

The Auto-Collimating Spectroheliograph of the Kodaikánal Observatory. By John Evershed. (Plates 19, 20.)

The spectroheliograph in daily use at the Kodaikánal Observatory for photographing the calcium flocculi and prominences in "K" light is one of the type in which a transverse uniform motion is imparted to the whole instrument, the collimator slit traversing a stationary solar image, and the camera slit moving at the same rate across a fixed photographic plate. The movement is effected by means of a heavy weight attached to the framework of the spectroheliograph by a steel tape passing over a pulley, and the necessary uniformity and smoothness of motion is attained by mounting the spectroheliograph on three steel balls running on horizontal plane surfaces. The movement is controlled and regulated by attaching part of the framework to a large plunger working in a cylinder of oil, with a valve to regulate the flow of oil through a small aperture in the plunger.

This instrument, which was built by the Cambridge Scientific Instrument Company, is admirably adapted for monochromatic photography in the violet region of the spectrum, but, owing to the small dispersion of the prismatic spectrum in the red region (two prisms of 60° are used), and to the troublesome readjustments required, involving a change in the curvature of the slits, it is not practically possible to obtain photographs with the hydrogen line $H\alpha$.

For this work an entirely new spectroheliograph has been constructed in the observatory workshop. It is of the auto-collimating type, and was designed for use with a train of prisms of large angle, having a 30° prism at the end of the train. This 30° prism was to be silvered on the outer face, in order to return the light a second time through the prisms, and so double the dispersive power of the train. The prisms need to be 4 inches in height in order to include the whole of the beam of light from the collimator; and of five large prisms which have been tested, not one was found to be sufficiently homogeneous to give good definition of the spectrum with the double transmission. As considerable dispersive power is necessary in work with the $H\alpha$ line, a large Michelson grating was substituted for the prisms. This grating has an effective ruled surface only 2.9 inches in height and 6 inches in length. Notwithstanding the great loss of light involved, this grating has proved fairly efficient for the work, and disc photographs of the Sun in $H\alpha$ light have been obtained with it regularly since April 1911. Limb photographs showing the prominences are not practically possible, owing to the very long exposures needed; and the disc photographs are slightly defective near the top and bottom of the images, because of the shortness of the ruled lines of the grating.

The new spectroheliograph is mounted on iron brackets bolted to the framework of the Cambridge instrument; it shares, therefore, in the very perfect transverse movement of the latter. The collimator slit projects about 15 inches in front of the collimator slit of the Cambridge instrument, as is shown in Plate 19, and the optical axis of the spectroheliograph is displaced laterally about $8\frac{1}{2}$ inches from the optical axis of the 12-inch image-forming objective. The Sun's image is, however, reflected on to the slit by means of two plane mirrors, one fixed immediately in front of the slit, and the other attached to a movable arm, so that it can be placed in the axis of the beam of light from the 12-inch lens when required, or removed out of the way when the Cambridge instrument is being operated. These mirrors are so adjusted relatively that when the 12-inch objective is focussed for "K" photographs with the Cambridge instrument, the $H\alpha$ image is also in focus for the auto-collimating spectroheliograph. Thus it is possible to go from one instrument to the other without loss of time.

A single meniscus lens by Cooke of $4\frac{1}{2}$ inches diameter and 8 feet focal length serves as collimator and camera lens. The

back surface is curved to a radius equal to its focal length. It is carefully "squared on," so that the white light image of the collimator slit reflected from the concave back surface coincides with the slit itself. The purpose of this is to eliminate the troublesome reflection which would otherwise be superposed on the spectrum.

The prism table or grating mount is placed immediately in front of the lens, and is supported by an extra strong bracket. The lens is mounted on a sliding frame, with rack and pinion for focussing. Attached to the sliding part is a small blackened screen, placed in the focus of the light reflected from the front surface of the lens. This effectively cuts out the white light from this surface. These arrangements are seen in the photograph (Plate 20).

The dispersed light from the prism train or grating returns through the lens in the direction of the collimating slit, where an image of the spectrum would be formed, but before reaching the slit it encounters a plane mirror, which reflects a short section of the spectrum downwards on to another mirror parallel to the first. The effect of the two mirrors is to bring the spectrum to a focus underneath, and about 7 inches behind the collimator slit. Here is placed the camera slit, attached to the moving parts, and the fixed support for carrying the dark slide. It is perhaps unnecessary to give the details of construction of this part of the apparatus, but some description may be given of the slits, which are of primary importance in spectroheliograph design.

Both camera and collimator slits are fixed in width, that is, they have no screw adjustments, as this is found to be entirely unnecessary. They can be opened or closed only after removal from their supports, and they are adjusted once for all to the width found by experiment to give the best results, and no subsequent alteration is ever made or needed.* This effects a material simplification, both in the construction of the slits and in the working of the spectroheliograph.

Both slits are alike, and worked to the same curvature. The jaws are of platinoid, screwed on to blocks of brass, which are, in turn, clamped to a supporting piece, also of brass, and having a slot along the centre, cut a little longer than the slit. One jaw is immovable when screwed down, and the other has a small range of adjustment, which can be effected by loosening the clamping screws. When the jaws have been worked to the right shape and approximate curvature, they are securely clamped to the perfectly flat surface of the support, and ground on the face with fine emery on a test plane, until the faces of the two jaws are in absolutely the same plane. This is a most necessary condition for the best results, and is easily attained in this form of slit. After the grinding process, the edges are quite sharp, but require to be figured and polished. This is done by unclamping the jaws, and carefully working the edges on specially prepared tools. The

* The width used is 0.06 mm.

tools consist of two pieces of thick plate glass, ground together with emery until perfectly uniform cylindrical surfaces, convex and concave, have been obtained. The radius of curvature is determined from time to time during the grinding by sticking small pieces of plane parallel optical glass to the wet surface of the concave tool, and observing the position of coincidence of the reflected images of a candle flame placed near the centre of curvature. In this way the tools were worked to a radius of 20 feet, which is the curvature of the second order $H\alpha$ line, computed by Walker's formula, when the collimator slit has the same curvature.

The slits were finally figured and polished on these tools, using a little graphite to facilitate the process.

The collimator slit is attached to the end piece of a brass mounting in a way that permits of a movement of rotation through a small angle by means of a screw acting against a spring. This is for the adjustment of parallelism with the camera slit, the latter being fixed truly vertical. The entire mounting of the collimator slit is movable laterally through a few millimetres by means of a fine-threaded screw. Thus the adjustment for coincidence of the camera slit with the spectrum line is made by moving the collimator slit.

The observation for coincidence is made by the method I have always adopted in spectroheliograph work, and found to be most satisfactory. A window or opening is made at one or both ends of the camera slit, through which a portion of the spectrum is observed with suitable lenses. For the $H\alpha$ work a single window at the bottom of the camera slit is found to be sufficient. The observation is made through a small telescope, provided with a collimating lens and a right-angle prism. When sunlight is made to fall on the upper part of the collimator slit (which is a few millimetres longer than the camera slit), the adjustment is very easily and quickly made, the grating having already been rotated so as to bring the $H\alpha$ line within the field of view.

A point of considerable importance with regard to the slits is the prevention of dust particles from settling on the jaws, and causing unsightly lines in the resulting photograph. This trouble has been completely overcome in the case of the collimator slit by the provision of a protecting cover of bright aluminium, having a narrow slot cut in it to admit light to the slit. This cover serves the double purpose of preventing dust from falling on the slit from above, and preventing the slit and adjacent parts from getting unduly heated by the Sun's image, a large proportion of the radiation being reflected from the bright surface.

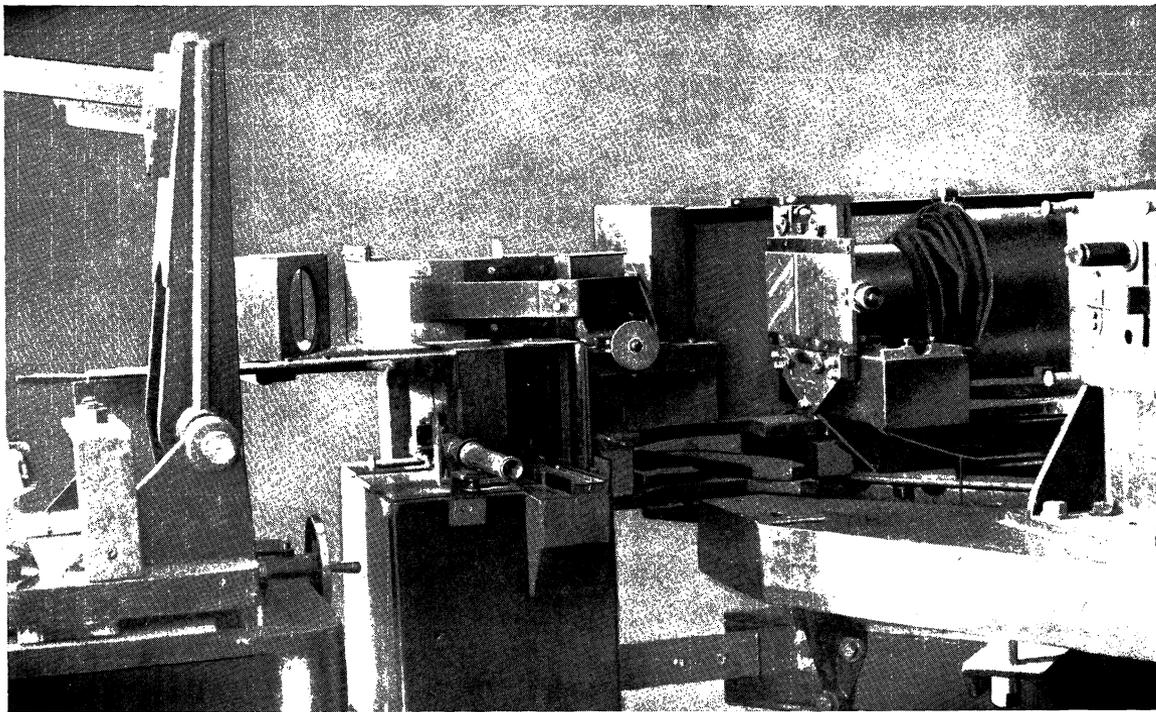
The camera slit is entirely protected from dust, as it moves in a chamber which is open only on the side where the dark slide is admitted.

In the photographs which accompany Dr. Royds' paper, dust lines are absent. There are, however, faint shadings at right angles to the direction of the movement of the spectroheliograph.

These are due to very thin clouds passing over the Sun during the exposure.

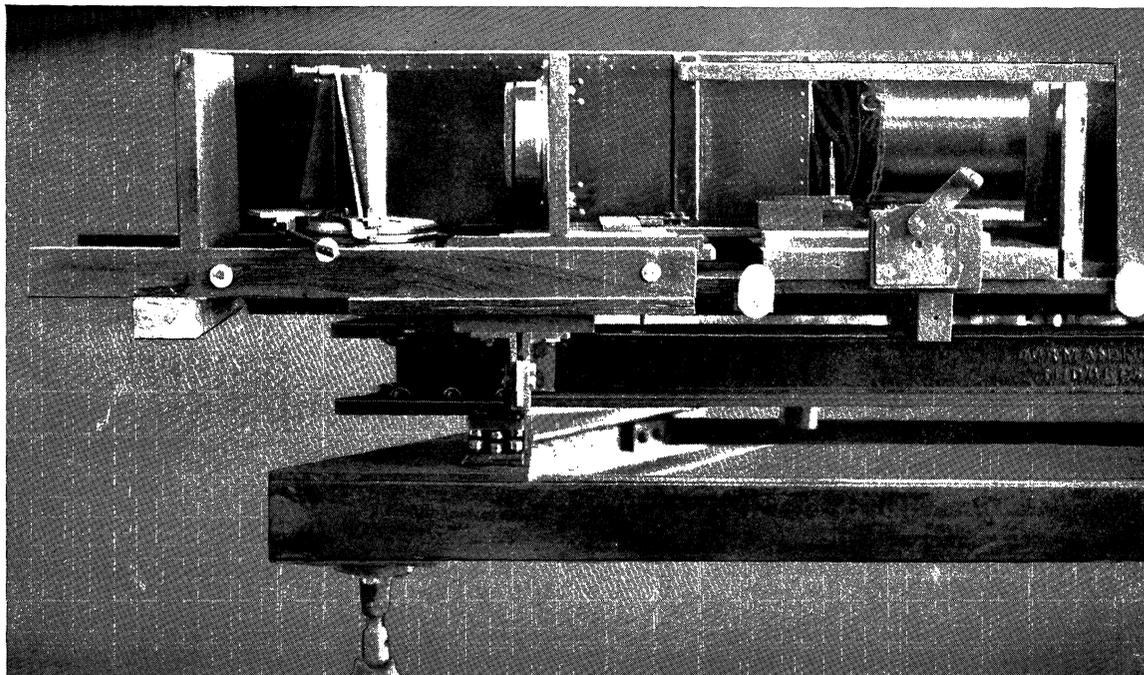
Owing to the enormous loss of light necessarily involved in the use of a grating, the exposure time needed to get a sufficiently dense image of the Sun's disc on Wratten panchromatic plates is comparatively long. In clear weather about five minutes is required for the H α line, and during this time the Sun's image must be kept quite stationary, otherwise a distorted photograph results. To effect this a subsidiary guiding arrangement has been devised. The elliptical beam of light coming from the heliostat considerably overlaps the 12-inch objective, and in the path of the waste light a small objective is mounted. With two plane reflectors and an enlarging lens an image of the Sun about 12 inches in diameter is projected on a ground glass screen, conveniently placed for observation, and the slightest movement of the image on the screen, due to irregularities in the driving of the heliostat, is corrected by means of the electric contacts actuating the slow-motion motors on the heliostat.

The second order spectrum is usually employed, as the exposure time needed is very little longer than with the first order, and the higher dispersion is a great advantage. The H α line in the second order is about 0.30 mm. in width, the slit being about $\frac{1}{3}$ th. of this. A plane parallel red glass screen is placed 6 inches behind the collimator slit to cut out blue light of the third order, as well as diffuse light from the grating surface.



SLIT END OF TWO SPECTROHELIOGRAPHS.

The slit of the Cambridge spectroheliograph is seen on the right hand, and that of the auto-collimating spectroheliograph behind it and projecting forward towards the left hand. The slit of the latter is covered by an aluminium screen, in front of which is seen one of the two mirrors used for projecting the Sun's image on the slit. The other mirror is attached to the end of the raised arm, which is lowered when this spectroheliograph is to be operated. Underneath the slit to the right is seen the chamber in which the dark slide is placed, and the telescope and right-angle prism for observing the camera slit and the spectrum.



GRATING AND LENS OF THE AUTO-COLLIMATING SPECTROHELIOGRAPH ATTACHED TO THE SIDE OF THE CAMBRIDGE SPECTROHELIOGRAPH.

The small screen for cutting out the white light image of the slit reflected from the front surface of the lens is seen near the focussing handle to the right of the lens.