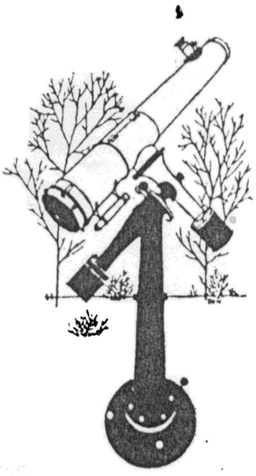


THE AMATEUR SCIENTIST

A new kind of spectrohelioscope for observing solar prominences

Conducted by C. L. Stong

Few natural spectacles compare in splendor with the glowing prominences that rise from the surface of the sun. Apart from astronomers few people ever see the display, which is usually lost in the sun's white glare. Those fortunate enough to be in the path of a total eclipse can observe the prominences as scarlet plumes that stand out in vivid contrast to the pearly background of the glowing corona.

Gene F. Frazier of 2705 Gaither Street S.E., Washington, D.C. 20031, views the spectacle routinely with a homemade instrument that in effect blocks from the eye light of all colors except the one emitted with maximum brilliance by the prominences. The hue approximates the darkest red of the setting sun. The emission is radiated by glowing hydrogen at a wavelength of 6,562.8 angstroms. In certain respects Frazier's apparatus resembles the spectrohelioscope previously described in these columns [see "The Amateur Scientist," SCIENTIFIC AMERICAN, April, 1958]. His instrument has an additional diffraction grating but requires no solar telescope or motor-driven optical parts. He describes the principles, construction and operation of the apparatus as follows.

"The effect that my instrument is based on (and that led to the development of the spectrohelioscope) was first described by the French astronomer Pierre Jules César Janssen following his observation in 1868 of the total solar eclipse in India. When Janssen focused the edge of the sun's image on the slit of his spectroscope, he was astonished by the brilliance of the spectral line at 6,562.8 angstroms. It was so bright that on the following day Janssen looked for the color in full sunlight. By opening the slit of the spectroscope he discovered that he could observe a portion of the prominence. A few days later the British astronomer Joseph Norman Lockyer hit on the same technique without the benefit of an eclipse.

"News of the discovery fascinated amateurs of the day, primarily because the brightness of the sun made observations possible with instruments of small aperture and proportionately low cost. It turned out, however, that home-built spectroscopes scattered too much light for satisfactory results. In addition clockwork-driven structures capable of keeping an image of the sun's edge focused exactly on the thin slit of the spectroscope called for a higher level of craftsmanship than most amateurs could attain.

"The design of my instrument sidesteps these requirements. Essentially the instrument employs an external diffraction grating to disperse and reflect sunlight to a concave mirror [*see illustration on opposite page*]. The mirror projects the rays through an adjustable plate of flat glass to a focus in the plane of the entrance slit of a conventional spectroscope.

"A photograph that could be made by putting a photosensitive plate in the position occupied by the slit of the spectroscope would not show the dark absorption lines that normally characterize the solar spectrum. In my system the image of the sun functions as the slit. Hence a photograph is composed not of the series of narrow absorption lines but of overlapping images of the solar disk separated by distances corresponding to the wavelength of the absorbed light.

"The adjustable plate of flat glass that admits incoming light to the slit acts as a vernier for displacing the rays laterally with respect to the slit. Rays that enter the plate at an angle to its perpendicular are refracted and emerge at the identical angle. The amount of deviation is approximately proportional to the angle between the plate and the entering beam. By rotating the plate the observer can shift the spectrum any small distance with respect to the slit. The plate functions as a precision tuner that enables the experimenter to admit any narrow portion of the spectrum to the slit.

"The selected rays, which may span a range of color only 10 angstroms wide, emerge from the slit as a diverging beam. The diverging rays fall on a concave mirror from which they are reflected as a bundle of parallel rays to the internal diffraction grating of the spectroscope [*see illustration on pages 112 and 113*]. The internal grating disperses the colors still more. The angle at which the internal grating is set can be adjusted to reflect rays of essentially monochromatic light to the second concave mirror of the spectroscope. The second mirror reflects the rays to focus in the plane of the eyepiece.

"The details of the filtering action can be demonstrated by replacing the external grating with a flat mirror and letting sunlight fall on the mirror. After adjustment an instrument so modified would display at the eyepiece the normal solar spectrum crossed by dark absorption lines. Assume that the geometry of the diffraction grating of the spectroscope is such that each angstrom of wavelength of the solar spectrum is dispersed through a distance of one millimeter in the focal plane of the eyepiece. This was essentially the case with Janssen's spectroscope. The chromosphere of his solar image was less than one millimeter wide. Therefore he could partly isolate the emission of the prominences from background light by carefully focusing this narrow feature of the image on the slit of his spectroscope.

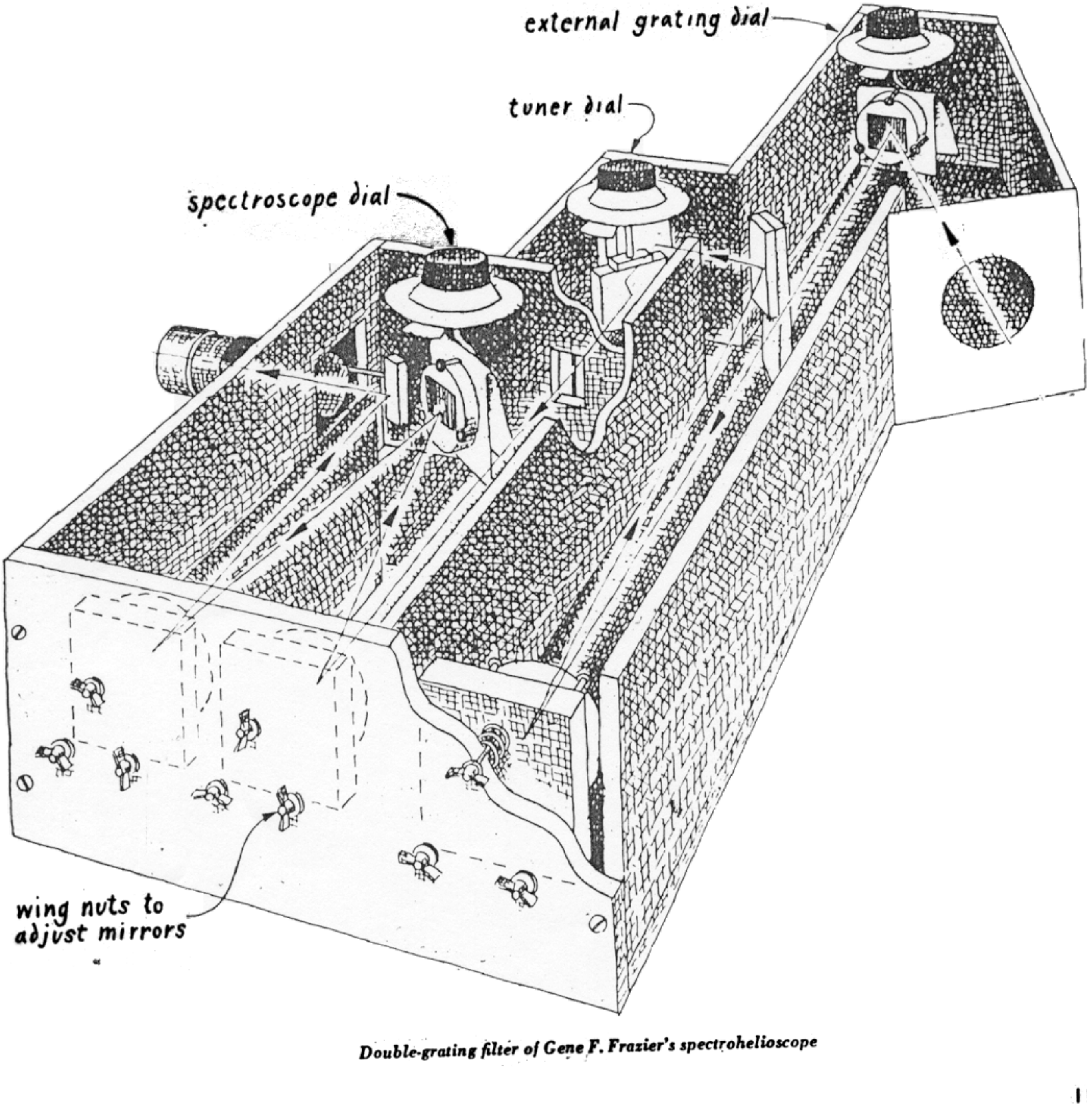
"Now assume that the flat mirror is replaced by the external diffraction grating of my instrument and that the angle of the grating is carefully adjusted to reflect a narrow band of light on the slit that spans 10 angstroms (from, say, 6,558 to 6,568 angstroms). The spectrum is noncoherent. For this reason the light that reaches the slit consists of many monochromatic images of the sun's disk that overlap on each side of the hydrogen line at 6,562.8 angstroms. If the dispersion of the gratings is assumed to be one angstrom per millimeter, the centers of each of the images of the sun's disk would be separated by one millimeter. At any setting 10 solar disks would overlap.

"This means that a band of color only 10 angstroms wide can enter the slit and that the scattering of light is significantly reduced. When the instrument is adjusted for observing prominences at 6,562.8 angstroms, unwanted light is reduced by more than 95 percent! Indeed, on a clear day it is not unusual for the field to appear completely dark five angstroms from the image. The full solar image appears in the field of view, which helps the observer to keep the edge of the image centered on the 6,562.8-angstrom line. With the aid of the tuner I have easily observed prominences continuously for intervals of more than two minutes.

"The construction requires no special skills, but the quality of the gratings is crucial. They must be mounted with care. The gratings should be ruled with at least 1,200 lines per millimeter for adequate resolution and high dispersion. The ruled area of the gratings in my instrument measures two inches square. The lines are blazed for 6,600 angstroms in the third order, which is to say that the surface of the rulings is cut at an angle that reflects light of maximum intensity at the 6,600-angstrom wavelength in the same direction as the grating disperses these rays in the third order.

"The gratings can be mounted in simple structures bent in the form of a V from sheet steel or brass. The gratings can be attached lightly to these mountings with machine screws and insulated from the metal with felt lining. The metal V's are supported by soldering the rear side to a quarter-inch copper rod that fits a radio dial of the vernier type [*see top illustration on page 114*]. The copper rod must be bent to an angle such that the projected axis of the vernier dial bisects the plane of the grating. When the rod is so mounted, the angle of the gratings with respect to the impinging rays can be altered without displacing the spectral orders at the eyepiece.

"I made adjustable cells of plywood for supporting the mirrors. The cells are supported at three equidistant points by



Double-grating filter of Gene F. Frazier's spectroheliocope machine screws fitted with compression springs and wing nuts. The mirrors can be lightly fastened to the plywood with wood screws insulated by rubber tubing and fiber washers. Incidentally, adjustable cells of cast aluminum are now available commercially at a reasonable price for mirrors of three-inch diameter or more. The cells also accept two-inch mirrors mounted in three-inch washers of plywood.

"The diameter of the mirrors is not critical, but it must be at least as large as the ruled area of the gratings to prevent vignetting (obscuration at the edges of the image) and the scattering of stray light into the image. In addition the focal length of the objective mirror should be an integral multiple ~~of the~~ focal length of the spectroscope mirrors, which, in turn, should be equal to within a tolerance of about 2 percent. The quality of the final image can be optimized by mounting the two mirrors of the spectroscope as close together as possible in order to minimize off-axis-aberrations.

"The tuning plate can be made of any optically flat glass about 50 millimeters wide and six to 10 millimeters thick. The piece can be circular or rectangular. Plates of this size that were originally intended for use as optical windows are now available inexpensively from dealers in surplus optical supplies. The plate can be mounted by a frame of sheet metal and adjusted by a supporting shaft and a vernier dial.

"The construction of an adjustable slit of adequate quality has through the years remained the most difficult problem that confronts amateurs who make spectroscopes. The best slits by far are the ones that can be bought from distributors of optical supplies, but they are currently priced from $100 up. The slit must remain rigidly centered when its width is increased from zero to two or three millimeters, which means that both jaws must move equal distances in opposite directions when the device is adjusted.

"A mechanical linkage in the form of a parallelogram can satisfy this condition [*see illustration at bottom left on page 114*]. The system of links can be assembled with snugly fitting machine screws. Excess play in the system can be eliminated by inserting a pair of helical springs to maintain a few grams of tension between the side links that support the jaws of the slit. The jaws can be made of single-edge safety-razor blades, which can be fastened to the supporting links with epoxy cement.

"I prefer jaws made of sections cut from a hacksaw blade. I first grind off the saw teeth with a carborundum wheel. The opposite edges are polished to remove surface irregularities. The procedure is not difficult. I grind two four-inch slabs of plate glass together with a thin slurry of No. 120 carborundum grit in water for a period of six minutes, making elliptical strokes about an inch long and turning the 'sandwich' over every minute. The edges of the blade are ground against the frosted side of either of the glass pieces for two minutes, again with elliptical strokes. I examine the edges for pits and hills and, if necessary, continue grinding until they are straight and smooth.

"One of the completed jaws is soldered or cemented with epoxy to its supporting linkage. After the jaw has been fastened the linkage is moved to the position where the separation of the side links is at a minimum. The ground edge of the companion jaw is placed in full contact with the ground edge of the jaw previously installed and similarly attached to its supporting link.

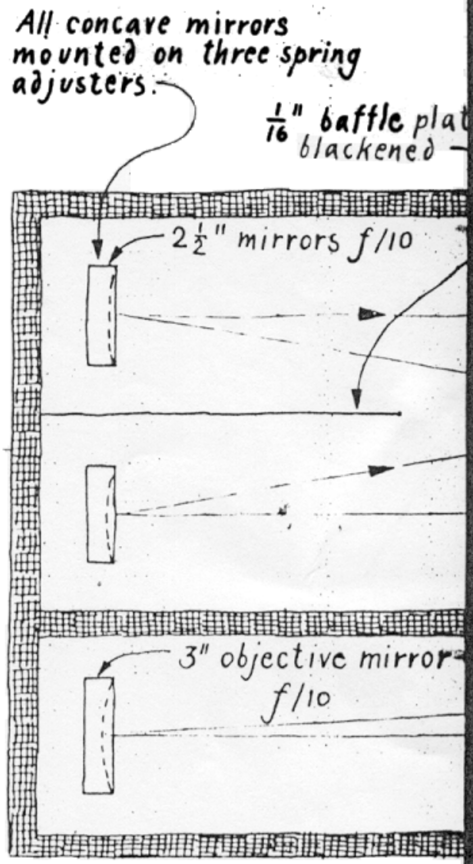
"All optical elements of the instrument must be installed in a lightproof housing. I improvised one of plywood. The spectroscope was made as a separate unit that could be bolted to the housing that supports the external grating and the objective mirror. This arrangement enables me to employ the instrument as a conventional laboratory spectroscope.

"The housings can take the form of simple boxes with removable lids to which the vernier dials are fixed. I minimized the overall dimensions of the apparatus by inserting a pair of plane front-surface mirrors between the objective mirror and the tuner to fold the incoming rays. The plane mirrors are set at an angle of approximately 90 degrees with respect to each other. They must be supported by mountings that can be adjusted a few degrees to align the optical path. Another plane mirror similarly mounted reflects converging rays from the spectroscope to the focal plane of the eyepiece. The interior of the spectroscope housing, including particularly the barrier that separates the concave mirrors, should be painted flat black to minimize the reflection of scattered light.

"All optical parts should be tested before they are installed. Testing the focal length of the mirrors is particularly important. A simple measurement of the focal length can be made by standing the mirror on edge, directing a flashlight toward the metallized surface and catching the reflected image of the lamp filament on a sheet of white paper placed next to the flashlight. Vary the distance of the flashlight and the paper from the mirror until the sharpest possible image of the lamp filament appears on the paper. The focal length of the mirror is equal to exactly half the distance between the image of the filament and the surface of the mirror. The focal length can be measured with greater accuracy by setting up the knife-edge test used for checking telescope mirrors [see *Amateur Telescope Making: Book One,* edited by Albert G. Ingalls, Scientific American, Inc.].

"An instrument similar to mine can be built for less than $250. The cost will increase exponentially with the diameter of the optical parts. The two-inch gratings and mirrors have enabled me to make most of the observations I had in mind when I undertook the construction and also to do a variety of laboratory experiments.

"The instrument has a maximum dispersion of about two angstroms per millimeter, which is equivalent to displaying the rainbow as an image more than six feet wide at the focal plane of the eyepiece. The zone in which the promi-



nences can be viewed at the edge of the sun is less than one millimeter wide, but even so it is sufficient to enable the observer to isolate the 6,562.8-angstrom spectral line of hydrogen.

"When the apparatus has been attached to an equatorial mounting that includes a clock drive to keep the ruled surface of the grating pointed approximately toward the sun, set the tuning plate at a right angle to the optical path and start the clock drive. Cover the objective mirror with a disk of white paper and adjust the external grating to the angle at which reddish light from the sun falls on the paper. Transfer the paper to the position of the slit of the spectroscope and adjust the flat mirrors to angles such that the reddish image falls on the paper at the position of the slit.

"Remove the paper. Adjust the first mirror of the spectroscope (the collimating mirror) to the angle at which the now parallel rays of the reddish light flood the diffraction grating of the spectroscope. If the light is difficult to see, cover the grating with a small sheet of white paper. Adjust the second mirror of the spectroscope to project converging rays to the flat mirror adjacent to the eyepiece. A sheet of paper inserted in the focal plane of the eyepiece should now display an image of the sun.

"While viewing through the eyepiece adjust the angle of both gratings to center the dark 6,562.8-angstrom spectral line on the slit of the spectroscope. The line is the darkest and broadest one in this region of the spectrum. The observer should now see in the eyepiece the complete scarlet image of the sun.

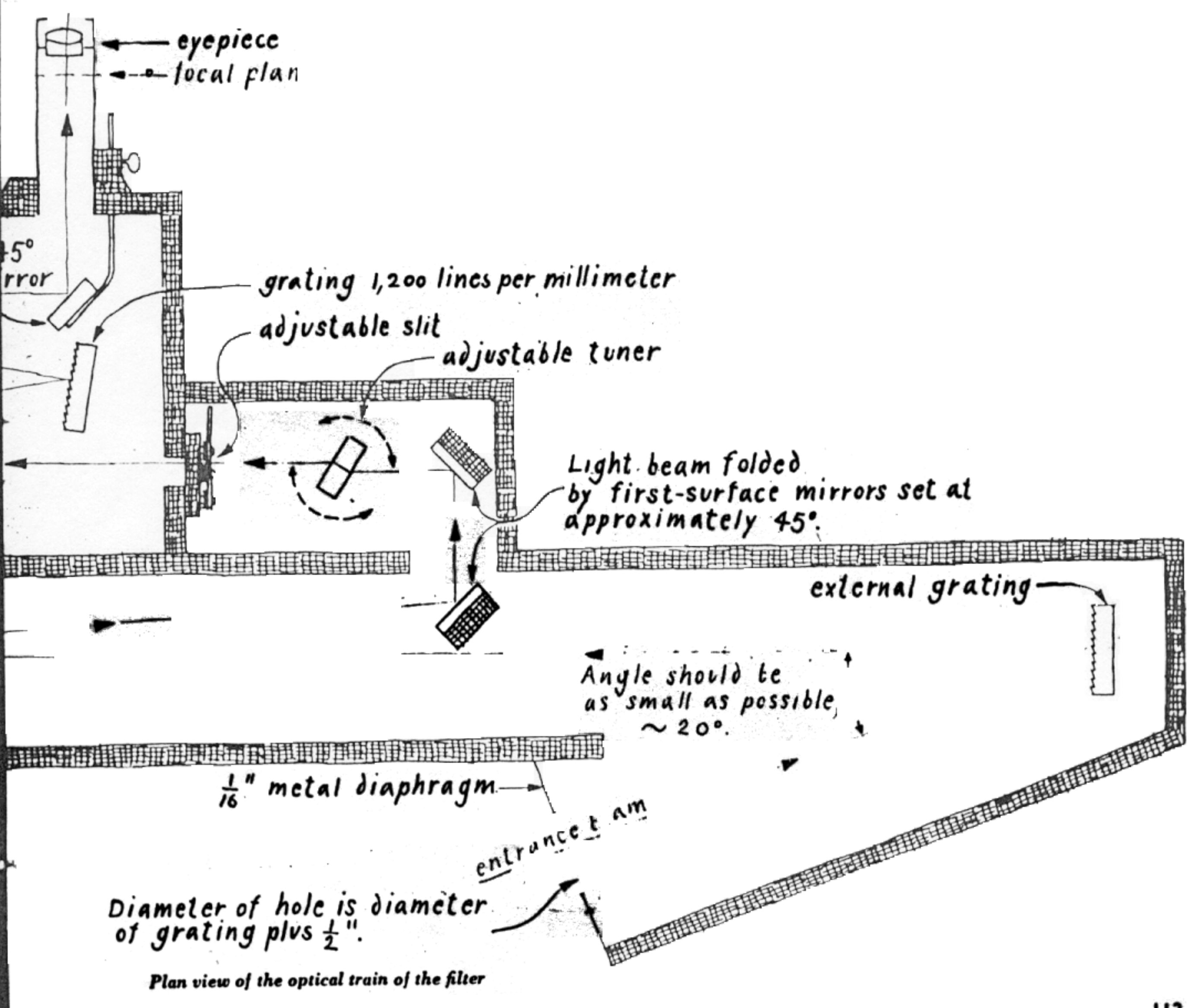
"To observe the limb, rotate the tuner so that the image appears to shift along the absorption spectrum to the point at which the edge of the sun is centered on the line at 6,562.8 angstroms. That is the adjustment at which Janssen made his initial observation. If a prominence happens to be located at this point, the observer will see the absorption line fade and be replaced by a bright area.

"Only a small area of the sun's edge is being observed. For this reason the edge will appear to curve away from the straight slit. To see prominences along a substantial portion of the edge the straight slit must be replaced by one that matches the curvature of the image.

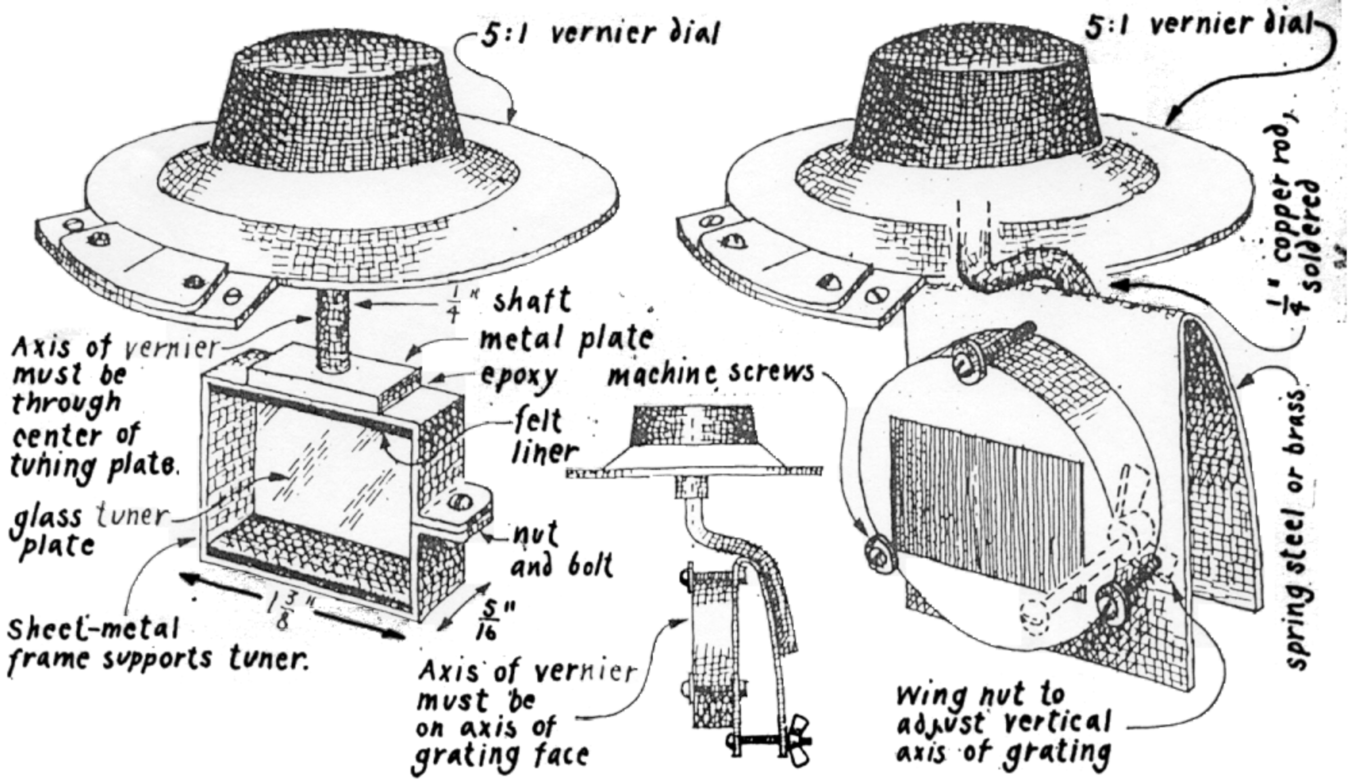
"Curved slits of two kinds are relatively easy to make. Of the two I prefer one that requires the use of an engine lathe to cut a disk of metal equal in diameter to the diameter of the solar image at the focal plane of the objective mirror. The dimension is very nearly equal to the focal length of the objective divided by 114.

"In the case of an objective mirror with a focal length of 30 inches the radius of the curved slit is approximately .131 inch. A hole .05 inch larger in radius is drilled in a metal sheet. The device is assembled by centering the disk in the hole and tacking it in place with a dab of solder or epoxy cement to leave a clear arc .05 inch wide and extending about 180 degrees.

"Another technique for making the curved slit is easier. Drill a hole slightly larger in diameter than the solar image and place it over a mirror that has been



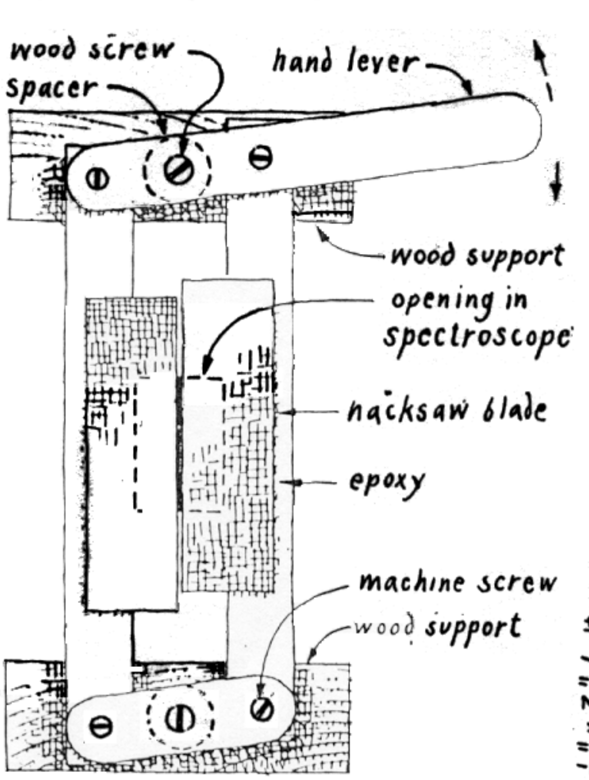
Plan view of the optical train of the filter



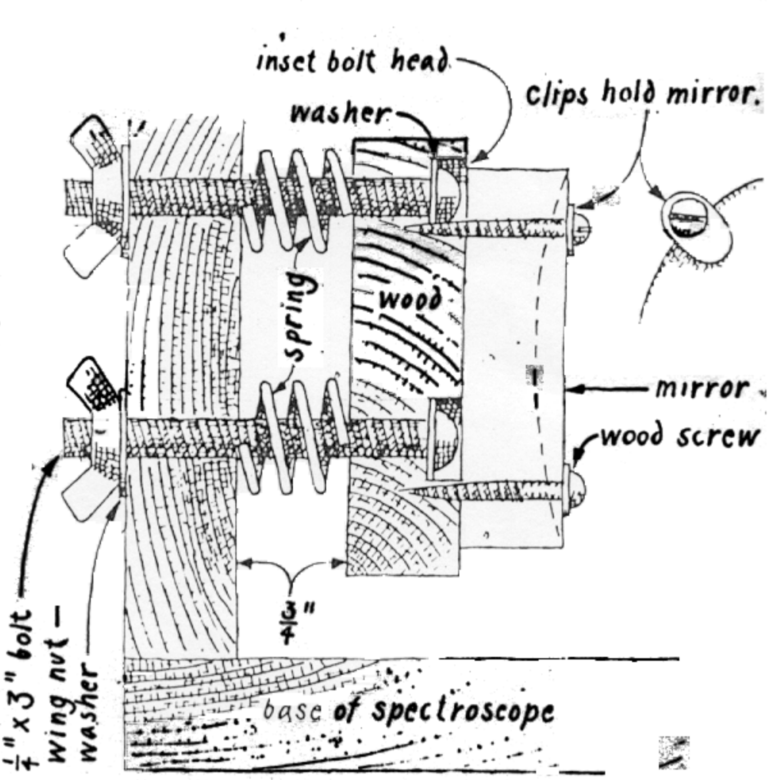
Vernier mounting of the tuning plate (left) *and the diffraction gratings* (right)

aluminized or silvered. Dip the sharpened tip of a wood toothpick in dilute nitric acid. Shake excess acid from the wood. Insert the sharpened tip through the hole in the metal and, with the metal as a guide, trace a semicircle on the coated glass. If the operation is performed with care, the acid will etch a usable slit in the metallic film. To observe solar prominences substitute the curved slit for the straight one.

"In a sense the double-grating filter is analogous to the tuning system of a radio set. It enables the investigator to select for observation a narrow band of light waves much as the dial of a radio set tunes in a narrow interval of the radio spectrum. The filter can serve in a variety of experiments other than the observation of solar prominences. For example, my interests include the use of



Details of the slit mechanism



Adjustable cells for concave mirrors

polarimetry for investigating the characteristics of minerals. At various orientations the surface of a rock can be seen in different colors, which depend on the crystal structure of the specimen. By examining the rock with the tuned filter, with both gratings adjusted to an appropriate angle, distinct colors appear in various areas of the surface that characterize the specimen.

"Mineralogists also routinely dissolve bits of unknown rock in a bead of incandescent borax to identify its constituents by the characteristic colors of the resulting flame. Each chemical element radiates a unique set of wavelengths. With the double-grating filter the experimenter can observe and even photograph the distribution of elements in the glowing gases.

"The rulings of a grating are cut at an angle that optimizes the efficiency of the device as a reflector of light of specified wavelength at a specified angle with respect to the plane of the rulings. As I have mentioned, the angle at which the rulings are cut is called the blaze. The angles at which gratings reflect bundles of rays dispersed in the form of spectra are known as the spectral orders.

"As I have mentioned, the gratings of my instrument are blazed to reflect most of the incident light at 6,600 angstroms in the third order. In general dispersion increases with the spectral order at the cost of brightness. My gratings were selected primarily for viewing solar prominences. Hence they were blazed for maximum brightness of the deep red in the spectral order that resulted in a dispersion of two angstroms per millimeter at the focal plane of the eyepiece. People who design the instrument for experiments of other kinds such as flame spectroscopy would doubtless select gratings blazed for other colors in other spectral orders.

"All optical parts from which the instrument is made are available from the Edmund Scientific Co. (300 Edscorp Building, Barrington, N.J. 08007). Diffraction gratings of the exact kind in my instrument are distributed by Jarrell-Ash Division of the Fisher Scientific Co. (590 Lincoln Street, Waltham, Mass. 02154) and by Bausch & Lomb Inc. (526–68 Lomb Park, Rochester, N.Y. 14602).

"Two people have helped me with this study. Timothy O'Hover of the chemistry department of the University of Maryland provided a laboratory and Gary A. Frazier supplied inspiration and electronic testing equipment for the original studies. I am deeply grateful to them."