Spectroheliograph

A spectroheliograph to observe details on the disk of the sun

April 1958

Ten years ago a young coal miner in West Virginia sent a letter to this department which began: "Those who helped make the amateur-telescope-making books possible have caused me to live two years of my life in complete contentment." The letter went on to tell how its author, Walter J. Semerau, who now lives in Kenmore, N.Y., had constructed a six-inch reflecting telescope. In the intervening years Semerau has had a remarkable career both in amateur optics and in his daily work. He left coal mining to become an electrician, then an instrument-maker, then a laboratory technician and finally an engineer. Meantime, as regular readers of this department have learned, his six-inch telescope has been succeeded by a whole galaxy of bigger and better instruments, including a 12½-inch reflector complete with a coronagraph and a spectrograph. Semerau now informs us that his telescope mounting supports a new apparatus which has long been the dream of amateur telescope makers; a spectroheliograph of the Hale type. This instrument provides him with a view of the sun rarely enjoyed by laymen.

"Although the sun is a fairly stable body of gas," writes Semerau, "it is neither as amorphous nor as placid as the casual viewer might suppose. Immense clouds of ionized hydrogen, calcium and other substances thrown up from the interior account for features as distinct as the earth's oceans and land masses. Although each of these features emits light of unique color and intensity which distinguishes it from its surroundings, they are lost in the white glare of the sun as it is seen by the naked eye. To see the details clearly the observer is obliged to examine the sun in light of a single color.

"One might suppose offhand that the details could be brought into view by looking at the sun through a filter of colored glass. This stratagem would fail because colored glass, however deeply it is stained, transmits a broad band of colors, just as a radio set of poor selectivity permits several broadcasting stations to be heard at the same time. One must use a filter with an extremely narrow 'pass-band.'

"Such a device was hit upon about a century ago in India by the French astronomer Pierre Janssen. Janssen was using a spectrograph equipped with two slits to observe a total eclipse of the sun. The image of the sun's edge was focused on one slit. Rays proceeding through the slit were spread out by the prism into the familiar ribbon of spectral lines. Janssen was examining one of the lines through the second slit—the dark red line characteristic of glowing hydrogen—when he saw a tongue of flame standing out from the solar edge. Opening the slit brought more and more of the prominence into view until the width of the slit exceeded that of the red line. At this point the image became blurred. To examine slit-shaped portions of the solar disk in other colors Janssen simply shifted the viewing slit to other lines of the spectrum.

"Some 40 years later George Ellery Hale and Henri Deslandres independently devised a method of using the double-slit spectrograph to make photographs of the whole solar disk. The two slits were simply coupled mechanically so that they could be moved as a unit. When the entrance slit is swept across the sun's image, the exit slit keeps in step with the similarly moving spectral line of any selected color. Solar features emitting light of that color are focused on a photographic plate and build up a composite image that resembles the scanned image of a television picture. The device, called the spectroheliograph, was only a step away from the spectrohelioscope, which presents the composite image to the eye. To make a spectroheliograph into a spectrohelioscope one simply arranges for the slits to oscillate across the sun's disk at a rate of 20 or more sweeps per second and substitutes an eyepiece for the photographic plate.

"Not many spectroheliographs have been built by amateurs because of the difficulty of procuring the element which disperses white light into its constituent colors. This may be either a glass prism or a diffraction grating. Prisms large enough for the job are hard to make, and no amateur has succeeded in ruling a diffraction grating of the required fineness and precision. In recent years, however, the Bausch & Lomb Optical Company has introduced an excellent and relatively inexpensive 'replica' grating: a plastic cast of an original grating. A replica grating two inches square with 15,000 rulings per inch costs no more than a set of good golf clubs. With it the amateur can build a spectrograph of exceptional performance and equip this basic instrument with an accessory for making spectrohelioscope observations. [For a description of Semerau's spectrograph see "The Amateur Scientist"; September, 1956.]

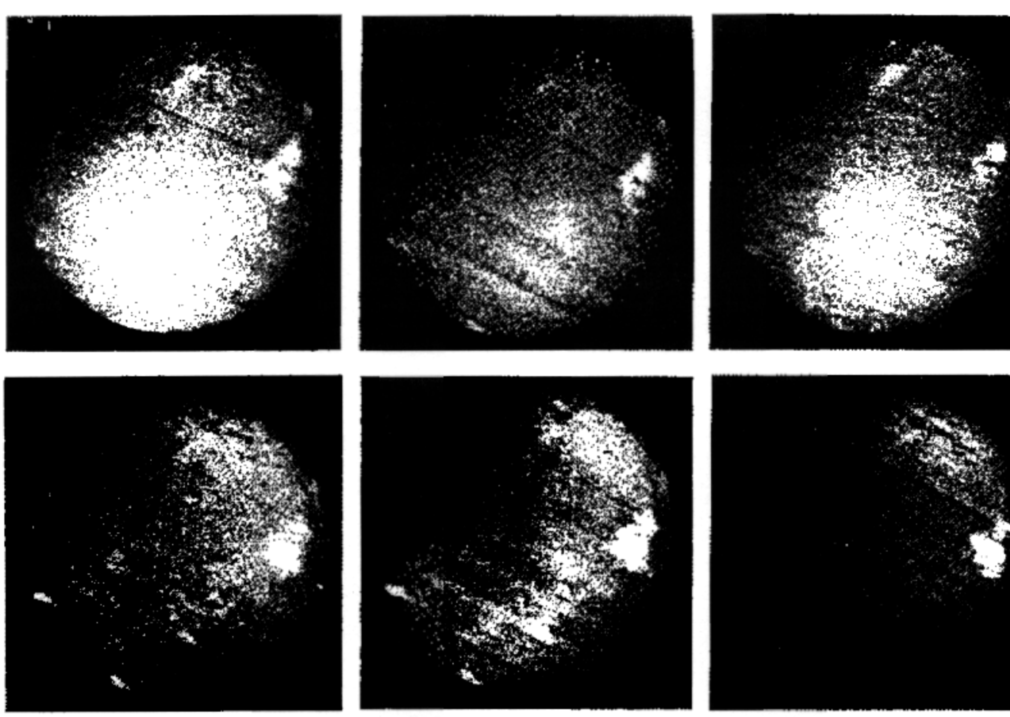
"Although it is possible to fit out a spectroheliograph for mechanical scanning, the arrangement is bulky, difficult to maintain and a remarkably effective generator of unwanted vibrations. For these reasons I adopted the optical-scanning system devised by Hale in 1924. The conventional rocker arm which carries the entrance and exit slits in the mechanical system is replaced by a pair of rotating glass cubes, or Anderson prisms. The image of the sun is focused on the fixed entrance-slit of the spectrograph through one prism. The image of the similarly fixed exit-slit is focused on the plateholder (or on the focal plane of the eyepiece) through the second prism. As the prisms rotate, refracted light sweeps past the slits as though the slits had been moved across the rays mechanically. The prisms are mounted on the ends of a shaft which turns on ball bearings; the unit can be assembled on the mounting of even a small telescope without introducing perceptible vibration.

"The spectroheliograph assembly consists of (1) a main housing to which the moving parts are attached and (2) a tube for the eyepiece, reflex mirror and 35-millimeter camera [*see drawing on page 134*]. The unit is relatively light, compact and simple in construction. It weighs 10½ pounds complete with eyepiece and camera, and measures 15 inches over all. An adapter makes the assembly interchangeable with the plateholder of the spectrograph, which is mounted beside the telescope. The bearings of the equatorial mounting have enough friction to offset the added weight of the unit; thus no change is required in the counterbalance when the spectroheliograph is used.

"Each prism is clamped between a flange at the end of the shaft and a metal disk held in place by through bolts. Rubber sheeting between the glass and metal protects the prisms against excessive mechanical strain. Center to center the prisms are 3.625 inches apart, the distance between the entrance and exit slits of the spectrograph. The flange supporting the outer prism is grooved for an 'O' ring belt through which the rotating assembly is coupled to a miniature direct-current motor. The facets of the prisms must be adjusted to lie in a common plane or the image will flutter when the unit is started up.

"Parallel rays entering my telescope come to a focus at a distance of 62.5 inches from the 12.5-inch objective mirror, a focal ratio of $f/5$. The focal ratio of the spectrograph is $f/23$. To feed the spectrograph with light from the telescope a set of negative achromatic lenses was introduced into the optical path between the objective and the spec graph. This compensates for the di ence between the focal ratios of the instruments. A pair of front-silvered tical flats was mounted at the upper of the telescope to receive rays refle from the objective and bend them degrees into the spectrograph.

"Incoming rays pass through one tating Anderson prism, scan the entr slit and diverge to an eight-inch sp ical mirror at the opposite end of spectrograph tube, where they are flected as parallel rays to the diff tion grating at the other end of tube. Here the white light is dispe into its component colors and retur to the spherical mirror, which br the resulting spectrum to a focus the plane of the exit slit [*see draw on next page*]. The exit slit may be justed to match the width of any sp tral line. The most useful lines are red 'alpha' line emitted by glowing drogen and the 'H' and 'K' calcium l in the violet region of the spectr Light transmitted by the exit slit p ceeds through the second Ander prism, the scanning action of which, gether with a final lens assembly,



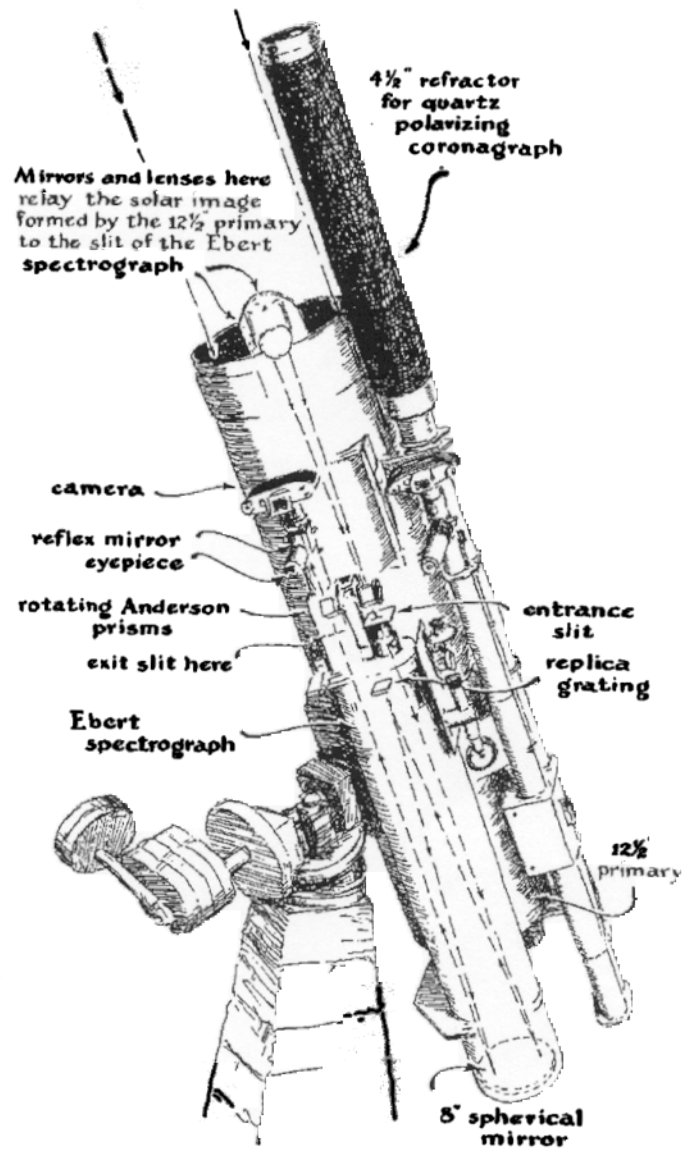
These spectroheliograms were made on October 20, 1957 at 14:15, 14:18, 14:29, 16:51, 16:53 and 16:57 Greenwich mean time constitutes a highly monochromatic image of the source in the focal plane of the camera. A reflex mirror in the beam permits the image to be examined visually through the eyepiece.

"The operating procedure is relatively simple. After the instrument is assembled and aligned, the angle of the diffraction grating is adjusted to bring the desired spectral line into view in the eyepiece.

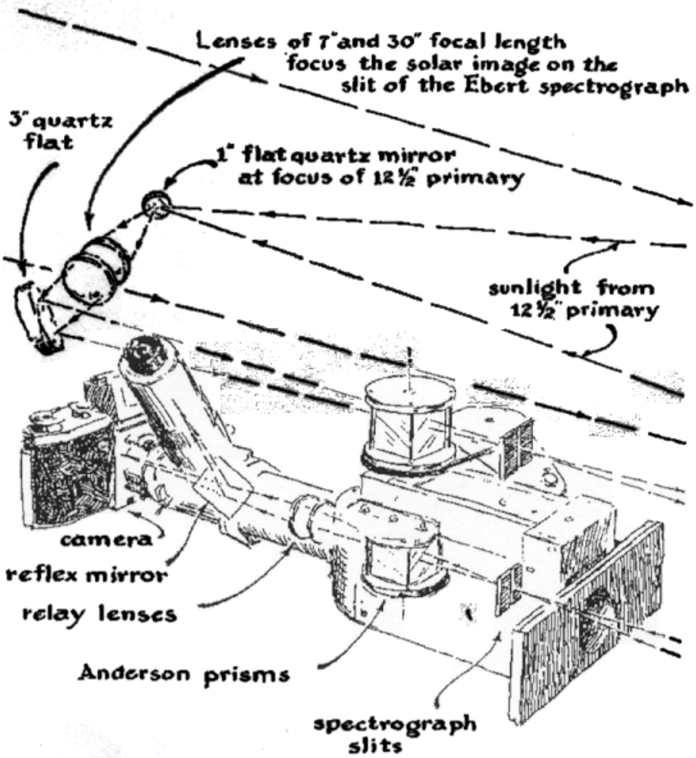
"Diffraction gratings produce a series of spectra (spectral orders), an effect analogous to a multiple rainbow. The extent to which the colors are dispersed increases with the 'higher' orders at the cost of brightness. When used in the first order, the grating of my spectrograph can spread 14.5 angstrom units of the spectrum enough to fill the exit slit when its jaws are spaced one millimeter apart. In other words, dispersion in the first order is 14.5 angstroms per millimeter. The second order gives a dispersion of 7.5 angstroms per millimeter, and the succeeding orders proportionately more. Thus, were it not for the fact that the brilliance of the diffracted light diminishes with each successive higher order, one could observe an extremely narrow band of color through an exit slit of substantial width. My grating is ruled for use in the second order (it is 'blazed' for 10,000 angstroms in the first order and 5,000 in the second). Hence, to observe a band of color one angstrom wide the jaws of the exit slit must be spaced about a seventh of a millimeter apart.

"The spectral orders produced by the grating tend to overlap; that is, the red end of the first order falls on the violet end of the second, the red end of the second order overlaps the violet end of the third, and so on. The effect must be minimized or the quality of the final image will suffer. This is accomplished by inserting in the optical path a glass filter which has maximum transmission in the region of the spectrum under observation. If one is observing the alpha line of hydrogen, for example, violet light from the unwanted order will be suppressed by a red filter such as the Corning Glass Works' No. N1661. Similarly, a violet filter is used when observing the H or K lines of calcium. The filter may be inserted at any point in the system, but a filter located at or near the primary focus may heat unevenly and break. Hence the filters are usually placed at a point between six and eight inches from the primary focus.

"With the filter in place, the entrance slit is opened to a width of about .02 inch. This admits considerably more light than is needed for observing but simplifies subsequent adjustments. The exit slit is opened so the spectral lines can be seen easily between the jaws. The desired line is selected and focused sharply by moving the entrance slit back and forth. The image of the exit slit is then focused so that the jaws appear sharp when viewed through the eyepiece. If spectroheliograms are to be made, the camera is similarly adjusted to bring the slit into sharp focus on the film. The instrument is next adjusted for maximum resolution. First, the jaws of the entrance slit are closed to the point where the spectral lines appear dark and sharply defined against a light background. Then the jaws of the exit slit are closed until they just frame the line selected. In the case of the alpha line of hydrogen the optimum width will be approximately a fifth of a millimeter. The motor is started. As



Semerau's telescope, showing the optical path used during spectroheliograph observations



Details of Semerau's spectroheliograph

the prisms reach a speed of about 16 revolutions per second, a monochromatic image of the sun, complete with the flaming detail of the solar surface, will come into view.

"This of course assumes that all adjustments have been carefully made. Each element of the instrument, from the objective to the eyepiece and camera, must be aligned with the optical axis of the system. If the telescope and spectrograph are out of line, for example, only part of the light will fall on the diffraction grating. The final image will not be as bright as it could be. In addition, the unused light will be reflected from the housing, will mix with the diffracted rays and reduce the contrast of the image. Similarly the system should be adjusted so that white light from the entrance slit approximately fills the diffraction grating. If the grating is not fully illuminated, its efficiency suffers. Conversely, rays which extend beyond the edge of the grating are lost to the final image and impair its contrast.

"The final adjustment consists in gradually narrowing the exit slit. This brings progressively finer details into view; prominences, mottling near the region of sunspots, dark filaments, flocculi and so on. It also reduces the brilliance of the image and sets a limit to visual observation. At this point the camera comes into use. The average exposure time is from two to four seconds; the instrument is guided during a time exposure as it is in conventional astronomical photography. The camera is also used in the violet region of the spectrum beyond the range of the eye. In this region lie the H and K lines of calcium.

"Although the instrument has many desirable features, I should also mention one disadvantage. The Ebert spectrograph, as I constructed it, introduces some distortion; the image of the sun's disk is somewhat elliptical. This is explained by the fact that the slits must be located somewhat off the axis of the spherical mirror. The distortion is partially compensated by tilting the camera. Curved slits would provide a better correction, but I have no way of making them. The distortion does not impair resolution but it introduces some complication in locating details a rately on the image. Advantages of design include simplicity, lightness, tively low cost and a cylindrical that is easy to assemble on an e torial mounting. In addition, des portions of the spectrum can be bro into view at the twist of a dial.

"The spectroheliograph is mou beside the coronagraph previously scribed in 'The Amateur Scie [September, 1955]. The two are simultaneously. The coronagraph sh prominences at the edge of the su great detail, but gives no hint of solar disturbances responsible for t because the central disk is masked a diaphragm. In contrast, the spec heliograph reveals faculae, flocculi, ments, spots and even prominence exceptional brilliance.

"Amateurs often ask which instru I prefer. The choice is difficult. were interesting projects. The cos influenced, particularly in the case the coronagraph, by the extent to w the final image is made monochrom The filtering element in my coronag is a quartz monochromator, a m layered sandwich of crystal quartz Polaroid film. It was designed to tr mit a band of color four angstroms w At current prices the raw crystal quartz from which it was made wo cost about $150. Four times this amo would be needed to narrow the p band to one angstrom. If, for exampl monochromator designed for a p band of four angstroms requires a st of crystal slabs four inches high, one a pass-band of one angstrom would quire a 16-inch stack. Moreover, e successive slab in the stack must twice as thick as its predecessor. T means that the final slab in a 16-i stack would have to be cut from a crystal more than eight inches lo Crystals of this size—and of the ne sary optical perfection—are not c mon in nature, and are priced acc ingly.

"Monochromators are not easy build. I would rather make two sets prisms for a spectroheliograph than two quartz slabs for the monochroma Not only is glass softer and easier work than quartz, but the prisms may cut in random directions from any lo tion in a block of glass. Quartz crys must be put through a complex se of tests to determine their optical pr erties in advance of cutting. The fects of quartz are many, and the s stance is so hard that a diamond-ed saw is almost a necessity.

"But one look through the eyepi

of a coronagraph, even one with a passband of four angstroms, justifies the investment of time and labor. When they are seen in detail, solar prominences are among nature's most impressive spectacles. I did not keep an accurate record of my cash outlay for the two instruments, but an estimate of $300 for each would not be far wrong.

"I had the good fortune to observe and photograph an interesting pair of solar events on October 20, 1957. No outstanding disturbance was evident when I began to observe at 14:15 Greenwich mean time, but within 15 minutes a scarlet flocculus appeared near the southwest edge of the sun. The intensity of the flocculus remained constant during the following two hours, but at 16:51 a small flare brightened near the east edge. At about this time the cloud first observed also started to brighten; thereafter both regions grew in size and brightness to the International Geophysical Year standard of 'Importance 3.' By 17:15 the east flare had diminished to normal brightness and 45 minutes later the one near the southwest edge similarly faded. The visual image was sharp and crisp. Poor seeing caused some blurring of the photographs, but conditions improved somewhat at 16:51 [*see photographs on page 132*]."

Semerau states that he is now working on an electronic servo guiding-mechanism, two 35-millimeter time-lapse cameras and a heavier equatorial mounting for his instruments. What he hangs on the mounting next is anybody's guess!