The Coronaviser, an Instrument for Observing the Solar Corona in Full Sunlight *

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INTRODUCTION

BECAUSE of the rarity of solar eclipses, their short duration, and their occurrence usually at inconvenient places on the earth's surface, the problem of observing the solar corona in full sunlight is an important one for astronomers. It is also of considerable interest to those telephone engineers who are concerned with radio transmission over long distances. The major disturbances of such transmission have their origin in the sun and studies to date have indicated that a day-to-day knowledge of the activity of the corona might prove useful in predicting the transmission conditions.

The first attempt to solve this problem was made by Huggins in 1878 and since that time every conceivable optical means to accomplish the desired result has been tried. The problem is to observe the corona, not in itself a faint object, through the blinding glare of the sky in the region around the sun. If one holds his hand at arm's length so that it blots out the sun, he will find the glare in the sky around it so intense as to be painful. It is generally at least a thousand times brighter than the corona. The trials have usually been made at very high altitudes where the atmospheric glare is greatly reduced but since the scattered light from the telescope itself, particularly the objective, is some hundreds of times brighter than the corona no success was obtained until M. Lyot [1] invented his *coronographe*, a telescope in which this latter kind of glare is greatly reduced. With this instrument at the top of Mt. Pic du Midi in the Pyrenees mountains he has obtained several photographs which show some of the features of the inner corona. At best he has to work with a glare that is nearly as bright as the brightest parts of the corona. There are only a few days in the year when the intensity of the glare is low enough to enable him to observe coronal features through it.

It is obvious that a method of greater discrimination is needed if day-to-day observations are to be made. Such a method was proposed several years ago.[2] It is based on the use of television technique;

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[1] Lyot, B., *M. N. R. A. S.*, 99, 8, 580, 1939.

[2] Skellett, A. M., *Proc. Nat'l. Acad. Sci.*, 20, 461, 1934.

the corona is separated from the glare by electrical filters while the image of the sky around the sun is temporarily represented by an electric current.

Apparatus and Technique

Dr. G. W. Cook, Director of the Cook Observatory, kindly offered the use of his 15-inch horizontal telescope for a trial of the method. Special television apparatus was developed at the Bell Telephone Laboratories for use in conjunction with this telescope. This apparatus has been called the coronaviser. Figure 1 shows a layout of the complete apparatus. Starting at the left, the plane mirror *M* is coupled to driving mechanism to form a siderostat so that sunlight may be continuously held on the axis of the telescope. The solar disc, about 2″ in diameter, is focussed by the objective of approximately 18 feet focal length to fall on the tilted mirror which reflects the direct sunlight out through a hole in the side of the telescope and into a light trap consisting of a black walled tube with a black velvet end. Figure 2 shows the scanning mechanism in greater detail. Immediately in back of the mirror *R*, which is the one just referred to for throwing sunlight out of the telescope, a black masking disc *D* further prevents sunlight from getting into the scanning apparatus. Several different sizes of this disc are used to take care of the different diameters of the solar image which occur throughout the year and to shield the scanner from sunlight which spills over with bad seeing. This mirror and disc are supported by means of the plate glass *P* so that there is no obstruction in the field around the sun.

To the right of the plate glass lies the scanning apparatus. This is a mechanical device which scans the region of the sky around the sun in a spiral path. The scanning motion thus consists of a circular and a radial motion.

The simple plano-convex lens *L* which is silvered on the back is equivalent to a concave mirror and forms an image of a portion of the sky image that lies in the plane of *D* on the scanning hole *H* which is on the axis of the telescope and scanner. The light that enters the scanning hole passes through the lens, the prism, and the light tunnel *U* into the photo-cell *E*. When the lens *L* is rotated about the axis by the motor, the effect is the same as moving the scanning hole around in the image plane at *D*. This takes care of the circular component of the scanning motion.

The radial component is obtained by changing the angle of tilt of the lens *L* while it is rotating. A worm *W* is mounted on the motor shaft but held stationary so that as the gear *G* revolves as a whole

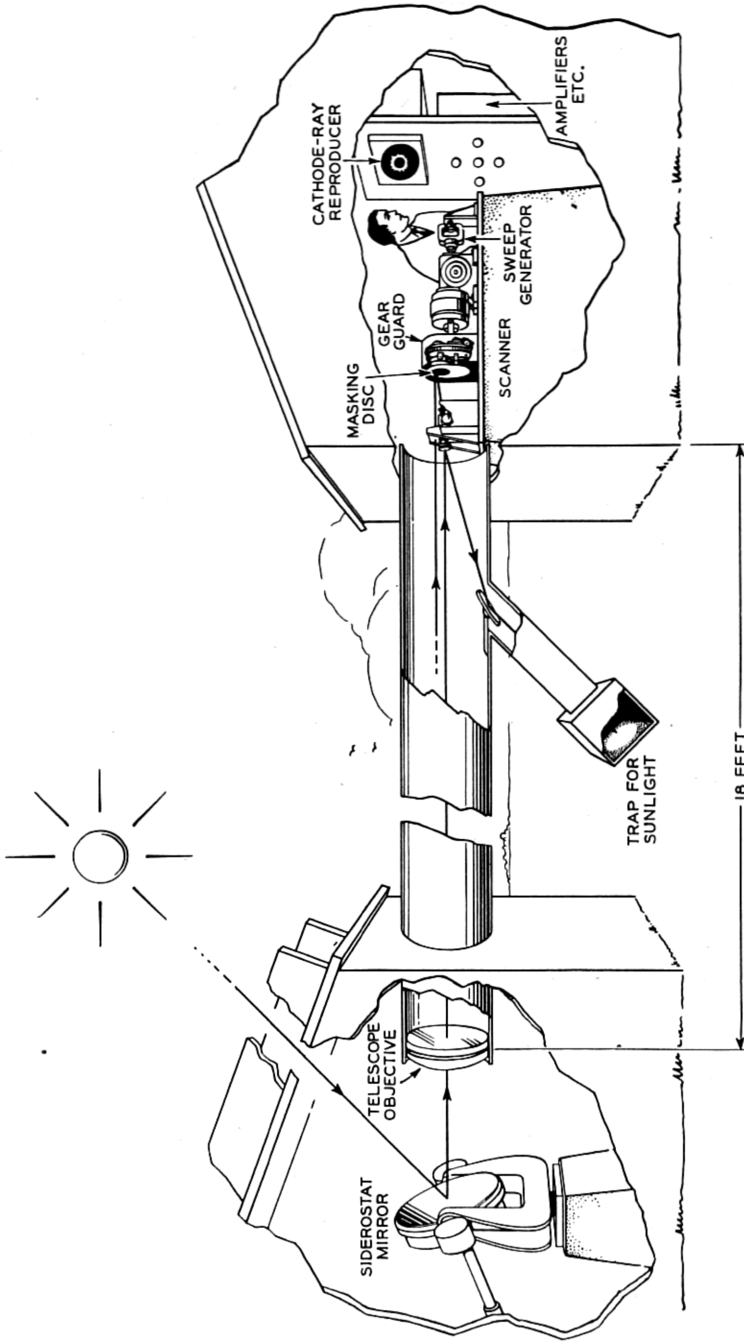

Fig. 1—Layout of apparatus at the Cook Observatory.

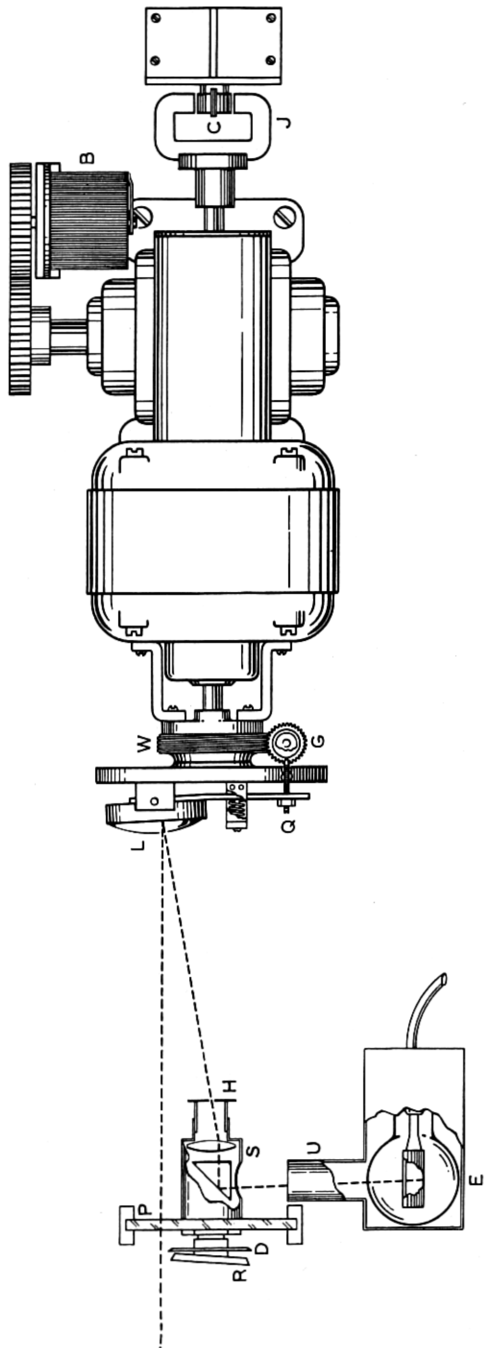

Fig. 2—The mechanical scanner and sweep frequency generator.

about the axis of the scanner it is turned more slowly about its own axis. A hardened pin Q attached to the arm of the lens mounting rides on a cam which is fixed to this gear and thus imparts a cyclic tilting motion to the lens. There are another similar gear and cam (not shown) mounted opposite this one which serve only to compensate for the weight of the working gear so that the rotating mechanism may be balanced to a high degree of precision.

The lens behind the scanning hole forms a stationary enlarged image of the scanning hole on the photosensitive surface of the photoelectric cell.

The reproduction of the image is done entirely by electrical means. At the opposite end of the motor a C-shaped permanent magnet rotates about a cylindrical iron core around which there is wound a coil of wire. The electric current thus generated in the coil is smoothed into a true sine wave by tuning the circuit of the coil so that it resonates at the frequency of circular scan which is approximately 30 cycles per second. The resulting wave is split into two components 90° apart in phase and these, after amplification, are impressed on the deflector plates of the reproducing cathode ray tube so that the spot may move in a circular path.

At the generator end of the motor there is also a reduction gear box, the slow speed shaft of which turns once for a complete cycle of the radial scanning motion, i.e. once a second. This shaft is geared to that of the potentiometer unit B so that its sliding contact also revolves at this rate. The potentiometer winding is continuous around the circle and connections are made at the opposite ends of a diameter. The scanning voltage from the generator circuit is fed into this unit and as the arm revolves the amplitude of the sine wave is made to vary uniformly between its minimum and maximum values. Thus the scanning spot spirals outward, scanning a complete image of the field, and then inward, giving another complete image, so that there are two images per cycle of the radial scanning motion. The spot does not follow the identical path on the two scans; the outward scan crosses over the lines of the inward scan along one diameter and interlaces along the diameter at 90 degrees to this. The radial resolution along the latter diameter is therefore double that along the former. Since the frequency of the radial component of the scanning motion is approximately one cycle per second, these two resolutions are 15 and 30 lines respectively.

The glare of a clear sky is uniform around the solar image and therefore as the scanning spot travels around the field it gives rise mainly to a direct current in the photo-cell. The coronal features, however, that is the streamers, arches, etc., give rise to alternating components and only these components are amplified, the direct current being eliminated by resistance capacity coupling of the cell to the amplifier. Inaccuracies of alignment and any non-uniformity of the intensity of the glare across the field give rise to strong low-frequency components and because of the high glare levels that were occasioned by the location and by the siderostat mirror it was found necessary to filter these components out of the amplified currents. A high-pass filter is inserted between the first and second stages of the amplifier for this purpose. A low-pass filter with a cut-off at 3750 cycles is also included to cut out the noise at frequencies above the desired band. The top frequency is 3600 cycles for the 0.04 inch diameter scanning hole that was generally used. After amplification the signal current is made to modulate the intensity of the cathode-ray beam.

The electrical frequency spectrum of the television image consists of the fundamental scan frequency (about 30 cycles) plus a large number of its harmonics. By varying the characteristics of the high-pass filter it was possible to eliminate the fundamental and several of the lower harmonics as desired. This became advantageous in studying the prominences and smaller coronal details which give rise almost entirely to higher harmonics and are reproducible therefrom with a good degree of accuracy. In addition, for these smaller details, the coupling capacity between the first and second stages of the amplifier was greatly reduced so that the gain at the upper end of the band was considerably enhanced in relation to that at the lower end.

The light of the corona is practically identical with that of the sun in its spectral characteristics and a caesium sulphide photo-cell which has a maximum sensitivity in the green was used. See Fig. 3. It was found that by using gas amplification in the photo-cell adequate sensitivity was obtained. The inner corona has a surface brightness of about the same magnitude as the full moon and the sensitivity of the apparatus was checked by obtaining images of the moon in its various phases.

It is convenient to measure light intensity levels in millionths of the brightness of the sun's surface. The brightness of the full moon is about 2 millionths and it is known that the inner corona falls off fairly rapidly with distance from a brightness of a little more than one millionth measured within one minute of the solar limb. The level of the glare was measured from time to time by means of a photronic cell behind an aperture placed at the focus of the objective. On days when the haze in the sky was very noticeable but yet not in the form of clouds its brightness at 2 minutes from the limb was as high as 6000 millionths or approximately 6000 times as bright as the corona. On very clear days the brightness was as low as 1250 millionths and this limit may have been set by the scattered light from the telescope parts, particularly the siderostat mirror, rather than the sky. The

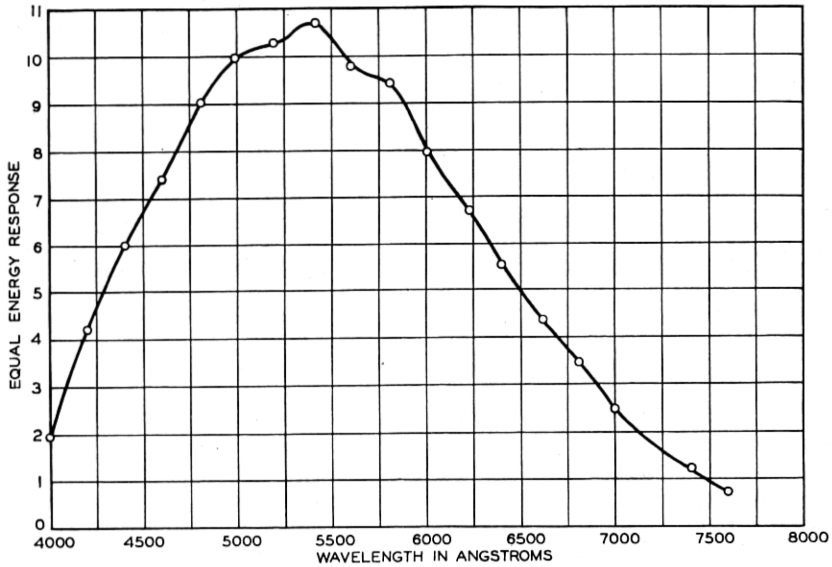

Fig. 3—Spectral characteristic of photo-cell.

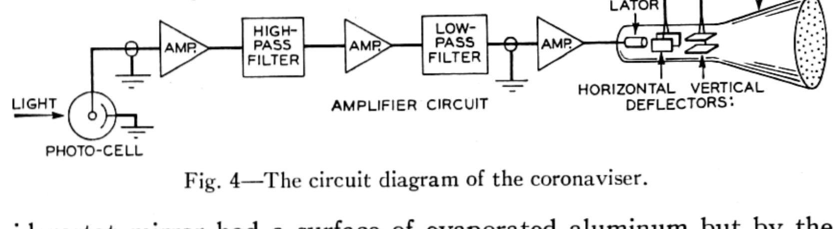

Fig. 4—The circuit diagram of the coronaviser.

siderostat mirror had a surface of evaporated aluminum but by the time the development of the equipment had progressed to the point where useful images could be obtained, its surface had begun to show blemishes.

The scanning rate was so slow (2 images per second) that even with a cathode ray screen having an appreciable time lag there was difficulty in studying the complete image visually. The expedient was therefore adopted of photographing the images and this proved advantageous in comparing images as well as in greatly reducing the effects of noise. The latter advantage was realized by taking exposures of from 20 to 30 seconds during which there were reproduced some 40 to 60 images and although the noise patterns might be very noticeable in a single scan the fluctuations balanced out in a statistical manner, leaving a uniform field.

Theoretically the limiting amount of glare through which it is possible to work with this method is determined by the shot noise in the photoelectric current but there are practical limits, set mainly by the cleanness of certain of the optical parts, which were the important factors in this case. Although the whole scanner is designed to reduce, as much as possible, the scanning of the optical parts of the instrument by the beams of light, certain parts are of necessity scanned, particularly the plate glass used to support the scanning hole unit. This plate is also near the focal plane and the slightest smudge or speck of dust on its surfaces gives rise to an overloaded image on the cathode ray screen. The glass itself was specially selected to be free from bubbles or blemishes of any kind and in addition it was carefully washed at frequent intervals. Great pains had also to be taken in keeping the other glass surfaces in the optical train clean, for the essence of the method is the amplification of minute variations in the intensity of the illumination from point to point in the field.

Occasionally tiny specks of brilliant light would float across the screen, the sources of which were very puzzling at first. They were finally traced to insects or wind-borne seeds which drifted across the sky in the path of the shaft of light. Being illuminated by direct sunlight, they scattered enough light in the direction of the telescope to give a bright diffraction pattern. They ruined quite a few plates.

Since the glare decreased in the direction outward from the sun (though not so rapidly as the coronal light), patterns that were caused by instrumental defects took on at times appearances which might easily have been confused with that of a coronal image. It was necessary, therefore, to have an absolute criterion by which one could distinguish between these spurious images and those which were associated with the sun. The siderostat mounting of the telescope furnished such a test. With this type of mounting the celestial field rotates about the optic axis of the telescope with time. This rate varies with the declination of the object and other factors and in our case it ranged within a degree or two of 7° per hour. Thus by taking a series of photographs over a period of several hours it was possible to determine definitely whether or not the image in question was associated with the sun or with the apparatus. In addition to this test, for the prominences, there was the spectrohelioscope at hand by which a direct comparison could be made. Another test applied to the prominence images was furnished by their color. A red glass filter, such as the Schott RG 2 which has a cut-off just below the H_α line, reduced the general glare level by about 30 times whereas its reduction of the light of the prominences which is a maximum at this wave-length was not nearly so great.

Results

The prominences shown in Fig. 5 are among the first of which good images were obtained. Seven photographs were taken of them be-

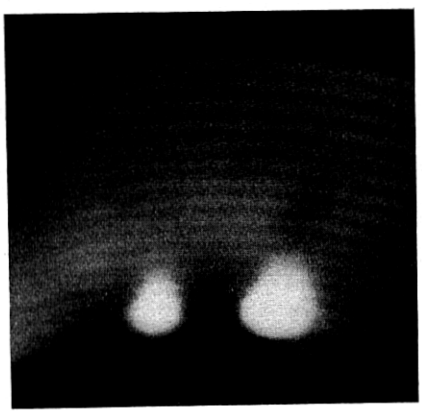

Fig. 5—Prominences taken with red filter on Feb. 21, 1938.

tween $16^h\ 58^m$ and $19^h\ 11^m$ G.C.T. on February 21, 1938, some in white light and the others with the red filter in front of the photo-cell. This particular photograph was taken in red light; those taken in white light were of considerably less contrast.

Figure 6 is another one of the many prominence photographs that have been taken with the apparatus. These are the prominences that were present around the sun at $18^h\ 30^m$ G.C.T. on October 31, 1938. This was also taken with the red filter.

Figure 7 shows a pair of bright prominences photographed in white light on October 3, 1938.

Figure 8 shows a jet or flare in the corona that was photographed on October 18, 1938. It is one of 11 photographs that were taken

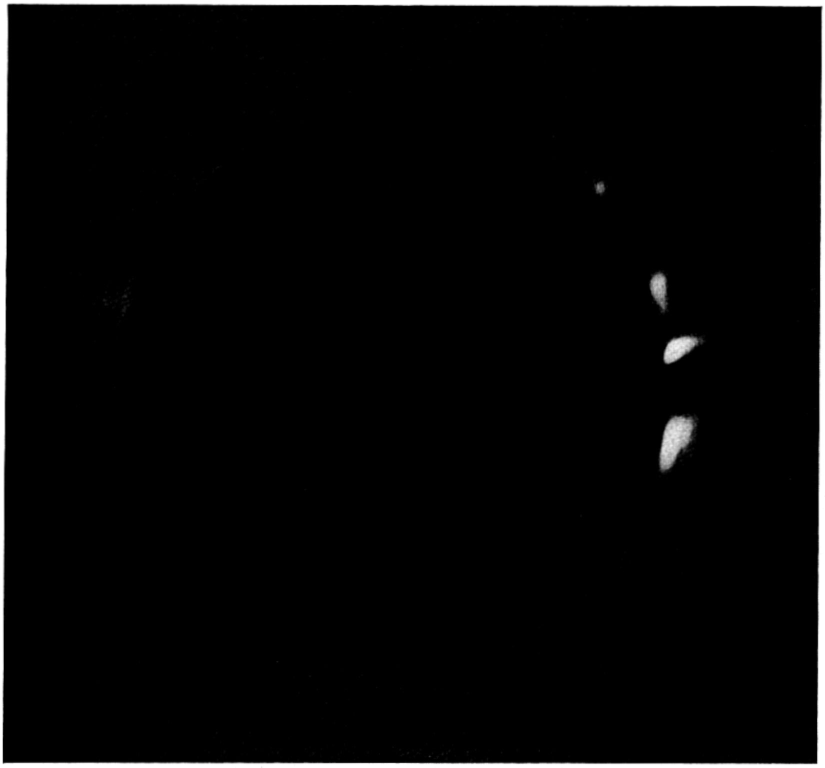

Fig. 6—Prominences around the sun on Oct. 31, 1938. This image was obtained with a scanning hole 0.013 inch in diameter which had 1/10 the area of that used for the other photographs.

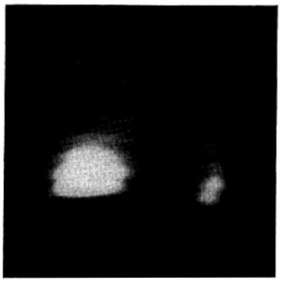

Fig. 7—A pair of prominences taken without optical filter (i.e., in white light) on Oct. 3, 1938.

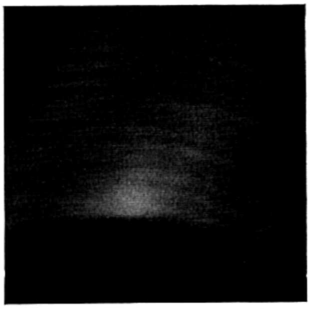

Fig. 8—A jet or flare in the corona photographed on October 18, 1938.

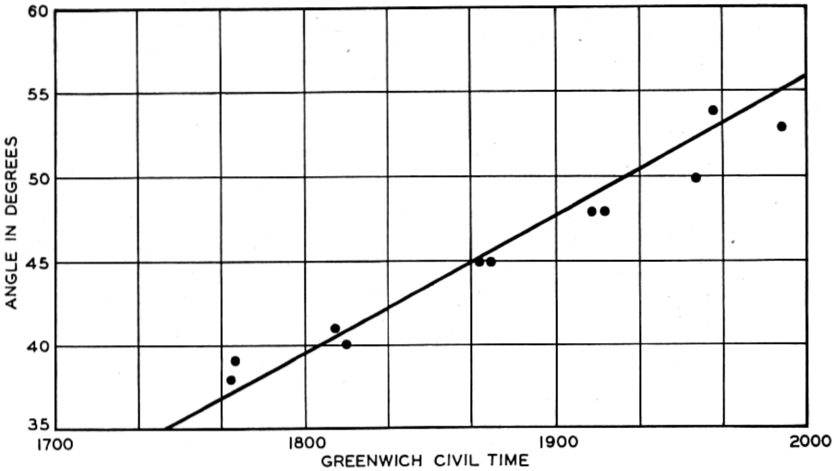

Fig. 9—Positions of the flare of Fig. 8 at the times shown. The turning of the image is due to the horizontal mounting of the telescope.

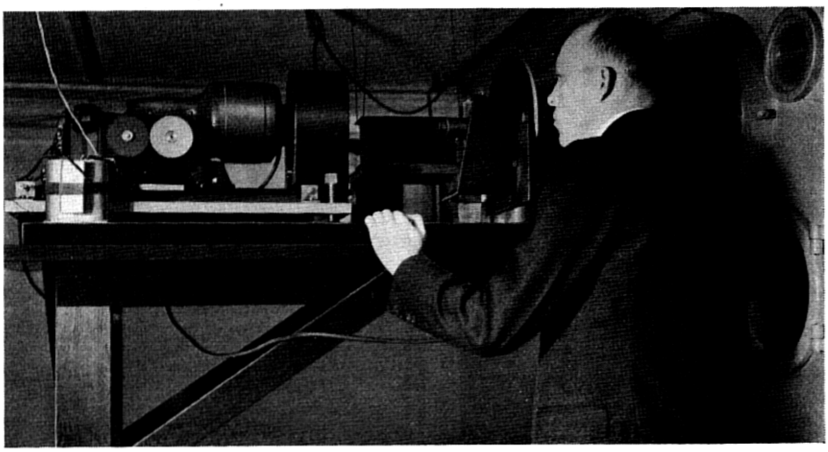

Fig. 10—The input scanner.

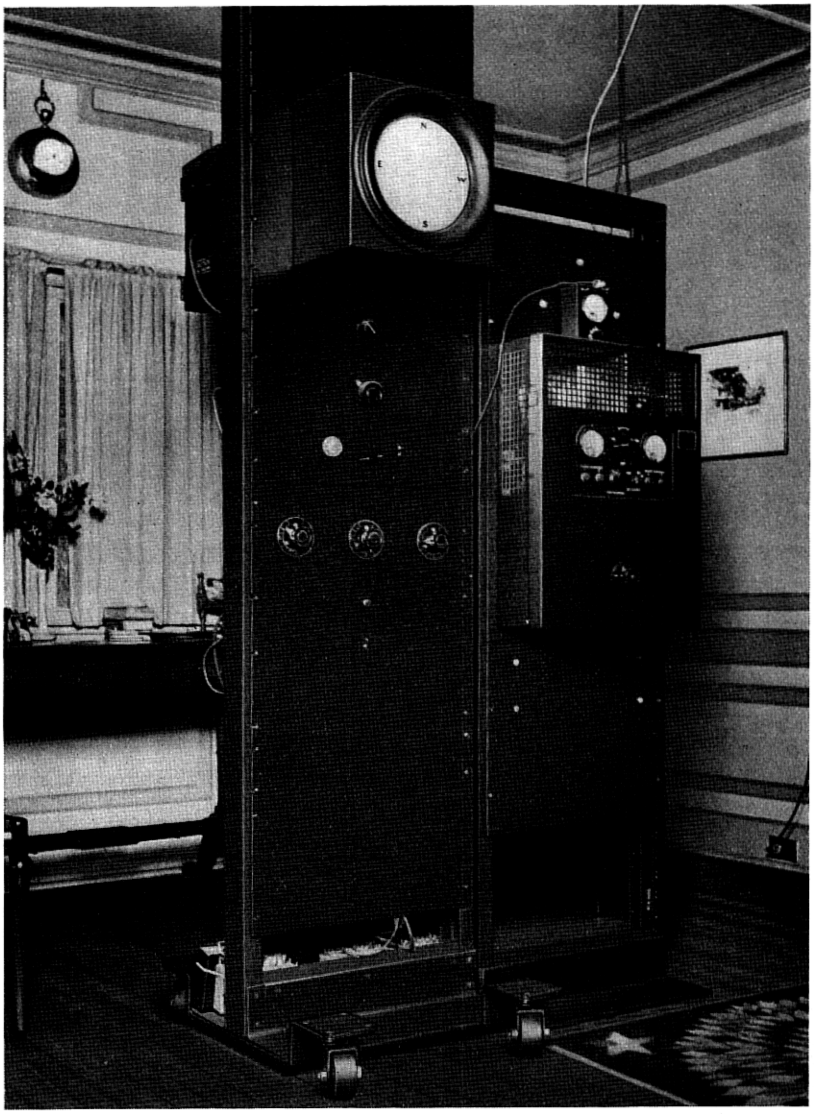

Fig. 11—The amplifying and sweep circuits and reproducing tube.

over a period of more than 2 hours. All these show this feature, and its position on each plate is plotted against the time of exposure on Fig. 9. The slope of the line is the correct rate for the turning of the celestial field in the neighborhood of the sun at that time. It was not brighter on the plates that were taken with the red filter than on those taken with white light, and it is concluded, therefore, that it was white in color.

There was no prominence at its position on the limb of the sun, but the next day the observatory at Huancayo reported that an eruptive prominence blew off from the limb at this position (28° N. Lat.). It seems quite probable that the unusually bright jet in the corona was lying over and probably associated with this active region.

A number of other plates have shown details which appear to have their origin in the corona, but generally they have been partly obscured by other patterns of instrumental or other origin.

The major objectives of this phase of the work which were the development of an adequate instrument and the proving in of the method have been achieved. The next phase of the investigation should be carried out under the most favorable conditions possible and this means a location on a mountain top with a telescope preferably pointing directly at the sun.

I wish to acknowledge the helpful cooperation of Dr. Cook and his associates at the Cook Observatory and of many of my colleagues in the Bell Telephone Laboratories. In particular, Dr. J. B. Johnson has greatly contributed to the investigation by his counsel and aid.