Photography of the Solar Prominences

by
George E. Hale

1890.

Introduction

The research described in the following pages claims to be nothing more than a beginning in an extended series of solar investigations which I hope soon to continue.

No branch of physics seems to me to offer richer returns to the patient investigator than that dealing with the constitution of the Sun. Although the work has been in progress for more than twenty years, questions of every degree of complexity yet remain to be answered. We are still compelled to wait for the rare and fleeting visits of the lunar shadow to show us the corona. And even when seen, the remarkable green line in its spectrum remains as much of a mystery as ever, and no terrestrial element has been found with any line corresponding to it in wave-length.

The D_3 line is equally peculiar in having its origin unknown, and many lines seen in the spectra of sun-spots might be placed in the same category. But space forbids the mention of even a tithe of these interesting instances, for they seem well nigh innumerable.

The prominences have been perhaps as thoroughly studied as any of the solar phenomena, but they still have many secrets to reveal.

It has long been my conviction, that photography might well play a prominent part in further attacks.

With this end in view I have carefully considered the various difficulties to be overcome, and thus have been led to devise the simple methods outlined in this paper.

Early Eclipses-

It is a remarkable fact that no observation of the chromosphere or prominences were recorded prior to 1706. At the eclipse of that year Captain Stannyan, observing at Berne, noticed upon the western limb of the sun a blood red streak of light which was visible for several seconds. In 1715 Halley and Louville described a similar phenomenon But it was not until 1733 that the prominences were seen by Vassenius in the form of small pinkish clouds, floating above the moons limb in what he supposed to be a lunar atmosphere-

In succeeding eclipses up to 1842, it is doubtful whether the chromosphere and prominences were seen at all, as no definite mention of them was made. But at the eclipse of July 1842, their great brilliancy attracted the attention of many skilled astronomers. A vigorous discussion ensued as to their real nature. Some held with Vassenius that the prominences were lunar clouds, others including Arago believed ~~believed~~ them to be clouds in the suns atmosphere. Some thought them to be solar mountains, others maintained that they were gigantic flames, and there were others who considered them nothing more than optical illusions. But the eclipse of 1851 strengthened the evidence of their solar origin, and a theory substantially that before enunciated by Arago became quite generally accepted. Their real existence in the solar atmosphere was finally established by the photographs of De La Rue and Secchi at the eclipse of 1860.

Meanwhile the spectroscope had demonstrated its analytical power, yielding in the hands of Bunsen and Kirchoff a means of determining the chemical constitution of the sun. At the eclipse of 1868 spectroscopes were attached to the telescopes of many observers, and it was at once concluded that the "lunar clouds" of Vassenius were for the most part vast masses of hydrogen gas rendered incandescent by the intense heat of the Sun. This conclusion has not lacked abundant confirmation.

Method of Observation

Up to this time these phenomena had only been seen at the rare occurrence of a total eclipse, and it was not surprising that such limited and infrequent observations had discovered but little of their true nature. It was eminently desirable, therefore, that some method should be devised by which they could be observed at any time in full sunshine. The problem was, to so reduce the light of the atmosphere that the prominences should no longer be hidden by its glare.

The first attempts were

made by Mr. (now Sir William) Grove, who made use of red glass in observing the limb of the sun, the telescopic image being stopped out by a diaphragm. But he was unsuccessful, for the atmospheric light was still sufficiently intense to completely drown the image of the prominence.

In October, 1866, Mr. Norman Lockyer suggested[1] that a spectroscope be used to overcome the difficulty.

The atmospheric light gives a continuous spectrum, crossed of course by the dark Fraunhofer lines. The brilliancy of such a

[1] Proc. R. S. v. 15, p. 256.

spectrum can be decreased any desired amount by multiplying the number of prisms in the spectroscope. On the other hand as the prominences are composed largely of hydrogen, most of their light is concentrated in the four or five lines of the hydrogen spectrum and increase of dispersive power only serves to separate these lines more widely, without materially affecting their brilliancy. It is thus seen that there is a limiting dispersion, at which the bright lines of hydrogen are of the same brightness as the overlying continuous spectrum of the atmosphere. With a somewhat increased dispersion the bright prominence lines should be distinctly seen upon a less brilliant background of the same color, when the image of a prominence is brought over the slit of a powerful spectroscope.

Acting on this idea, Mr Lockyer had constructed a spectroscope provided with seven 45° prisms of dense flint glass. It was attached to an equatorial refractor of 6 3/4 inches aperture and about 8 ft. focal length; the image of the sun on the slit plate was therefore something less than 1 inch in diameter. The completion of the spectroscope was so much delayed, that it was not tried until October 16, 1868.

The search for bright lines was for a time unsuccessful, but on October 20 Mr. Lockyer announced to the Royal Society the existence of three bright lines in the following positions -

"I Absolutely coincident with C.
II Nearly coincident with F.
III Near D.

The third line is more refrangible than the more refrangible of the two darkest lines by eight or nine degrees of Kirchoff's scale".[1]

Curiously enough, the latter

[1] Proc. R. S. # 105, 1868.

announcing this discovery to the French Academy of Sciences was followed the same day by a letter from M. J. Janssen who was just about to return from observing the solar eclipse at Guntool.

During totality he ~~had~~ had been so struck with the brilliancy of the bright lines seen through his spectroscope, that he attempted the next day to see them again, and at once succeeded. He was thus enabled to continue his observations from August 19 until September 4, "a period" to use his own words, "like an eclipse of seventeen days".

Thus established, the new method at once came into general use. But as yet only a rough idea of the true form of the prominences could be made out by moving the solar image across the slit. What was desired was a means of seeing the whole prominence at once, and not alone a small strip through a narrow slit.

At the very outset Janssen and Lockyer tried to form persistent images on the retina; the former by giving a rotatory motion to a direct vision spectroscope, the latter by causing the slit to rapidly oscillate. Prof. Young also used an oscillating slit, placing at the focus of the eye-piece a diaphragm which should move with the slit, thus cutting off the light of the neighboring portions of the spectrum. But he found that "although seen in this way, the prominences appear very bright, yet the working of the apparatus always causes a slight oscillation of the equatorial, which interferes with the definition of details"[1]. He retained, however, the moveable slit, finding it very convenient in observations of spots or prominences.

The method now ordinarily employed was first proposed

[1] Nature - Dec. 8 - 1870.

by Zöllner in a paper communicated to the Royal Saxon Academy of Sciences in February, 1869. He argued that the brightness would be much diminished by using a moveable slit, and ended with the statement that "it is only necessary to open the slit so far that the protuberance or a portion of it, appears in the opening.

By polarizing or absorbing media, placed before the eye-piece, the light in the whole field of view can be so diminished that the proper relation of intensity between the protuberance and the superposed spectrum may be obtained".[1]

A few days later Mr. Huggins published in the Proceedings of the Royal Society of London, an account of a successful observation of a prominence through an open slit, the stray light being reduced by the use of ruby glass and a diaphragm placed at the focus of a positive eye-piece.

It was soon seen by Lockyer that the ruby glass used by Huggins was unnecessary[2] and that it was only essential to open widely the slit of the spectroscope. The width to

1. Translated in Jour. Franklin Institute v. 88, p. 410
2. Proc. R. S. L. v. 17. 302.

which it may be opened depends upon the dispersion of the instrument employed, and also upon the condition of the atmosphere. If the sky has a whitish appearance, due to the presence of ice particles, a narrow slit must be used, if observation can be carried out at all.

Another method which has been suggested for observing the prominences, necessitates the use of a direct vision prism placed before the slit, or a prism of small angle, placed just outside the object glass of the telescope. The dispersion could be thus very largely increased. Such an arrangement is very highly recomended by Secchi[1] as it allows not only the chromosphere and prominences to be observed, but also the photosphere and spots at the same time. This is very desirable at times, as the relation of a prominence to a neighboring spot would be at once recognized.

In 1872, Messrs Lockyer and Seabroke, described to the Royal Society, a method of observing the whole of the chromosphere by means of a ring slit[2] as follows. "The image of the sun is brought to

1. Le Soleil. v. 1, p. 232
2. Proc. R. S. v. 21, p. 105.

focus on a diaphragm having a circular disc of brass (in the centre) of the same size as the sun's image, so that the sun's light is obstructed and the chromospheric light allowed to pass. The chromosphere is afterwards brought to a focus again at the position usually occupied by the slit of the spectroscope; and in the eye-piece is seen the chromosphere in circles corresponding to the C or other lines." The same device had also been tried by Zöllner and Winlock, but without success. I shall again refer to it in this paper.

Prominence Photography

As photography has been so largely employed in almost every department of astronomical research, and with such remarkable success, it is rather to be wondered at that very little has been done toward photographing the prominences.

A simple and reliable method would not only do away with the tedious and inaccurate task of drawing, but might possibly discover new phenomena of value in clearing up the perplexing questions of the solar theory. A series of photographs of the same prominence, taken at exactly equal intervals of time, would be of much greater value than a similar series of drawings. And if in time the method could be perfected and made automatic, so that it would photograph the whole circumference of the limb at equal intervals throughout the day, its value would be beyond question.

There are yet other opportunities for photography. In eye observations we are limited to the visible portion of the spectrum; photography would lay open the ultra violet and ultra red.

It would permanently register all the phenomena of the distortion and displacement of lines in the spectrum, and render their measurement a leisurely and exact process with the dividing engine. And it might ultimately lead to a more certain knowledge than we now possess of the true form of a prominence.

In an observation of a prominence through, say, the C line, what is seen is that ~~t~~ that portion of the prominence which is composed of incandescent hydrogen. A photograph of the prominence taken through an iron line, if one were visible at the time, would show the region occupied by iron.

In the same way the parts played by calcium, sodium and other elements might be shown; and a composite photograph from such a series of negatives would for the first time (outside of an eclipse) show the true form. It is now known from observations made just before and after eclipses, that the C line gives the true form of the prominence very nearly if not exactly, but there is still room for plenty of work in this direction and in many others. For instance, is the form seen through D_3 <u>exactly</u> the same as that seen through C? If not, are they more alike at some times than at others? Answers to questions such as these might render less mysterious the true nature of "helium," and define its relation to hydrogen.

Perhaps sufficiently good photographs for these purposes will never be made; - certainly

they would surpass anything
one could ever hope to get with
a horizontal telescope in the
atmosphere of Cambridge, but
it seems to me that in the lapse
of time some of our mountain
observatories will accomplish
all this and much more.

Account of Previous Methods

The first experiments in prominence photography were made by Prof. Young in 1870. The following is his own account of the work - "The protuberances are so well seen through the F and 2796 (K) lines that it is even possible to photograph them, though perhaps not satisfactorily with so small a telescope as the one at my command - Some experiments I have recently made show that the time of exposure, with ordinary portrait collodion, must be nearly four minutes, in order to produce images of a size which would correspond to a picture of the solar disc about two inches in diameter. -------- Negatives have been made which show clearly the presence and general form of protuberances, but the definition of details is unsatisfactory. --------

We worked through the hydrogen γ line, which though very faint to the eye, was found to be decidedly superior to F in actinic power. The photographic appatus employed consisted merely of a wooden tube, about 6 inches long attached at one end to the eye-piece of the spectroscope, and at the other carrying a light-frame. In this frame was placed a small plate-holder, containing for a sensitive-plate an ordinary microscope slide 3 inches by 1."[1]

We see, then, that Prof. Young brought the γ hydrogen line into the field, opened the slit widely, and made it tangent to the sun's limb at a point where a prominence was known to be. An exposure of about four minutes was then made and this produced a negative of the prominence upon a wet collodian plate. Prof Young has very kindly shown me silver prints from the best original negatives. In these, little more than the general outline can be seen. This is due partly to

1. Journal of Franklin Institute Oct 3, 1870

a slight displacement of the image during the exposure, as the polar axis of the telescope was slightly out of adjustment. But a much more radical defect lies in the broad and nebulous character of H γ. As seen through this line every point in the prominence is drawn out into a short line at right angles to the slit, thus rendering good definition impossible.

Neglecting for the present the claims of Zenger[1] I have been unable to find any account of other photographs of the prominences taken without an

[1] Comptes Rendus - t. 88. p. 374

eclipse. But methods have been invented for the purpose, and these merit description.

In 1874 Dr. Lohse made several unsuccessful attempts to photograph the chromosphere and prominences by direct methods - i.e. - using the direct image of the sun without a spectroscope - In 1880 he devised a special form of apparatus. It consisted of a direct-vision spectroscope held in a suitable frame, with its axis of collimation parallel to the axis of the telescope to which it was attached. The centre of the sun's image was brought on to the axis of the telescope, so that the slit was radial. A hand motion then served to rotate the spectroscope about the telescope's axis, and in this way it was hoped to build up an image of all the prominences on a stationary photographic plate at the focus of the spectroscope. Before the plate a slit was placed to cut out any desired region in the spectrum. The line Hγ was ordinarily used.[1]

Several objections might be raised against this instrument: 1° The dispersion of the direct-vision prism was necessarily small, and therefore the atmospheric light was not ~~generally~~ greatly reduced.

[1] Z. Instrumentenkunde, 1, 22

2°. The nebulous line H γ was used. The difficulty with this line has already been mentioned.

3°. The motion of rotation was produced by hand, and was therefore more or less unsteady. Even with a good clock, my experience has shown the extreme difficulty if not impossibility of obtaining perfectly uniform motion; and of course hand motion is incomparably worse.

These combined defects lead me to doubt the value of Lohse's rotating spectroscope, and the fact that no photographs taken with it have been mentioned strengthens this opinion.

In the paper before quoted from[1] Lockyer and Seabroke propose to use their ring slit in photographing the prominences in the following manner;—"A large Steinheil spectroscope is used, its usual slit being replaced by the ring one.
A solar beam is thrown along the axis of the collimator by a heliostat, and the sun's image is brought to a focus on the ring slit by a 3¾ inch object-glass, the solar image being made to fit the slit by a suitable lens. By this method the image of the chromosphere received on the photographic

1. Proc. R. S. v. 21, p. 105.

plate can be obtained of a convenient size, as a telescope of any dimensions may be used for focusing the parallel beam which passes through the prisms on to the plate."

Drawings were exhibited showing the prominences observed with the ring slit, but no photographs were shown, probably because none had been obtained. The apparent width of the slit upon the photographic plate would necessarily be quite large, if any prominences of even medium height were on the limb. Thus a large amount of atmospheric light would be admitted which would seriously fog the plate unless very high dispersion were employed.

In 1879 a letter was published in the Comptes Rendus[1] describing a method imagined by C. W. Zenger for photographing the chromosphere, prominences, and corona without the use of a spectroscope.

The plate was first put into a solution of pyrogallic acid and citrate of silver, and then given a very short exposure to the direct solar image, using "une couche absorbant tous les rayons dont est composée la lumière de la couronne et des protubérances solaires." The author goes on to add;- "C'est en étudiant par

[1] Comptes Rendus t. 88. p 374.

le spectroscope des pellicules ainsi obtenues, que j'ai constaté l'absorption de raies caractéristiques de la couronne et des protubérances, et c'est pourquoi les protubérances et la chromosphère sur les épreuves négatives, apparaissent blanches, la couronne en est moins prononcée, seulement blanchâtre, ce qui montre que la lumière coronale est très-distincte de celles de la chromosphère et des protubérances."

Altho a number of photographs, said by M. Zenger to show the prominences and corona, were forwarded to the Academy, I should be inclined to hesitate in pronouncing upon the value of the method, at least until the composition of the remarkable absorbing solution were made known.

Mr. Janssen has also tried to use the direct solar image. In a short note on the subject he says:-'

Il faut que l'action lumineuse solaire s'exerce assez longtemps pour que l'image solaire devienne positive jusqu'aux bords, sans les dépasser. Alors la chromosphère se présente sous forme d'un cercle noir, dont l'épaisseur correspond à 8" ou 10"."

In this case, and in all others where a direct image of the sun is received upon

' Comptes Rendus - t. 91. p. 12

a photographic plate, it is very improbable that chromosphere or prominences produce any appreciable effect. The "black circle" is solely due to the bright disc of the sun, and would be formed, even if the chromosphere did not exist.'

'See note by Capt Abney - Schellen's Spectrum Analysis, 2nd English Edition p. 372.

New Methods Proposed.

I believe that the following considerations will ultimately lead to a successful solution of the problem:-

1° A sufficient dispersion may easily be obtained by the use of a large diffraction grating, mounted with a pair of telescopes of large aperture. This grating should be very bright in the second or third order, if a ruling with about 14,000 lines to the inch is used. Suitable absorbing substances will be required before the slit to cut out the overlapping spectra.

2°. It is a well known fact that the solar line C is by far the sharpest line in the hydrogen spectrum. It is almost exclusively used in observations of the prominences because of the brilliant and well-defined images seen through it. Therefore it is desirable that this line be selected in preference to any other for prominence photography. Hence special plates will be required, which are sensitive to this region of the spectrum.

D_3 is another very sharp line and as it is always visible as far above the limb as C, it is also recommended for photographic work, tho the extreme brilliancy of this part of the spectrum may prove troublesome. Plates sensitive to the yellow rays will of course

be needed for this region.
3.° Instead of moving the whole spectroscope as proposed by Lokse, I have devised the three following methods:—
(a) Change the rate of the driving clock of the telescope, so as to make the sun's limb move slowly across the slit of the spectroscope. Move the photographic plate in the plane of dispersion and at right angles to the axis of the observing telescope; its velocity depending upon the ratio of the focal lengths of the collimating and observing object glasses; if these are equal, the velocity must equal that of the sun's image. Thus a series of images of the slit would be found, side

by side, and merging into each other, thus building up an image of the prominence.

This method would allow the use of a narrow slit, thus greatly reducing the atmospheric light, and increasing the sharpness of the photograph. A second slit should be placed immediately in front of the plate, and so nearly closed as to allow only the C (or D_3) line to pass through. This would cut out the troublesome continuous spectrum on either side and leave the photograph of the prominence in strong contrast on a clean background.

In practice it is impossible to fully realize this, but still the second slit can be closed to such an extent as to greatly reduce the superfluous light. The use of a second slit is in itself not new, as it was employed by Huggins and others as an aid in observation, and also, as we have seen, by Lohse.

It is easy to see that a radial slit would probably prove most useful for this work. But there are, at a given time, only two positions on the sun's limb at which the slit may be radial, when the direction of the sun's motion is at right angles to it. If the prominences did not happen to be at either of these points, they could not be photographed to the very best advantage. But it is not absolutely essential that the motion should be at right angles to the slit, and in this case a prominence could be photographed at any point on the limb. The chromosphere, and all the prominences visible, could be taken upon one plate, by reducing the diameter of the solar image until it became less than the length of the slit; the sun being then allowed to move across centrally.

The above arrangement may be modified in such a way as to greatly increase its value and extend its range of application. By a suitable combination of prisms or mirrors, cause the image of the sun to rotate about its center in such a way that the whole circumference of the limb will move across the center of a radial slit.

The clock of the equatorial used, should be electrically controlled, so as to keep the sun's center in a fixed position with regard to the slit.

Arrange a brass disc at the focus of the spectroscope and cause it to rotate synchronously with the solar image ~~by~~ by means of a tangent screw connected with a clock, which also drives the device for rotating the sun. On the brass disc secure a photographic plate by spring clips, and let the distance from the center of rotation to the edge of the spectrum on the plate, be equal to the semi-diameter of the sun's image, supposing that there is no magnification in the spectroscope. Then place a stationary second slit just in front of the plate and through it allow C. (or D_3) to pass.

It is thus seen that one complete revolution of the plate and solar image would photograph the whole chromosphere and any prominences present on the limb.

A simple addition would make the apparatus entirely automatic so that it might be set on the sun in the morning and allowed to run all day making complete pictures at intervals equal to the time of one revolution. Substitute, for the glass plate used above, a photographic roll holder loaded with a thin sensitive film. Place a spiral spring, or cord and weight, on one of the rollers, so that on releasing a catch the film will be transferred from one roll to the other. At the end of each revolution of the disc a platinum point should make contact with a light spring, thus throwing into circuit a small Electro-magnet attached to the disc, and revolving with it. This would release the catch, and enough film for a new exposure would be brought into position.

(B) This method is similar in principal to the above, but the result is effected in a diffeent way, making a radial slit applicable to any portion of the limb.

Provide the slit with a uniform motion across the axis of the collimator. Before the photographic plate arrange a second slit, and cause this to move at the same rate as the first slit, (if there is no magnification in the instrument) by means of a screw cut with the same thread; both screws being provided with grooved heads for a cord, and driven by a single clock. In this case the plate and sun's image must be stationary. The slit then moves across the prominences and the second slit prevents the plate from fogging.

This device seems to promise greater usefulness than any other proposed. It can, of course, only be used on an Equatorial telescope provided with a good clock.

(7) This method was suggested by W. B. Hale, and is a modification of Lockyer's ring slit. Mechanical difficulties would probably render its actual operation very difficult, but it is a least interesting theoretically.

Suppose the ordinary slit of a powerful spectroscope removed, and for it substitute a ring slit made in two parts; the outer like the "iris" diaphragm used on photographic cameras, and the inner a disc capable of radial expansion. Suppose the disc to be fixed within the opening of the diaphragm, and the two so connected by gearing that the edge of the disc and the inner circumference shall always be separated by a very small distance - say a tenth of a millimetre. A clock motion connected with a rotating collar might then expand the diaphragm and disc together, so that the annulus of light would start from the sun's limb and travel slowly outward, passing over the chromosphere and prominences, and admitting but little atmospheric light because of the narrow slit.

The photographic plate would of course be held stationary at the focus, and the sun's image would necessarily be maintained in a fixed central position.

In all of the above methods, slow development of the plates is desirable, in order to obtain the greatest possible contrast.

Description of Apparatus:

Through the kindness of Prof. E. C. Pickering, the 15 inch Equatorial of the Harvard Observatory was placed at my disposal in November 1889.

But in the opinion of Mr. George Clark the weight of my large spectroscope was considered too great to be safely carried by the wooden tube of the Equatorial, and it was finally decided to adapt the instrument to the 12 inch horizontal telescope, which Prof. Pickering very kindly gave up to my use, altho it was at that time employed in photometric work.

The Horizontal Telescope.

See Plates I + II

The mirror is 18 inches in diameter and 4 inches thick, and its surface is said by the Clarks to have a radius of curvature of several miles. It rests upon an iron plate in a cradle, which can be rotated by a friction roller attached to a long rod leading into the eye-end of the telescope. This is the motion in altitude. The axis of the telescope is at right angles to the meridian, and a screw at the back of the mirror gives the motion in azimuth. This screw is driven by an endless cord in connection with a clock placed convenient to the hand of the observer, so that its rate can be easily regulated by screwing down the friction disc of a centrifugal governor. As the mounting is alt-azimuth, the image of the sun cannot be kept stationary by the clock except at the meridian passage, and this is one of the strongest objections to the instrument, of course unfitting it for part of the work proposed.

The object glass is an excellent one, and was made by the Clarks. Its clear aperture is 12 inches and it has a focal length of about 17 feet. The image of the sun at the focus is therefore about 1.9 inches in diameter.

The Spectroscope.

The spectroscope and eye end of the telescope are shown in Plate III.

The spectroscope was specially constructed for me by Mr. J. A. Brashear, of Allegheny. It has proved to be a most excellent instrument, and I am glad to testify to the fine workmanship of its skillful maker.

The slit is made of glass hardened steel, gilded to prevent rust, and opens equally in both directions from the center, the width being read off from a graduated head. The whole slit-plate is provided with a screw motion across the end of the collimator, a very convenient adjustment in prominence or spot observations and also necessary in the second method proposed for photographing the prominences. A simple little device of my own allows three spectra to be taken edge to edge on the same plate - It consists merely of three small strips of brass, each cut with a small window one third as long as the slit. With the first one slid into position behind the slit the lower third is uncovered. Replacing this by the second uncovers the middle third, and the last one leaves all but the top third covered.

The lenses of the collimator and observing telescope are exactly alike, 3 1/4 inches in

diameter and $42\frac{1}{2}$ inches focus.
Thus there is no magnification in the instrument when no eye-piece is employed, and the motion of the photographic plate will be the same as that of the sun in the first method proposed. The whole collimator tube can be moved by a screw through collars in the frame, and thus the slit can be brought exactly to the sun's focus.

The grating is one of the excellent rulings of Prof. Rowland, and is remarkably bright in one of the second spectra. It is ruled with 14438 lines to the inch on a highly polished surface of speculum metal, and contains altogether more than 48000 lines. It is mounted in a holder with adjusting screws at the top and side, and stray light is excluded by a cylindrical brass cover, provided with close fitting openings for the two telescopes. The circular plate upon which the grating holder stands is divided on its edge to degrees for convenience in setting, and a rod connected with a tangent screw carries the slow motion to the eye-end of the spectroscope. A quick motion is also supplied. Eye-pieces of various powers are used for observation, either with an adapter at the end of the tube, or at the side with a total reflecting prism, when the sliding plate-holder is in position.

The sliding plate-holder was designed by myself for the first method of prominence photography. An ordinary 3¼ × 4¼ plate-holder is held by a spring clip in a light frame made of brass tubing, which slides with little friction between V shaped guides. Its direction of motion is at right angles to the lines in the spectrum. The method of producing this motion will be described with the adjustments of the instruments. When in use the plate-holder, guides, etc. are completely enclosed by a tight fitting mahogany cover. To draw the slide a brass rod is pushed in through a small opening on the left, and ~~and~~ screwed to a threaded piece on the end of the slide.

Directly in front of the plate is an adjustable slit, the purpose of which has already been mentioned.

The whole spectroscope is supported in a strongly braced frame of steel tubing, and by means of a gear and either one of two pinions, it is easily rotated about the axis of the collimator. This allows the slit to be made tangent or radial at any point on the sun's limb.

Adjustments of Spectroscope

The spectroscope was first put in place on the horizontal telescope, and fixed in such a position that the Sun's image was in focus on the slit.

The collimator and observing telescope were next roughly focused for parallel rays- The plane of the grating was then put at right angles to the plane through the axis of the two telescopes by placing a hair across the center of the slit, and bringing it on to a micrometer line in the center of the field by turning the back screw of the grating holder. The observing telescope was next removed from the spectroscope and carefully focused for parallel rays. The mean of a series of observations was taken, and the telescope replaced, and clamped at this reading. The grating was then turned until the reflected image of the slit came into the field. When the focus of the collimator was adjusted until the edges of the slit in the image were perfectly sharp.

The draw-tube of the observing telescope was then unclamped, the photographic plate-holder put in position and secured from sliding, and a series of photographs taken of the third spectrum near G. the focus of the telescope being changed and recorded for each exposure. From this series the sharpest was selected as most nearly giving the true focus for the part of the spectrum used, and the observing telescope was then clamped at this point in preparation for a series of exposures to find in what position of the grating its lines were parallel to the slit.

In order to record the various positions of the grating, measurements were made between each exposure from the plate on which the grating stands to the projecting arm of the grating holder. These were expressed in millimeters plus fractions of a turn of the adjusting screw.

In all, over 40 exposures were made in the adjustment of the spectroscope, G and the H and K lines of the third order being used.

Solar Observations.

The spectroscope was in good adjustment and ready for solar work on Jan. 14, 1890. On that date the limb of the sun was brought to focus on the slit jaws by making the slit radial, and moving the whole collimator by the slow motion until the edge of the spectrum appeared sharp. Many attempts to observe the reversal of the C line were made with both radial and tangential slit at various points on the limb, but they were entirely without success. On the next date of observation a slight arrowhead appearance of C was suspected, but the definition of the same image on the slit was very poor, and work had to be suspended for this cause. In short, on the six available days for observation before Feb. 19, no decided evidence of reversal was obtained. On that date, by the aid of a piece of red glass before the slit, the arrowhead appearance was well seen, but nothing further could be made out. On Feb 22 the general form of the chromosphere was seen, and D_3 observed for the first time.

These observations are mentioned here in order to give an idea of the way in which the definition varied, now allowing the general outline of the chromosphere to be discerned, and again rendering any work out of the question.

From this time until the middle of March there were but five clear days for observation, and on these the definition was variable, and the chromosphere but poorly defined, while no prominences had been seen. It was at length concluded that the trouble must be due in some way to the horizontal telescope, and on March 22 I carefully resilvered and polished the 18 inch mirror of that instrument. This to a great extent removed the difficulty, and on March 24, a small prominence was faintly observed. But still the mirror performed badly at times. On the morning of

March 31 the mirror was set on the sun, and in a short time a small prominence was found. With the slit tangential, and not too wide, the definition was remarkably good, both in the prominence and in the chromosphere at its base. After observing at this point for a time I began a search around the limb, and soon noticed that the definition was changing rapidly, and becoming much poorer. I was so much struck with this fact, that I rotated the spectroscope into its first position, and attempted to observe the prominence so clearly seen before, But it was no longer visible, and the chromosphere was so blurred and indistinct that its form could not be made out. That this was not due to a change in the prominence itself, the poor definition at all other points on the limb attested. It was evidently caused by a change in the definition of the solar image given by the horizontal telescope, and this change seemed in all probability to be due to a distortion of the mirror by the sun's heat.

Some other observations led to the same conclusion. The slit was opened widely, and a portion of the limb made to lap over it. The grating was then rotated until it reflected the solar light directly, and the image was examined with a low eye-piece and shade glass. The limb was seen to be very poorly defined, and no changes in the focus on the slit or the focus of the eye-piece would make it sharp. A sun spot which happened to be on the disc at the time was examined in the same way with similar results.

On April 1 a small prominence was found in the same position as on the previous day.
Observation was begun about 1 h 30 m, and from that time until 3^{h} 30^{m}, (when the sun was too far west for further work) the definition was excellent, in spite of the experience of the day before. Using the longest Beck eye-piece, and observing the image by direct reflection from

the grating, it was found to be very sharply defined, and the mottling of the surface could be well seen.

The explanation of this variable definition is probably to be found in the condition of the atmosphere. On March 31 the air was warm and still, while the next day a brisk breeze was blowing, and it was much colder. This would tend to keep the density of the air between the mirror and object glass more uniform, and also keep down the temperature of the mirror, and diminish the effect of radiation. Not long after I paid a visit to Mr. George Clark at his shop, and found that he entirely agreed with me as to the cause of the difference in definition. His experience with the mirror when it was first set up is well worth noting. It had been tested at the shop and found to be perfect, after which it was taken to the Observatory, and placed in position. It was immediately found to be so concave that no star images of any sharpness at all could be obtained. When taken back to the shop the sodium flame at once demonstrated its perfect flatness. The mirror was then silvered, as the light in the first instance had been very weak. The Newton's rings test still showed it to be flat, but when mounted upon the iron plate of its stand it became decidedly convex, and again no sharp star images could be obtained. The difficulty was soon conjectured. The brick pier, having absorbed heat during the day, radiated it at night upon the back of the mirror. This caused it when first used to become concave. After the coat of silver had been put on, the front surface became a poor radiator of heat, and now, instead of being concave, the mirror was convex. A partial remedy was found in covering the back and circumference of the mirror with bright sheet tin. This equalized the radiation, and secured very fair definition.

But it is easily seen that exposure to the direct rays of the sun would very probably affect the definition by unequal heating, and this I have found to be the case. Perhaps the best way to obviate this would be to support the mirror only by its circumference, leaving the back surface open and silvered or not according to the condition of the front surface. It was found necessary to support in this way the small mirrors used on the Transit of Venus photoheliographs. But a mirror 18 inches in diameter could not be held in this way without bending, and thus destroying the definition by its

own weight.
It has been said that the definition was good on cool, breezy days. As such days were not to be had for the asking, all that could be done was to make the best of as many as good fortune might bring. I was forced to this rather unsatisfactory conclusion, as Mr. Clark did not think it safe to attach the spectroscope to the 15 inch equatorial, and the 11 inch equatorial was so encumbered with heavy prisms and balancing as to render its use entirely impracticable in the short time remaining for my work. However, most of the time the definition has been

fair, and by no means so hurtful to these photographic experiments as is the large amount of diffuse light.

My experience with the horizontal telescope does not lead me to echo the unqualified praise given by M. Thollon to this instrument.[1] It is true that in many respects it is remarkably well adapted to spectroscopic work, especially when a large and heavy spectroscope is used. The tube always remaining in the same position gives great rigidity, and the spectroscope is always conveniently situated for

1. Comptes Rendus - t. XCVI - p. 1200

observation. In the case of the equatorial, the contrary is true. But an alt-azimuth mounting is very objectionable, and the range of a large mirror held in this way is exceedingly small. For instance, the instrument I have been using can be employed for solar work only from about $9^h 30^m$ in the morning until about $3^h 0^m$ in the afternoon, when the sun is not far from the equator. But as it was built for work near the meridian, a slight change in design would somewhat extend its range. I think it would also be much better for work on the sun if its mirror were much smaller, and supported only by its circumference, as recommended above. A still further improvement would be the use of some form of equatorial mounting, tho I doubt if a perfectly satisfactory siderostat has yet been constructed.

But supposing all these improvements added, there are yet difficulties from which the equatorial is free. Between the mirror and object-glass there is necessarily a considerable air-space, and there unequal heating must seriously affect the definition. And there is moreover a large amount of diffuse light reflected by the mirror - a most radical defect in prominence observation, and especially objectionable in such photographic experiments as I have undertaken.

This diffuse light will perhaps account for the extreme difficulty I have experienced in seeing F bright with a radial slit. With a tangential slit there has been less trouble, but observations have not been satisfactory –

The Method (a) in Practice.

The various imperfections of the horizontal telescope already enumerated soon made it evident that no photographs of any intrinsic value could be obtained, but the possibility of demonstrating the practicability of the method still remained. For this purpose the F and h lines were largely employed, principally because of the difficulty in obtaining plates sufficiently sensitive for use with C and D_3. A discussion of the experiments with several organic dyes and other sensitizers for the less refrangible rays will be taken up later.

It has been said, that

observations of reversal in the case of F and h were quite rare. This statement needs some qualification, but a word must first be said with regard to the magnitude and brilliancy of the prominences experimented upon. Only one prominence has been seen which could be called bright, and this was of small size, and in the most inconvenient position possible upon the limb. All others have been faint and cloud-like, tho they frequently have attained greater elevations. I do not consider this faintness to reside so much in the absolute brilliancy of the prominences themselves, as in the conditions under which they have been observed. In fact, from observations made with the 6 inch equatorial at Princeton - for the use of which I am much indebted to Prof. Young - I am convinced that the diffuse light from the mirror of the horizontal telescope must increase in a marked degree the difficulty of distinguishing the prominences.

This is no doubt the reason why good reversals in the blue and green have been so hard to obtain. With Prof. Young's refractor it was very easy to see the form of the prominence through F, while with my instrument only the merest outline can be seen even under the very best conditions, and aided with a screen of blue glass close in front of a tangential slit. With a radial slit I have seen F bright on only one occasion, and then it was extremely difficult to pick it out from the brilliant background. As for h, I have never been able to see it reversed, with either tangential or radial slit.

The first attempt to photograph a prominence was made on April 1. With a radial slit the C line of the second order rose to a height of about 1' 30" above the limb, while F could not be seen bright. I nevertheless decided to use this line, as no plates were at hand for the red end, so it was brought into the center of the field, and the jaws of the second slit closed up until little more than the F line passed through. An ordinary Seed plate, sensitometer number 26 x, was put in the plate-holder, and moved slowing across the end of the telescope by cords connected with an independant clock. At the same time the speed of the regular driving clock of the horizontal telescope was so altered that the sun's image moved across the slit with a velocity equal (or nearly so) to that of the plate. On developing the plate, a portion of a nearly circular disc, corresponding to the photosphere appeared to have had about the right exposure, but the region above the limb was undertimed, and showed no prominences.

Of course for each plate many variables had to be recorded; all of the following were noted in every in every case; Number of plate; date; hour; position of prominence; line and order of spectrum employed; length of exposure; focus of observing telescope; focus of sun's image on the slit; width of slit; speed of driving clock, speed of clock moving plate. In addition to the number just mentioned (which is placed in the lower right-hand corner), each plate is marked in the upper right hand corner with a number correspond-ing with one on the box from which it was taken. A record of these box numbers is kept, giving;- the size of plate; date received; name of maker; number of emulsion; sensitometer number; and remarks, stating dye (if any) used, and process of drying, etc. Thus by noticing the two numbers upon any negative, its complete history can be obtained.

With so many variables, each having its peculiar influence on the photograph, it is evident that the effect of any one can only be obtained by making the other constant in a series of photographs, and noting the changes produced by giving different values to the variable under consideration. The amount of light falling upon the plate depends upon the width of the slit, while the time

of exposure of any point on the plate to this light is inversely proportional to the speed of the clock moving the plate. But this speed must be such that the plate and sun's image will move together, and is therefore proportional to the speed of the telescope's driving clock.
Finally, the rate at which the sun's image travels across the slit determines the time during which light from a prominence passes through the slit, and falls upon some portion of the plate.

The best values of all these variables were obtained by making several series of photographs in the manner described, using in most cases the F-line in the second order. For a given plate, a change of line means a change of focus of the telescope, as well as a different exposure. There seems to be some latitute in the possible width of slit, altho of course a narrow slit is desirable, as the ratio of brilliancy of atmospheric to bright-line light is much decreased. But values of the width from one thousandth up to several thousandths of an inch can be used, thus changing the time of exposure without altering the clocks.

On April 14 a cool breeze was blowing, making the seeing fair in spite of a little whiteness in the sky. A hasty examination of the limb discovered a prominence in good position for the work, and a photograph was made through F, the slit being about .0015 inch wide. On developing the plate, the outline of two prominences could be seen rising above the limb. As only one prominence had been noticed in observing the point in question, I returned to the telescope, and found that there were in fact two prominences in the exact positions shown in the photograph.

In this plate (A 45) the exposure was about right, and the focus excellent, so that the limb is sharply defined, tho it is of too great radius of curvature, owing to a slight difference in speed of the plate and sun's image. The region above the limb is somewhat fogged by the atmospheric light, but the two prominences can be clearly seen, tho of course only in their general form.

A word must here be said in regard to the difficulty of obtaining a perfectly steady motion of the photographic plate. The friction of the guides prevents the carriage from starting until a certain force has been applied. When the pull becomes sufficiently great the carriage suddenly moves forward, then comes to rest again; and remains stationary until the same thing is repeated. At first a small independent clock was used to pull the carriage against a weight attached to its other end. But the clock was not strong enough for the purpose, and a weight was then made to do the work, the clock regulating the motion by unwinding a cord from a cone pulley. Photographs made with this arrangement were crossed with numerous vertical lines, due to inequalities in the clock's motion, and stretching of the cords. So the driving clock of the horizontal telescope was made to turn a small counter-shaft fixed to the table and a cone pulley on this shaft conveyed its motion to the carriage through a fine wire, which thus replaced the cord at first used. A piece of cat-gut carrying a weight was passed over a pulley suspended from the ceiling, and fastened to the upper of the carriage. This gave the necessary tension, and secured a fairly constant motion, tho most of the plates are crossed by more or less lines. The photograph of the spectroscope shows the arrangement.

As a greater uniformity of motion is more easily obtained with a higher speed, we have an argument for the use of as wide a slit as possible, allowing the plate and solar image to move more rapidly. In practice the width of slit is regulated by the density of the negative above the limb.

During the rest of April and the first two weeks of May there was a great deal of hazy weather, and even when perfectly clear there were no prominences of any brilliancy in favorable positions for work. A large number of exposures were made, however, but none of the plates showed more than the general form of the prominence.

Photographic Work with the Less Refrangible Rays.

A number of experiments have been carried on with several organic dyes, in the hope of obtaining plates of sufficient sensitiveness to the red and yellow rays. Cyanine was first tried in the method employed by Burbank, and described by him as follows:-[1]
"Fifteen grains of cyanine are gently heated (over a steam bath) for from 30 to 40 minutes with 1 oz chloral hydrate and 4 oz water. The whole mixture should now be stirred

[1] Proc. Am. Acad. of Arts and Sciences. 1888. p. 301

vigorously. While this operation is going on, 120 grains sulphate of quinine are dissolved by heat in a few ounces of a solution of 90% alcohol and 10% wood spirits. One ounce of strong aqua ammonia is now slowly added to the cyanine mixture above. Violent Ebullition takes place immediately, chloroform being evolved, and cyanine is deposited in a soluble form on the sides of the vessel. After decanting off the supernatant liquid, 3 or 4 ounces of the above mixture of alcohol and wood spirit are added to dissolve the cyanine; the quinine solution is then added, and to the whole, more of the alcohol mixture until the whole measures from 8 to 9 ounces. This constitutes the "stock" solution, and should be kept away from all light, as it is very apt to become decomposed."

"All the above operations should be conducted in as little light as possible. The following straining and drying processes should be conducted in absolute darkness.

" To 3 oz water are added 1½ drachms of the cyanine stock solution; the graduate that contained the cyanine is now washed out, 1½ drachms of strong aqua ammonia are added, and the whole mixture is stirred vigorously. Into this bath two or three plates, or half a dozen strips, can be dipped at once. They should be left there about four minutes; meanwhile, rocking the tray continuously so as to insure a uniform action of the dye."

All of the operations were carefully carried out as directed, Seed plates of sensitometer number 26 being used, and developed in total darkness with a pyro developer of the following composition:-

Sodium sulphite ------	2 oz
Sodium carbonate ------	2 oz
Distilled water ------	32 oz
Alcohol --------	1 3/8 oz
Salicylic acid --------	1/4 oz

The salicylic acid is dissolved in the alcohol and added to the others.

One mustard spoon of dry pyrogallic acid with every 2 oz of the above makes an excellent developer, such as has been used in all my photographic work.

An aqueous solution of bromide of potassium may be used as a restrainer, but my own experience tells me that proper dilution with water is more convenient, and just as efficacious, perhaps even more flexible.

Photographs made with the cyanine plates show them to be quite sensitive to the red rays, but hardly sufficiently so for my purpose.

The next dye tried was a soluble variety of alizarine blue. This was made up in a 1:10,000 aqueous solution, to which 1% strong aqua ammonia was added. This addition changed the brownish solution to a deep blue, which gradually become a light green if left exposed to the light. So the plates were stained in total darkness immediately after adding the ammonia. They were left in the bath about three minutes, and then dried in the dark.

Plates treated in this manner were somewhat more sensitive to the spectrum near C than were the cyanine plates, but still they would hardly do for prominence work.

These experiments with dyes having proved rather unsatisfactory, it was resolved to try the emulsion used by Abney for his photographic work in the infra red, as the curve given in his paper[1] would indicate

1- Phil. Trans. v. 171- p. 653.

a considerable sensitiveness to the region including C. The work of preparing the emulsion and coating the plates was undertaken by the foreman of the Harvard Dry Plate Co. After much delay the process was fairly started, when an explosion occurred while adding the solution of silver nitrate to the bromized collodion. The collodion caught fire, and all but the solids was consumed. As this took place on May 8, the experiments were reluctantly given up for the time.

The dye erythrosine was used for work on D_3 line. The use of erythrosine was introduced by myself at the Harvard Observatory in 1888, and it has been found very valuable in extending the limits of star spectra. The following formula gives the most satisfactory results:-

(a) Erythrosine - - - - - - - 50 m.g.
Distilled water - - - - - - 50 c.c
(b) Silver nitrate - - - - 50 m.g.
Distilled water - - - - - - 50 c.c.

Add (a) and (b) together, and then add 100 c.c distilled water to the whole. Bathe plates in this 2 minutes, allow to dry an hour or so, and then bathe 1 minute in distilled water, finally leaving plates to dry in total darkness.

Plates thus treated are quite

sensitive in the violet and blue, and so far as the D lines, tho they show a marked minimum in the green. They have enabled me to obtain very good photographs of D_3 by using a narrow tangential slit, but as no bright prominence was visible, they could not be tested for prominence photography.

Conclusion.

Altho I have not been able in these limited experiments to produce photographs of any intrinsic value, nor to realize in any degree the possibilities of the photographic process, it is at the same time true that some results have been obtained. In spite of the insurmountable defects of the horizontal telescope, and in spite of the poor weather and limited number of prominences, the photographs demonstrate at least the feasibility of the method employed. Given a good refracting equatorial and a plate very sensitive to the longer waves of light, and I am confident that the spectroscope and attachments described in this paper will be sufficient to produce prominence photographs of real value for study and measurement.

This work I hope to continue at an early date. Meanwhile I shall pay special attention to the purely photographic questions involved, and to discover if possible some more efficient dye or sensitive salt. I am also anxious to try the method (B), as it seems in theory to have many advantages over (a), tho probably these would be somewhat reduced in practice.

The photography of the line D_3, tho amounting to little in itself, is perhaps new, and at least testifies to the value of erythrosine as a dye.

In closing, I wish to owe

more express my great obligations to the Director of the Harvard Observatory, as it is through his kindness that any experiments have been rendered possible.

George E. Hale

Plate I

Plate II

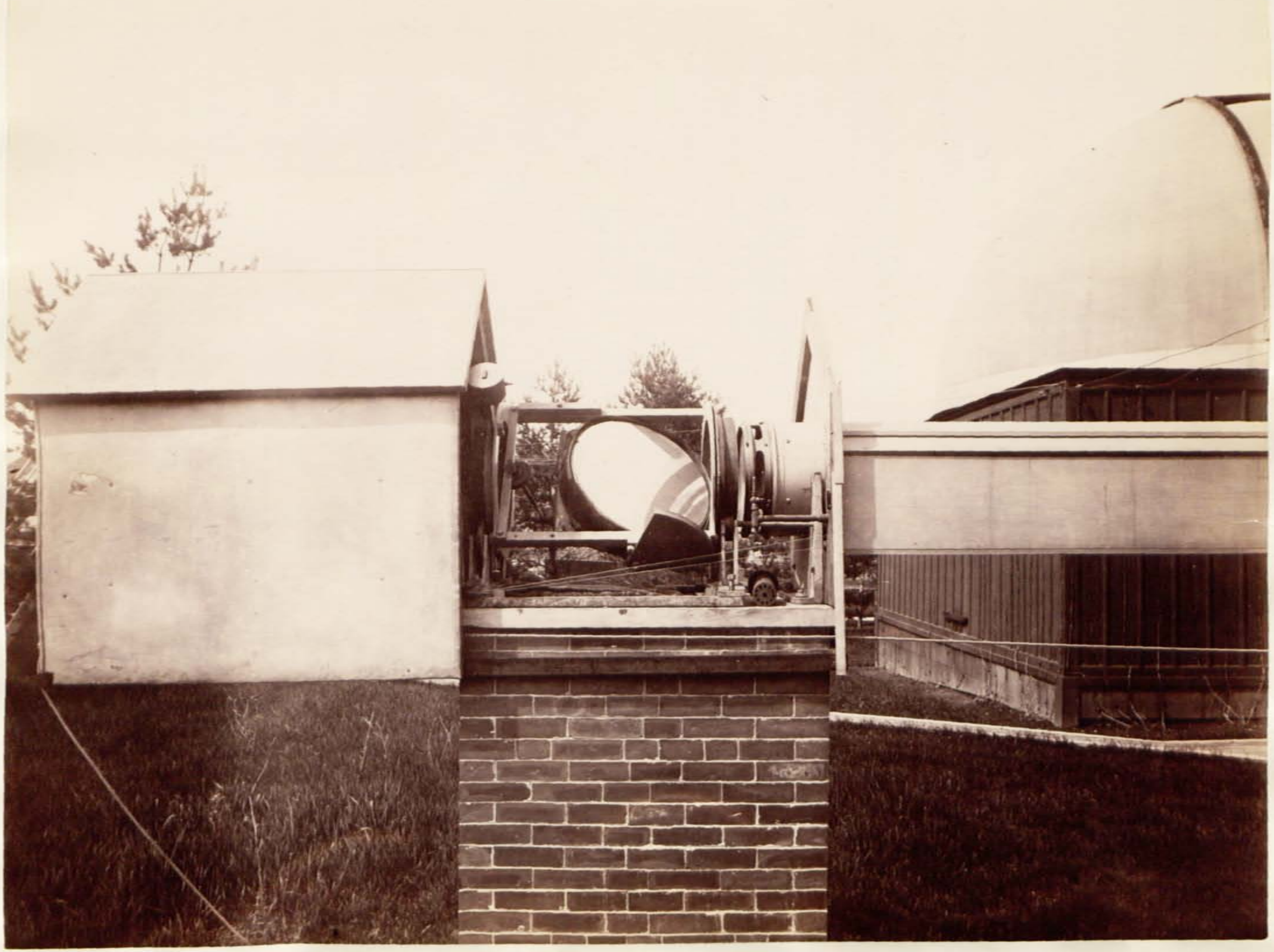


PLATE III.

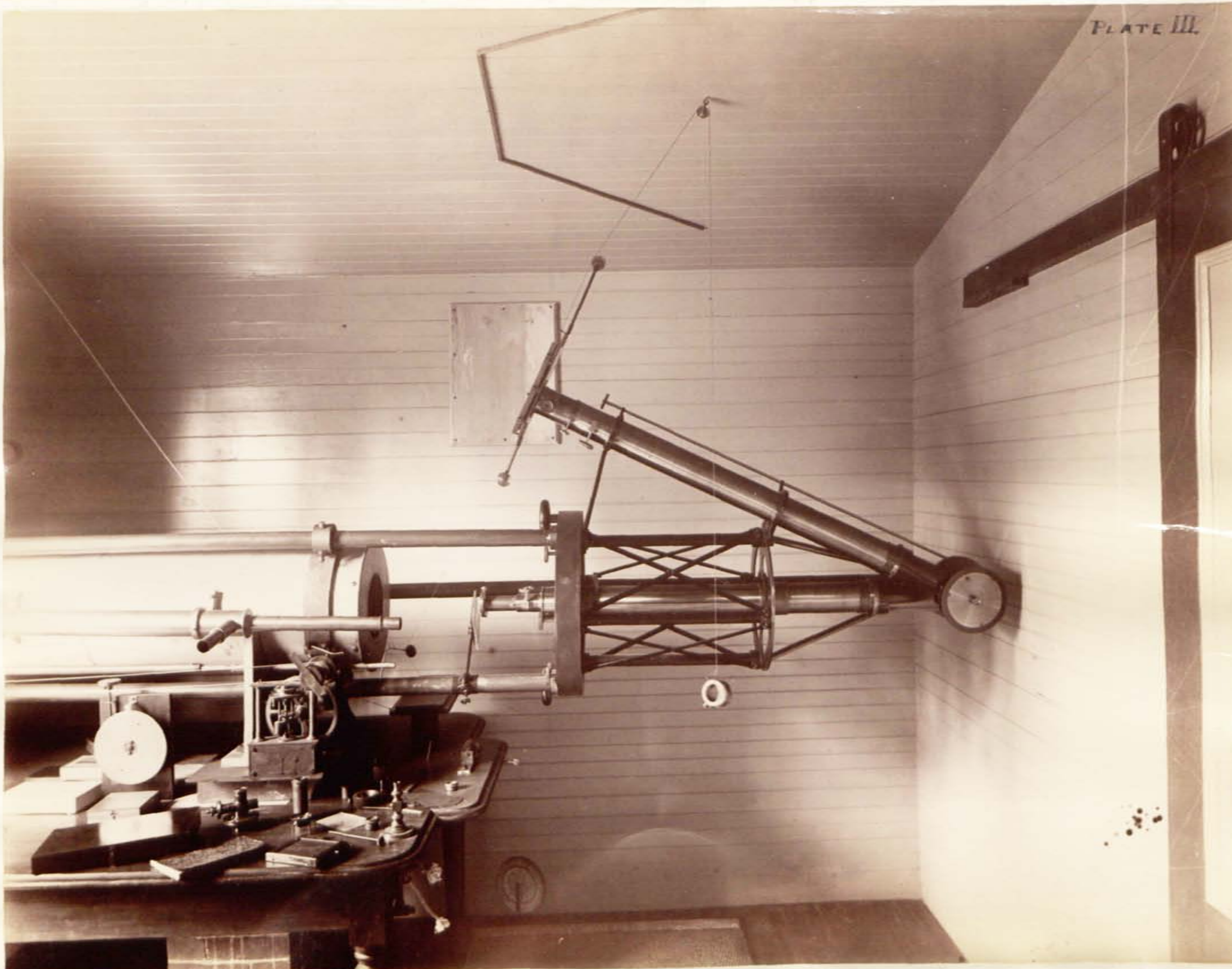
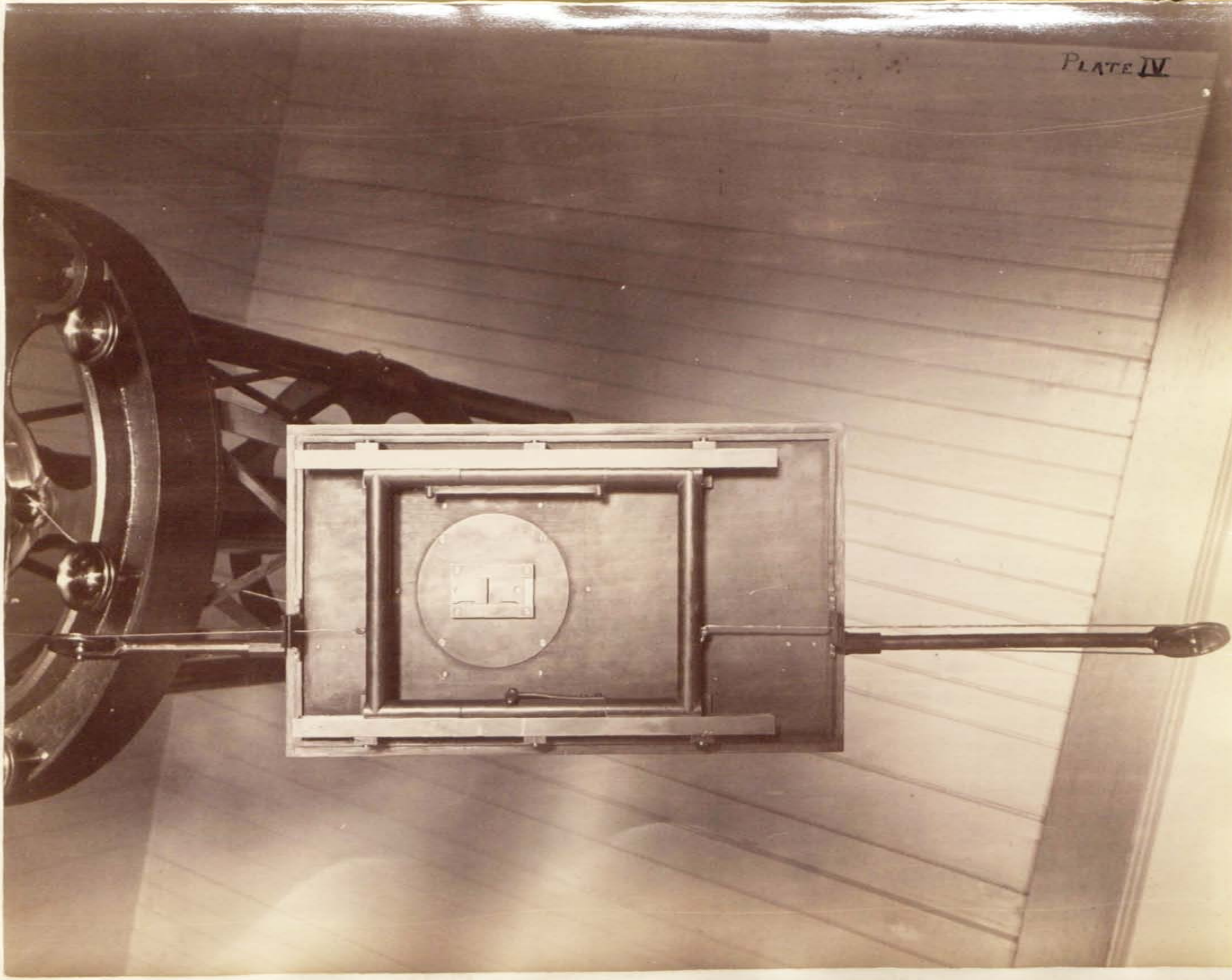


PLATE IV




Special Spectroscope Designed for G. E Hale
Scale 6" = 1"
July 1889
Full Size
Lower End View of Ring to support Spec.
Pinion
Brass Lower Ring.
Plan.
Cross Sectional view of Collimator & Frame.
From lower collar (Ring) = 20⅝"
3 tubes each 7' 1" long with collar and set screw between rings.
3 – 1⁵⁄₁₆" tubes 19⅜" long.
This frame to be braced by ⅛" × 1" braces.
41⁹⁄₁₆" to cen of grating
Tube 36⅛" long
Tube 33½" long for 42½" focus objective
17⁹⁄₁₆" between collars.
1½" tube to carry grating
Tube 3⅞" long.
Brace to extend to bearing casting.
3 Clamping screws.
4 Screws
2 Pinions
Grating Mount
Grating
Circle divided to degrees & pointer for same
To rotate grating
Split clamp
Rings on tube 4" cen to cen.
Screw 2" adj.
Rack 2" motion to work stiff
Tube 7⅛" long
Brace