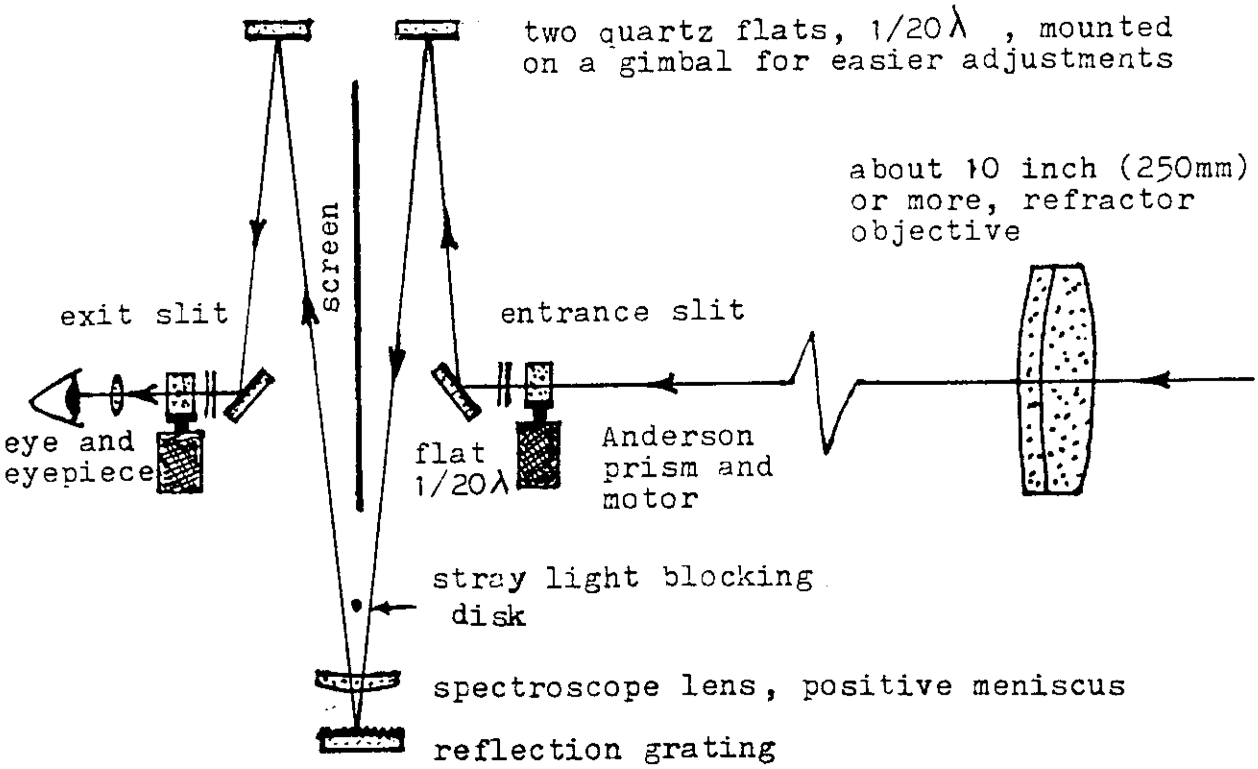
Just add one reflection or a reversing prism will satisfied the correspondence condition.

<u>W-spectroscope design.</u> It is possible to mount a powerful, compact spectroscope onto a medium-large refractor. T he long focal length will be a distinct advantage, giving about two to three inch (50 to 76mm) diameter sun image at the prime focus. The W-design can be equipped with Anderson prisms inthe Pettit arrangement, converting it to a spectroheliosope.

1. The best design would be a spectroscope with about nine feet (2.7 m) focal length. P lus or minus six inches is all right. A 52x52mm grating is minimum, preferably 64x64mm. Buy 1200 gr/mm. If money is no problem, 1800 gr/mm is best. The F:15 refractor must be masked down to the F:ratio of the spectroscope. This minimizes heating effects also. Spectrum 4.5 feet long, or more.

2. A good design is a spectroscope with about six feet (1.9 m) focal length. A 30x32mm grating is minimum. But 52x52mm is better. You get a brighter sun in H-alpha light, and you can use narrower slits for a narror bandwidth, s ay about 0.2Å HBW or less. Again 1200 gr/mm is minimum but 1800 gr/mm is good. Spectrum, 3 feet.

3. As a bare minimum design, use the Arcetri design of two achromats with an 1800 gr/mm grating. Two guide scopes of 60mm diameter and 900mm focal length are workable. Solar spectrum will be about 2.2 feet long (0.7 meter).

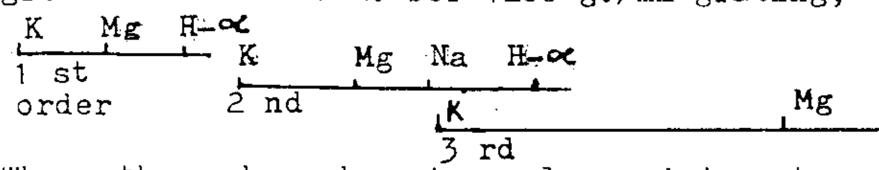


Stretch the spectrum. Different spectroscope focal lengths and gratings will widen the spectral lines to a n advantage.

Grating	Focal length	Lin. disp. in green	Spectrum length	H-α * 0.6Å	He, metal* 0.1Å
600 gr/mm 1 st order	6 feet, 2 meters	8.6Å/mm	1.5 feet, 0.5 meter	0.003" 75µ	0.0005", 12µ
1200 gr/mm 1 st order	6 feet	4.3Å/mm	3.0 feet	0.006"	0.0010"
	9'	2.8Å/mm	4.5'	0.009"	0.0015"
	12'	2.1Å/mm	6.0'	0.012"	0.0020"
1200 gr/mm 2 nd order	6'	1.9Å/mm	6.5'	0.013"	0.0020"
1800 gr/mm 1 st order	6'	2.7Å/mm	4.5'	0.009"	0.0015"

* The 0.6Å and 0.1Å are the dark core, not include the wings.

As you tilt the grating to higher orders, the spectra become longer and some parts overlap. A 600 gr/mm grating has orders from one to eight. A 1200 gr/mm grating has orders one to violet of the fourth. An 1800 gr/mm grating has orders one and up to green of the second. For 1200 gr/mm grating,



Violet K light in 3rd order is faint, not cause problem near Na of 2nd order.

Where the orders do not overlap and do not require blocking filters, this is called the free spectral range. For the 1200 gr/mm grating, it is the green and yellow of the second order and green only in the third order.

The linear dispersion of a grating at various gr/mm is linear at low gr./mm (300 gr/mm and 600 gr/mm) and low orders (one to about four). With gratings of 1200 gr/mm and 1800 gr/mm, the linear dispersion is not linear in higher orders. For example, a grating of 1200 gr/mm displays 2.2 times more dispersion in the second order in the green, three times more in the second order a t H-alpha. In the s ame order, particularly higher orders, the dispersion varies a bit from the violet to the red. Some lines to memorize:

orange red H-α	H	C	6563Å λ	green, two iron	Fe	b_3	5169Å λ
yellow sodium	Na	D_1	5896Å	green, Fe and Mg	—	b_4	5167Å
yellow sodium	Na	D_2	5890Å	blue H-beta	H	F	4861Å
yellow helium	He	D_3	5876Å	violet calcium	Ca	H	3968Å
green magnesium	Mg	b_1	5184Å	violet calcium	Ca	K	3934Å
green magnesium	Mg	b_2	5173Å				

Using commercial optics. If you can not make or buy long focal length lenses or mirrors, some commercial items are available as a good compromise.

For the telescope, use a 3" (76mm) diameter refractor achromat of F:15, -10"f.l. Barlow, giving about 100" e.f.l. Or pick a 4½" (112mm) diameter Newtonian mirror about F:25 and use without a Barlow. Diaphragm down to about 2½" (63 mm) opening.

For the spectroscope, there are a few possibilities:

A. Ebert design, 6" (150mm) diameter mirror, F:10 is good but F:12 is better, 32x30mm grating, 1200 gr./mm, Young's nodding mirrors and fixed slits. Rotating glass disk will not work.

B. Hale design, two 3" (76mm) diameter mirrors, about F:25 if possible, 32x30mm grating, 1200 gr./mm, Young's nodding mirrors.

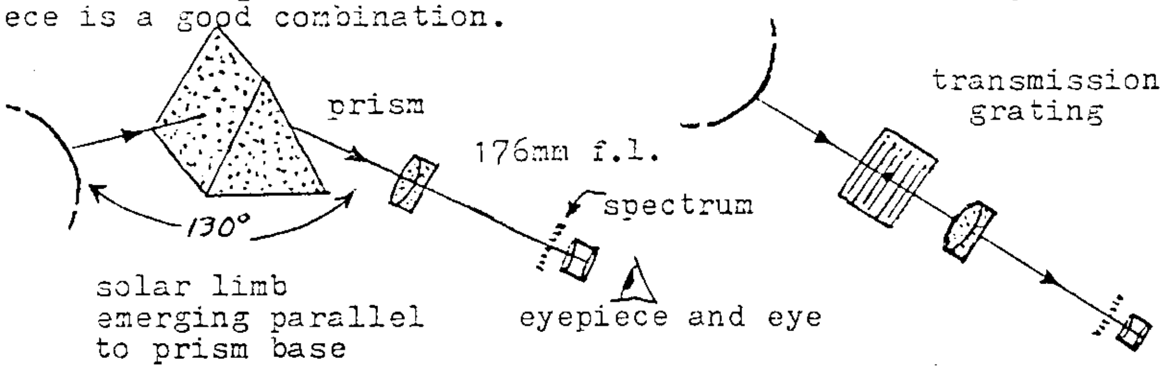
C. Arcetri design, two 60mm achromats, about 900mm (36") f.l., one diagonal 1/20 wave, 32x30mm grating, 1800 gr./mm, and Arcetri sideways moving slits, about 12mm maximum motion.

D. Littrow design, one 3" (76mm) diameter achromat, about F:15 preferably, 32x30mm grating, 1800 gr./mm, Young's nodding mirrors. Two reflections are removed: one narrow black strip on back of achromat, one small black disk several inches (200mm) from back of the achromat. Tilt the achromat will move reflections to the side.

The above designs can be in a straight line, or folded up with one or two diagonals. A large diagonal, about 2½" (67mm) minor axis, can be used for a heliostat. A two mirror coelostat is not needed in most instances. All designs above will produce about 35" (0.9 m) long solar spectrum. The H-alpha core will be about 0.005" (125 microns), which is still quite good to work with. In designs A, B, and C, the cross reflections will be blocked out with screens placed along the focal lengths of the optics. If you can obtain two Anderson prisms, you still can use the above designs.

In regards vibration of the whole instrument, if the instrument shakes about 0.001" (25 microns) and the slits are about 0.005" (125 microns) wide, you do not have a problem. But if the instrument shakes about 0.005" (125 microns) and the slits are about 0.002" (50 microns), then you have a problem with seeing fine detail on the solar disk in H-alpha light. Keep the amplitude of moving slits about ¼" to ½" (6mm to 12mm) in most cases. If you can not get reasonably the same focal length for two lenses or two concave mirrors, use the conjugate foci principle. For example with two mirrors of 47" and 50" f.l. With the 50" f.l. mirror for the entrance slit, have the slit moved in about the 48.5" f.l. position. This will refocus the H-alpha line at about the same mutual focus at the exit slit. Use the same technique for two lenses of almost the same focal length. Just juggle the conjugate foci.

For a solar eclipse. Use half a spectroscope in order to see the flash spectrum, which lasts only a few seconds of time. A prism or a low cost reflection grating is workable. A high quality transmission grating is unnecessary, also expensive. The prism or grating must be properly orientated to the sun or the spectroscope will not work. The grooves of a grating must be parallel to the emerging solar limb, which forms a natural slit in the sky. The grooves do not have to be exactly parallel, just close. A single achromat of about 176mm f.l. and a 25mm f.l. eyepiece is a good combination.

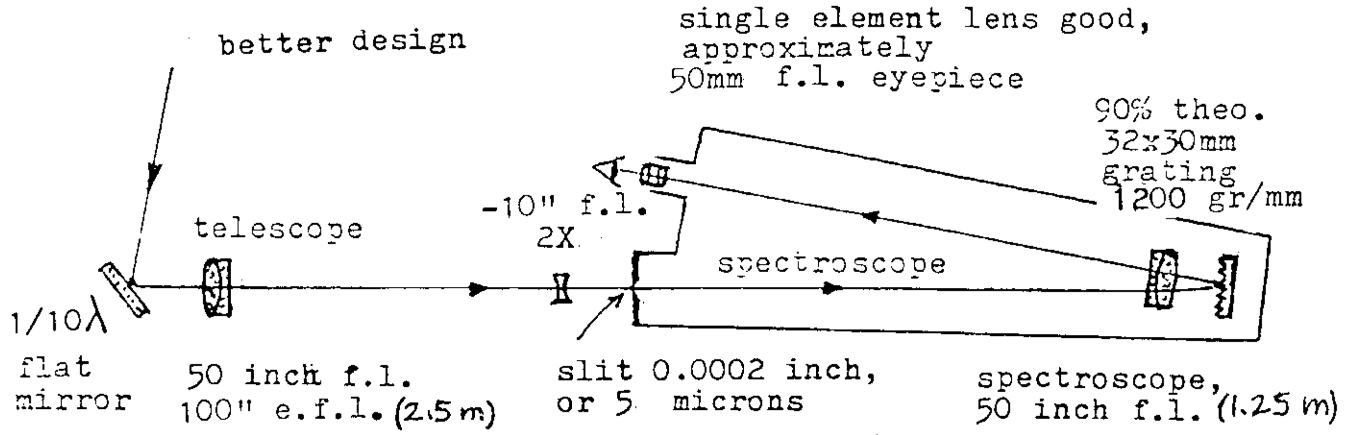


Set up and adjust complete spectroscope (collimator/telescope).

1. Focus the telescope with the 25mm f.l.eyepiece. Look at an object about 300 yards (300 meters) or more away. Hold the eyepiece in place with masking tape,or otherwise.
2. Put the telescope and collimator together on a table and in line with each other. Focus the slit in the collimator by pushing the slit mounting back and forth. The slit will appear sharp in the telescope when in correct focus.
3. Put the telescope and collimator on the mounting board. Set the prism in the middle. Put a cover over the prism and achromats. Place a blocking wall (B) on the base of the prism to stop stray light from the collimator entering the telescope. Make 130° angle.
4. With a small flat mirror, low cost, reflect the sun light into the collimator. Swivel the telescope from 127 to 133 degrees to better see the ends of the spectrum.

Compact solar spectroscope. If you do not have much room and would like to have a powerful solar spectroscope,here is a tested design. It works good. There are about 4,000 spectral lines to be seen from the violet to the red with a quality 32x30mm reflection grating of 1200 gr/mm, resolution about 90% of theoretical. There will be two small strong reflections off the biconvex achromat. Also a third fainter one. They are caused by the sun light bouncing off the front and rear convex surfaces. By just tilting the achromat a few degrees, the three reflections will move off the achromat and to the side of the spectroscope box. The solar spectrum lines will be slightly tilted but no serious problem.

Tilt the grating from the first order, 13 to 26 degrees, up to higher orders, 50 degrees or more. Glass filters will be needed to see through the overlapping orders. The design will be a revelation for amateurs at a convention. Pick the green region with the magnesium lines. Make a drawing in the first order. Go to higher orders. Notice how strong lines become much stronger and wider. Faint lines become darker. You can photograph the solar spectrum too. Take out the eyepiece of the spectroscope. Remove the camera lens. With an adaptor set the camera body on the eyepiece holder of the spectroscope. Focus carefully. Make exposures of the spectrum.

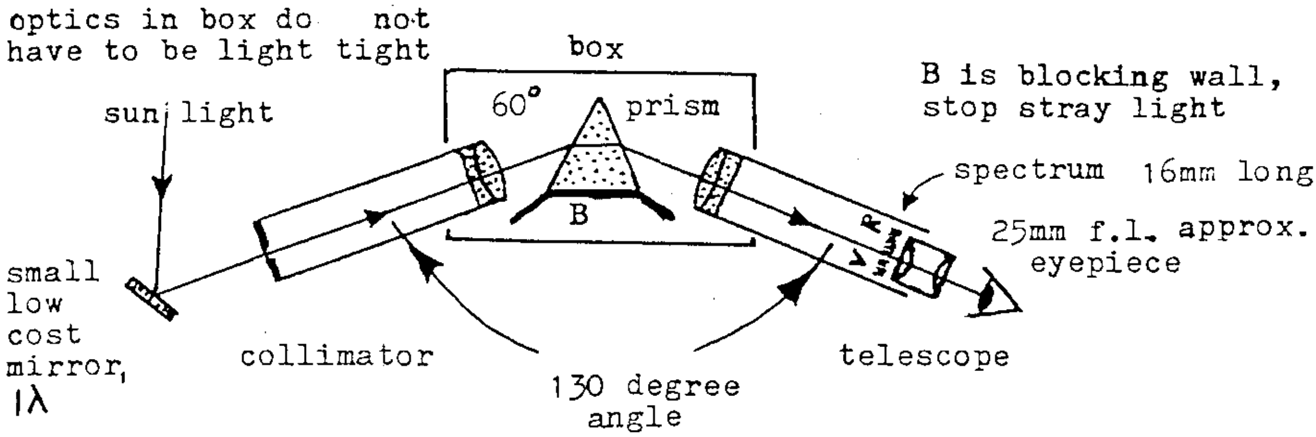


Here are two designs: acceptable low cost; better more expensive. The dimensions of the optics are not critical. But the achromat for the spectroscope must be good quality. The telescope can be a cheap lens. You need a telescope in order to fill the grating with sun light. From the first order up to the violet of the fourth is possible. Without the telescope, you will only be able to observe in the first order. The second order will be too faint.

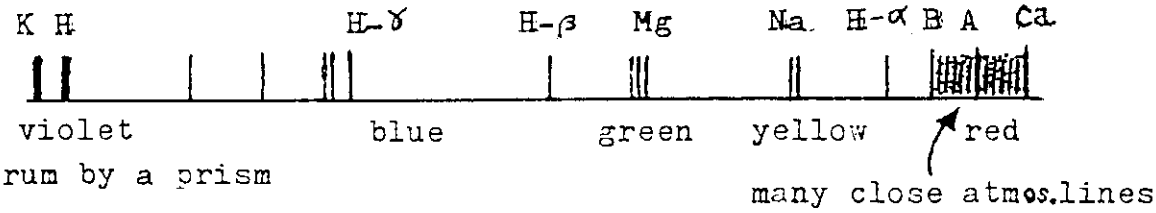
With a good quality achromat for the telescope, it will be possible to view bright prominences in emission in the spectrum. It will not be easy to do with about a 50" f.l. telescope because the sun image on the entrance slit is small, about half inch diameter. With about a 50" f.l. achromat and a 2X Barlow (-10" f.l.) giving 100" e.f.l., the sun image will be almost an inch in diameter. Now the detection of prominences is better. The flat mirror also must be high quality, about 1/10 wave flatness.

A high resolution grating will resolve about 0.2Å or better in the first order. You will need about 6' f.l. spectroscope lens to see this detail. The resolution of a prism depends upon the length of the base. A 30mm base will resolve about 2Å; 10mm base, about 6Å. A large prism will be well worth it, costing about $80. A low cost grating will have about 45% theoretical resolution. A grating of 12x25mm ruled area with 600 gr/mm (15,000 total grooves) will have the equivalent of about 8,000 grooves to resolve the sun light. It takes about 1000 grooves to resolve 6Å, just barely separate the two sodium lines. So 8,000 grooves will resolve about 1Å. A small grating will cost about $80. The writer has tried both a 30mm base prism and a low cost grating. Both give interesting results. The grating is the preferred first choice, particularly 1200 gr/mm and 1800 gr/mm.

<u>Hand spectroscope.</u> An inexpensive way to observe the solar spectrum is to build a small, efficient spectroscope. An equilateral 60 degree prism , dense flint, about 32mm base, or a low cost reflection grating, 12x25mm, from Edmund Scientific Co. will work fine. About 400 strong and faint spectral lines can be studied. Two achromats, 32mm diameter and 176mm focal length, are adequate.



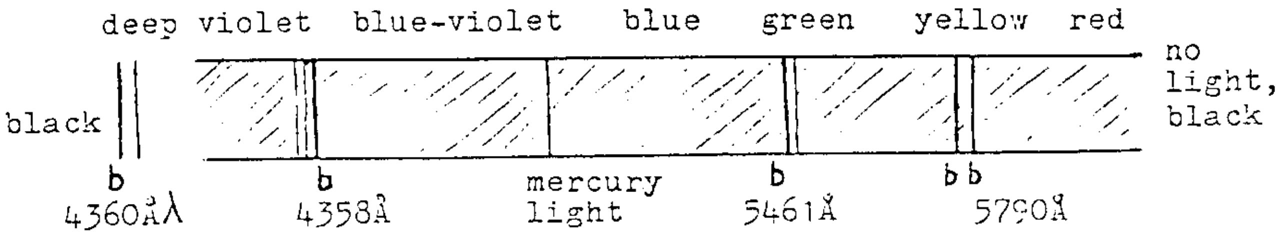
The field lens of the eyepiece will be about 25mm diameter. The spectrum will be about 16mm long. You will see the whole spectrum. Mount two razor blades close together. One blade is fixed . The other is slightly moveable by finger pressure. Hold the mounted blades up to a light bulb. A very narrow, barely seen slit will be about 0.0002" (5 microns) wide. Gently touch the moveable blade so that the separation increases to about 0.001" (25 microns). The narrow slit now will be definitely seen but still not too bright. Use a 7X eyepiece micrometer to check the slit width.



spectrum by a prism

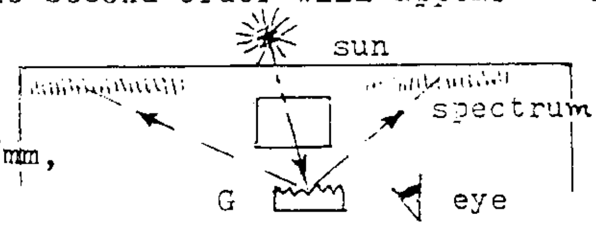
With a 5 micron slit, many delicate faint spectral lines can be discerned. The strong lines are obvious. The three green magnesium lines and the two yellow sodium lines are resolved easily. The ends of the spectrum in the violet and in the red will be a bit faint but the presence of the violet H line and the red B line will be noticed. With a 25 micron slit, from the violet K to the red A line now can be observed with the increase in light through the slit. With careful scrutiny the deep red Ca is there too. It is three strong calcium lines centered about 8542Å wavelength. The red A and red Ca are strong lines but are not sharply outlined. The red B line is strong and sharp. The violet H and K lines are also strong but fuzzy. Many sections of the spectrum are faintly shaded due to many close lines that are not resolved. There are many lines in the violet and blue, some in the green, and few in the yellow-orange-red.

Emission spectroscope. A simple hand spectroscope can be used to study the emission lines of a mercury light. With just the spectroscope (prism or grating), point it at a room light bulb. An incandescent light will show a bright continuous spectrum. The second order can also be viewed. With a mercury light, you view a faint continuous spectrum with bright (b) and faint emission lines which are sharply outlined.



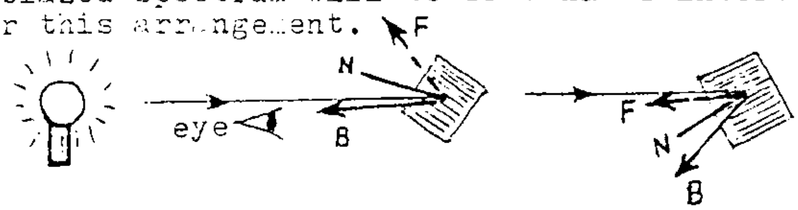
Other ways. With just the reflection grating in the hand, you can make a preliminary study of the orders. Stand in a semi-dark room. Let the sun light pass through the window and fall upon the grating. Solar spectra will form on the ceiling. Tilt the grating, and the second order will appear fainter but much longer.

Any grooves/mm is useful: 600 gr/mm, 1200 gr/mm, 1800 gr/mm.



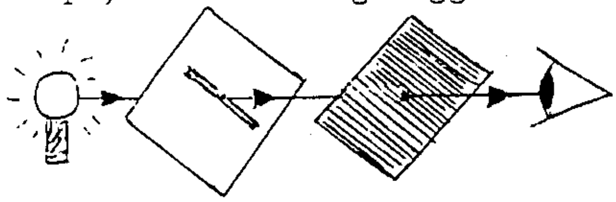
Edmund 12 x 25mm will work fine. Not need costly, high resolution grating.

Have a light bulb about ten feet behind your back in a room. Hold the grating so that the bulb spectra reflect into your eyes. Tilt the grating. A spectrum on one side of the grating normal will be bright. On the other side of the normal, the unblazed spectrum will be somewhat fainter. Do not use the sun for this arrangement.



Reflection grating, 12 x 25mm ruled area, 5000Å λ blaze.

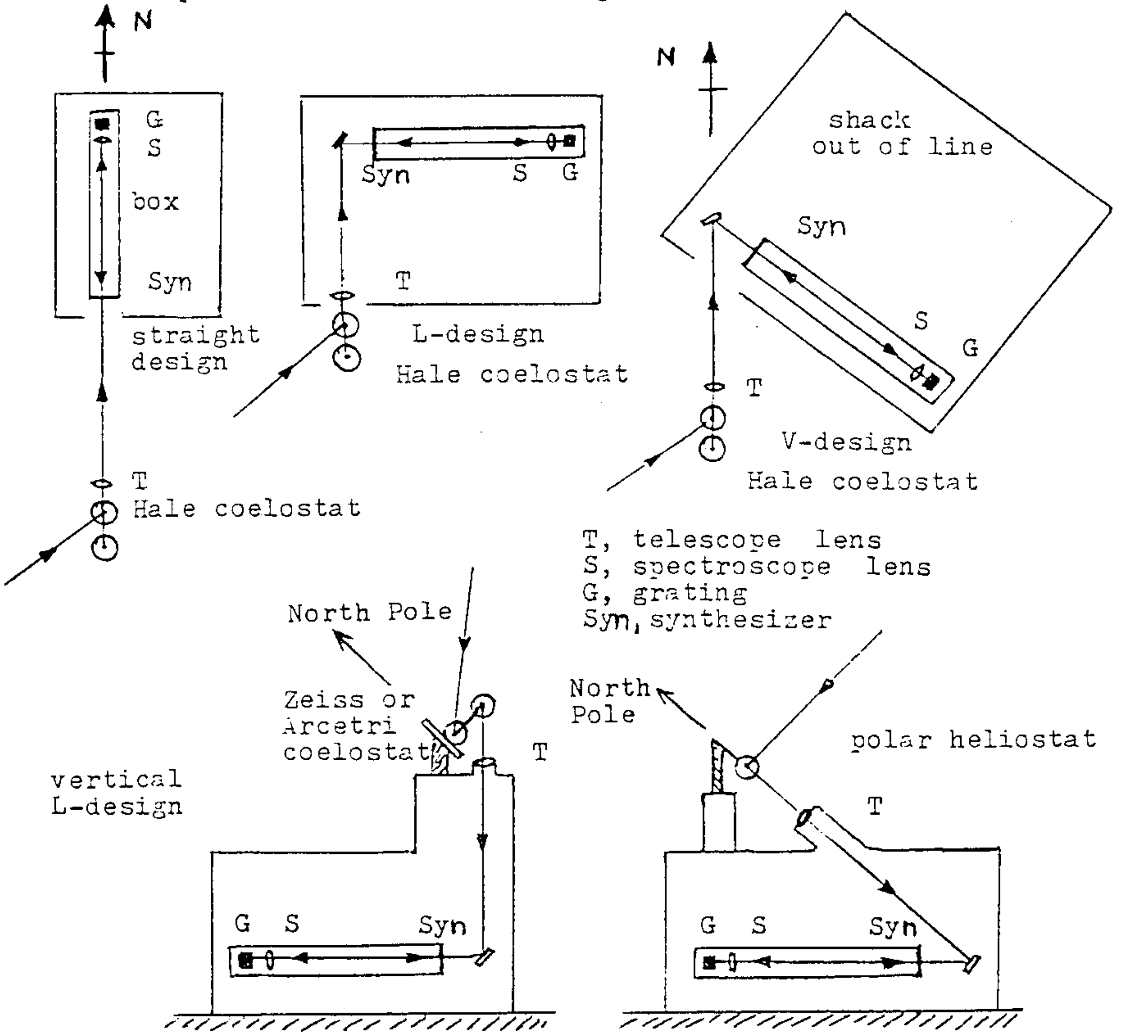
Hold a low cost, Edmund slide transmission grating close to the eye. Look at a light bulb covered with only a narrow slit showing. Short spectra will enter your eye. The technical concept of first and second orders sometimes confuses an amateur. But with a little practice with simple grating materials, one becomes confident in handling a grating so to proceed to make a spectroscope, or something bigger.



Can use reflection grating, 12 x 25mm; just reorientate the bulb, slit position.

For simple demonstrations, low cost grating will work good.

Layouts for a spectroheliscope. If you have an observatory or a small shack, there are various ways to put the somewhat long focal lengths in a shelter, depending upon north-south orientation and other factors. For the northern hemi-sphere, the sky in the southern direction must be free of obstructions so that a two mirror Hale coelostat can be used. Here are some top views with the optics horizontal to the ground.

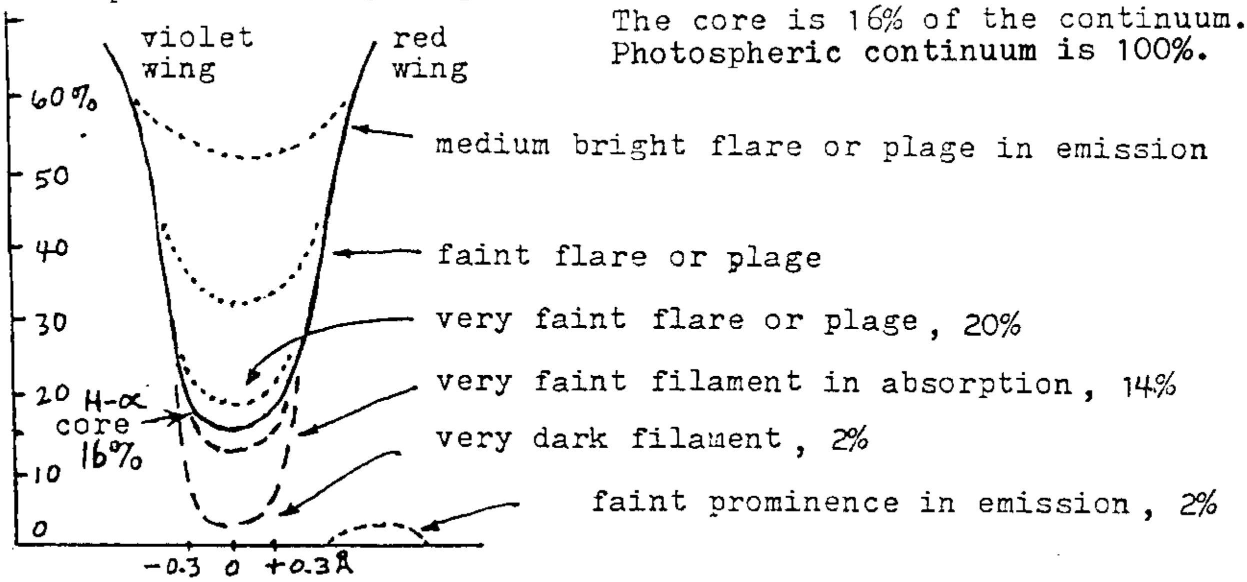


If you have only clear sky in the northern direction, then use a simple or polar heliostat design. The above two designs are a V or a half vertical arrangement for a good compromise.

A spectroheliosccpe in a straight line of 16 feet (5 m) occupies a fair amount of space. A folded up design with two flats can put the focal lengths in a box about nine feet long, but the latter can be a bit awkward to handle. This was the author's first design in 1964. A more compact folded up design is suggested. Thus a permanent or semi-permanent solar observatory is best.

Design	Arrangement	Piers	Set up time
straight line optics	all permanent parts	fixed piers, spec-box, tele-lens, coelostat	zero minutes
ditto	semi-permanent	3 fixed piers, movable spec-box and coelostat	about 5 min.
ditto	semi-permanent	3 movable piers left on marked concrete pads, movable spec-box and coelostat	about 5 min.
ditto	all portable	3 movable piers, spec-box, coelostat	20 minutes
folded up optics	permanent	box sets on 2 fixed piers	zero minutes
ditto	semi-permanent	box movable, 2 fixed piers	2 minutes
ditto	all portable	box movable, also piers	5 minutes

Profile of the H-alpha line. Examples of details in emission and absorption. The dark core of the line is 0.6Å wide at 4Å/mm disp. The core is 16% of the continuum. Photospheric continuum is 100%.



SETTING UP A SPECTROHELIOSCOPE

Basic procedure. To discuss all the necessary facts at one time for setting up a spectrohelicscope would be rather detailed. Confusion may ensue. Therefore, a brief outline will be mentioned first. Then further pointers thereafter. With a little experience, it will be realized that the instrument is easily mastered.

It is assumed that the optical axis of the spectroscope lens is adjusted almost down the middle of the spectroscope box. More discussion later. It is also assumed that the optical axis of the telescope lens is adjusted parallel to the side of the baseboard of the heliostat-telescope platform. And more on that later.

The procedure for setting up is as follows:

Step I. Put the heliostat-telescope platform and the spectroscope box on their respective piers.

Step 2. Mutually align the optical axis of the telescope and spectroscope lenses.Use spectroscope disk first.

Step 3. Move sideways the grating mounting to reflect the solar spectrum back to the exit slits.Use 2" f.l. eyepiece.

Step 4. Focus spec-lens first.Turn the micrometer which tilts the grating in order to place the H-alpha line in the center of the field of the eyepiece.Focus tele-lens.

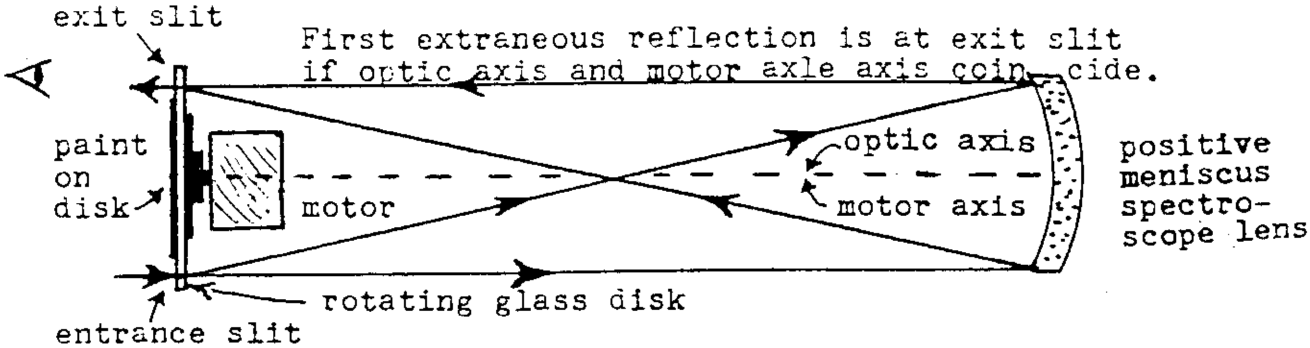
Step 5. Exchange the spectroscope disk for the24 slit spectrohelicscope disk. Turn on the motor and observe the sun in H-alpha light. Use 5 " (125mm) f.l. eyepiece now.

Adjust the spectroscope lens. Now for all the extra details. The optical axis of the spectroscope lens must pass almost down the middle of the spectroscope box within about half an inch (a centimeter). This is not difficult and is sufficient. Open the front door of the spectroscope box. Remove the 60 rpm motor. With a flash light close to the eye, look down into the middle of the box to observe the reflection off the rear of the surface of the spectroscope lens. Shift the lens focusing platform up and down and sideways. Set the focusing platform permanent and replace the motor. The first reflection off the spectroscope lens now bounces off the lens and back to the side of the exit slit by about half an inch. The output axle of the motor must also be mounted so that the axle is in the middle of the front of the box. Accuracy within I/32"(I mm) is alright. Exactly in the middle is not necessary.

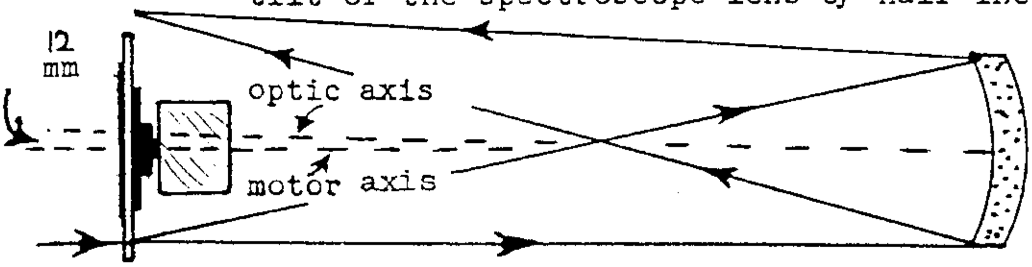
The second reflection off the spectroscope lens must be blocked with a I/8" (3mm) diameter disk which is mounted from the bottom of the spectroscope box and about I2" (300mm) behind the spectroscope lens. Put the spectroscope disk on the output axle of the motor. Have the ½" x ½" (I2mm x I2mm) clear area lined up with the eyepiece holder.Put the sun on the entrance slit. Remove the

ELIMINATE SPECTROSCOPE LENS REFLECTIONS

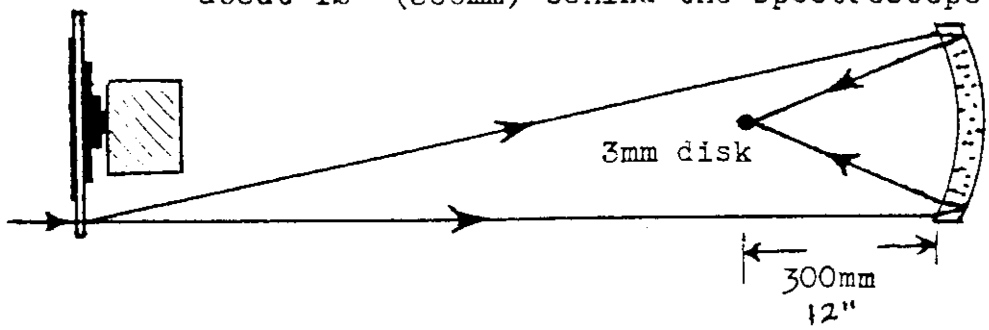
First extraneous reflection is at exit slit if optic axis and motor axle axis coin-cide.



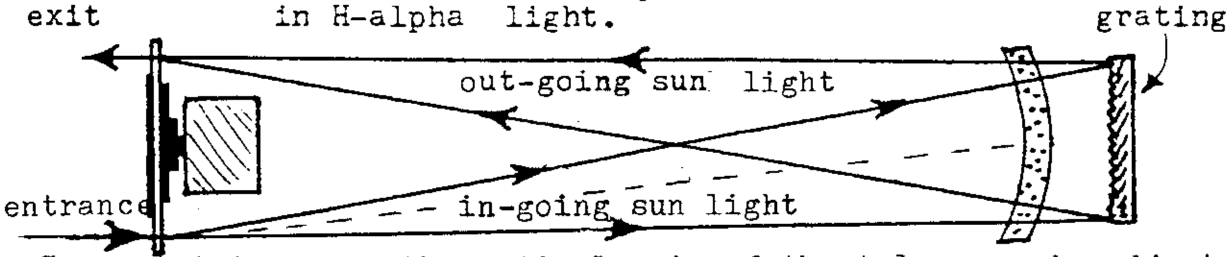
Remove first extraneous reflection by off-axis tilt of the spectroscope lens by half inch (12mm).



Remove second extraneous reflection by blocking out with a 1/8" (3mm) diameter disk placed about 12" (300mm) behind the spectroscope lens.



Sun light to and from the grating in order to observe the solar spectrum and the solar disk in H-alpha light.

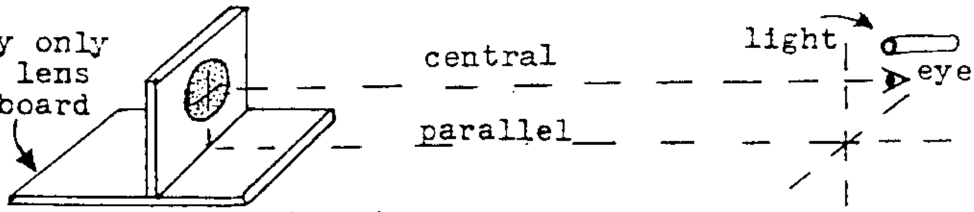


In a strict sence, the optical axis of the telescope is adjusted with the in-going axis of the sun light into the spec-box. Read discussion carefully.

eyepiece and look into the spectroscope box. The second reflection will be small but very bright and easy to see. Adjust the disk mounting until the reflection is blocked out.

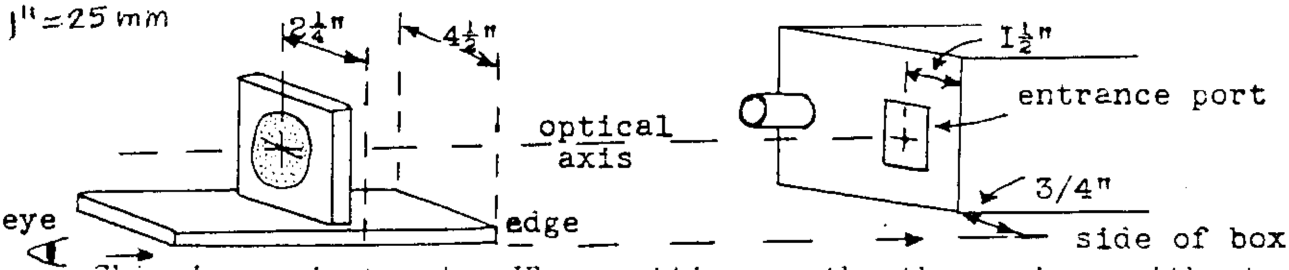
Adjust the telescope lens. The optical axis of the telescope lens must be parallel and centrally aligned with the heliostat-telescope platform baseboard which holds the focusing rails. Adjust the optical axis of the telescope as follows. Use a long table for mutual leveling of the eye with the baseboard.

For simplicity only the telescope lens and the base board are shown.



Place the eye about 9' (2.7m) away from the telescope lens. Have the eye central and parallel to the baseboard. Use a flash light close to the eye and observe the reflection off the rear surface of the telescope lens. Shift the telescope lens until the flash light reflection bounces back to the eye. The adjustment does not have to be exact; close within ½" is good and easy. Special collimators are not necessary.

Step I details. The heliostat-telescope platform must be mounted so that the optical axis of the telescope lens passes within ½" through the entrance port of the spectroscope box. Put the heliostat-telescope platform on its pier 9' away fromthe spectroscope box. Look along the edge of the baseboard of the platform. Rotate the platform until the edge is lined up only with the front side of the spectroscope box. Now the telescope lens enters the entrance port of the door. Next the rear of the spectroscope box is moved up and down and sideways in order to line up the spectroscope lens with the telescope lens.

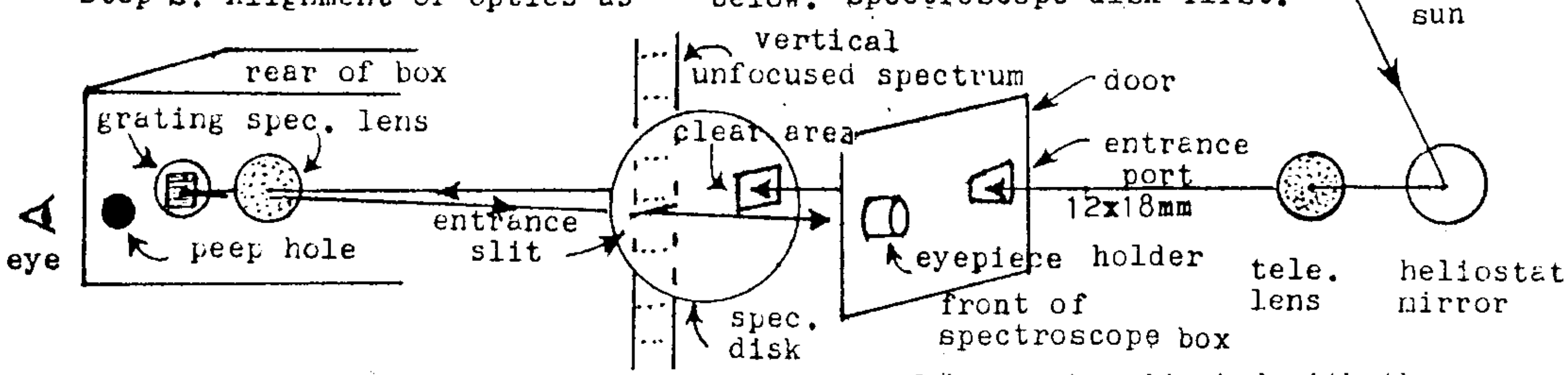


Shimming adjustments. When setting up the three piers with attendent heliostat-telescope platform and spectroscope box, it may not be possible to place the piers so that the optical axes of the two lenses can be easily and mutually aligned. Some shimming may be necessary in the height of the heliostat platform and/or the rear of the spectroscope box. The middle pier is not moved; only the two other piers.

The first possibility may be that the heliostat pier is a bit too short. Therefore, make and keep on hand a piece of wood about one inch (25mm) thick with the length and width the same as the top

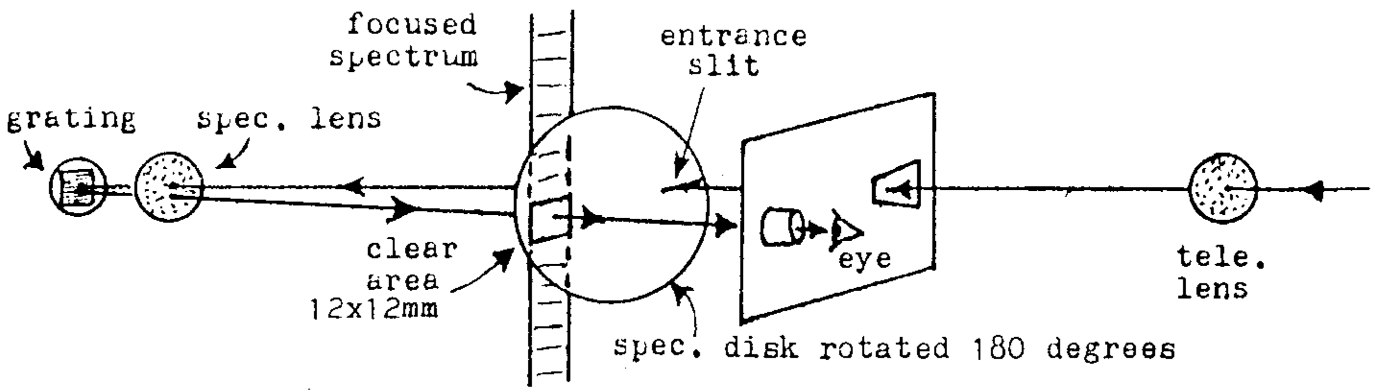
SETTING UP THE SPECTROHELIOSCOPE

Step I. Mount telescope with heliostat and spectroscope box on piers.
Step 2. Alignment of optics as below. Spectroscope disk first.



In a strict sence, the optical axis of the telescope is adjusted with the in-going axis of the sun light into the spec- box, not with axis of spec-lens. Read discussion carefully.

Step 3. Position spectrum at the exit slit as below.



Step 4. Mutual focusing of optics;locate H-alpha line.
Step 5. Change one slit spectroscope disk for the 24 slit rotating disk. Exchange 2" f.l. eyepiece for 5" f.l. eyepiece. Turn on motor. Observe the sun in H-alpha light.

2" = 50 mm
5" = 125 mm

dimension of the pier. This wood shim elevates the heliostat platform one inch so that the rear of the spectroscope box can be moved up or down a bit more when aligning the spectroscope lens.

Now perhaps the rear of the spectroscope box must be only raised ½" above the top of the rear pier. Well, a half inch of air space supports nothing. Then make and keep on hand two wood wedges about 3" (75mm) long, I" (25mm) wide, and tapering from I/8" (3mm) to I". This gives a variation in small amounts for wedging the end of the spectroscope box. The reason for two wedges instead of one is that it is easier to shim each side of the rear of the box. Adjusting the spectroscope and telescope lenses here and there half an inch(centimeter) is not too crude and will not cause trouble in the performance of the instrument. Long focal length optics of high F:ratio , about F:50, permit some leeway, thereby greatly minimizing criticality of adjustments.

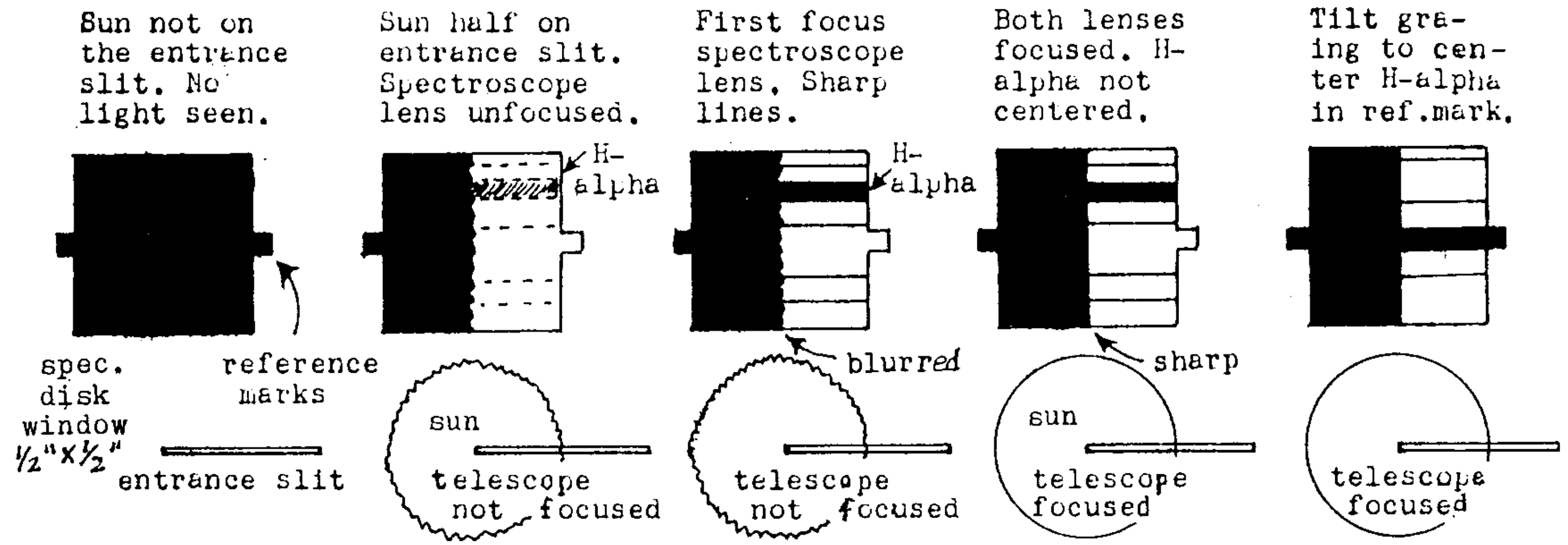
Step 2 details. After the heliostat-telescope platform and the spectroscope box are mounted on their respective piers, the optical axes of the telescope and spectroscope lenses must be mutually aligned. This alignment does not have to be exact, just close. No special optical devices are required. The spectroscope box pivots at the front on the middle pier by a nut and bolt holding them together. The rear of the spectroscope box moves up and down and sideways so that the light passing through the entrance port of the front door falls upon the diffraction grating via the spectroscope lens. The rear door of the box is lifted in order to see if the grating is properly illuminated.

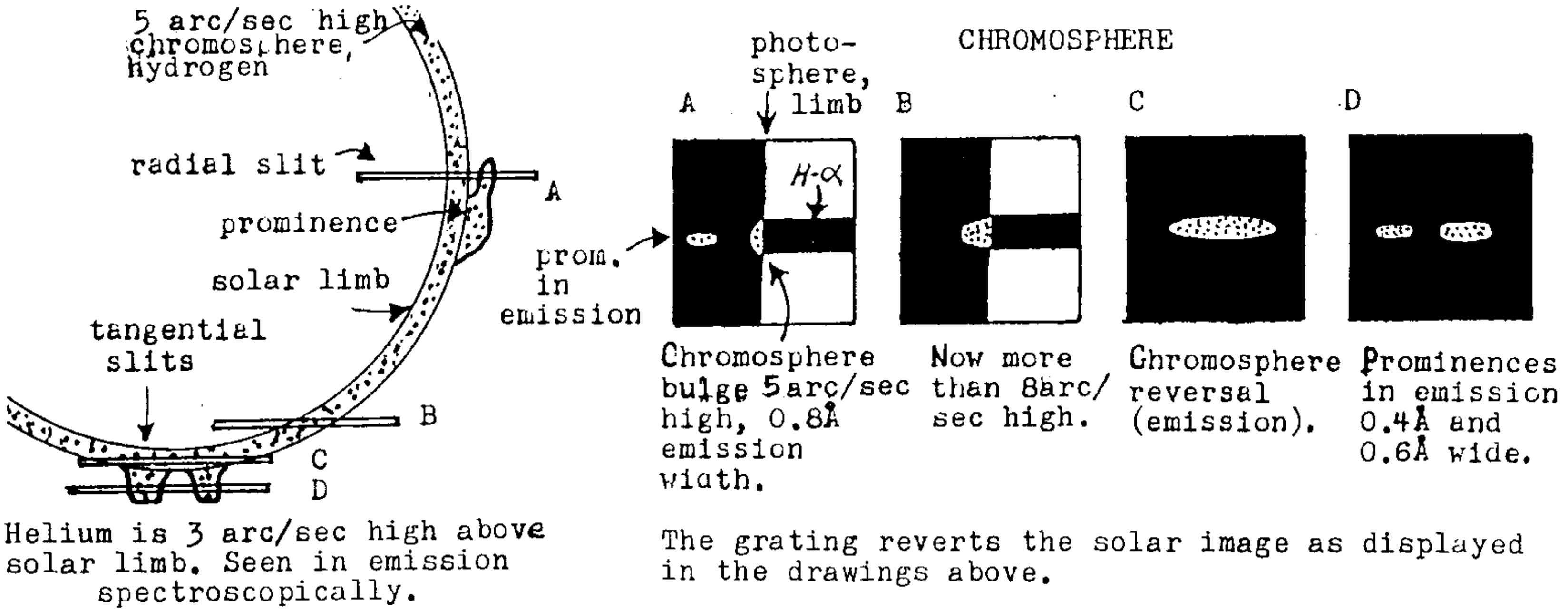
Have the sun image centered and covering the entrance port of the front door of the spectroscope box. The spectroscope disk has a clear area on one side which is ½" x ½" (I2mm x I2mm) square. Opposite the clear area is the slit about 0.00I" (0.025mm) wide. Now put the spectroscope disk on the output axle of the motor, and turn the disk until the clear area is lined up behind the entrance port. Thus the light from the telescope lens passes through the entrance port and through the glass disk clear area to the spectroscope lens and to the grating. If the spectroscope box is correctly aligned, the light passing through the spectroscope lens will fully and evenly illuminate the grating. This is not likely to happen the first time, but a little practice is sufficient.

If the top half of the grating is illuminated, then the rear of the spectroscope box must be moved up about one inch (25mm). If the bottom half of the grating is illuminated, then the rear of the box must be moved down. If the left half of the grating is illuminated, then the rear of the box must be moved to the left, and so forth. The clear area of ½" x ½" on the glass disk must not be too big or too small.

Step 3 details. Now the optical axes of the two lenses are aligned. The light falling on the grating and reflecting off it passes back through the spectroscope lens to the vicinity of the exit slit. Look through the peep hole at the end of the spectroscope

MUTUAL FOCUSING OF THE OPTICS (Step 4)





The grating reverts the solar image as displayed in the drawings above.

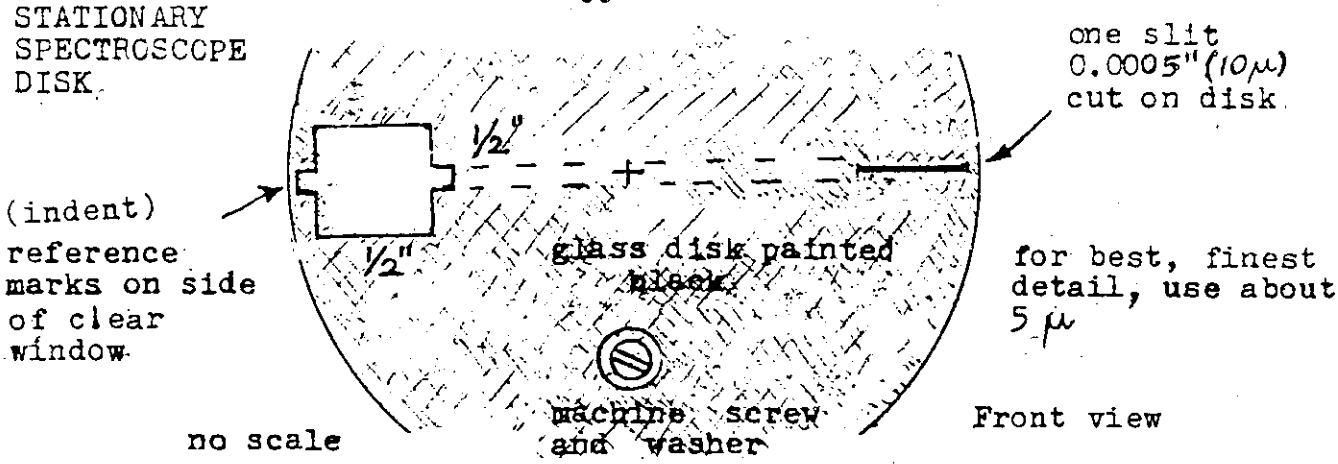
box in order to see where the spectrum is located near the exit slit. Move the grating mounting horizontally (sideways) in order to position the spectrum at the exit slit. Within I/16" (about 2mm) is good enough. Manually rotate the grating cell so that the spectrum is vertical with the exit slit. Verticality does not have to be perfect.

Step 4 details. Rotate I80 degrees by hand the spectroscope disk so that the clear area of ½" x ½" is now lined up with the exit port of the front door where the eyepiece is located. The entrance slit of the glass disk is lined up with the entrance port of the front door. Now the entrance slit passes a narrow section of the sun light to the grating which resolves the light into fine detail in the spectrum, which is seen through the glass disk clear area with the eyepiece.

Focus 2" f.l. eyepiece on a speck of dust on the painted surface of the spectroscope disk. Mark on the side of the eyepiece so that locating it in the eyepiece holder will be faster next time. Focus the spectroscope lens by pushing the focusing rod in and out. The H-alpha line is not likely to be seen. Tilt the grating down by turning the micrometer head. It will put the H-alpha line into the center of the field of the eyepiece. Line up the H-alpha line with the reference marks on the side of the ½" x ½" clear area. Double check the focus of the spectroscope lens and leave it; see below for the reason, Step 5 details.

With the spectroscope disk still on the output axle of the motor, shift the heliostat mirror to place the sun image so that about half of it covers the entrance slit. Looking into 2" f.l. eyepiece; half the field of view will be black due to no sun light passing through half the entrance slit. The other half of the field of view will be the red part of the spectrum due to sun light going through the other half of the slit. The H-alpha line will still be visible. Actually the region of the spectrum around the H-alpha line will be an orange-red, not a true red, but for the sake of simplicity the word red is used. Now focus the telescope lens by looking at the edge of the spectrum located in the middle of the clear area. This is the edge of the sun and will be a blur if not focused. When the telescope is focused, the blurred edge of the spectrum becomes sharply outlined. Now exchange for 5" f.l. eyepiece.

Step 5 details. Exchange the spectroscope disk for the spectroheliosccpe 24 slit disk. Turn on the motor and observe in H-alpha light. When the spectroscope lens is focused at the H-alpha line, make no further focusing adjustments because a slight shift of the lens will slightly shift the H-alpha line so that it will not coincide with the exit slits. The focusing mounting for the spectroscope lens must be free from play and wobbling. Slight spring tension is desirable. The high F:ratio of the lens gives great depth of focus so that mutual focusing of two lenses is not difficult. Depth of focus for an F:44 lens is about ¼" (6mm). Depth of focus for two such lenses together is half, about I/8" (3mm). For comparison, a 6" (I50mm) F:8 mirror has about 0.006" (0.I50mm).



The spectroscope disk has one cut about 0.001" wide on the disk surface. In the spectroscope disk drawing the cut (dotted line) passes through the center of rotation of the glass disk, which is mounted on a metal flange. The width of the cut is exaggerated for better visualization of the parallel relationship of the entrance slit formed by the one 0.001" slit and the reference marks on both sides of the clear area. When the H-alpha line is in the center of the reference marks, this means the H-alpha line is exactly lined up with the center of rotation of the disk and the entrance slit. Thus when the spectroscope disk is changed for the spectroheliocope 24 slit disk, you know that the 24 slits are automatically lined up with the H-alpha line as the 24 slit disk rotates. The spectroscope disk and the 24 slit disk must be the same thickness, 2.4 mm. When the spectroscope disk is used to focus the spectrum and position the H-alpha line, you know that the 24 slit disk is mutually focused when changed from the spectroscope disk.

<u>Air current wall.</u> When observing the solar disk in H-alpha light with the 24 slit disk, all of the field of view of the sun may be dark H-alpha light. Sometimes the extreme top and bottom of the field of view may be slightly brighter and the middle of the field will be darker. This is due to air currents in the spectroscope box slightly moving the H-alpha line on the exit slits. The brighter top and bottom, if it occurs, are a slightly different wave length.

A few inches behind the 60 rpm motor is placed a piece of thin material (metal) with two 1" (25mm) diameter holes to let the light from the entrance slits to pass to the spectroscope lens and grating; then back to the exit slits. The wall prevents stirring up the air in the spectroscope box as the 24 slit disk rotates on the motor output axle. The two holes are covered with good quality reticle glass, which can be purchased from Edmund Scientific. Microscop e slides are acceptable. All glass should be tested by autocollimation for quality. The air current wall helps to give a very uniform field of H-alpha light, which results in viewing the solar disk detail much better performance by about two times. The author has been the first to use such a simple device for the past several years. Other observers are strongly advised to put it in their instrument.

CONSTRUCTION OF A SPECTROHELIOSCOPE

Warning. The spectroscope lens must be a positive meniscus lens shape in order to function with the rotating glass disk acting as the solar image synthesizer. The telescope lens can be any lens shape or an achromat. A Newtonian or Cassegrain mirror design may be used.

A linear dispersion (spreading out the spectrum) about 4Å/mm in the first order is necessary. A 75" (I.9m) f.l. spectroscope lens used with a reflectance diffraction grating of I200 gr/mm produces the proper linear dispersion. The spectroscope lens does not have to be exactly 75". Plus or minus a few inches (centimeters) is allright and allows making the lens somewhat easier. Slit widths of 0.006" (0.I50mm) on the 24 slit spectroheliocope disk will pass 0.6Å and will give excellent contrast of the solar disk detail in H-alpha light. Do not use slits wider than 0.008"(0.200mm), or 0.8Å.

Spectroscope box. The front door of the box can be I/8" (3mm) thick brass or aluminum. Anything thinner is not good. Wood ½" thick is sufficient. The door must be painted black to prevent the sun reflecting off the door into the eyes in a manner similar to a mirror. Flat black paint is best, but glossy black is acceptable. Another dark color (deep brown perhaps) might work, but do not use white. The rest of the box can be any color. The 85½" (2.I72m) long spectroscope box is for a spectroscope lens of 75" f.l. (I.905m) in the red part of the spectrum. If the lens is shorter or longer, then construct the box proportionately shorter or longer. It is best to make the box about 90", for it can always be shorten later.

One revolution/second motor. The rotating glass disk with 24 slits rotates on the output axle of a synchronous motor of I rps, or 60 rpm (rev./minute). The motor is placed inside the front of the spectroscope box. The motor is bolted to an L-shaped metal flange of I/8" (3mm) thickness. The metal flange and motor are bolted to the bottom of the front of the box. With the 24 slit disk passing 24 solar images into the eye per second, there no flicker in the H-alpha core. But out of the H-alpha core, a trace of flicker.

The motor should be of synchronous design so that the rotating glass disk revolves at exactly one revolution per second. If the motor revolves less than I rev./sec., this results in annoying flicker. If the motor revolves slightly more than I rev./second, there will be no troubles. It may not be possible to conveniently obtain a I rev./second motor of synchronous design. A series motor design may work. It has I725 revolutions/minute (or almost 29 rev./second) without any gear reduction. Use a 30:I gear reduction ratio with such a motor to have it function at almost I revolution/second.

A synchronous motor is about 2¼" x 2¼" x 2¼" (57 x 57 x 57mm) and will easily fit in the front of the spectroscope box. During motor operation, the warming of the motor will cause no serious heating problem. No insulation is needed. A series designed motor of similar size might be placed outside the box and mounted there.

Have an output axle extension into the box to join with a 30:I worm and gear ratio. The latter is mounted on a piece of axle which is supported by two small bearings. This axle has the glass rotating disk placed on one end. Some motors have slight vibrations. Never use them, for such tiny vibrations slightly shake the spectroscope box and also ripple the air inside the box. The result causes the H-alpha line to shimmy on the exit slits and presents a dark and light messy H-alpha view of the solar disk. Always buy a very smooth turning motor.

The motor must be about 7 to IO watts, depending upon the manufacturer, in order to have enough torque (axle turning power). D o not use a small motor of about FOUR watts, for they do not have enough torque to safely rotate the glass disk without danger of stalling and burning out. Small watt motors also have too much output axle eccentricity, which can cause the glass disk to wobble too much as it rotates. A trace of glass disk wobbling of about 0.001" (25micron)is all right, but too much more than that can give eye strain, for as the 24 slit glass disk wobbles, it also wobbles the sun as the latter passes through the glass disk.

Near the motor is a I/4" (6mm) diameter hole to bolt the front of the spectroscope box to the middle pier. This hole is a pivotal point, both horizontal and vertical motions for the rear of the spectroscope box in order to align the optical axis of the spectroscope lens relative to the telescope lens which is bolted on another pier nine feet (2.7m) away.

Address for procuring a synchronous motor and gears:

Winfred M.Berg	Minarik Electric Co.	Stock Drive Products
499 Ocean Avenue	224 East Third St.	55 S. Denton Avenue
East Rockway,L.I.	Los Angeles	New Hyde Park, NY
NY 11518	Calif. 90013	11040

Minarik is a distributor for Bodine motors, which cost about $93 for a IO watt I revolution/second speed. Bodine motors have absolutely no vibration. They would be excellent for a spectrohelioscope mounted even on an equatorial mounting. Send for free pamphlets.

Making the spectroscope box. The spectroscope box is four planks of wood that are nailed together. Drill a hole about half the diameter of the nail in order to avoid ugly splitting of the wood. Pine is a good wood and is inexpensive. Oak costs more but is more rigid. Thickness of the wood should be about half an inch (I2mm) as minimum. Up to about 3/4" (I8mm) as a maximum .Plywood about I/4" (6mm) thickness is equivalent to wood about twice as thick, such as pine. First paint one side of the four planks with flat black paint. Then nail them together. This is much easier than nailing the planks first and then frustratingly painting the inside of the box later. A 5" (I25mm) diameter aluminum tube can be used.

Line shifter glass. The I/6" (4mm) thick line shifter can be made from good quality reticle windows of government surplus. A I"

(25mm) window will cost about 5 dollars or less. Do not use commercial window or picture frame glass unless it has been tested. Most commercial glass has striae or surface irregularities that will seriously warp the solar light passing through it to the eye. Two microscope slides, 1" x 2" of 1/12" (2mm) thickness, can be mounted together to give 1/6" thickness. The microscope slides will be not quite as good as reticle glass but the slides will suffice. The line shifter must not be too thick. Use about 1/5" (5mm) as a maximum thickness. At the same time the glass must not be too thin. About 4mm to 5mm is good. Too thick or too thin glass will result in a line shifter that is too sensitive or not sensitive enough in order to have small wave length changes at H-alpha.

Dust on the grating. Dust is the enemy of a diffraction grating. When the spectroheliöscope is not in operation, always put a cover over the grating. Never touch the surface of the grating. Any slight human mark will be permanent, for the surface is extremely delicate. When the grating is received, the ruled area will not be seen. The grating will appear as a common optical flat, but the 1200 gr./mm ruled area is there. Never blow with the mouth at any particle on the grating surface, for there is a high chance that a bit of saliva will be scattered on the grating. Generally, it is best just to leave the dust alone, for a few specks of dust will cause no harm.

When the instrument is set up for observing and there is a dusty surface nearby, water the ground a little. This keeps dust off the grating via gusts of wind. If no water hose is available, walk carefully. Never have children playing near the instrument. Put up a 3 feet (1m) high fence around the instrument if relatively complete isolation is not possible. Put up a sign that you do not wish to be disturbed, unless the sign states otherwise. Remember that when a surge filament or prominence occurs, you will have only 30 minutes to observe the event. This will require full concentration on your behalf. Children, adults and animals are distractions. Have little or no talking by people near you during observations.

Diffraction grating addresses. Two high quality grating companies.

Diffraction Products, Inc.	Richardson Grating Laboratory
P. O. Box 645	820 Linden Ave.
Woodstock, Ill.	Rochester, N. Y.
60098	14450

Write for a free catalog. If not sure of catalog number, then just write grating wanted: reflection, ruled area, grooves/mm, blazed wavelength. They will fill in details. Years ago Bausch and Lomb changed ownership.

Diffraction grating mounting. A good quality micrometer, costing about $60 can be used to easily and precisely control the vertical tilt of the grating angle. The H-alpha line must be placed exactly at the narrow exit slits. A high quality micrometer also permits measuring the grating angles versus the spectral lines observed. Have a vernier on the micrometer. Put a crosshair in the

2" f.l. spectroscope eyepiece. Place the spectral line on the cross-hair and read the inch or mm value on the micrometer to 0.000I" (2.5 micron).With a known wave length, such as the H-alpha line of 6562.8 Å wave length, other wave lengths can be determined. Now a solar spectral atlas can be tabulated. A top quality micrometer has no backlash but a low quality, low cost micrometer does have some, perhaps about 0.002"(50micron) reading error.

Source of a top quality micrometer head:

Campbell Tools Co. 2100 Selma Rd. Springfield Ohio 45505	J. T. Slocomb Co. 68 Matson Hill Rd. So. Glastonbury Conn. 06073

Micrometer desired is a one inch (25mm) spindle travel; no ratchet or lock nut needed; vernier is optional. Average price about $60.

If you are short on money or not interested in measuring wave lengths, then buy an inexpensive micrometer. The main point to understand is that vertically tilting the grating the proper angle for the H-alpha line at the exit slit is impossible by direct manual means. Mechanical leverage of some design must be employed. The writer uses an excellent micrometer head. Turning the micrometer 0.0001" (25micron)will shift the H-alpha line at the exit slit by 0.2Å. Placement of the H-alpha line is not difficult.

The grating mounting consists of I/8" (3mm) thick aluminum or brass. This thickness gives excellent rigidity which is absolutely necessary. Very slight flexture of thinner metal will easily shift the spectrum at the exit slit. A slight bending perhaps of 0.00I" of thin metal due to tension on the grating mounting can shift the spectrum about half an angstrom at the exit slit. The H-alpha line will barely miss the exit slit, rendering inoperable the instrument. Anything thicker than I/8" is not necessary. Massive parts are also not required. Much precision lathe work or expensive metal castings are completely ridiculous. Just simple pieces of metal of good strength and proper shape will give rigidity for a grating mounting. Precision drilling of the holes is not needed in most instances. Placement of the holes in the plans to within I/32" (about Imm) is enough.

The edge of the grating has a small bevel of 45 degree angle. Three small machine screws spaced I20 degrees apart barely touch the glass bevel to retain the grating in its cell. Thick paper or cork act as a shim on the sides of the grating in its cell to prevent any slight movement which could shift the spectrum at the exit slit with the result that the H-alpha line will barely miss the exit slit. Do not put any mechanical pressure directly on the grating. Never.

There are three motions of the grating in its grating mounting:

(I) rotation of the grating cell with grating; (2) horizontal movement of the whole grating mounting; and (3) vertical movement of the grating cell with grating. The rotation of the grating cell gives the mutual parallelness of the lines on the grating with the exit slits. This mutual parallelness does not have to be exactly perfect. Plus or minus 2 degrees will result in no serious loss of resolution of the grating. The horizontal movement of the whole grating mounting positions the spectrum at the exit slit. This horizontal movement is not delicate but a simple slow motion device to push at the rear of the grating mounting is desirable. The vertical movement of the grating cell shifts the spectrum vertically (up and down) at the exit slit. Only this motion is delicate.

With the micrometer several feet (few meters) distant from the eyepiece, it would be handy to have bevel gears or some system with a long control rod to turn the micrometer, thereby saving a goodly amount of walking back and forth. Do not depend upon an assistant all the time. A bevel gear system will cost about $40. To save money, just wrap a piece of string around the micrometer head and pull on it. This technique allows overall viewing of the solar spectrum. For exact placement of the H-alpha line at the exit slit, the fingers must turn the micrometer head.

Instead of turning the micrometer head by finger control, it is possible to move the line shifter which will quickly put the H-alpha line at the exit slit. Of course, this is not the true function of the line shifter, for now it can not be used as such, since it is tilted at an uncalibrated angle which initially should be 90 degrees with the optical axis of the spectroscope lens. It is a good idea to have two line shifters near the exit slit, one behind the other. One is always used as the true line shifter and the other - call it an H-alpha tuner - as a fine adjustment for the H-alpha line. This arrangement retains one of the line shifters for measuring Doppler shifts of solar disk detail. The thickness of the two shifters should be about the same.

Behind the back of the grating cell is attached a long piece of metal. It is called the grating cell arm and gives long delicate leverage for the vertical motion of the grating cell. The length should be about 5" (I25mm). The micrometer spindle presses on the end of the grating cell arm in order to vetically tilt the grating cell. To connect the motion of the end of the micrometer spindle to the end of the grating cell arm, a small L-shaped flange is used. The flange is held to the end of the grating cell arm by a machine screw and nut. The L-shaped flange has a $\frac{1}{4}$" diameter depression (about I/I6", Imm) so that the end of the $\frac{1}{4}$" spindle diameter fits into the depression. Now turning the micrometer will not push sideways the flange which would move the grating cell and shift the spectrum at the exit slit. Have very little play for the spindle in the depression, certainly not more than 0.002" (50 micron).

A 1" (25mm) spindle travel of the micrometer is desired in order to tilt the grating from the violet to the red regions of the spectrum. A $\frac{1}{2}$" spindle travel is acceptable but only about 2/3rds of the spectrum can be viewed, namely from the red to about the green. The plans for the grating mounting have a grating cell distance (from the surface of the grating to the micrometer spindle) of $5\frac{1}{4}$" (I34mm). For a $\frac{1}{2}$" micrometer spindle travel, this distance must be decreased to about $4\frac{1}{4}$" (108 mm), but no less. Now from the violet to the red of the spectrum can be studied. A tilting down of the grating to a I3 degree angle places the violet region of the spectrum at the exit slit; a tilting of 23 degrees shows the H-alpha line. These values are for the first order with a 1200 gr/mm grating.

Wood parts. The telescope and spectroscope lens focusing arrangement is a simple wood slide with wood rails. To avoid binding have a I/32" (about Imm) recess along most of the side and bottom of the wood slide, for the wood rails or bottom board may be slightly warped. A bit of vaseline or light grease gives a smooth motion. The lenses are mounted in a hole with a metal retaining ring. The telescope lens may be allowed a tiny bit of play, preferably none. But the spectroscope lens must have no play, for a slight shift of the lens in its mounting will slightly move the spectrum and H-alpha line off the exit slit. The edge of the lenses should be slightly beveled to guard against chipping.

The RA wood pedestal consists of four pieces of wood that are nailed together. The pedestal is bolted on the same wood base board which supports the lens focusing slide and rails. On the top of the wood pedestal is a sheet of metal which prevents the RA ball bearings sinking into the wood. Bearings can be bought from Sears and Roebuck and Montgomery Wards retail stores. Check their catalogs. For other bearing sources, look in the telephone directory.

Heliostat. A 4" (IOOmm) pyrex mirror of I/8 wave flatness is good for the heliostat. It will cost about $400. The heliostat fork can be I/8" thick aluminum bent into a U-shape. For the Declination axis, small bearings can be mounted on the arms. Half inch diameter bearings are large enough, but even $\frac{1}{4}$" bearings may work. Be careful to line up the bearings to avoid binding. Although not obvious in the plans, the mirror surface must be in the plane of rotation of the center of the Declination axis. Tilting the mirror platform by the fingers can be tedious at times. A simple slow motion Declination control is recommended. Can use 3" (76mm) minor axis diagonal.

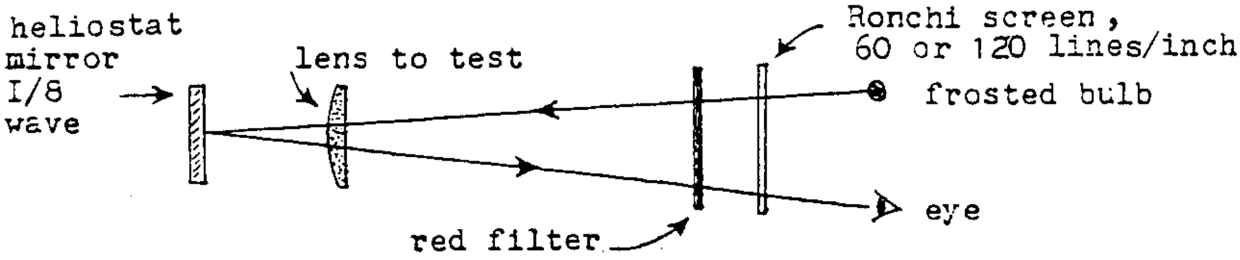
RA drive. The RA motor is not shown in the plans, just the 96:I gear (Boston GI03I) and its worm (Boston LTHB). The worm and gear can be obtained from Edmund Scientific Company for about $40. But Boston Gear Works has many offices in the largest cities. Look in the telephone directory. A solar RA drive for an equatorial mounting needs a I revolution per minute motor with a 96:I and I5:I gear ratios. This gives a total gear reduction ratio of I440:I. Now if a telescope is mounted horizontal to the earth in a north-south direction and coelostat reflects sun light into the telescope, then the mirror doubles the motion of the sun across the ground. The RA drive must have the gear reduction ratio doubled (2 x I440= 2880:I) in order to reduce by half the doubled motion of the sun. The doubled motion of the sun now is a simple physics law of optics of light reflecting off a surface. Thus, a 96:I and a 30:I gear ratios equals 2880:I total reduction ratio with a I rev./minute motor for a polar heliostat or a coelostat. Do not use slow revolution motors, about I/30 rev./minute, because slight backlash will not be taken up quickly. Do not use low watt motors in the 4 watt range, for they do not have much torque and they tend to stall. A stalling motor will not drive the gears. The mirror will not follow the sun in order to keep the sun image on the entrance slit. A motor stalling periodically for a few seconds will result in the sun drifting on the entrance slit. This can be most annoying at times. AN 8 watt motor will cost about $30 versus a 4 watt motor costing about $15. Therefore the amount of dollars saved is not worth it.

Optics and testing. The radii of curvature (ROC) of the biconvex telescope lens ARE plus 64" (I.626m) and plus 384" (9.754m), for an equivalent focal length (e.f.l.) of IIO" (2.794m). The ROC of the positive meniscus spectroscope lens ARE plus 25½"(648mm) and minus 75" (I.905m), for an e.f.l. of 75". A tolerance of plus or minus four inches (IOOmm) for the e.f.l. is quite ALL right. This saves time in making the lenses. The clear aperture of the two lenses is 2.5" (64mm) and 2.0" (50mm). The glass is about ¼" (6mm) more in diameter and serves to mount the lenses. Order Schott glass blanks of 2.7" (70mm) and 2.2" (58mm) diameter. The working F:ratio of the lenses is F:43. This is calculated by the I.7" (44mm) diameter (diagonal) of the ruled area of the grating, which is I.2" x I.2" (32mm x 30mm). Thus, I.7" is divided into the spectroscope f.l. of 75" to give F:43. The ROC above are for crown glass, grade A.

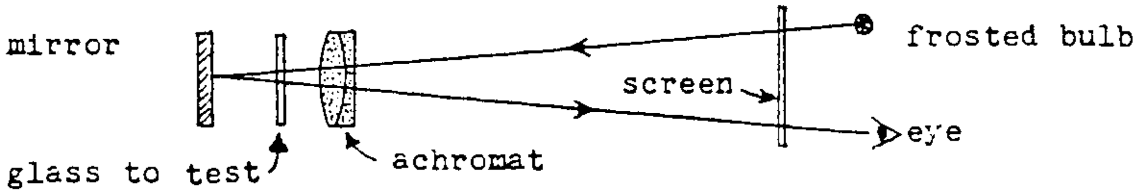
The F:ratio of the spectroscope and telescope lenses should be the same in order to cover the full ruled area with sun light from the telescope lens. When the grating is tilted 23 degrees for the H-alpha line, the ruled area forshortens to 30mm x 30mm. Although the spectroscope lens is 2.0" clear aperture, only I.7" is used. The two lenses can be crown or flint glass. Crown glass is a bit less costly. Grade A is strongly recommended for the lens blanks if you attempt to make the lenses. Grade B sometimes has slight variations of the index of refraction, rendering it useless. And on occasion even Grade A will exhibit this variation. The lenses will cost about $300 each by an optical company, for it is custom work.

The lenses can be tested by autocollimation in order to check the spherical aberration. A Foucault test or Ronchi screen test is suitable. A Ronchi screen WITH IOO lines/inch is good. The I/8 wave mirror of the heliostat can be used. A deep red filter (gelatin or glass) must be used because the single element lens has chromatic aberration. If no red filter is used, the straightness of the Ronchi lines is not seen. Instead, a colorful mess is observed.

The set up for testing spherical aberration is simple. Notice in the diagram that the light source is a frosted bulb. Or a piece of frosted glass can be used with an unfrosted bulb. About a 25 watt bulb is best, although less watts can be used.



To test the flat glass to be used for the line shifter and for the rotating glass disks and for the air current WALL, a small variation of the autocollimation test is devised as follows:



The flat glass is placed between the mirror and the achromatic lens. If the glass is good, the Ronchi screen lines will be straight. If not acceptable glass, the lines will be zig-zagged or other odd appearance. The focal length of the achromat is not critical, from 10" (250mm) or more will work; diameter of the lens is not critical. All flat glass should be tested. When purchasing the glass from a store, do not take their word of honor that it is quality glass. Honest mistakes can occur. Just one piece of poor quality glass can seriously warp the sun light passing through it and ruin the entire performance of the optical system of the spectrohelioscope.

Eyepieces. The focal length of the eyepieces does not have to be exactly the same as used by the author. There is some leeway. The 5" (125mm) f.l. eyepiece can vary from 4½" (112mm) to 5½"(135mm). The 2½" (63mm) f.l. eyepiece can be from 2" (50mm) to 2½". The diameter of the lenses need be about 1". The eye relief is high and takes some practice to becomeaccustomed to it. The spectrum has much fine detail. An eyepiece about 2" f.l. is best. Spectrohelioscope detail, using the 24 slit disk, on the solar disk in H-alpha light requires a longer focal length eyepiece because short focal lengths give too much power,which will reduce the contrast of the solar disk detail in H-alpha light.

Optical addresses. Glass blanks and lenses can be bought from:

Edmund Scientific Co.	Newport Glass Works Ltd.
300 Edscorp Bldg.	1629 Monrovia Ave.
Barrington	Costa Mesa, CA
N.J. 08007	92627

OEM. It is original equipment manufacture for an instrument. OEM grating is about 45% theoretical resolution, about 1/4 wave or less. A precision grating is about 90% theoretical resolution.

Sources for lenses, optical flats, and other items can be found in popular astronomical magazines. Check advertisements.

Concrete piers. Three concrete-wood piers are used. One is 40" (I.0 meter) high for the heliostat-telescope platform. The other two are 42" high (I.050m) for support of the spectroscope box. A pound of concrete occupies about I2 cubic inches (I87 cu. cm). One pound equals 454 grams. When pouring the concrete, remember that it sets fast, within about 30 minutes. Have three metal knobs on the bottom of the pails, or box, to give a three point contact with the sidewalk or patio surface. This prevents wobbling of the piers. The piers can weigh about 70 pounds as a minimun and will not be difficult to handle. Put two small wheels on each side of the bottom of each pier. Just pull back on the top of the pier and push forward. Then again, a low cost (about $I2) dolly can be bought from Sears and Roebuck store. The plans show a box at the bottom of the pier with inside dimensions of 9" x 9" (225mm x 225mm) and height of I0" (250mm). Volume is 8I0 cubic inches. The latter value divided by I2 cubic inches gives about 67 pounds of concrete. Add a few pounds for the nails and the wood frame brings the total to about 70 pounds (32 kilograms).

If lawn or ground is always available, then dig a hole 2 feet by 2 feet by one foot deep (0.7m x 0.7m x 0.3m). Fill it with concrete. Buy concrete drymix at a nursery. Bags cost about five dollars. The instrument does not have to be in an exact north-south direction. The RA axle does not have to be pointing exactly to the North Pole. Only for large instruments and long observing times is better alignment needed. After the first day of setting up the instrument, mark with a small paint brush, or other manner, on the concrete surface around the base of the piers. This permits rapid setting up the instrument the next day. To keep curious people a safe distance from the instrument, put a light fence around the whole instrument. It can be made of concrete filled coffee cans with a short pole. A rope links up all the poled coffee cans.

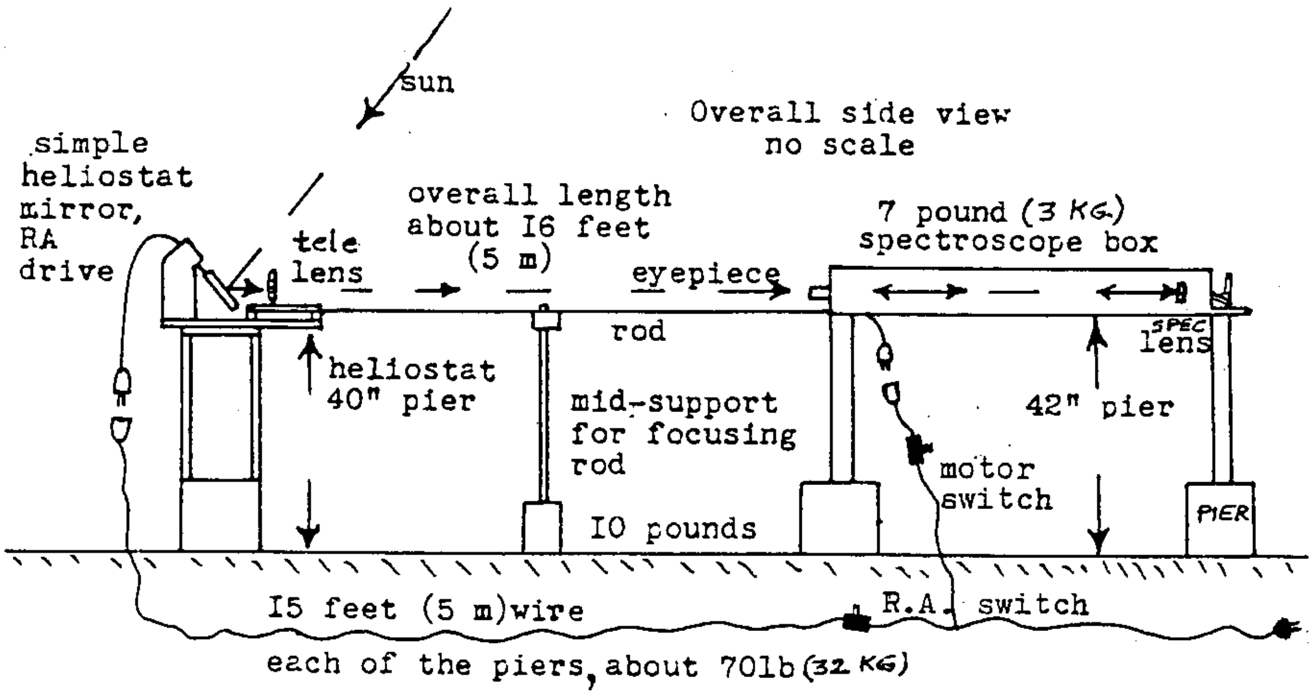
Canvas shroud. The 5" f.l. eyepiece has a short piece of canvas tubing around it. The observer's shroud has a smaller diameter tubing. It fits into the eyepiece canvas tubing. The direct sun light must be kept from the eyes. The shroud and eyepiece can be easily separated for storage. White canvas must be used, for that usually is all that can be bought, as from an upholstery shop. A piece of black cloth sewed inside the shroud keeps out the excess diffusing sun light. Total exclusion of the sun light is not necessary. When setting up the instrument, put on sun glasses. By the time the eyes are put under the shroud, they will be sufficiently dark adapted for immediate H-alpha observations. Before you take your head out of the shroud, close your eyes and put on the sun glasses. Never look into the heliostat mirror to locate the sun in order to position it on the entrance slit. Watch the sun image on the ground and place it on the entrance slit by tilting the mirror.

PLANS FOR STRAIGHT LINE DESIGN

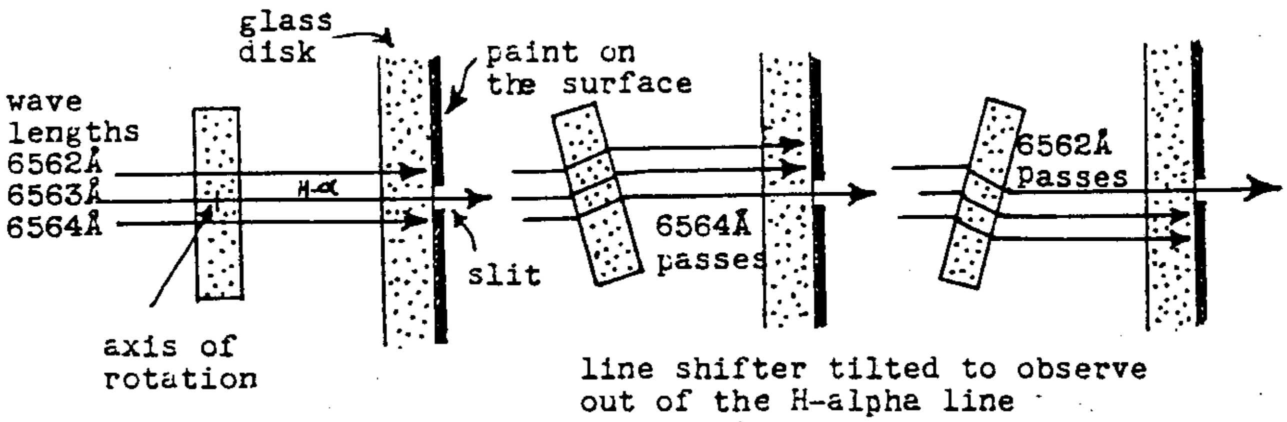
SPECTROHELIOSCOPE

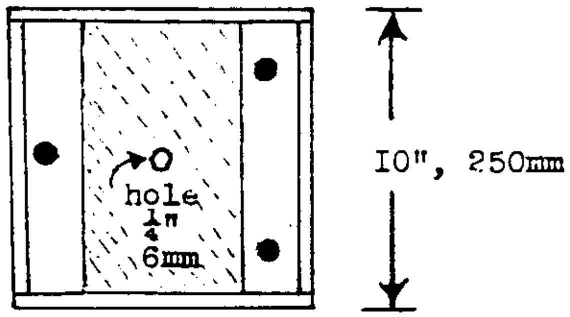
A heliostat is easy to build and low cost. It is good for a few hours long observing. For almost all day viewing the sun, a coelostat is best. Draw plans up to full scale.

Instead of an all concrete filled pier, just fill half the pier bottom with concrete of 30 pounds; then have a 30 pound sack of dirt or sand to put inside the pier.



HOW THE LINE SHIFTER FUNCTIONS



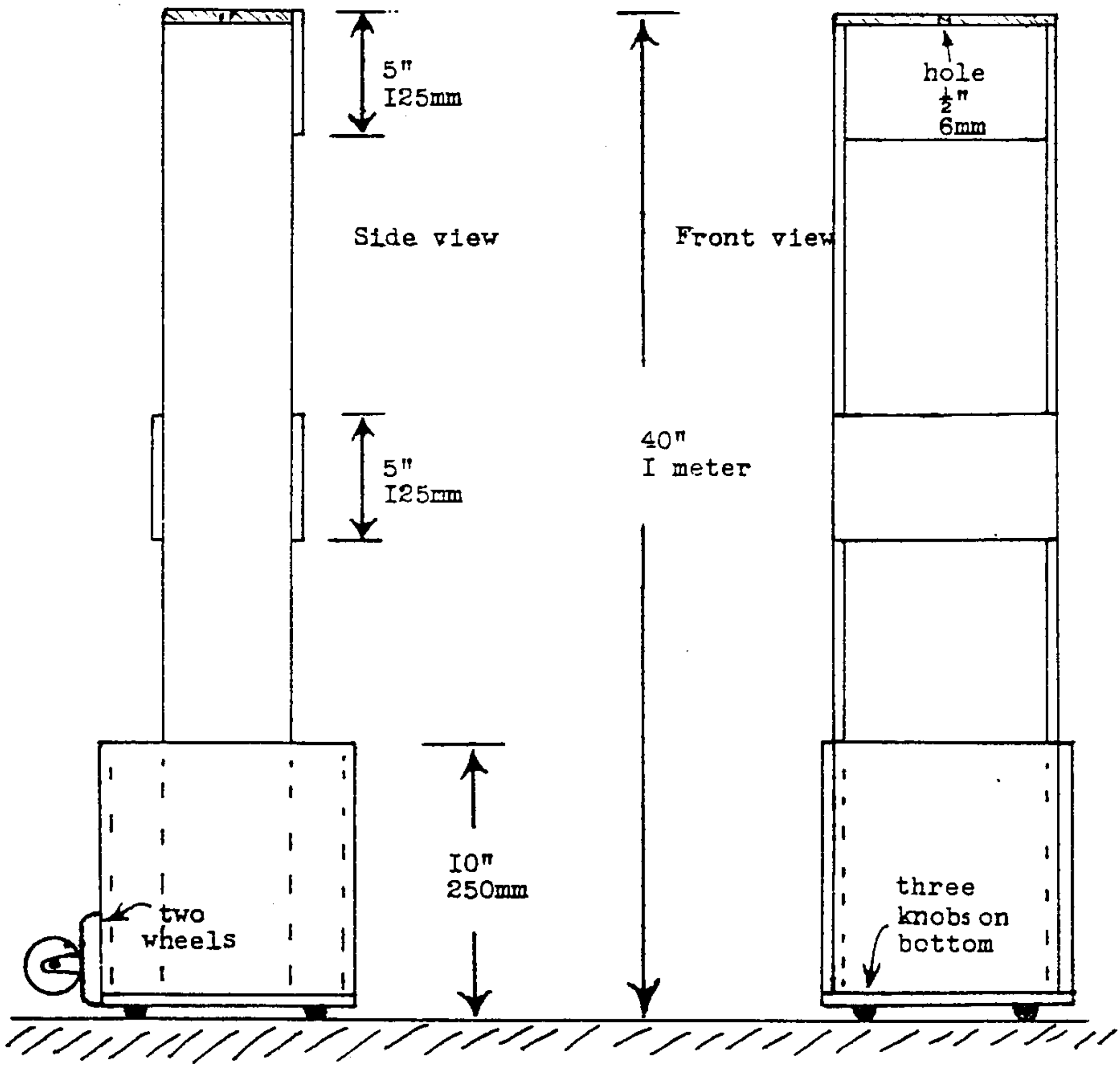


Top view

HELIOSTAT PIER for the heliostat-telescope lens platform. Three views.

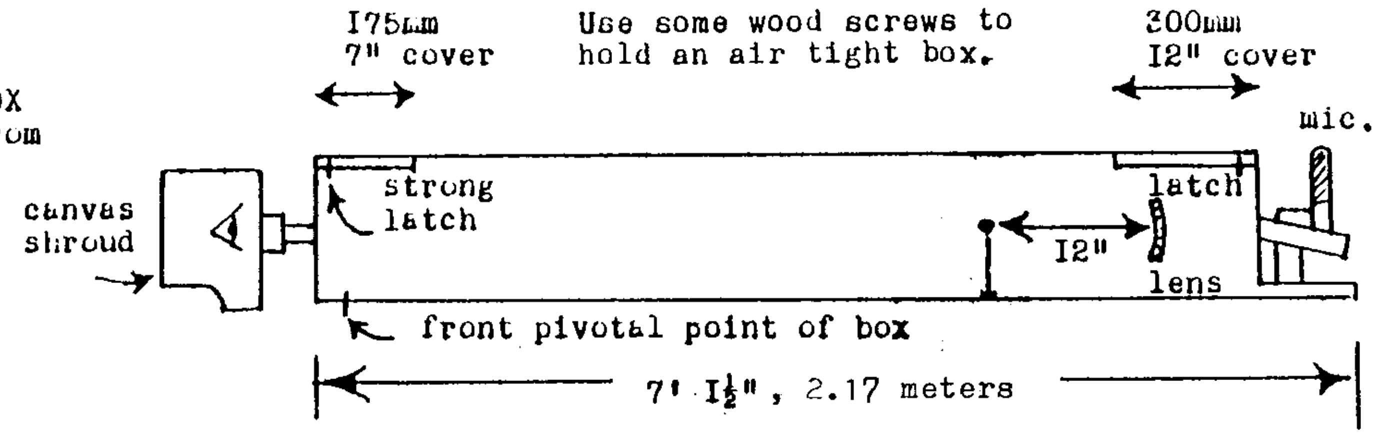
Scale none

The other two piers for support of the spectroscope box are 42" high (1.05m). One of them has a ¼" hole (6mm) on the top board for placement of the front of the spectroscope box.

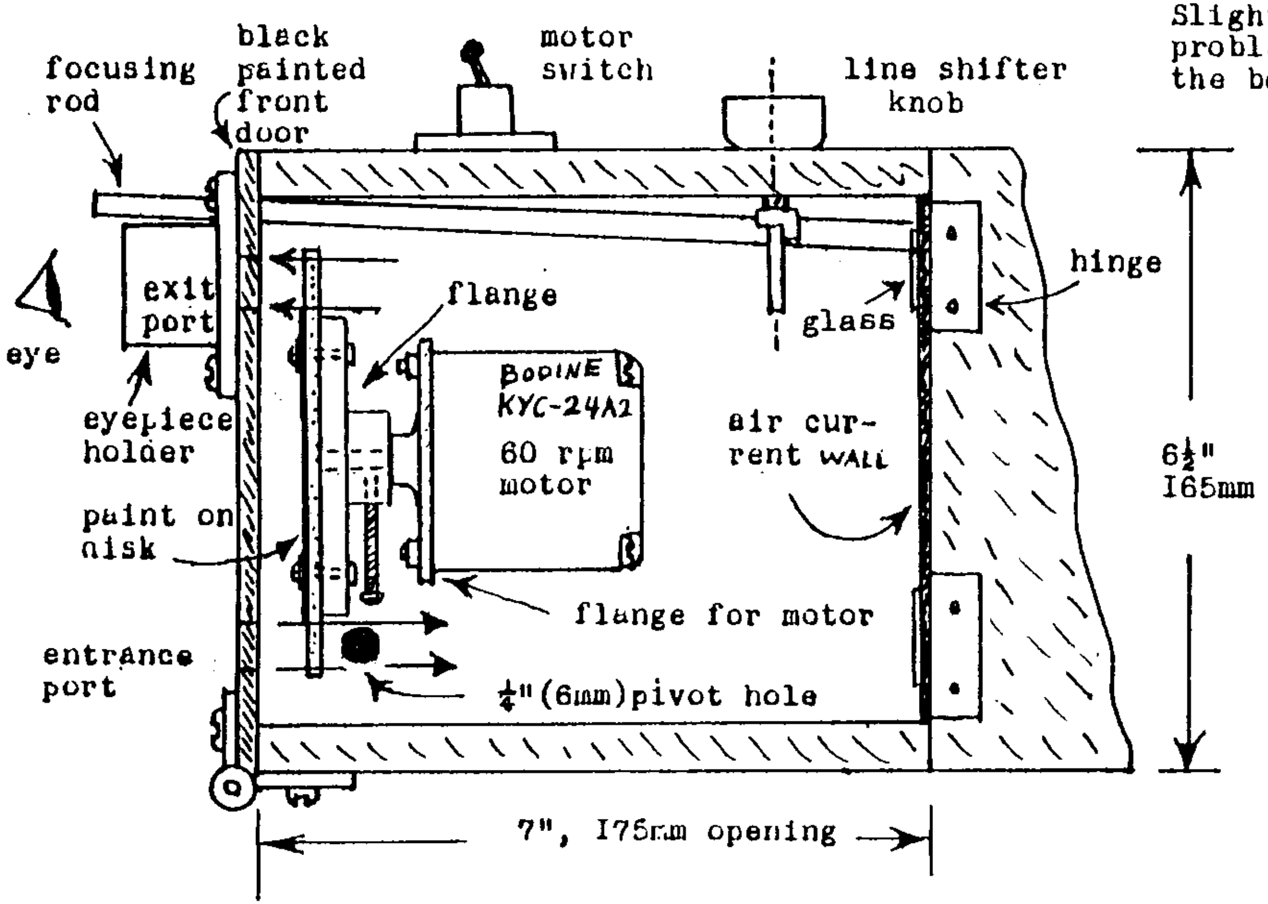


SPECTROSCOPE BOX
Overall view from
the side

no scale



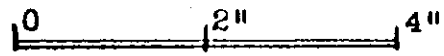
Slight air currents are not a problem, But put many baffles in the box anyway as precaution.



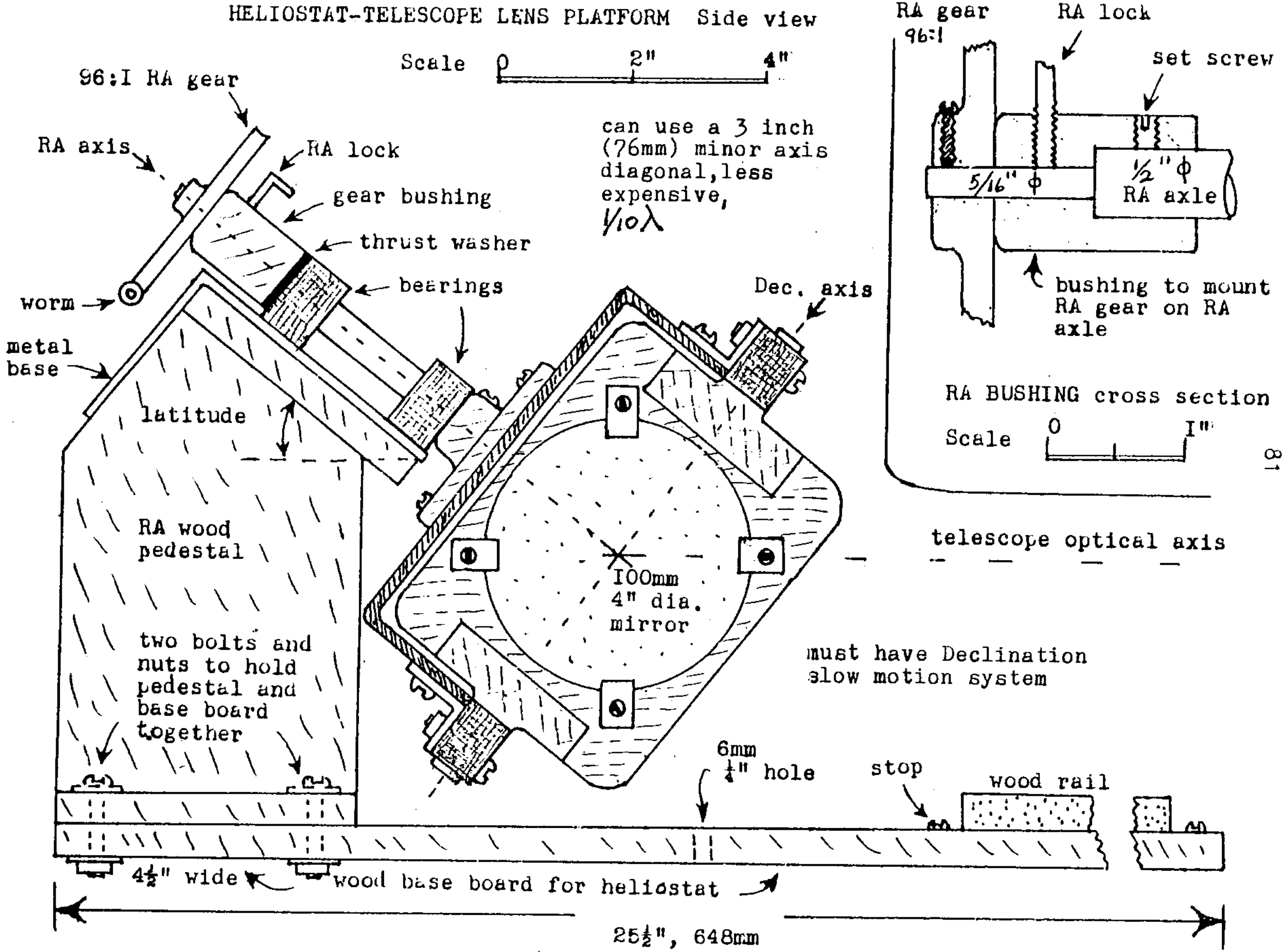
A Bodine or Hurst motor is not necessary. Use a secondary axle support. On one end of the axle place the glass disk. On the other end have spur gears link up with a motor.

FRONT OF
SPECTROSCOPE
BOX
Top view

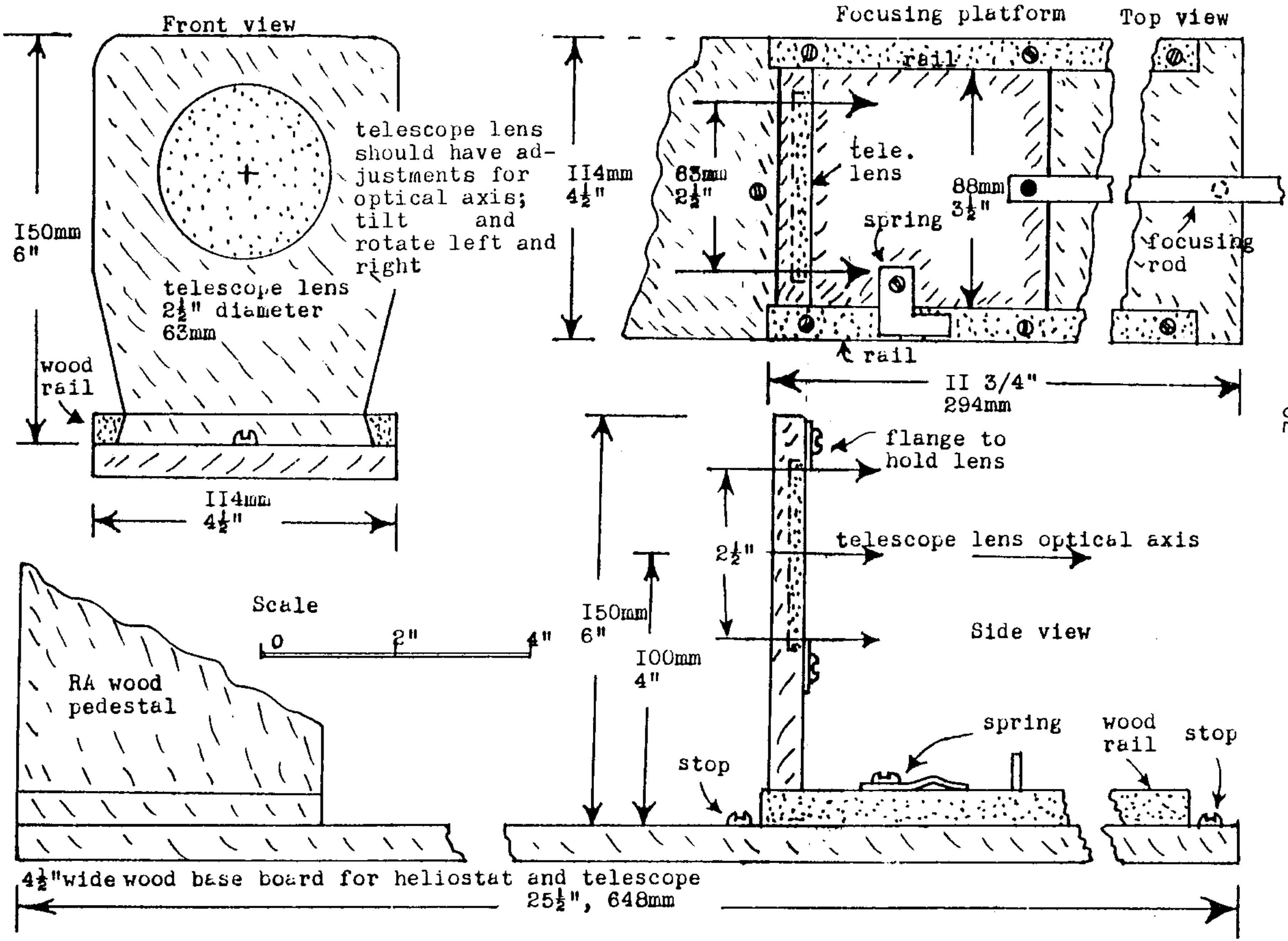
Scale

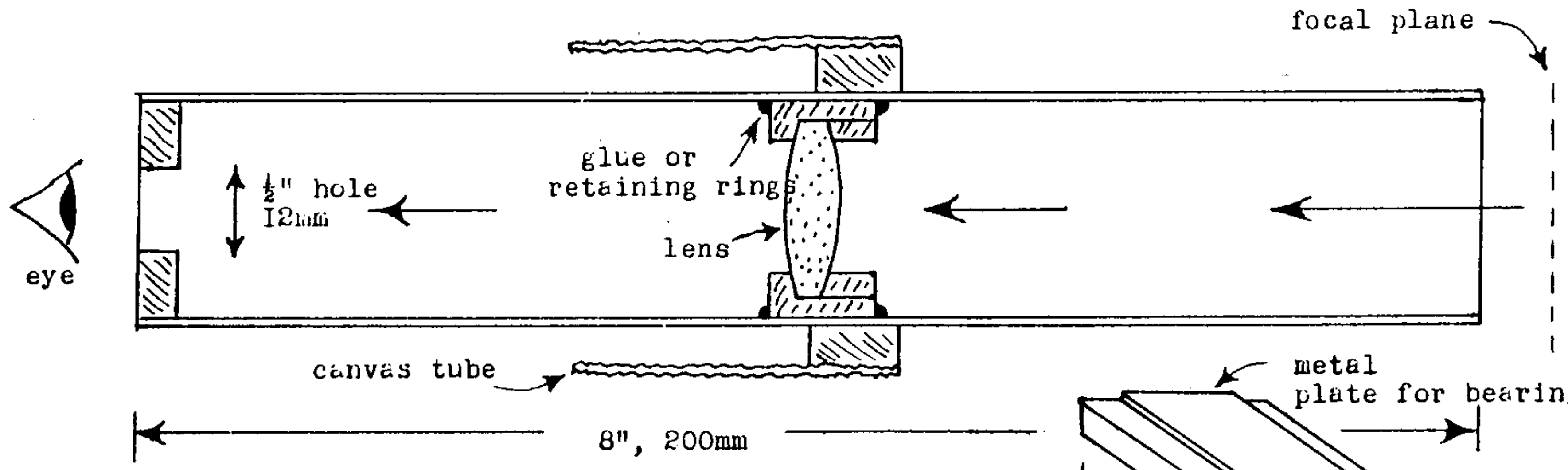


HELIOSTAT-TELESCOPE LENS PLATFORM Side view



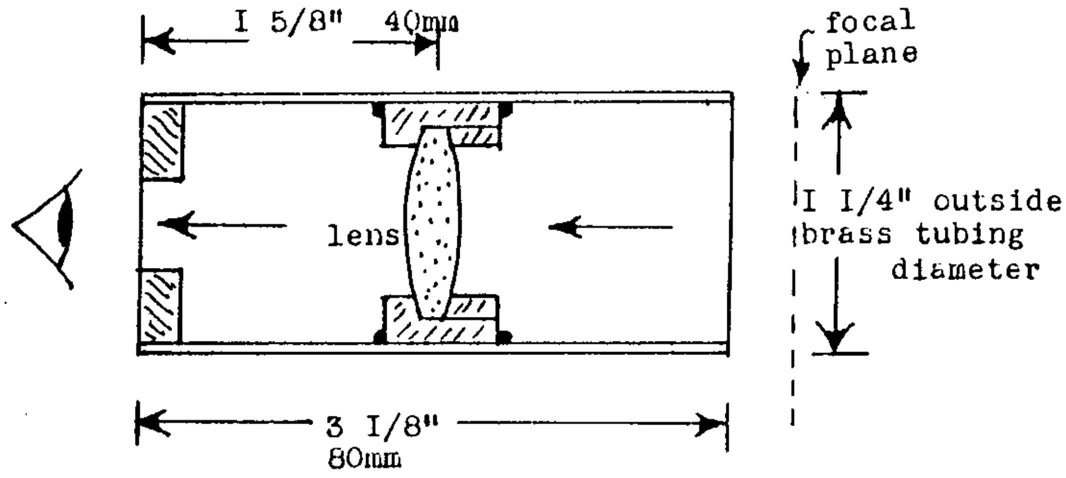
HELIOSTAT-TELESCOPE LENS PLATFORM showing focusing arrangements





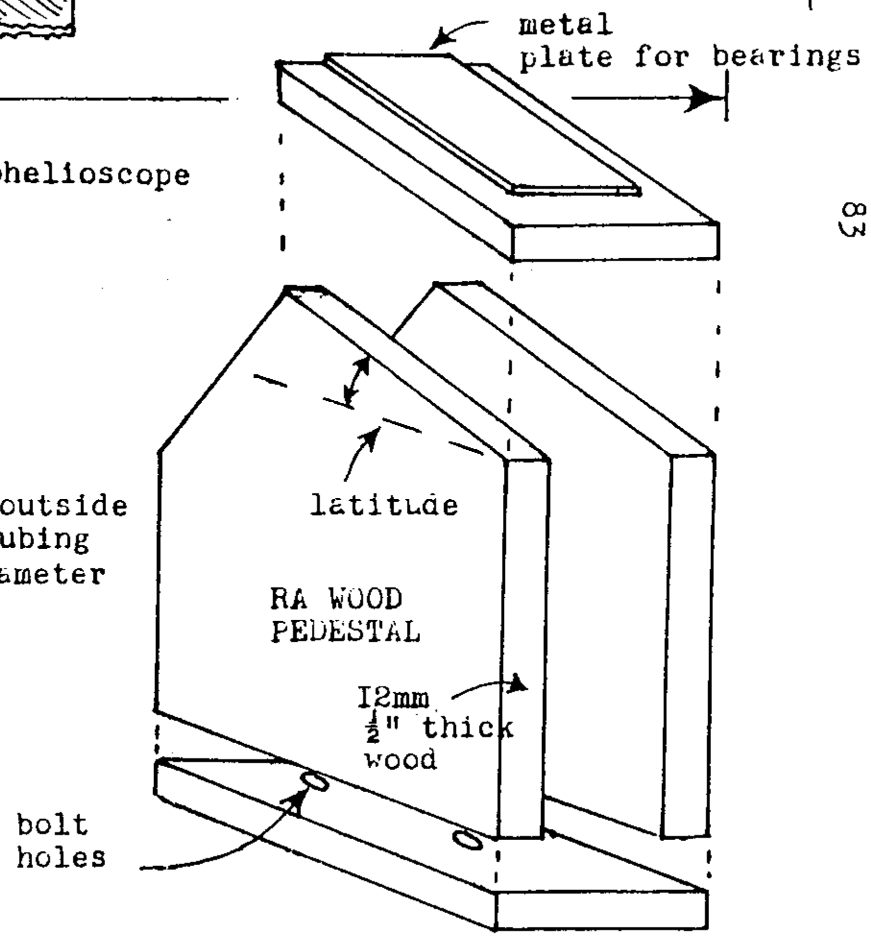
EYEPIECE 5", I25mm f.l., spectrohelioscope

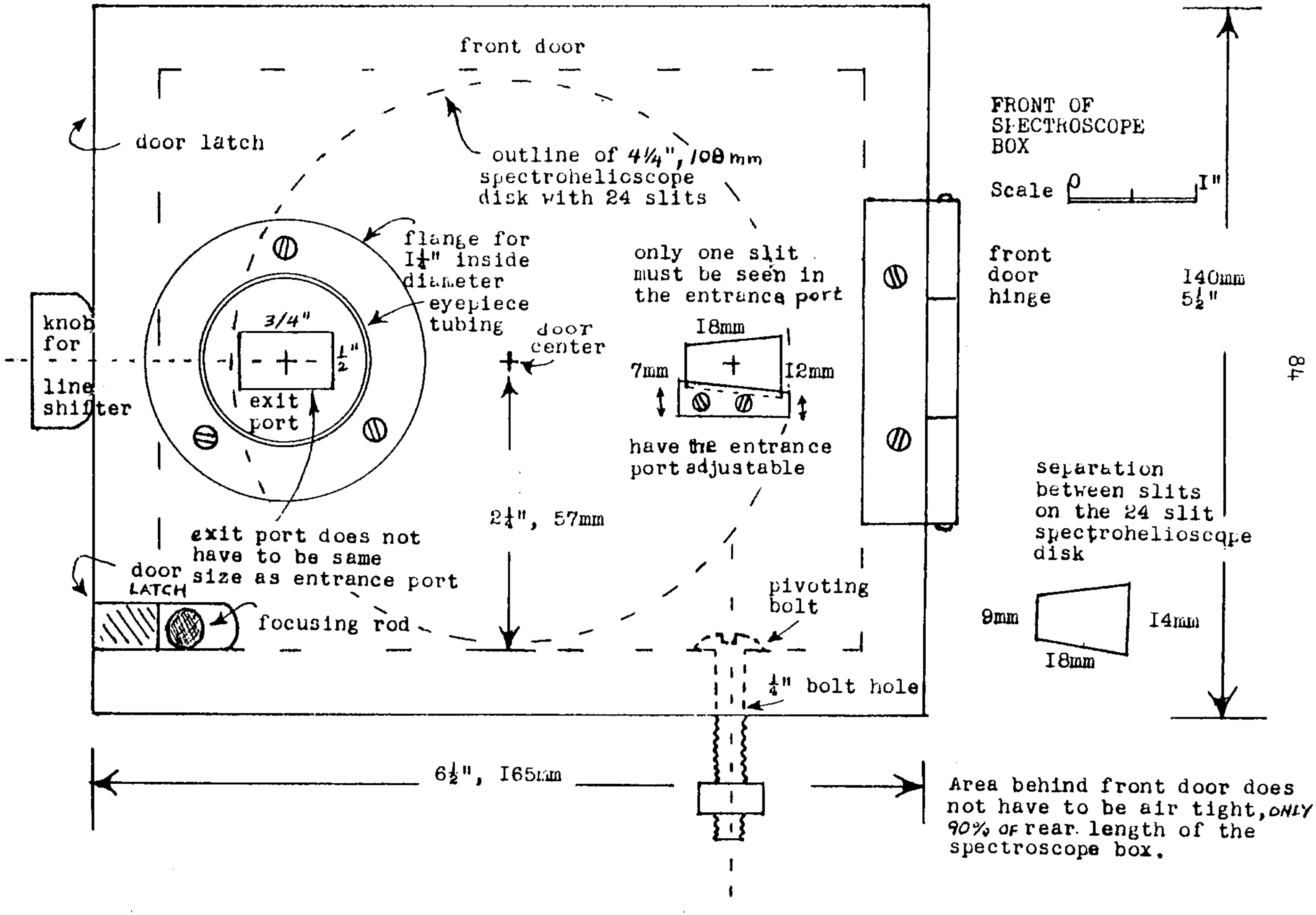
Scale 0 I" 2"

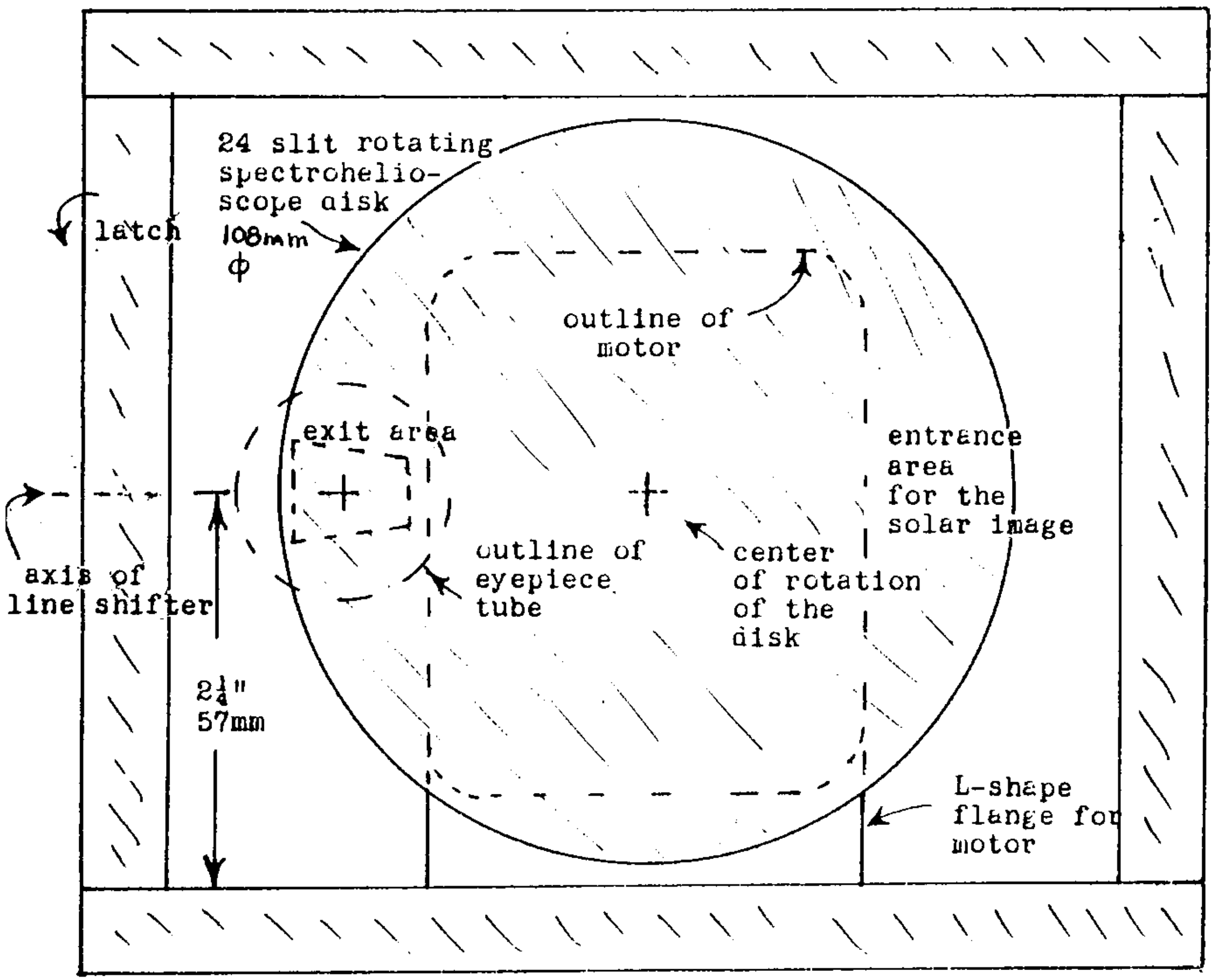


EYEPIECE 2", 50mm f.l.,

spectroscope



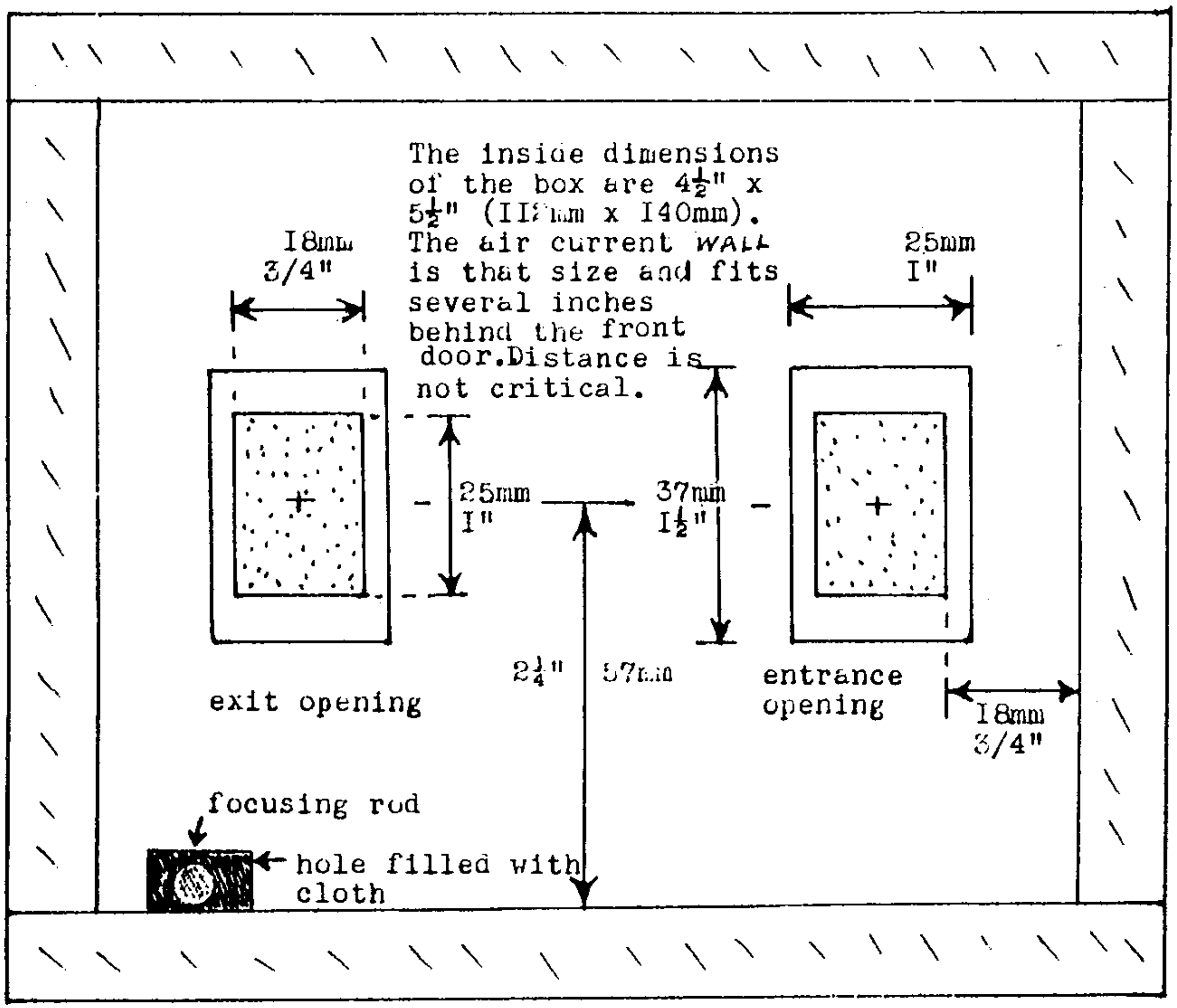

FRONT OF SPECTROSCOPE BOX
Scale 0 1"
front door hinge
140mm 5½"
separation between slits on the 24 slit spectroheliloscope disk
9mm
14mm
18mm
front door
door latch
outline of 4¼", 108 mm spectroheliloscope disk with 24 slits
flange for 1½" inside diameter eyepiece tubing
3/4"
½"
exit port
knob for line shifter
door center
only one slit must be seen in the entrance port
18mm
7mm
12mm
have the entrance port adjustable
2¼", 57mm
exit port does not have to be same size as entrance port
door LATCH
focusing rod
pivoting bolt
¼" bolt hole
6½", 165mm
Area behind front door does not have to be air tight, ONLY 90% OF rear length of the spectroscope box.



FRONT OF
SPECTROSCOPE
BOX
Front door is
removed.

Scale
0 1"

Small motors with 1/8" diameter output axle have 0.005" eccentricity, causing wobble of the glass disk. Bodine KYC motor has 0.001" eccentricity, causing no problem.



Different shape of glass can be used instead of square.

AIR CURRENT WALL

Front view showing the glass.

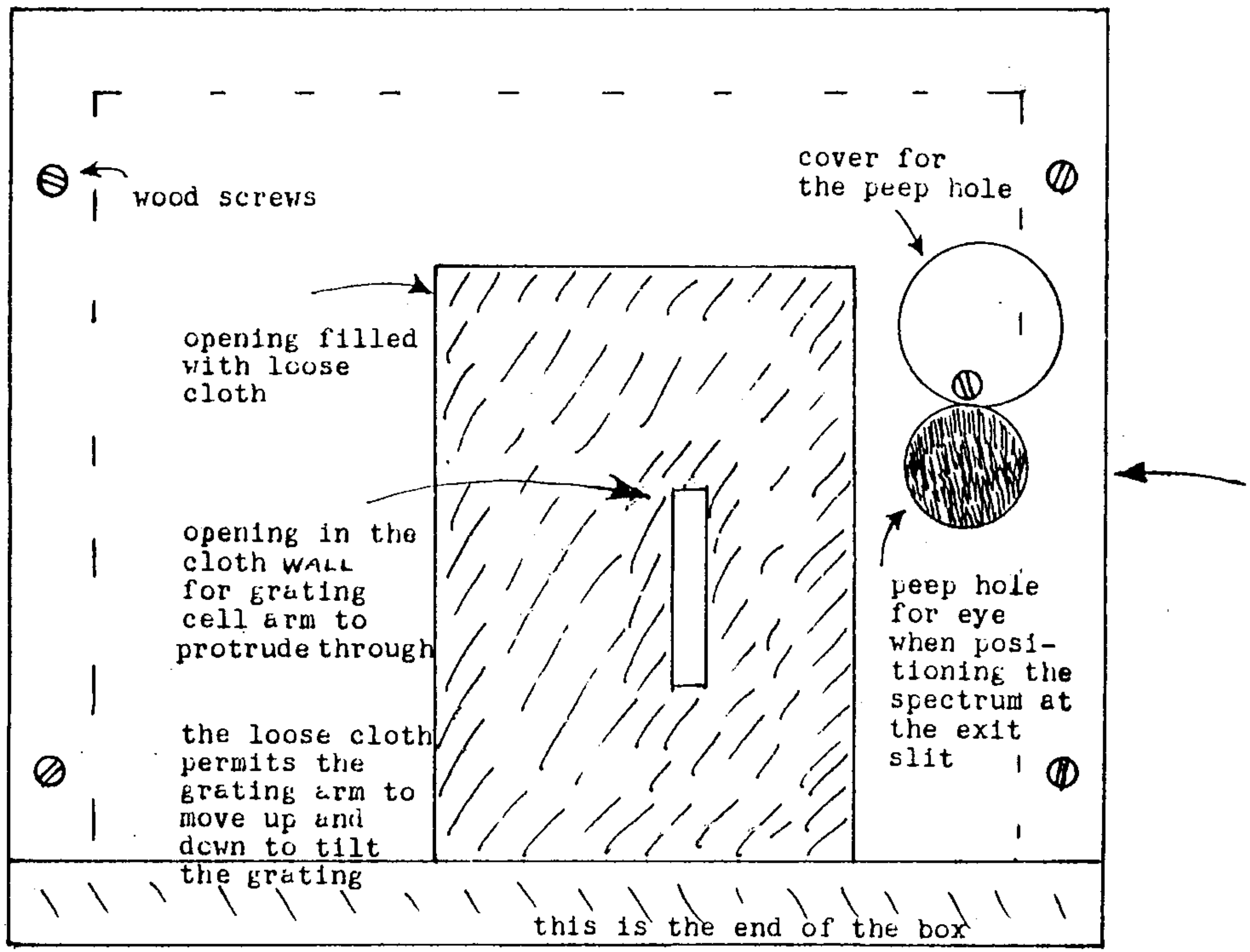
Front door and motor removed for this view.

Scale
0 I"

This thin wall isolates the spectroscope box from the motor and rotating glass disk so ripples of air do not go down the full length of the box. This will give a more even view of the solar disk in H-alpha light.

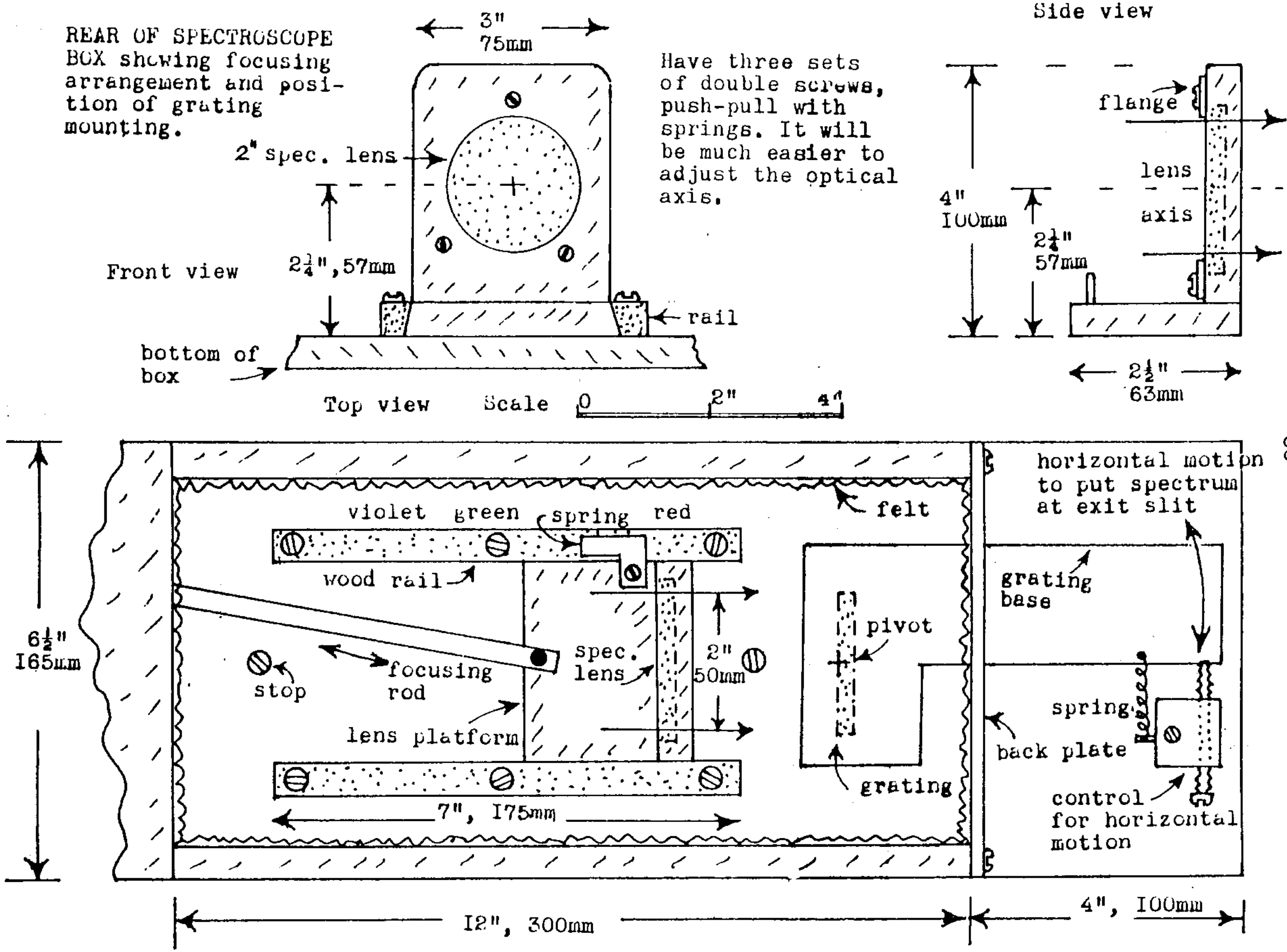
REAR OF THE
SPECTROSCOPE
BOX

Scale
0 I"

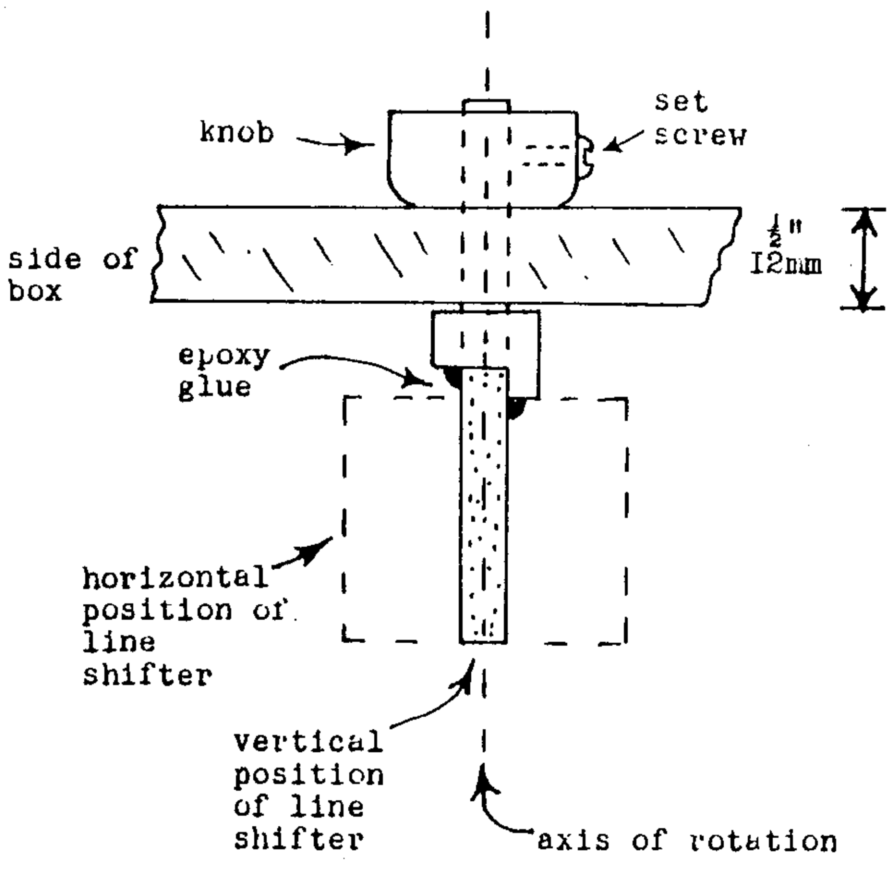


metal back plate I/8" thick (3mm) to cover end of the box

The cloth opening must be attached to the grating cell arm so that air can not flow through it.



REAR OF SPECTROSCOPE BOX showing focusing arrangement and position of grating mounting.



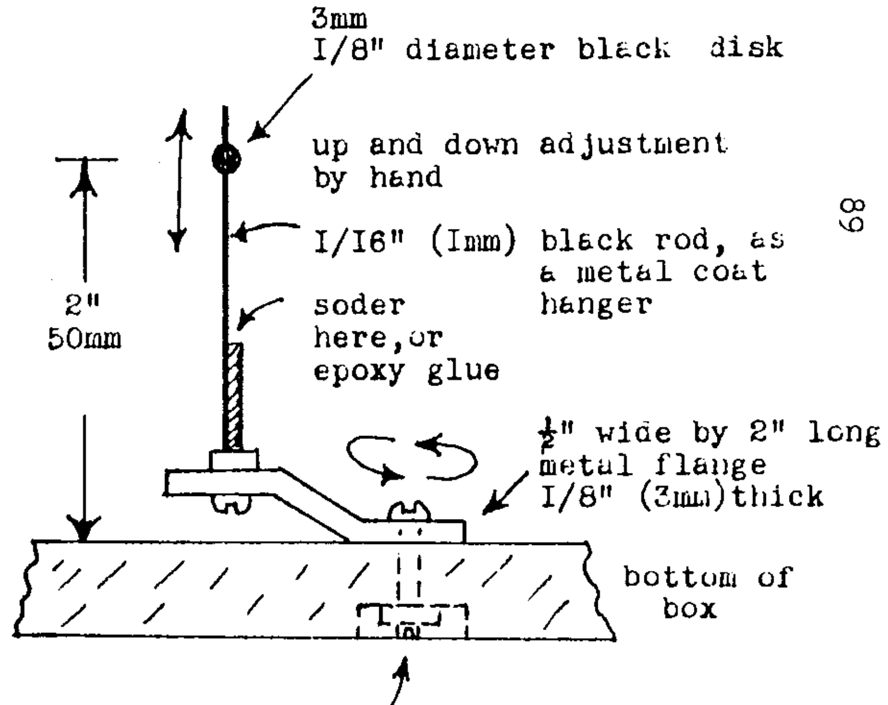
LINE SHIFTER
Top view

Scale 0 I"

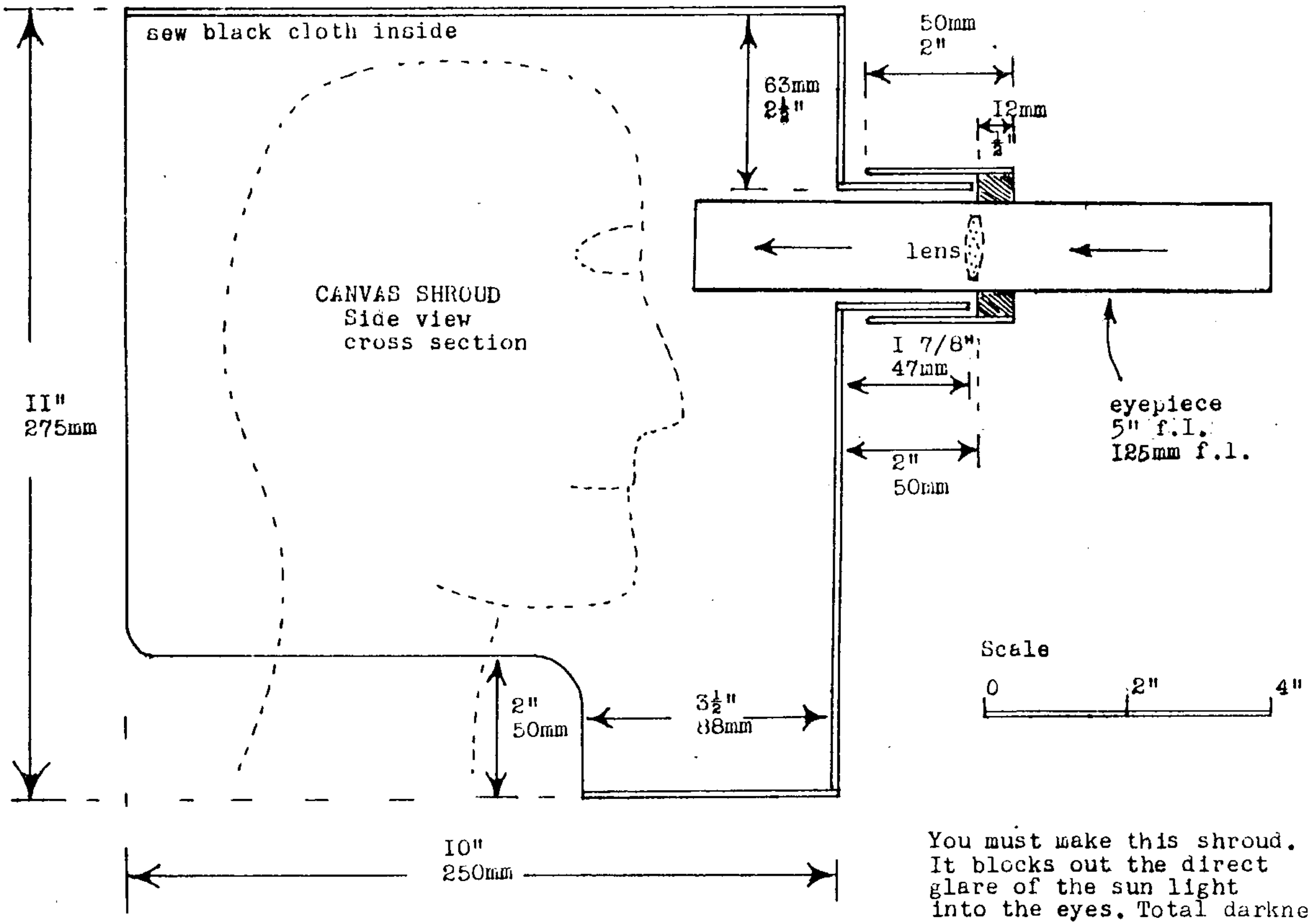
The distance of the line shifter from rotating glass disk is not critical. A few inches (cm) or more is workable.

BLOCKING DISK
for the spectroscope lens. Side view.

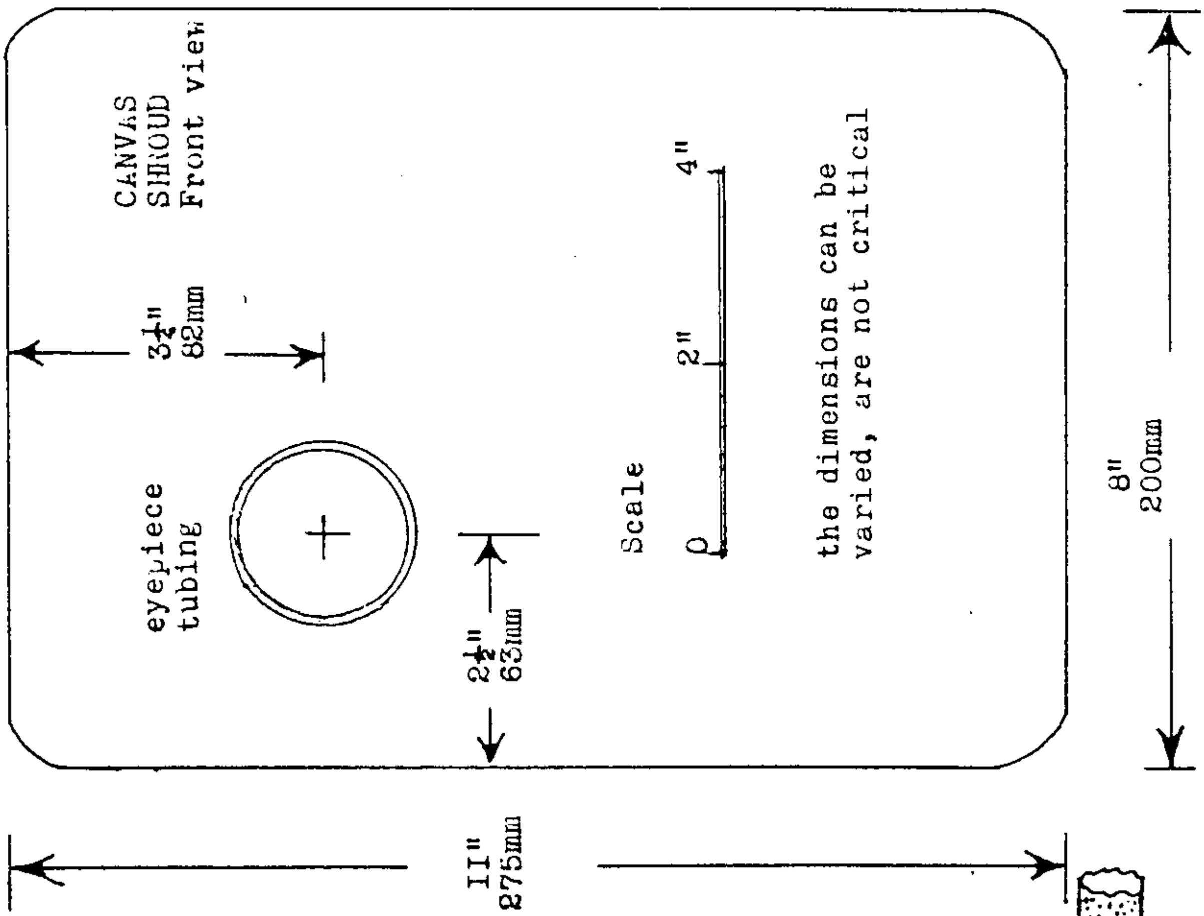
Scale 0 I"

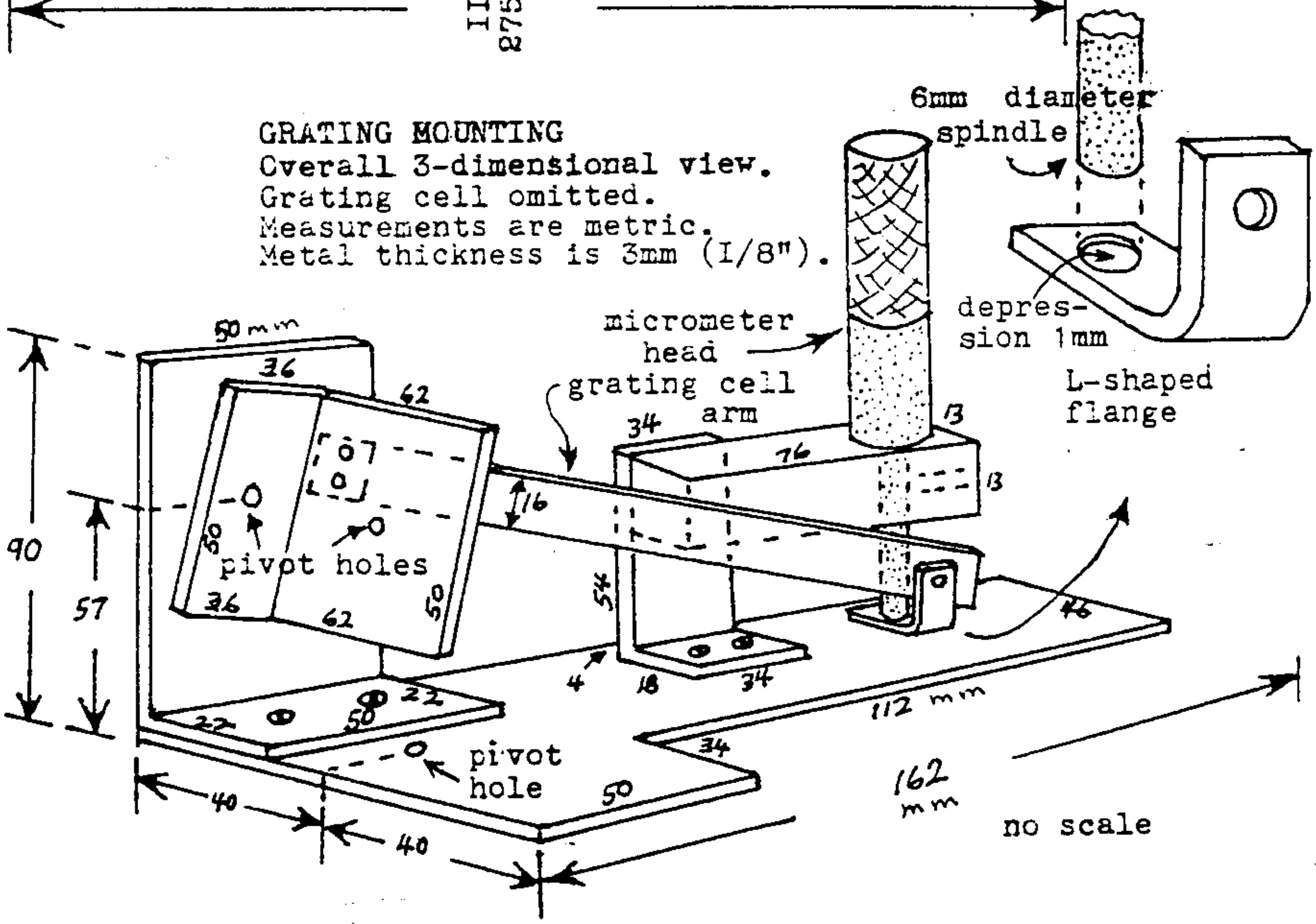


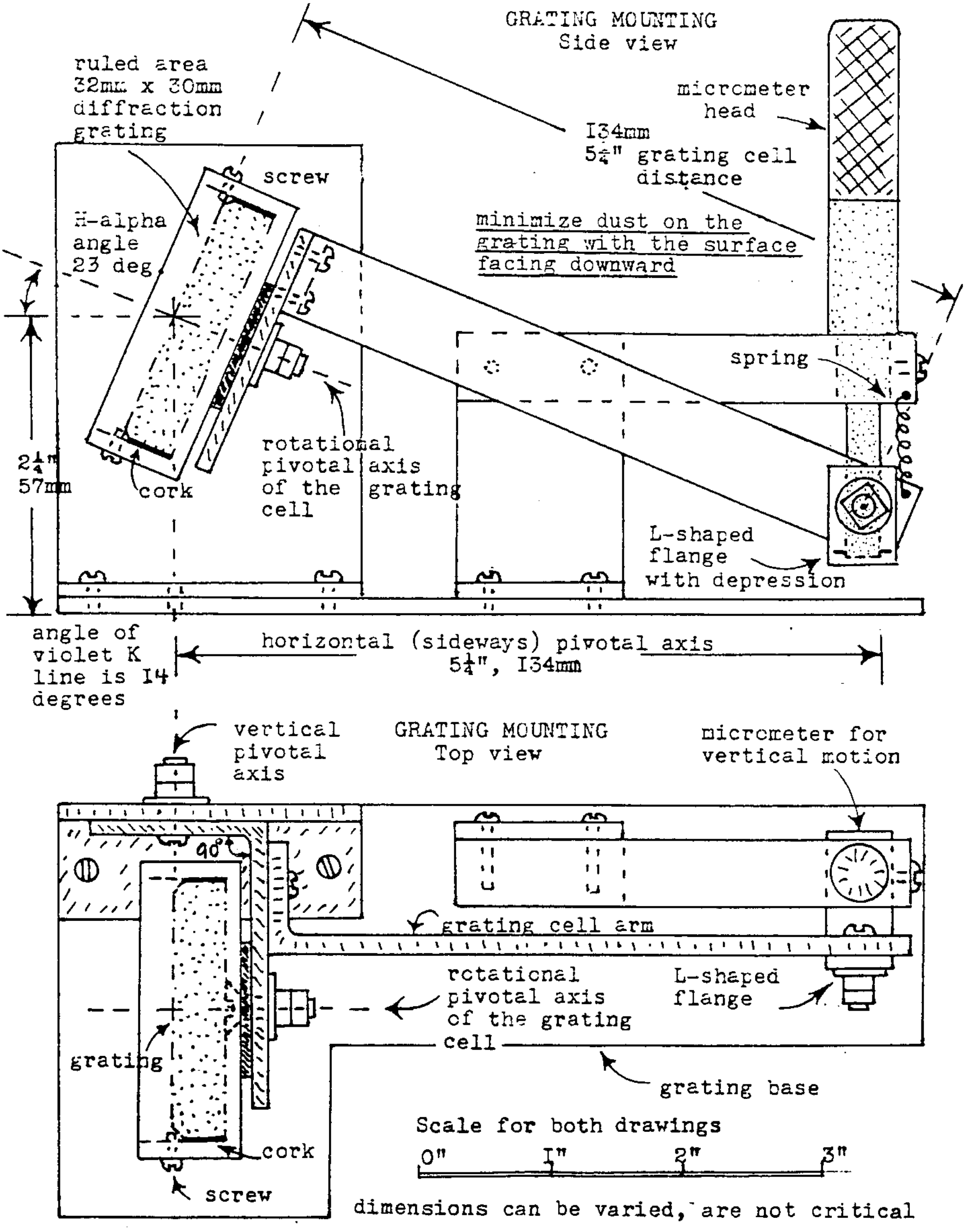
Rotate here with screw driver to block out extraneous reflection; should have an assistant to rotate WHILE you are looking into the box through the eyepiece holder; saves time.

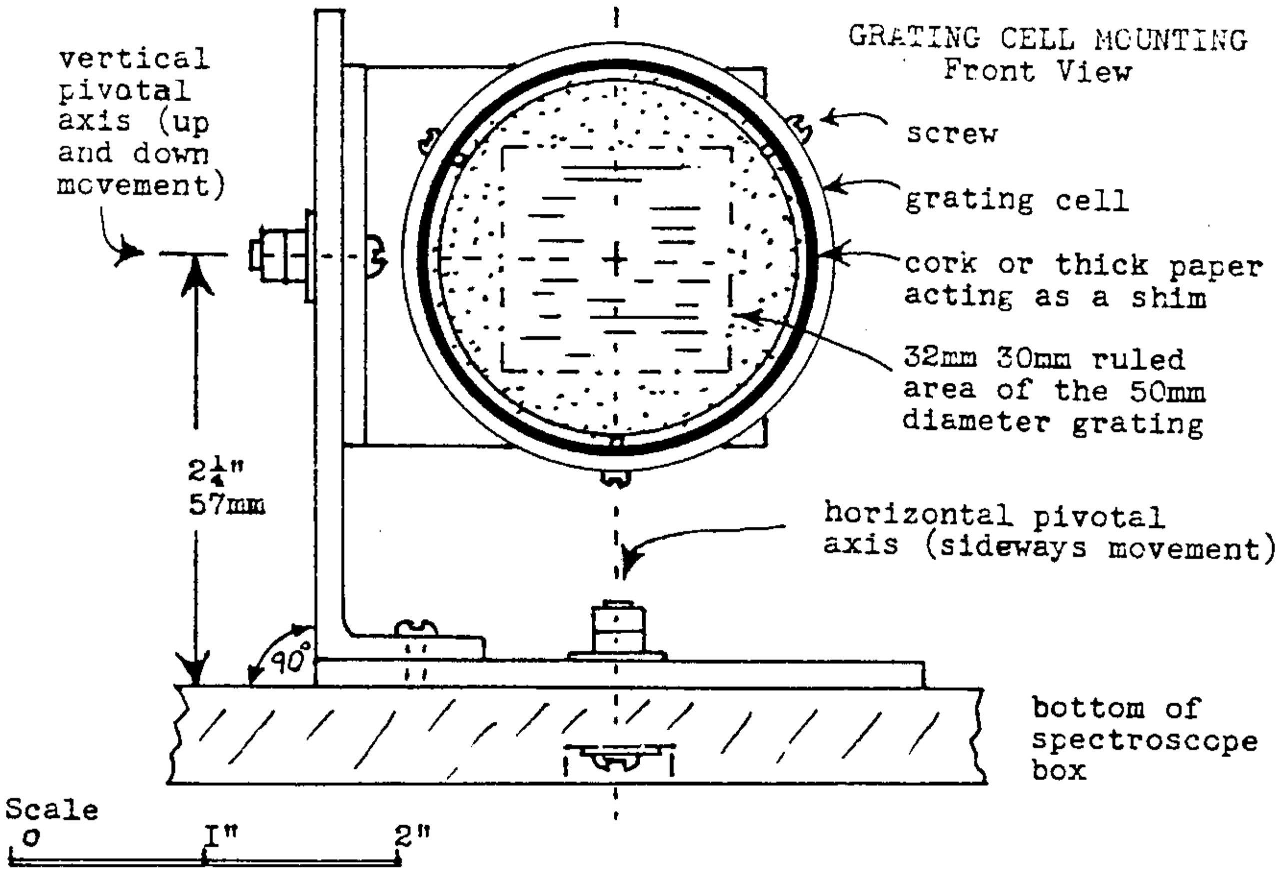


You must make this shroud. It blocks out the direct glare of the sun light into the eyes. Total darkness is <u>not</u> necessary.


CANVAS SHROUD Front view
3¼" 82mm
eyepiece tubing
2½" 63mm
Scale
0
2"
4"
the dimensions can be varied, are not critical
8" 200mm
11" 275mm


GRATING MOUNTING
Overall 3-dimensional view.
Grating cell omitted.
Measurements are metric.
Metal thickness is 3mm (1/8").
6mm diameter spindle
micrometer head
grating cell arm
depression 1mm
L-shaped flange
pivot holes
pivot hole
no scale
50 mm
36
62
34
76
13
13
16
30
26
62
50
54
4
18
34
46
22
50
22
34
112 mm
162 mm
50
40
40
90
57


GRATING MOUNTING
Side view
ruled area
32mm x 30mm
diffraction
grating
screw
H-alpha
angle
23 deg
micrometer
head
I34mm
5¼" grating cell
distance
minimize dust on the
grating with the surface
facing downward
spring
2¼"
57mm
cork
rotational
pivotal axis
of the grating
cell
L-shaped
flange
with depression
angle of
violet K
line is I4
degrees
horizontal (sideways) pivotal axis
5¼", I34mm
GRATING MOUNTING
Top view
vertical
pivotal
axis
micrometer for
vertical motion
90°
grating cell arm
rotational
pivotal axis
of the grating
cell
L-shaped
flange
grating
grating base
cork
screw
Scale for both drawings
0"
I"
2"
3"
dimensions can be varied, are not critical



Dust. Drawing on the previous page for the grating mounting, the grating is tilted backward, facing upward at an angle. In this position dust will slowly settle on the surface of the grating, even if the cover is over the grating most of the time. A trace of dust will scatter a little solar light down the spectroscope box. A trace of dust is no serious problem. But too much dust over a period of years accumulated on the surface of the grating will scatter too much light. It was realized by the author years later that the best orientation of the surface of the grating is to have a forward tilt of the grating, facing somewhat downward at an angle. Thus no dust will ever settle on the surface of the grating, keeping it clean a long time. The grating will function a long time if properly protected.

For the first order of the grating, a simple micrometer and spring arrangement will work. But for higher orders, it is best to have a worm and gear arrangement to rotate the surface of the grating at steep angles, about 40 to 50 degrees in the second order, and about 70 to 80 degrees in the third and fourth orders of a 1200 gr./mm grating. In most spectroscopes for finest spectral detail possible, about 5 to 10 microns entrance slit (.0005") is best in order to sharpen up the spectral lines, particularly the faint lines. The medium strong to strong spectral lines take care of themselves. An entrance slit of 25 microns (.001") is an acceptable compromise only.

MIRROR REFLECTION SYSTEMS

There are many flat mirrors reflection systmms, which can direct the solar beam into the telescope. Quartz is preferred, at least to 1/10 wave flatness, and pyrex is next best. If the surface is 1/10 wave, the wave front off the mirror will be 1/5 wave into the telescope. For a two mirror system, both 1/10 wave, this produces about 1/2 wave into the optics. So 1/15 to 1/20 wave mirrors are best. The center axis of the Declination axle must pass along, within 0.5mm or less of front surface of the mirror. Counterweights will be needed to balence the mirror and its cell.

A siderostat has one mirror to reflect the sun light horizontally to the ground into the telescope, which is orientated in a north-south direction. The RA axle is separated from the nearby mounted mirror, which is connected to the RA axle by a special linkage that keeps the sun light directed at the telescope. Refer to J. B. Sidgwick for more details.The construction is a little complicated but the system works good.

A simple heliostat uses one mirror, which reflects the sun light horizontal to the ground into the optics, orientated in a north-south direction. A polar heliostat employs one mirror, placing the sun light into the telescope such that the optical axis and the RA axis both point towards the North Pole. A Dove prism located near the prime focus counters the rotation of the sun image. A two mirror heliostat has the RA axis of the primary mirror directed to the North Pole. The fork mounted primary mirror reflects sun light to a fixed secondary mirror, which places the sun light in a horizontal or vertical direction. There is no shadow by the secondary mirror on the primary during the year.

A two mirror coelostat places the sun beam in a horizontal or vertical direction. The twomirrors are located in a north-south direction. Rotation of the sun image by the primary mirror is countered by the secondary mirror so that the sun image at the prime focus is stationary. The angle of the primary mirror is set by the latitude of the worker. The primary mounting must be shifted in a north-south position in order to reflect the sun light onto the secondary mirror, for the sun changes its Declination during the year. In the autumn and spring, the secondary mirror casts a shadow; therefore, the primary mirror must be moved eastward at forenoon and westward in the afternoon. This offset method slightly changes the orientation of the sun image at the prime focus. Just let the sun drift in RA in order to determine the angle with the horizontal to the ground.

There are two other interesting coelostat arrangements. At the Arcetri Observatory, Italy, the north-south movement of the primary mirror is along a plane in line with the North Pole. This simple change reduces the north-south travel distance by about half as compared tothe primary mirror moving in a horizontal manner. At the Kitt Peak National Observatory on top of the 120-foot Solar Tower,the primary mirror moves on a track about the vertical telescope .Also the secondary mirror adjusts up and down during the year. The primary mirror is on a platform, and the latter moves on a semi-circular track about the telescope objective. To maintain alignment on the North Pole, if the primary mirror is placed, for example, 40 degrees eastward on the track, then the mirror platform must be rotated 40 degrees in the opposite direction. This Zeiss two mirror coelostat was first used in the Einstein Solar Tower in Potsdam, Germany, about 1930.

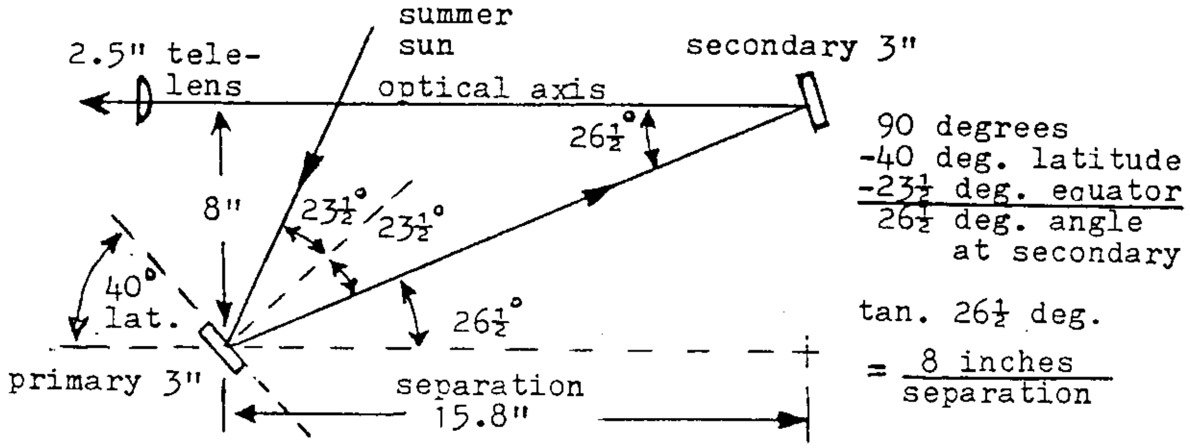
An equatorial mounting with a solar rate for the RA axle is 1440:1 total gear reduction ratio with a I rpm motor. A 96:1 and a 15:1 gear ratio is appropriate. For a 2 mirror coelostat, a 2880:1 total gear reduction ratio with a 1 rpm motor is needed. This is equal to 96:1 and 30:1 gear ratios, or equivalent. For a simple heliostat, a 2000:1 total gear reduction ratio is good for a latitude about 36 degrees. So use a 96:1 and a 20:1 gear ratios, being sufficiently close. If you can not obtain a 96:1 gear ratio, then use a 100:1 gear ratio. Any drifting of the solar image can be corrected by slow motion controls.

With a portable spectroheliscope, there is no need for exact adjustment of the RA axle towards the North Pole and no need for exact alignment of the instrument in a north-south direction. Small errors will cause little drifting of the sun image in RA and in Declination but slow motion controls can correct it. For observing a few hours a day, about once or twice a week, the needed slow motion corrections will not be bothersome. For all day observation spells, day after day, it is necessary to have exact adjustments. A permanent observatory is then desired.

Mirror system	RA drive rate	Final gear red. ratio	Constant slow motion controls	Rotation of sun image
2 mirror coelostat	1.0 rev/ 48 hours	2880:1	no	no
siderostat	1.0 rev/ 24 hours	1440:1	no	yes
2 mirror heliostat	1.0 rev/ 24 hours	1440:1	no.	yes
polar heliostat	1.0 rev/ 24 hours	1440:1	no	yes
simple heliostat	0.7 rev/ 24 hours	2100:1	yes, in Dec.	yes

For more details on the siderostat, see J. B. Sidgwick.
The author does not have time to make and test all mirror systems above. The 2 mirror coelostat and simple heliostat have correct RA drive gear ratios. The other mirror systems are inferred.

As the sun changes Declination in the sky from month to month, the primary mirror must be moved towards or away from the secondary mirror. The maximum separation of the primary in the summer time from the secondary mirror can be calculated. Assume an 8" (200mm) vertical height difference of the primary mirror from the telescope axis. A n example will be 40 ° latitude.

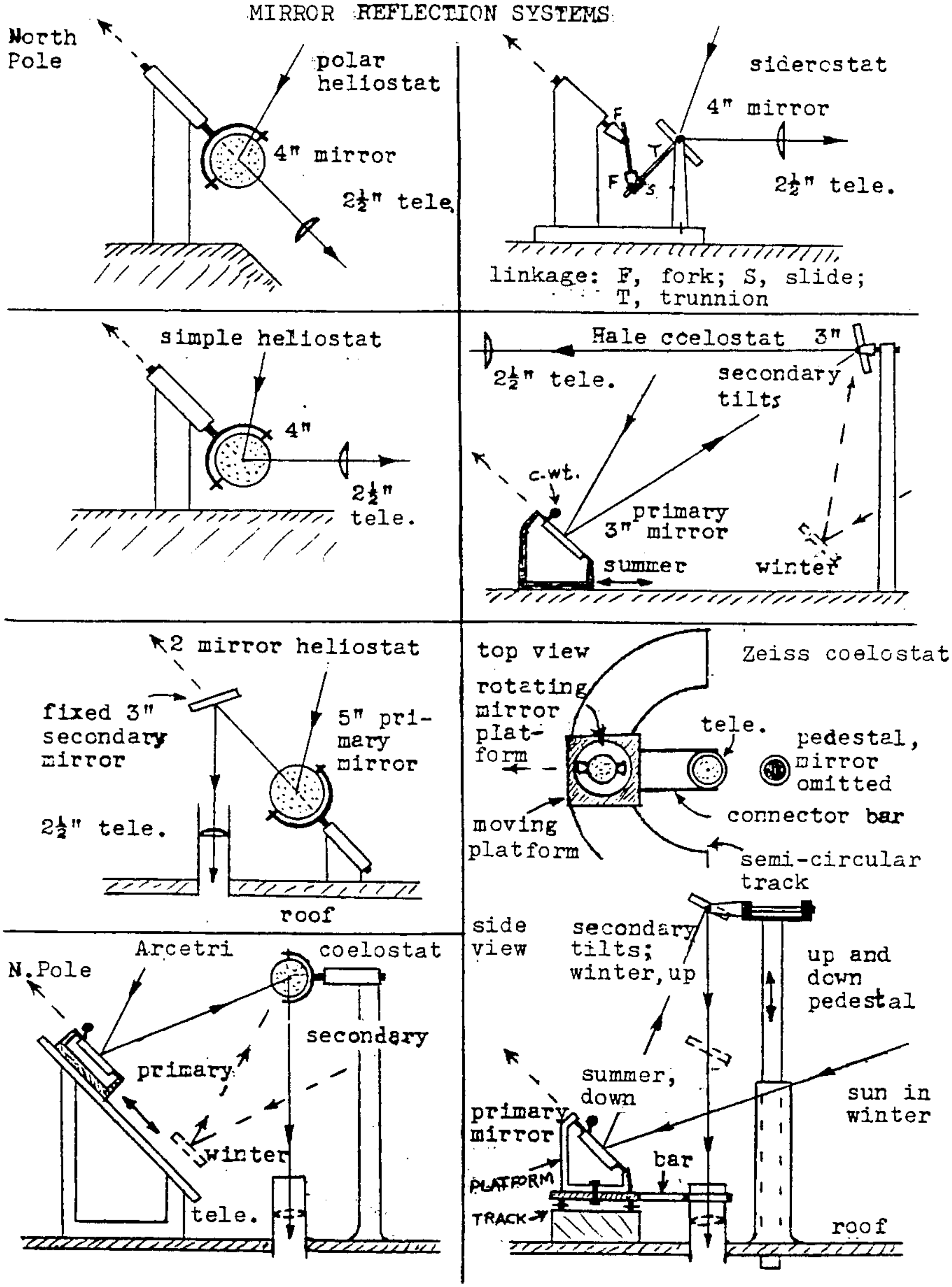


Add extra distance to the rear of the primary mirror and to the front of the coelostat platform in order to get the total length of the platform. The length of the stainless steel rails will be about four inches (100mm) less than the total length.

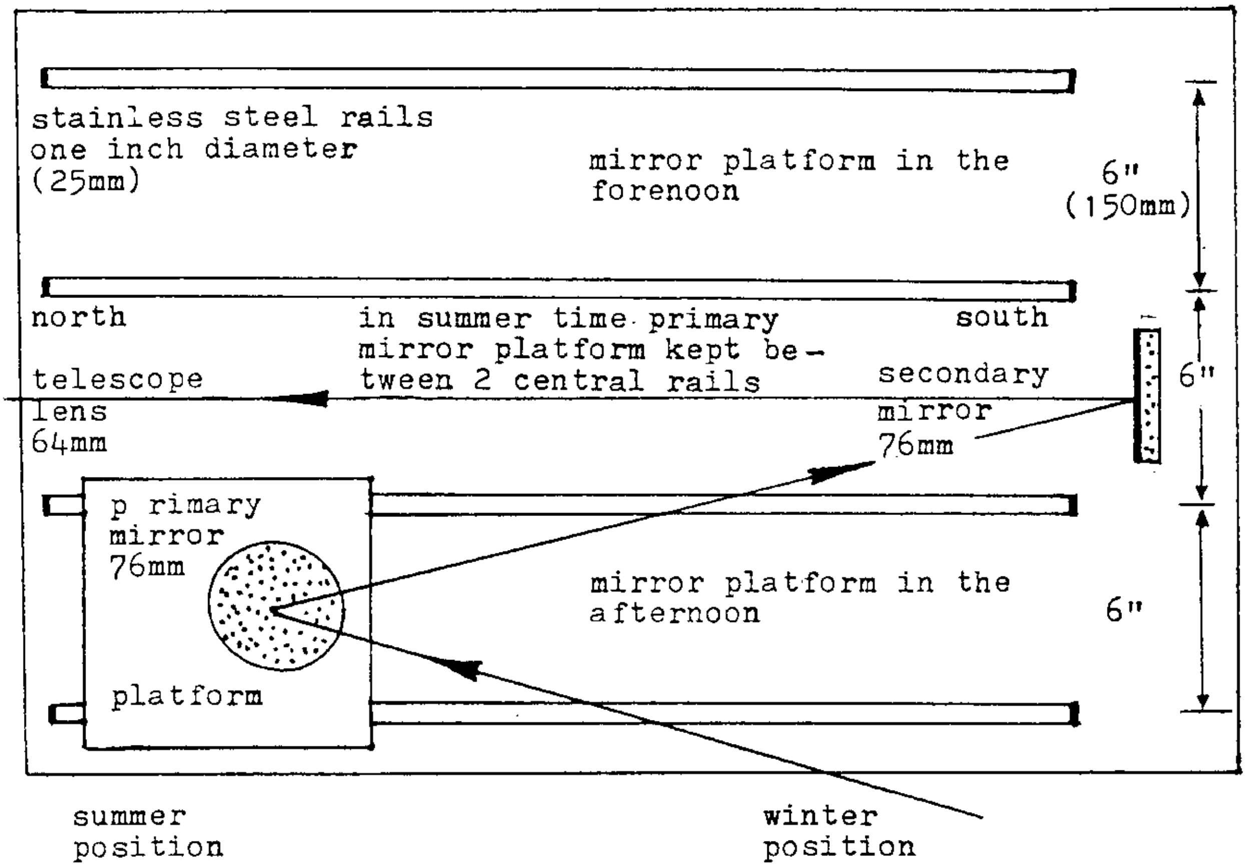
lat.	separation of mirrors		coelostat platform add to rear		add to front		total length of platform	
30°	270mm,	10.6"	175mm,	7"	250mm,	10"	700mm,	28 "
32	291	11.5	"	"	"	"	712	28½
34	314	12.4	"	"	"	"	738	29¼
36	340	13.5	"	"	"	"	763	30½
38	368	14.5	"	"	"	"	788	31½
40	401	15.8	"	"	"	"	825	33
42	439	17.3	"	"	"	"	863	34½
44	483	19.0	"	"	"	"	913	36½
46	535	21.0	"	"	"	"	963	38½

The slewing motor for the axles of the secondary mirror for up-down and left-right motions are determined as follows. A motor with one revolution per minute of time equals 360 arc/degrees. If the motor moves a mirror, the latter doubles all motions off of the surface by two times, or 720 degrees. A 100:1 gear ratio reduces the 720 degrees down to 7.2 degrees per minute of running of the motor, or half arc/degree (diameter of the sun) per four seconds of time. This is a compromise rate, not too fast or too slow. The half arc/degree per four seconds of motor time means that the sun crosses its own diameter in four second of motor time. This rate is acceptable for a nine feet focal length telescope.

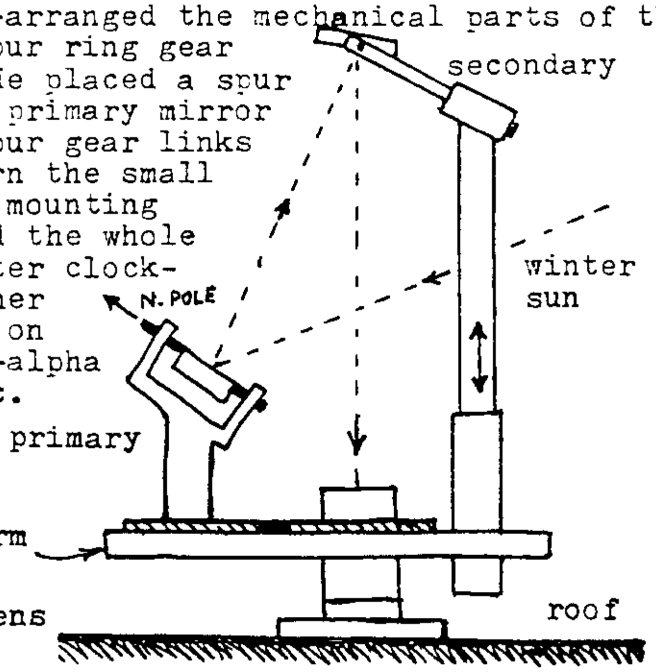
MIRROR REFLECTION SYSTEMS

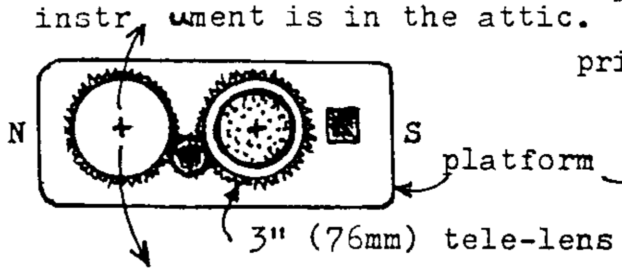


HALE COELOSTAT
Top view



Beeker coelostat. Heinrich W. Beeker, Germany, invented a new coelostat design. He re-arranged the mechanical parts of the Zeiss coelostat. He put a spur ring gear around the telescope tube. He placed a spur gear around the base of the primary mirror mounting. A small central spur gear links up the two larger gears. Turn the small gear clockwise, the primary mounting turns counter clockwise, and the whole platform turns equally counter clockwise. And vice versa the other direction. The coelostat is on the roof of his home. The H-alpha instrument is in the attic.





SPECTROHELIOGRAPHIC METHODS

There are three excellent methods to photograph the sun in H-alpha light in order to make a spectroheliogram.

The first method was used by Dr. G. E. Hale with the 40 inch (1 m) aperture refractor at Yerkes Observatory about 1895. The spectrograph was mounted on the tube of the refractor. Two flat mirrors bend the light 180 degrees into the entrance slit. With the RA drive, the telescope follows the sun in a normal manner. The Declination slow motion control has a motor, which moves the telescope tube in a north-south direction, or vice versa. On the spectrograph, the plate holder moves over the fixed exit slit in a north-south direction, or vice versa. Both the motion of the Declination axis and the plate holder are coordinated in a synchronous motion. At the end of an exposure, a new plate was put at the exit slit. Then the telescope and new plate move synchronously in the opposite direction in Declination. This method is recommended only for heavy pier mounted instruments.

The second method is still used at the 60-foot (18m) tower telescope on Mt. Wilson, built about 1907. A 30 feet focal length (9m) fixed spectrograph is in a well beneath the 60-foot tower. On top of the latter is a two mirror coelostat. The RA drive follows the sun with the primary mirror. For the Declination motion, the secondary mirror is tilted by a long tangent arm with motor in a north-south direction, or vice versa, in order to move the sun image at the prime focus across the fixed entrance slit. The plate holder is moved across the fixed exit slit in a south-north direction synchronously with the secondary mirror motion. At the end of the exposure, a new plate is placed at the exit slit. Then the secondary mirror and the plate are moved in opposite direction (Leighton, 1962).

The third method is used at the Arcetri Observatory, built about 1930, outside Florence, Italy. The telescope in the 60-foot tower produces the sun image on the entrance slit. The 13 feet focal length (4m) spectrograph hangs in a well beneath the solar tower. The solar image at the entrance slit and the plate holder at the exit slit are stationary. The whole spectrograph with slits moves in an east-west direction, or vice versa. At the end of the exposure, a new plate is put at the exit slit, and then the spectrograph goes in a west-east direction (Abetti, The Sun).

All three methods give about one arc/sec resolution of solar detail in H-alpha light with a telescope of 60 feet f.l. An amateur does not have much room. So about six arc/sec detail can be resolved with a nine feet f.l. telescope. Narrow slits of 0.002" to 0.003" (50μ to 75μ) are desired. A tower telescope can be costly. Have the telescope and coelostat horizontal to the ground. The spectrograph can hang in a shallow well. A small flat reflects the sun light vertically downward into the spectrograph. A six feet f.l. spectroscope lens with a 32mm x 30mm grating will give good spectroheliograms. This L-arrangement is compact.

The average resolution of detail is discussed at the beginning of the book. A nine feet f.l. telescope produces a one inch (25mm) diameter solar image. The calculation of the exposure time of the solar disk is simple. First, take a photograph of the spectrum in the H-alpha region. With ASA 160 color film, it will be about 1/60 second of time with an F:50 optical system. As a spectroheliograph and 0.003" (75 microns) slits, the sun is exposed in sections as the solar image is moved across the entrance slit (Mt. Wilson method). With each section of 0.003" wide (0.3A HBW), the full diameter of the solar image,

$$\text{total exposure} = \frac{\text{one inch sun image}}{0.003''\text{ slit }(75\mu)} \times \frac{1}{60}\ \text{second time} = 5.6\ \text{seconds total time}$$

The 1/60 second of time per each solar section is fairly fast exposure time, partially freezing the seeing conditions for sharp solar image detail in H-alpha light.

The first method is no longer used at Yerkes Observatory. Only the second and third methods are still employed. For convenience a spectrohelioscope can be changed to a spectroheliograph by placing a camera behind the 5" f.l. eyepiece. The camera lens may be about 5" f.l., and it is set on infinity focus, also opened to full aperture. Then an exposure is taken. A cloth tube must connect the eyepiece and the camera lens so no stray light enters the camera lens.

As a spectrograph the slit must be narrower in order to have sharp spectral lines. With 0.0004" (10 microns) slit, exposure is about 1/10 second of time at H-alpha region, and about 1/10 second of time in the green of the spectrum.

Commercial black and white films are sensitive out to about 6300Å wavelength, then dropping off rather quickly in the red. Color films have three peaks of sensitivity, namely violet, green and red. They can be used for H -alpha work. There is one black and white special film, Kodak 2415, that can be used from the violet to the red. It is ASA 50, fine grain.

In ATM Hale gives a compact spectroheliograph. The telescope is nine feet f.l. The spectrograph has two 15" f.l. lenses, a flat mirror, and a prism. All folded up in a U-shape. At the time of the 1930's, replica gratings did not exist in high quality. And original gratings were expensive. So a prism was used. But times have changed, and new products must be used. Instead of a prism, use a replica grating. Hale took the violet K line because the prism could not make a wide enough H-alpha line. Now with a grating you can use the H-alpha line with about 0.001" slits to give 0.6Å bandwidth for good spectroheliograms. Instead of 15" f.l. lenses, better to use longer focal lengths, about 30" f.l. or longer.

Hale (74, 1931) used a reversing prism for a spectroheliograph on Mt. Wilson. The slits are fixed. The prism is perpendicular to the entrance slit. The prism and plate are on a long bar with a 2:1 ratio of length. The moving prism wipes the solar image across the entrance slit. Excellent results obtained.

SUNSPOT POLARITY SPECTROHELIOSCOPE

Most solar observatories use a Babcock magnetograph to study the magnetic fields of sunspots. It has very long focal length optics and a large expensive plane grating. The detector system is complicated photoelectric equipment. If one uses the human eye as the detector, then the focal lengths can be shorter, and the grating may be smaller and less costly. A visual polarity instrument was first used by solar scientists, NOAA, Boulder, Colorado.

Telescope 8" (200mm) diameter mirror, 18 ft. f.l. (5.4 meters).
Spectroscope 8" concave Ebert mirror, 5 ft. f.l. Two Pettit prisms.

The principle for the determination of the polarity of a sunspot group depends upon the longitudinal Zeeman effect, which is for a sunspot near the center of the solar disk. There is also the transverse Zeeman effect but it is for sunspots near the solar limb. At the center of the solar disk, the magnetic lines of force are almost perpendicular to the solar surface. The excited magnesium atoms are orientated in one direction by the lines of force from the sunspot. The light from the excited atoms is parallel to the line of sight of the solar observer. The magnesium spectral line consists of two circular polarized components, which are marked Sr (sigma, red) and Sv (violet). For a solar spectral line in absorption(inverse Zeeman effect), the Sr component is left circular polarized light, which shifts to the red, and the Sv component is right circular polarized light, which shifts to the violet.

In front of the entrance slit of the spectroscope is placed a manually rotating 1/4 wave plate (retardation), which changes circular polarized light to plane polarized light. Behind the 1/4 wave plate is located a fixed Polaroid filter, which suppresses left (or right) plane polarized light and passes right (or left) plane polarized light. Now half of the polarity of the sunspot group is viewed. Next, one rotates the 1/4 wave plate 90 degrees, changing the left plane polarized light to right plane polarized light, and right plane polarized light is altered to left plane polarized light. The other half of the polarity of the sunspot goes through the Polaroid filter and is now seen.

The average field strength of the umbra in a sunspot is about 2500 gauss, and the penumbra is about 1000 gauss. Plage vary from 200 to 800 gauss. The field strength of a penumbra or a plage will shift the solar line about 0.05Å. The spectroscope must have very high linear dispersion to detect this small Doppler shift. One puts the core (center) of the solar line about 0.05Å on the blue side of the exit slit of the 5167Åλ magnesium line. The visual bandwidth must be about 0.05Å. This gives best contrast (Howard, 1971).

The resolution of the grating ought to be about half of the bandwidth desired, or close to it. Pick a grating with ruled area 64x64mm, 1800 gr./mm, blazed 10,000Å in the first order. Tilt grating to second order shifts blaze to 5000Å wavelength.

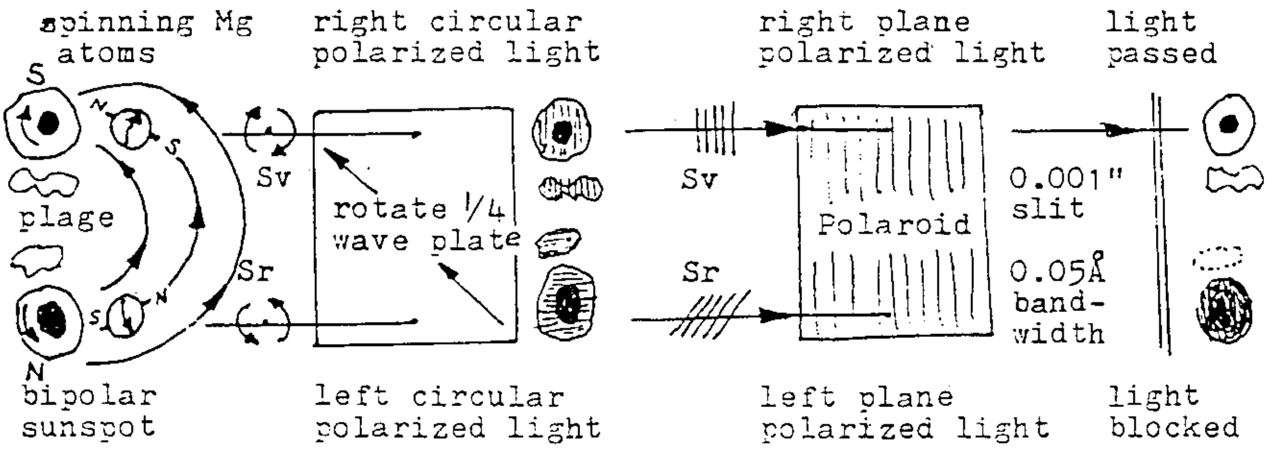
$$\text{grating resolution} = \frac{5167\text{Å wavelength (green)}}{64\text{ mm} \times 1800\text{ gr./mm} \times 2\text{nd order}} = 0.02\text{Å}$$

A magnetic region (Sv) on the solar disk will shift the spectrum towards the blue so that the core moves into the exit slit in order to observe the polarity. The Mg core is 9% of the solar continuum. The H-alpha core is 16%.

The polarity spectroheliscope designed by the author has a telescope of 3" (76 mm) aperture and 9-foot f.l., also a spectroscope of 3" (76 mm) aperture and 9-foot f.l. About F:35 system. Use about 5" f.l. (125mm) eyepiece for viewing for polarity work.

first order, 1.8 Å/mm in the green linear dispersion;
0.05Å bandwidth = 0.001" slit (25 microns),
length of spectrum about 6.7 feet;
second order, 0.4Å/mm, spectrum about 28 feet.

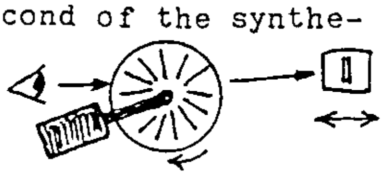
Anderson prisms are preferred. The Polaroid will absorb about 40% of the sun light. The visual polarity scope must be designed properly, or the sun in magnesium light will be too faint.



Strong spectral lines, as H-alpha and H-beta, violet H and K lines of CaII, and the two sodium D lines, show multiple splitting, which makes the interpretation of polarity difficult. Lines with simple Zeeman splitting are recommended, yielding components with a longitudinal doublet.

Very faint and faint spectral lines originate in the photosphere. Best contrast to solar disk of bright-dark areas is in the red wing of the faint line. Medium strong and strong lines develop in the reversing layer and chromosphere. Best contrast to bright-dark area detail is in the blue wing of the strong line. There is a velocity correlation of bright areas and dark areas (Leighton, 1962).

<u>Motor</u>. To get the exact vibrations per second of the synthesizer, put a paper disk, say with 28 slits, on the output axle of a one rev/second motor. Look through the slitted disk and at the motion of the synthesizer. The latter will stand still at 28 vibs/second, or move ahead or slowly behind if at a different rate of motion.



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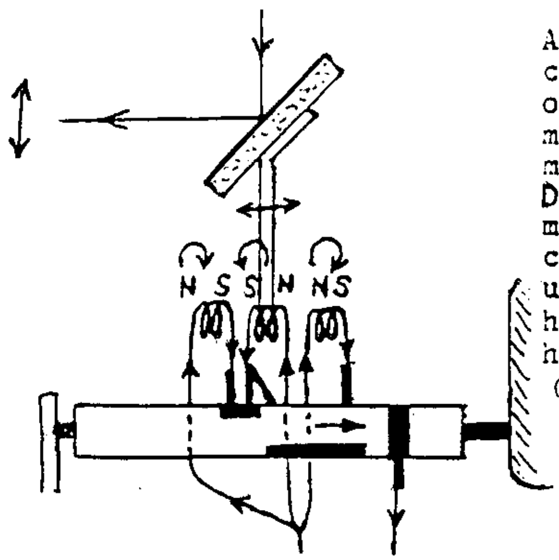
APPENDIX

HYLOV—YOUNG mirror synthesizer. About 20 years ago Jeffery Young was first to make knodding two mirror synthesizer with fixed slits. He visited the author's home in 1992 for a demonstration of his spectroheliosope. The knodding synthesizer needed some improvements. The author has communication with other amateurs. Vittorio Lovato, Italy, tried the knodding synthesizer. He strongly recommended grease or oil on the rotating knob on the output axle of the DC motor, greatly reducing vibration on his spectrohelioscope. Toshio Ohnishi, Japan, used folded-up oscillating slits synthesizer with small ball bearings to greatly reduce vibration on his folded up spectrohelioscope. The author read a book on vibration, suggesting a heavy motor put on a heavier steel base and the latter supported with springs, greatly minimizing vibration. Leonard Higgins worked with the author. He had a few extra refinements. All these thoughts were put together to make a modified new knodding synthesizer that was incorporated in Higgin's spectrohelioscope: 4" heliostat, 3" concave mirror of nine feet f.l., spectroscope 8" diameter mirror of nine feet f.l., 1200 gr/mm grating, 52x52mm ruled area by Diffraction Products,Inc. The 3" telescope mirror is reduced to 2.5 inches and used slightly off-axis. His instrument works excellent. He lives in California.

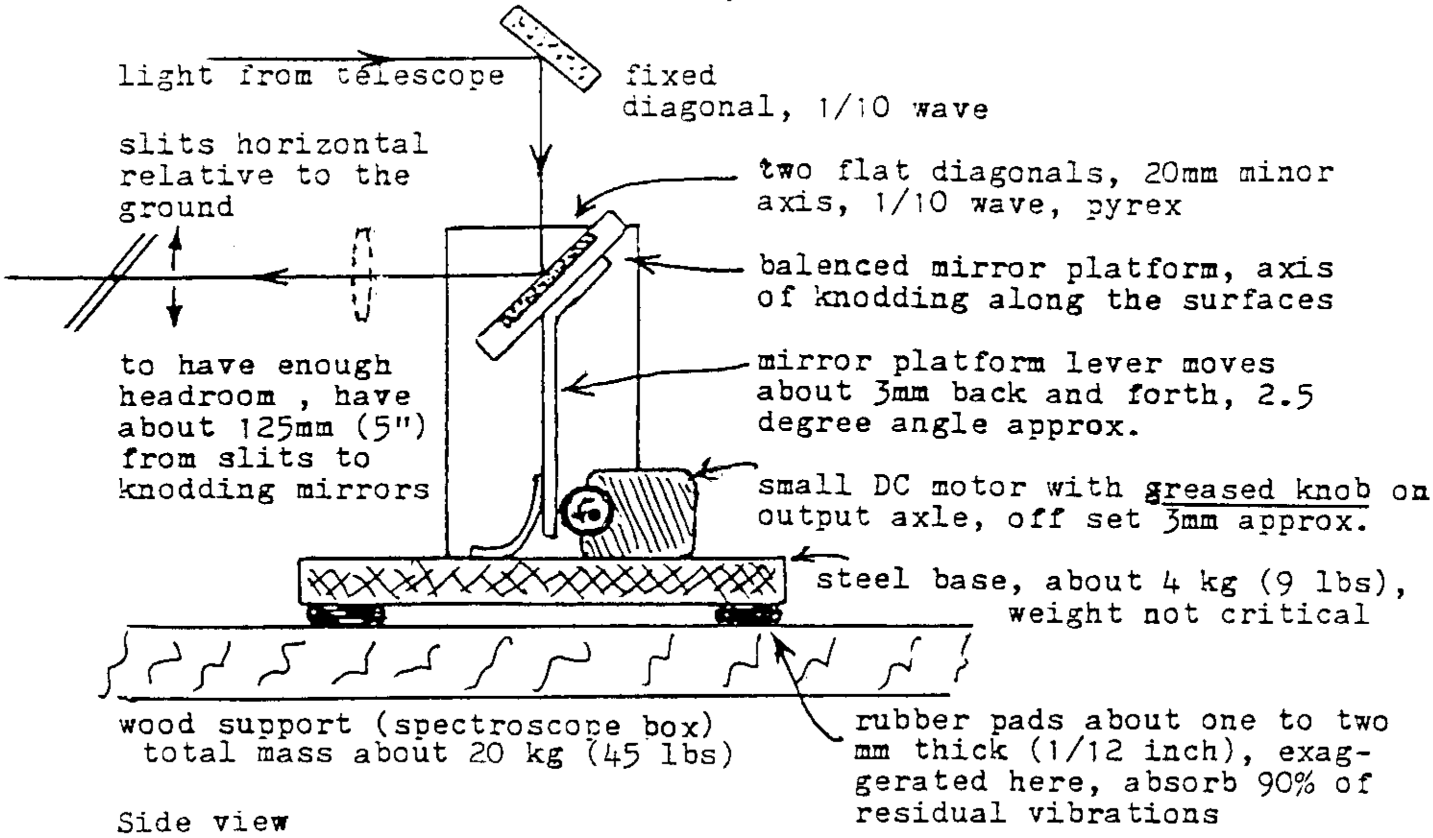
Five persons perfected the knodding synthesizer. It will not be necessary to select Anderson prisms with fixed slits . Take the first letter of the last name of the five persons and combine to H.Y.L.O.V., pronounced high-love. Hereafter the synthesizer should be called the HYLOV synthesizer (omit the periods for simplicity).

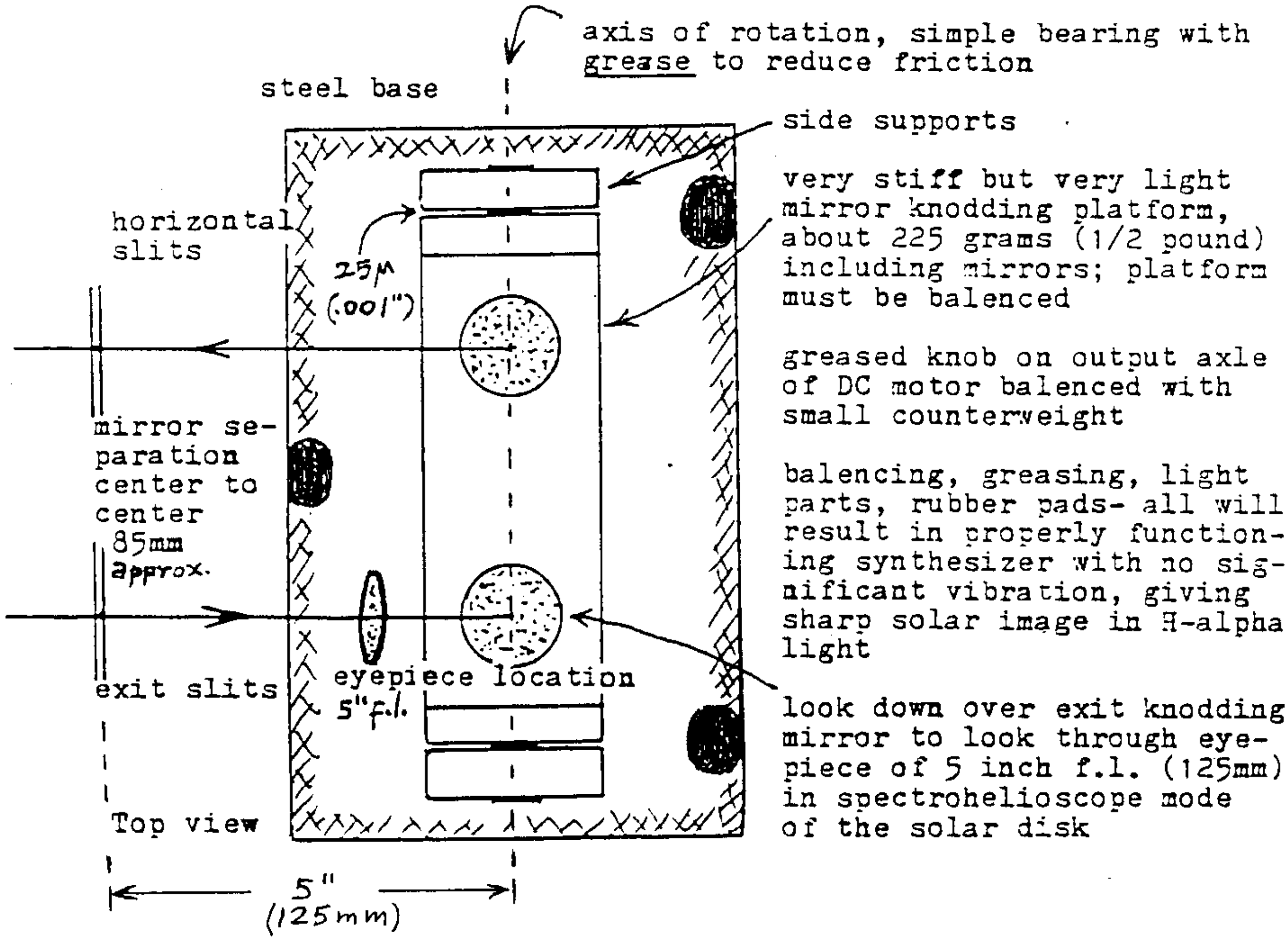
Here is an important comparison of synthesizers. The Veio rotating glass disk must be used with a positive meniscus lens of about six feet f.l. (1.9 meters) because of a trace of H-alpha lag as the disk rotates. Do not use two small concave mirrors or one large concave mirror, latter having too much H-alpha lag. The HYLOV synthesizer can be used with one large mirror, two small mirrors, or a spectrscope lens. The reason is the slits are fixed,and there is no H-alpha lag. Halfband widths of 0.6Å for H-alpha and 0.1Å for metals and helium are possible for both synthesizers if certain designs are followed correctly.

A magnetic driver to push the lever can be three coils of wire, 32 guage, or two coils of wire and one small magnet. A commutator and small motor energize the coils with DC current. Slamming back and forth must be avoided. Use rheostat to control current strength. B. Manning used an elegant elctronic drive for his synthesizer. Complete details in his article in Journal of B.A.A. Can use AC/DC inverter.



motor and axle

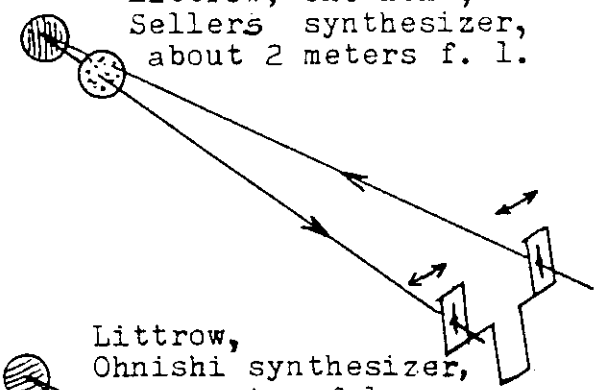

light from telescope
fixed diagonal, 1/10 wave
slits horizontal relative to the ground
two flat diagonals, 20mm minor axis, 1/10 wave, pyrex
balenced mirror platform, axis of knodding along the surfaces
to have enough headroom , have about 125mm (5") from slits to knodding mirrors
mirror platform lever moves about 3mm back and forth, 2.5 degree angle approx.
small DC motor with greased knob on output axle, off set 3mm approx.
steel base, about 4 kg (9 lbs), weight not critical
wood support (spectroscope box) total mass about 20 kg (45 lbs)
rubber pads about one to two mm thick (1/12 inch), exaggerated here, absorb 90% of residual vibrations
Side view


axis of rotation, simple bearing with grease to reduce friction
steel base
side supports
very stiff but very light mirror knodding platform, about 225 grams (1/2 pound) including mirrors; platform must be balenced
horizontal slits
25µ (.001")
greased knob on output axle of DC motor balenced with small counterweight
mirror separation center to center 85mm approx.
balencing, greasing, light parts, rubber pads- all will result in properly functioning synthesizer with no significant vibration, giving sharp solar image in H-alpha light
exit slits
eyepiece location 5" f.l.
look down over exit knodding mirror to look through eyepiece of 5 inch f.l. (125mm) in spectrohelioscope mode of the solar disk
Top view
5" (125mm)

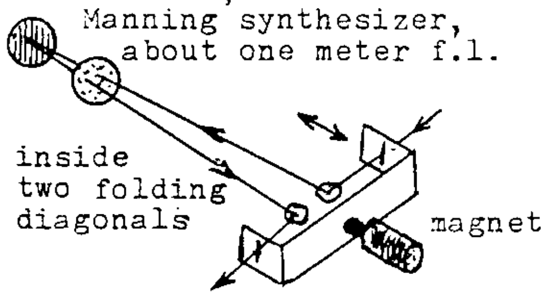
Other synthesizer possibilities. Any moving slit synthesizer will have a trace of H-alpha lag at the exit slit. With a straight through optical pathway and center to center separation of the slits about three inches (76mm), the spectroscope focal length should be about 75 inches (1.9 meters). If you bring closer together the off-axis optical pathwaysomehow, you can use a shorter focal length lens of about 40 inches (one meter). If you go from a slightly off-axis optical pathway (Littrow) to an on-axis pathway, you have less H-alpha lag even moreso. And a shorter focal length spectroscope and compact design will be the result. The author does not favor short, short designs. He prefers long, long focal lengths. But the following discussion will help.

Assume positive meniscus spec-lens, 1200gr/mm or 1800 gr/mm grating.

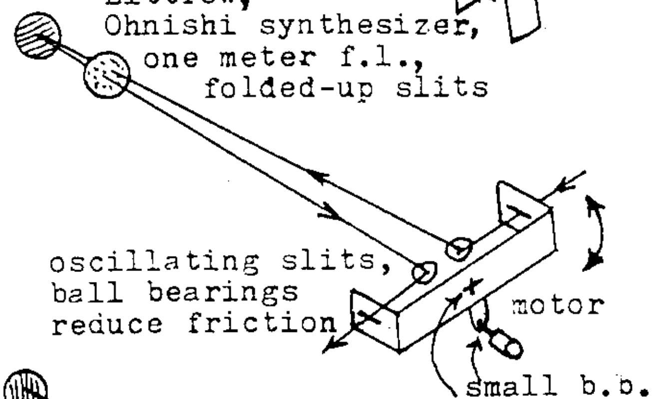
Littrow, one lens, Sellers synthesizer, about 2 meters f. l.



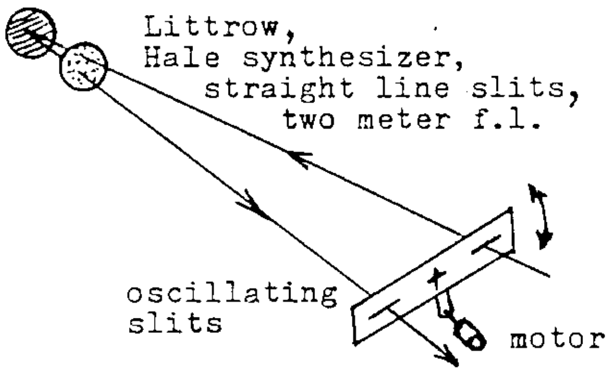
Littrow, Manning synthesizer, about one meter f.l.



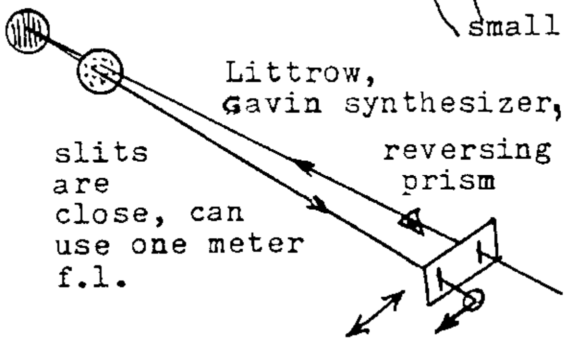
Littrow, Ohnishi synthesizer, one meter f.l., folded-up slits



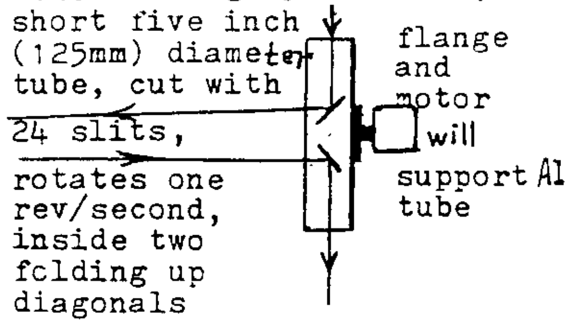
Littrow, Hale synthesizer, straight line slits, two meter f.l.



Littrow, Gavin synthesizer,



Littrow, two meters f.l., Veio-Manning synthesizer, short five inch (125mm) diameter tube, cut with 24 slits, rotates one rev/second, inside two folding up diagonals

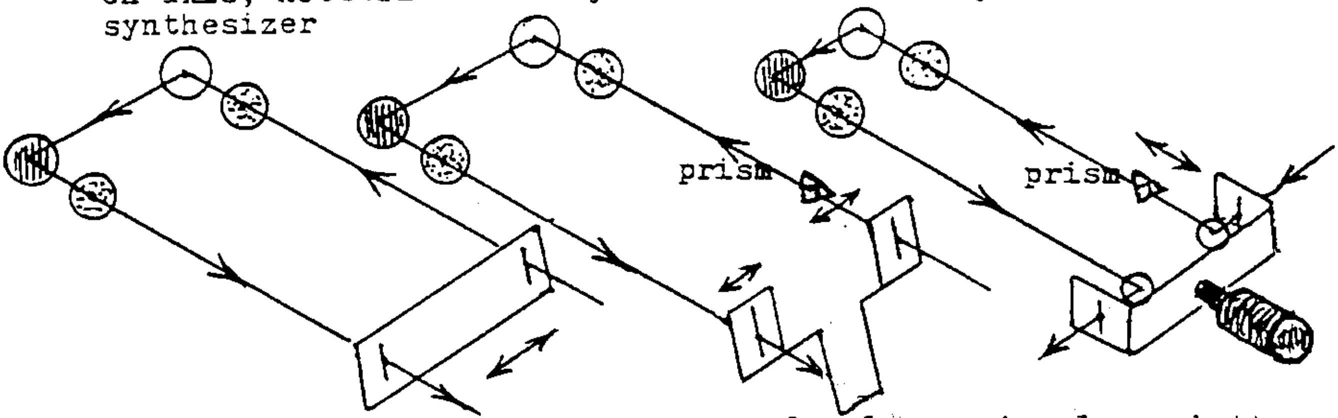


Note: With folding up diagonals, one meter f.l. spec-lens is good, but longer is much better.

Arcetri spectroscope, two achromats used on-axis, Arcetri synthesizer

Gavin-Sellers synthesizer

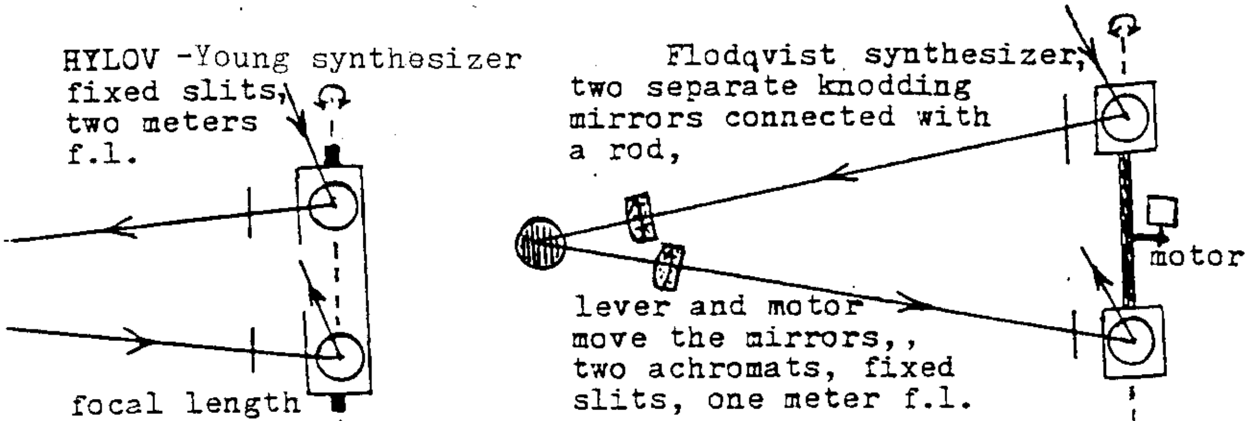
Gavin-Manning synthesizer



Achromats can be about one meter f.l. Longer is always better.

HYLOV -Young synthesizer fixed slits, two meters f.l.

Flodqvist synthesizer, two separate knodding mirrors connected with a rod,

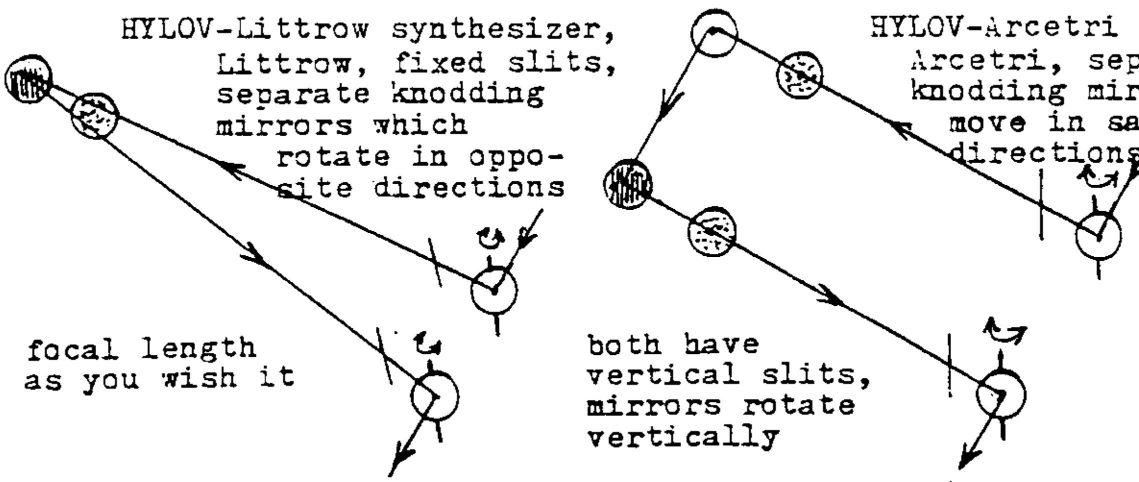


focal length as you wish it

lever and motor move the mirrors,, two achromats, fixed slits, one meter f.l.

HYLOV-Littrow synthesizer, Littrow, fixed slits, separate knodding mirrors which rotate in opposite directions

HYLOV-Arcetri synthesizer, Arcetri, separate knodding mirrors, move in same directions



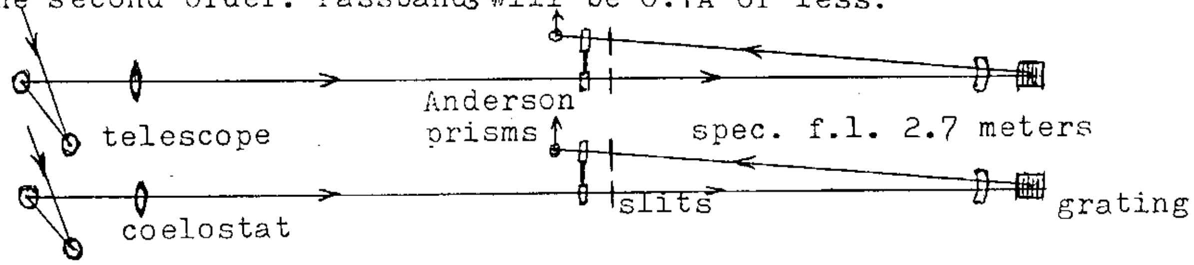
focal length as you wish it

both have vertical slits, mirrors rotate vertically

Warning: It is to be repeated, if you use two small concave mirrors for the spectroscope, the focal length must be about 12 feet (about 3.8 m) in order to minimize the H-alpha lag at the exit slit, assuming a moving slit synthesizer.

Wave disturbance spectrohelioscope. Two spectrohelioscopes cann be combined together with or without a beam splitter in order to detect wave motions on the solar surface. One spectroscope is adjusted to +0.3Å on the red wing of the H-alpha line. The second spectroscope, -0.3Å on the violet wing of H-alpha line. Any motions toward or away from the observer will be seen as flickering of the event. To avoid any H-alpha lag, use Anderson prisms or the HYLOV-Young synthesizer. Both employ fixed slits, having no H-alpha lag. The field of view will be all one pure wavelength. The two spectroscopes might have about 90% of the length in a tube with a vacuum about 70mm of Hg. A very high vacuum is not necessary.

Have two sets of pairs of gratings. For H-alpha work, have 52x 52mm ruled area, 1800 gr/mm, blazed at 5000Å wavelength in the first order. Passbands will be 0.2Å to 0.6Å. For narrower passbands and for the metals (Fe, Mg, Na) and yellow helium, have the second pair of gratings with 52x52mm ruled area, 1200 gr/mm, blazed at 10,000Å λ(one micron) in the first order; use it at 5000Å λblaze in the second order. Passbands will be 0.1Å or less.



Use telescope focal lengths from two meters up to about ten meters.

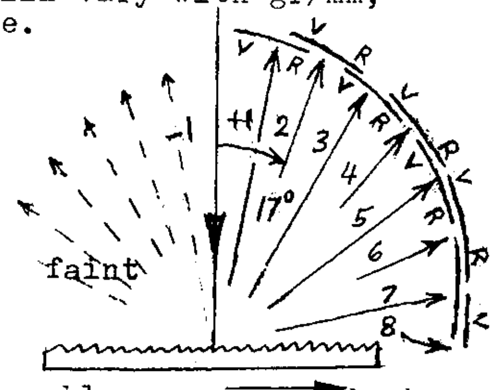
Orders of a grating. For sake of simplicity, the drawings below show the sun light falling perpendicular upon the surface of the grating. Actually the grating is tilting somewhat. When sun light impinges upon the grating, 90% goes to one side of the normal (perpendicular) of the grating; this is the blazed side. About 10% of the sun light goes to the other side, nonblazed side. The sun light is broken up into various overlapping orders (spectra). The grooves per millimeter of main interest are 600 gr/mm, 1200 gr/mm and 1800 gr/mm. These are the best compromises, and costs are nominal. The spectra (violet to red) will vary with gr/mm, orders and focal length of the spectroscope.

600 gr/mm grating, eight orders

spectra length vs focal length

angle	order	1.9 meters	3.8 meters
8°	1st	0.5 m	1.0m
17°	2nd	1.0	2.0
35°	4th	2.0	4.0
75°	8th	violet	violet

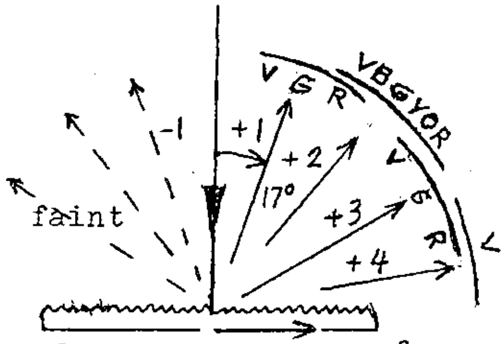
Several very short to short spectra. Green and yellow do not overlap. They are clear areas on the spectrum.



blaze arrow on back of grating

1200 gr/mm grating, 4 orders
spectra length vs focal length

angle	order	1.9 meters	3.8 meters
17°	1st	1.0 m	2.0 m
35°	2nd	2.0	4.0
60°	3rd	3.0	6.0
75°	4th	violet	violet

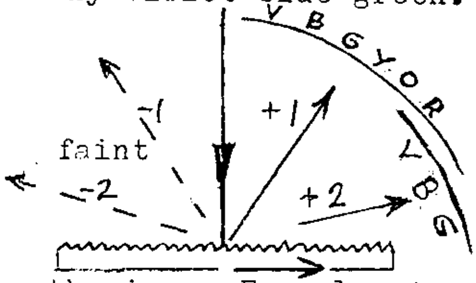


Three medium long spectra. The 4th order violet is at about 80° tilt of the grating. Not see blue-green-yellow-orange-red.

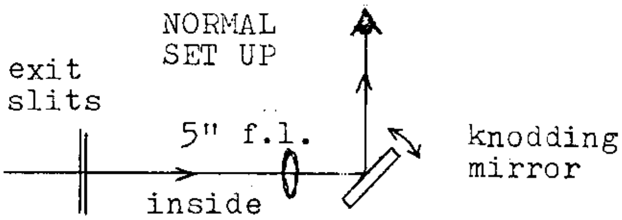
A grating of 1800 gr/mm has a long first order spectrum. Only a half spectrum seen in the second order, namely violet-blue-green.

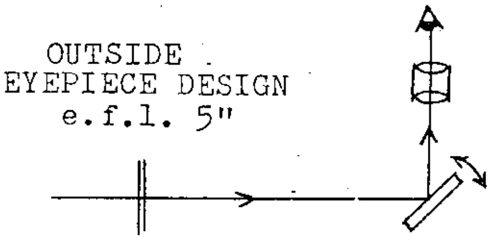
1800 gr/mm grating, 1 and ½ orders
spectra length vs focal length

angle	order	1.9 meters	3.8 meters
25°	1st	1.5 m	3.0 m
70°	2nd	green	green



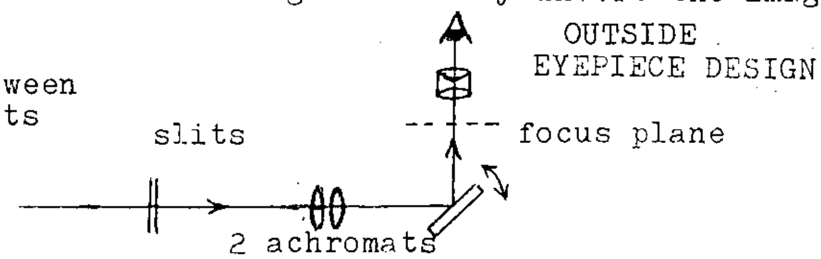
<u>Eyepiece designs for the HYLOV-Young synthesizer.</u> For almost all solar image synthesizers, a single element lens will workvery good. The one exception is the HYLOV-Young synthesizer. Normally the eyepiece will be between the knodding flats and the exit slits. This is a minor inconvience. There are three ways to bring out the eyepiece to a more comfortable position. One method is to employ two single lenses of suitable focal length, using the Edmund formula from their book <u>Popular Optics</u>, Edmund Scientific Company. It has 192 pages, $18, much basic information.





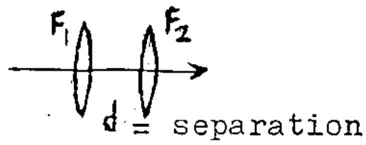
The second method is based upon the principle of a rifle scope. Between the telescope objective and the eyepiece are two short focal length achromats close together. They invert the image from the telescope.

The distance between the knodding flats and the slits should be about 5 inches (125mm).



The single element 5" (125mm) focal length eyepiece itself can be redesigned using the Edmund formula.

$$\text{equivalent focal length} = \frac{F_1 \times F_2}{F_1 + F_2 - d}$$



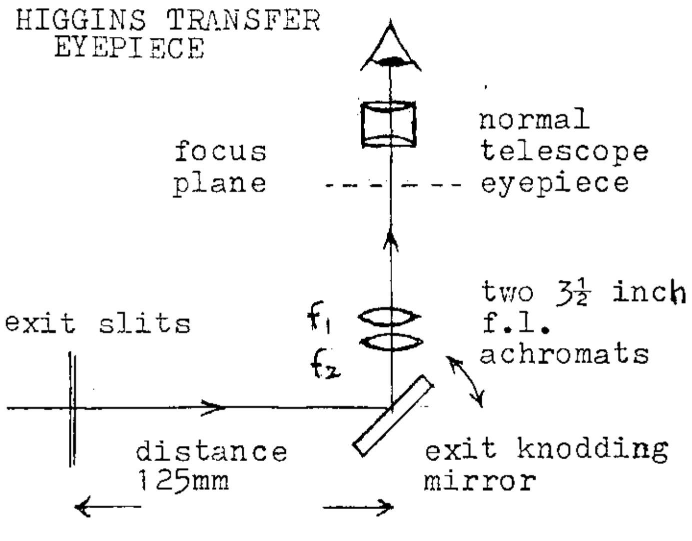
The single lens eyepiece and long brass tube will be about eight inches (200mm) long. This can be shortened conveniently to about half. With two 6 inch (150mm) f.l. lenses and a 5 inch (125mm) separation, the e.f.l. will be 5.1 inches (about 130mm). Or two eight inch (200mm) f.l. lenses and a four inch (100mm) separation, the e.f.l . is about 5.3 inches (130mm). The previous examples are an eyepiece for the solar disk in H-alpha light.

For the s olar spectrum,about two to 2½ inch f.l. (50 to 62mm) is best. Different lenses must be selected for the correct combination. Edmund Scientific Company sells a variety of short focal length lenses. About one (25mm) diameter is sufficient.

A fourth eyepiece design is by Leonard Higgins, Napa city, California. Two 3½ inch f.l. achromats (88mm) mounted close together are placed above the knodding mirrors. They function like a microscope working backwards, e.g., taking an image at the slits and reducing it smaller via the conjugate foci. The reduced image is examined with normal telescope eyepiece of a about 25mm f.l. The Edmund formula is not used here. Rather the object-image formula,

$$\frac{1}{f} = \frac{1}{p} + \frac{1}{q}$$

f is positive for lens,
p is real object,
q is real image.



Reflection gratings from Diffraction Products, Inc. The following gratings will be the main selection for a spectrohelioscope and a solar spectroscope. When ordering a grating, give ruled area, blank size, grooves/mm, blazed wavelength in nanometers usually (ex.: 500 nm is 5000Å). They will fill in the order number. This will prevent errors and confusion.

Blank diameter 50mm, ruled area 30x32mm, 1200 gr/mm, 5000Å blazed wavelength, $327.

Blank diameter 50mm, ruled area 30x32mm, 1800 gr/mm, 5000Å blazed wavelength, $376.

Blank diameter 80mm, ruled area 52x52mm, 1200 gr/mm, 5000Å blazed wavelength, $502.

Blank diameter 80mm, ruled area 52x52mm, 1800 gr/mm, 5000Å blazed wavelength, $640.

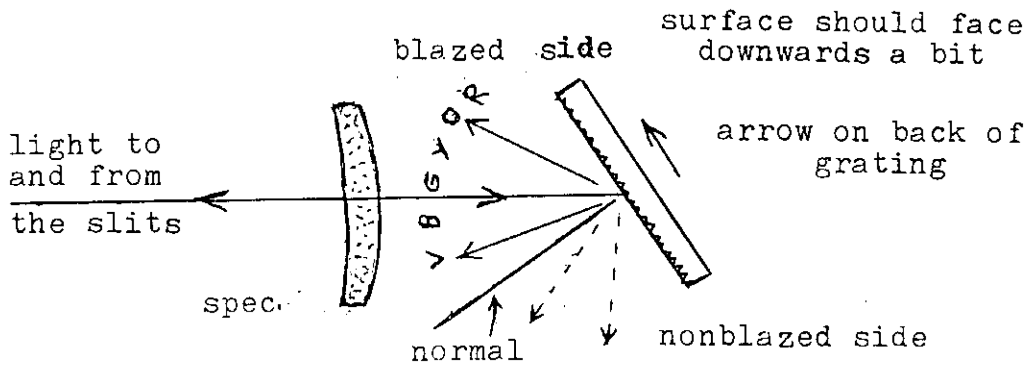
The gratings will be tilted somewhat. Determine the diagonal of the ruled area. This sets the diameter of the spectroscope lens and the F-ratio of the instrument. The telescope and spectroscope do not have need for exactly the same F-ratio. It is not that critical. The focal length of the optics do not have to be exactly this or that. Just close is good enough. Do not drive yourself crazy with precision.

The 5000Å blazed wavelength selected above for the first four gratings is an excellent compromise for the spectrum from the violet to the red. If you want to do photography in the violet and in the red, that is, H-alpha light, the grating gives a good ballence of sun light. If you buy a 6000Å wavelength blazed grating, it will be excellent for the red but not so good for the violet.

A certified precision grating has about 90% theoretical resolution, surface about 1/10 wave flat. Certificate can be obtained. An OEM grating (original equipment manufacture) is about 45% of theoretical resolution, about 1/4 wave or less flat. No certificate is produced. Much less than a precision grating in costs.

A high quality holographic grating is about 10% more expensive that a classical ruled grating. Theoretical resolution is about 90 %. No blazed arrow on the back. Does not need one. Scattered light is much less than a classical ruled grating, but it does not make any difference for a spectrohelioscope.

Blazed arrow on back of grating. An arrow on the back of the grating indicates the side of the blazed spectra. You want to tilt the grating downward so dust will not settle on the surface of the grating. So have the arrow pointing upward somewhat. If you have doubts about correct orientation of the blazed side, you have two choices. Just rotate 180° to check for a comparison of both sides of the arrow.



A grating doesnot need the sun light at infinity focus in order to produce spectra. In other words, the entrance slit can be inside or outside of the focus of the spectroscope lens. The sun light passing through the entrance slit and lens will still result in spectra at the exit slit.

Positive meniscus lens. Dr. G. E. Hale mentions (1929) the use of a positive meniscus lens for the spectroscope. He recommends the optical axis be placed back to the entrance slit. This arrangement will be all right with Anderson prisms as the synthesizer with fixed slits. But it will not be acceptable with moving slits. The reason is the H-alpha lag will be very high, and the field of view will be very limited in H-alpha light. Also the spectral lines will be tilted too much, requiring special wedge prisms at the entrance and exit slits.

With moving slits synthesizer it is best to have the optical axis of the positive meniscus lens placed between the entrance and exit slits, not through the entrance slit. The result will be very little H-alpha lag. Also no tilt of the spectral lines. Keep the separation of the entrance and exit slit within about three inches (76mm) for most spectroscope designs.

The author used a positive meniscus lens with the optical axis adjusted between the slits. His idea was published in the Maksutov Club Circulars in 1964 by Allan Mackintosh. The lens shape easily allows blocking out scattered light off the surfaces. In later years three new solar observatories had a spectroscope with crown and flint combination, and the flint had a concave rear surface. The observatories are Big Bear Solar Observatory, San Fernando Solar Observatory, both of California, USA, and the Solar Vacuum Telescope (SVT) on Kitt Peak, Arizona.

Depth of focus. About 25 years ago Robert E. Cox published a brief but interesting article on depth of focus in Sky and Telescope. He gives a simple formula to calculate the depth. Here it is slightly modified to give at least a 90% accurate result. It is assumed a one inch (25mm) f.l. eyepiece is used.

$$\text{depth of focus} = \frac{(\text{F-ratio})^2}{10{,}000} = \text{in ten-thousands of an inch}$$

For example, with an F:8 Newtonian telescope, the depth of focus will be 64/10,000 of an inch, or 6/1000 inch (150 microns). With an F:15 refractor, the depth will be 225/10,000 inch, or 23/1000 inch (about 0.5mm). This is with a one inch focal length (25mm) eyepiece.

Now with the F:50 telescope of a spectrohelioscope, depth of focus will be:

depth = 2500/10,000 inch, or 250/1000, or 1/4 inch.

And the latter is about 6mm. Extrapolating with other eyepieces, a 2" f.l. (50mm) will give 1/2 inch (12mm) depth of focus. A 4" f.l. (100mm) will yield one inch depth (25mm). This is with just the telescope of F:50. Now with the telescope and spectroscope together, the depth of focus will be halved, namely half an inch (12mm) with the 4" f.l. eyepiece (can be single element lens). This is why a high F:ratio instrument is easy to focus. It is assmued the telescope and spectroscope pass a 1/8 wavefront.

Low cost achromats. Somewhat long focal length achromats about one meter (40 inches) are sold by two companies. They advertise in Sky and Telescope. This is very convenient in order to build a spectrohelioscope. You must test the optics to be sure of 1/8 wavefront through the optics. A Ronchi screen can be used, having about 50 to 100 lines/inch. Not too expensive. Edmund Scientific Company sells the screens.

Sky Instruments MPO Box 3164 Vancouver BC Canada V6B 3X6	Apogee, Inc. P.O. Box 136 Union, IL 60180-0136
82/1000 mm, $59	60/1000mm, $25

If the optics have a little spherical aberration, you can correct the aberration yourself. If slightly overcorrected, use the concave side of the flint element. If slightly undercorrected, use the convex side of the crown element. It should take about five to ten minutes of figuring with cerium oxide. Test frequently. The pitch lap must be medium soft. Use the thumb test upon the pitch lap. Or get a friend with optical experience.

Long negative focal length Barlow. A telescope with a good Barlow can double the equivalent focal length. For a spectrohelioscope the Barlow lens should be about -15" to -20" f.l.(-500mm), preferably the latter. One company makes a good Barlow.

Newport Corporation 1791 Deere Ave., Irvine, CA 92606 USA	plano-concave lens, BK-7, grade A, 50mm diameter, -500mm, coated, $77, order no. KPC064 shipping is extra

The lens as stated in the catalog is 1/4 wave sphericity or better. A spectrohelioscope at F:50 has narrow beams of sun light go through about half the diameter of the Barlow. So the sphericity involved is about 1/8 wave, which is excellent. Newport has many branch offices in large cities of the world.

Short focal length Barlows are never recommended for a spectroheliocope. About -10 inch (-250mm) will be considered the bare minimum. And this assume 1/8 wave sphericity of the surfaces. Test the Barlow with a telescope to be sure the spherical aberration is within 1/8 wavefront. Use a Ronchi screen. Point at a planet or a bright star. If the Ronchi lines are straight, it is an excellent combination.

Solar spectrum atlases. The Paris Observatory, France, offers a low and a high resolution atlas of the solar spectrum from the violet to the red, 3000A to 9000A wavelength. The National Solar Observatory on Kitt Peak offers six solar atlases for various purposes, ranging also from the violet to the infrared.

http://mesola.obspm.fr/	Meudon Solar Observatory
http://www.nso.noao.edu/	NSO, Kitt Peak, Arizona

Astrophysical Journal over the Internet. Harvard Observatory presents scanned articles from technical journals, notably the Astrophysical Journal and Astronomical Journal. Type in the journal volume and the page, and it appears on the screen.

http://adswww.harvard.edu/

They offer an Astrophysic Data System (ADS).

Dr. G.E. Hale's original four articles on the spectroheliocope can be obtained from the Astrophysical Journal.

70:265 (1929), part 1
71:73 (1930), part 2
73:379 (1931), part 3
74:214 (1931), part 4

Dr. Hale had a private solar observatory next to the California Institute of Technology campus. The four articles refer to it. Mt. Wilson with the two solar towers is located miles away. Do not be confused.

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