THE THEORY AND APPLICATION OF THE CONCAVE DIFFRACTION GRATING

Thesis for the Degree of M. S.

C. Fred Clarke

1935

Spectrograph
Title: Concave diffraction grating

Ulysses

With best regards & sincere wishes

[illegible] Clarke

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IN APPRECIATION

I wish to express my appreciation to Dr. C. D. Hause who suggested this problem and who has guided throughout; to Prof. C. W. Chapman for his cooperation in furnishing the necessary equipment; to George L. Chapman for his guidance in the mechanical construction, and to the physics staff for the many helpful suggestions and encouragements.

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INTRODUCTION

The purpose of this paper is to explain the construction and operation of a small grating spectrograph.

In order to accomplish this, it will be necessary; 1) to review briefly the theory of the grating, 2) to give the mechanical details of the necessary construction of the spectrograph, 3) to consider in detail the difficulties and limitations arising in the adjustment and operation of the apparatus, and 4) to compare its resolving power with the equipment available in this labratory.

The grating is a Wallace Replica of a Michelson concave diffraction grating. It has 25,110 lines per inch and a focal length of 1060 mm. To meet the above objectives it was necessary to provide a mounting for this grating which would; 1) be flexible, 2) provide easy adjustment from one setting to another, and 3) give accurate re-setting to any desired region of the spectrum.

THEORETICAL CONSIDERATIONS

An optical grating consists of a piece of glass or speculum metal which has been ruled with from 3000 to 30,000 lines to the inch. The glass allows the light to pass between each ruled line but the ruled line is practically opaque. The speculum metal acts as a mirror each groove acting as a small reflector. The ruling of these gratings is a delicate, expensive, and slow task. There has been developed, by T. Thorp, R. J. Wallace, and others, a method of reproducing these gratings by making a collodion or pyroxilin cast of the original, and mounting this case on some suitable foundation.* Rowland discovered that if a grating were ruled on a concave mirror the grating would produce sharp images, itself, without any lens system being necessary.

The concave grating used in this problem is a Wallace replica of a grating ruled on Michelson's engine at the University of Chicago. The cast is mounted on a silvered glass mirror, which in turn is mounted in a block of plaster of paris. This grating has 25,110 lines to the inch, and a focal length of 106.0 cm. The lines are 3 cm. long and the ruling extends for 5 cm.

From the elementary theory of the diffraction grating the relation between the angle of the incident ray θ_1, the angle of the diffracted ray θ_2, and the wavelength λ, for any plane grating, is given by the equation**

(1) $$n \lambda = a(\sin \theta_1 + \sin \theta_2)$$

* Chas. F. Meyer--The Diffraction of Light,-p. 130 --p. 182

**Chas. F. Meyer--The Diffraction of Light--p. 116

where n is the spectral order observed and a is the grating spacing vis., the distance from a point in one ruled line to a corresponding point in the adjacent line, or simply, the reciprocal of the number of lines per unit length in the grating. This elementary theory is applicable to any plane transmission or reflection grating. If this equation is applied to each element of a concave reflection grating an expression should be found which would determine the focal relation.

In the development of this focal relation for the concave grating, the grating space a is considered constant along the arc. In practice a grating is ruled with the spacing constant along the chord. However, since the aperture of a grating is small, the spacing along the arc or chord will not differ appreciably. (It can be shown that this constant spacing along the chord instead of along the arc is essential in the perfection of the image.)*

In figure 1 let O be the source and its image I formed by the grating MM'. With DL, the radius of curvature of the grating, as a diameter draw a circle tangent to the grating at its center. Consider the two rays from O, OM and OM' incident on the grating. Let e represent the small element of the grating between M and M'. The angles θ_1 and $\theta_1 + d\theta_1$, and θ_2 and $\theta_2 + d\theta_2$ are the angles of incidence and diffraction respectively since any line

*Chas. F. Meyer--The Diffraction of Light--p. 430.

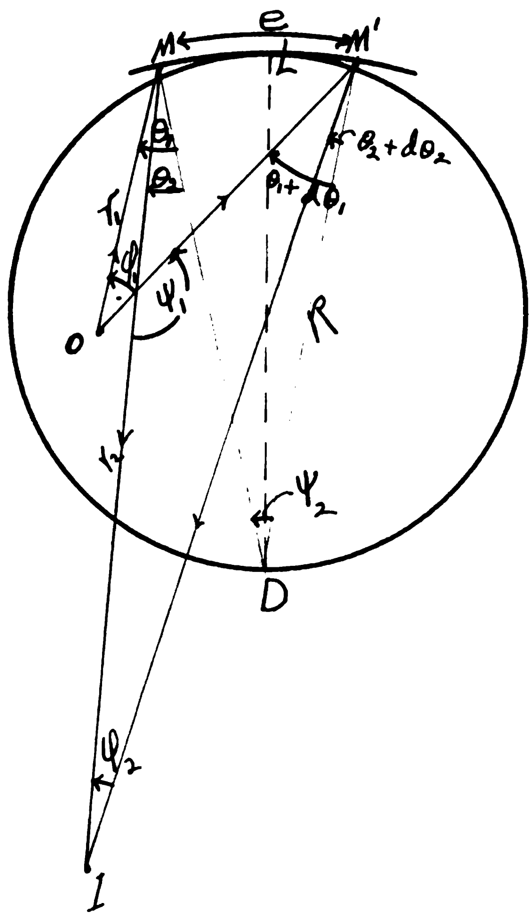


Figure 1

from D is normal to the grating surface.

*In order to form a diffracted image in a given order of a particular wavelength it is necessary that $n\lambda$ remain constant over the surface of the grating. This condition may be expressed by differentiating the grating equation with respect to θ and setting this equal to zero. The correct focal relation will then be that which satisfies this equation.

$$d(n\lambda) = d[a(\sin\theta_1 + \sin\theta_2)]$$

Since a is a constant for any particular grating this equation reduces to

$$\cos\theta_1 d\theta_1 + \cos\theta_2 d\theta_2 = 0. \quad (2)$$

In order to have an image, θ_1 and θ_2 must compensate for each other to satisfy equation (2).

*Chas. F. Meyer--The Diffraction of Light--page 155

Letting R represent the radius of curvature of the grating, r_1 the distance OM, and r_2 the distance IM in figure 1, by geometry

$$\varphi_1 + \theta_1 = \psi_1 = \psi_2 + \theta_1 + d\theta_1 \quad .$$

Or

$$d\theta_1 = \varphi_1 - \psi_2 = \frac{\ell}{r_1} - \frac{e}{R}$$

by using radian measure to represent the angles φ_1 and ψ_2 .

$\ell = e \cos\theta_1$ since for small arcs the arc may be substituted for its chord or the chord for the arc, (the error introduced being small) and the element of the grating surface is small.

Therefore $d\theta_1 = \frac{e\cos\theta_1}{r_1} - \frac{e}{R}$ and similarly $d\theta_2$ may be

(3) written $d\theta_2 = \frac{e\cos\theta_2}{r_2} - \frac{e}{R}$.

Substituting these values in equation (2) gives

(4) $$\cos\theta_1\left\{\frac{e\cos\theta_1}{r_1} - \frac{e}{R}\right\} + \cos\theta_2\left\{\frac{e\cos\theta_2}{r_2} - \frac{e}{R}\right\} = 0$$

If $r_1 = R\cos\theta_1$ and $r_2 = R\cos\theta_2$ equation (4) is satisfied. This condition exists when O and I both lie on the circle having DL as a diameter. Other conditions may satisfy this equation but this one is of particular significance. This circle is commonly called the Rowland circle and is understood to be the circle tangent to the center of the grating using the radius of curvature as its diameter.

In general practice a narrow slit is used as the source O . It follows from equation (4) that if the slit is placed any where on the Rowland circle, its image will be in focus on this circle also, and for any given θ_1 its position will depend upon γ and λ of equation (1).

Figure 2 is a sketch of the Eagle mounting.* Light enters the slit S and is reflected to the grating G where it is diffracted to the plate P. Here the various wavelengths are separated over the plate. Optically the slit S is just above or below the center of the plate P. Since it is necessary that the grating and plate remain on the Rowland circle as they are rotated, the corresponding change in the chord is made, as illustrated in figure 3. The center of the Rowland circle moves along the normal to the line PG as the machine is adjusted to the various spectral orders. From figure 2 it is evident that the angle of incidence θ_1 and the angle of diffraction θ_2 are identical. Therefore equation (1) reduces to

(5) $$n \lambda = 2 a \sin \theta$$

for the Eagle type of mounting. It is also evident from equation (4) that if all points on the plate P are to be in focus at the same setting it must have the curvature of the Rowland circle.

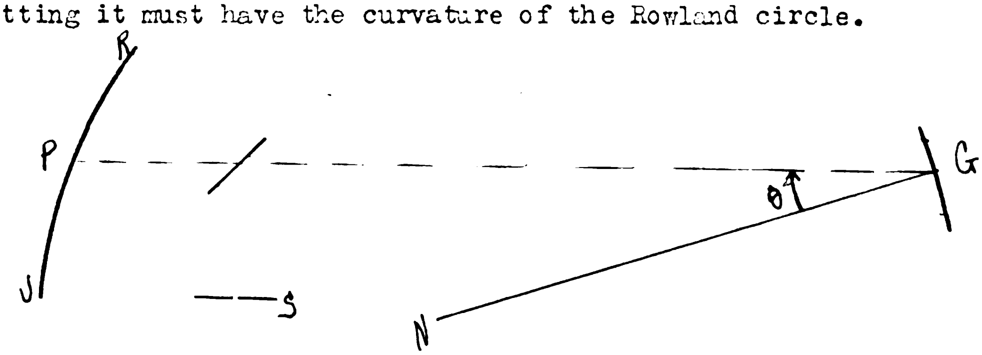


Figure 2

To definitely illustrate these positions, take the iron line $\lambda =$ 4859.757 A. and calculcate the required positions with equation (5). This particular grating has 25110 lines per inch,

*--Astrophys. Journ. Vol. 31,-p. 120,-1910.

or 9885.8 lines per cm. Therefore a = 10115.4 A . R=106.0 cm.

From equation (5) is obtained

$$\theta = \arcsin \frac{n\lambda}{2a}, \qquad \overline{PG_i} = 106.\cos\theta \tag{6}$$

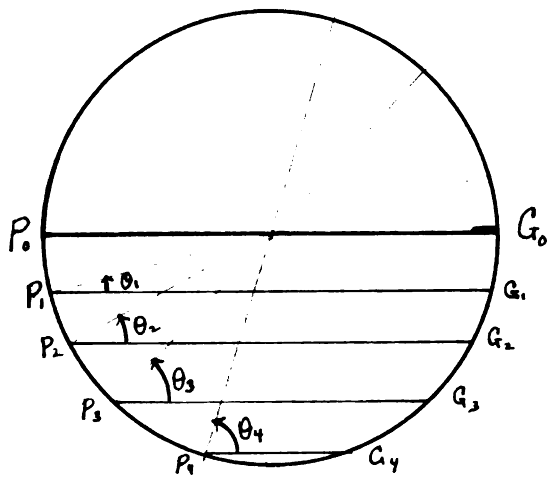


Figure 3

λ = 4859.757 a = 10115.4A°

N	θ	[illegible]	[illegible]	[illegible]
1	13° 34'	[illegible]	7.5	[illegible]
2	28° 43'	92.96	15.9	6.2
3	46° 6.5'	73.49	25.6	14.3
4	73° 55'	29.36	41.2	30.9

Table I

Figure 3 gives graphically the relative positions of the camera and grating for the orders as shown in table 1. As the length of the chord is changed, the grating and plateholder must rotate equal amounts in opposite directions in order to remain tangent to the Rowland circle.

It is clear from equation (6) that in the same position in which the first order diffracted image of $\lambda = 4859.75$ A is obtained, will occur the second order of $\lambda = 2429.87$ A . and the third order $\lambda = 1619.75$ A . Neglecting, of course, the probability of absorption of these shorter wavelengths.

CONSTRUCTION

There are four main parts to a grating spectrograph, 1) the grating support, 2) the camera or plate holder, 3) the slit and mounting, 4) the general support for these three arranged in a manner which will provide the necessary adjustment.

In the Eagle mounting* it is necessary to have the slit and center of the plate optically coincident. This is impossible mechanically. However, a very close approximation to this ideal may be had by lifting the plate just above the plane of the Rowland circle which includes the optical axis of the grating, and then placing the slit just below this circle, both coincident with a line through the circle perpendicular to the plane of the circle.

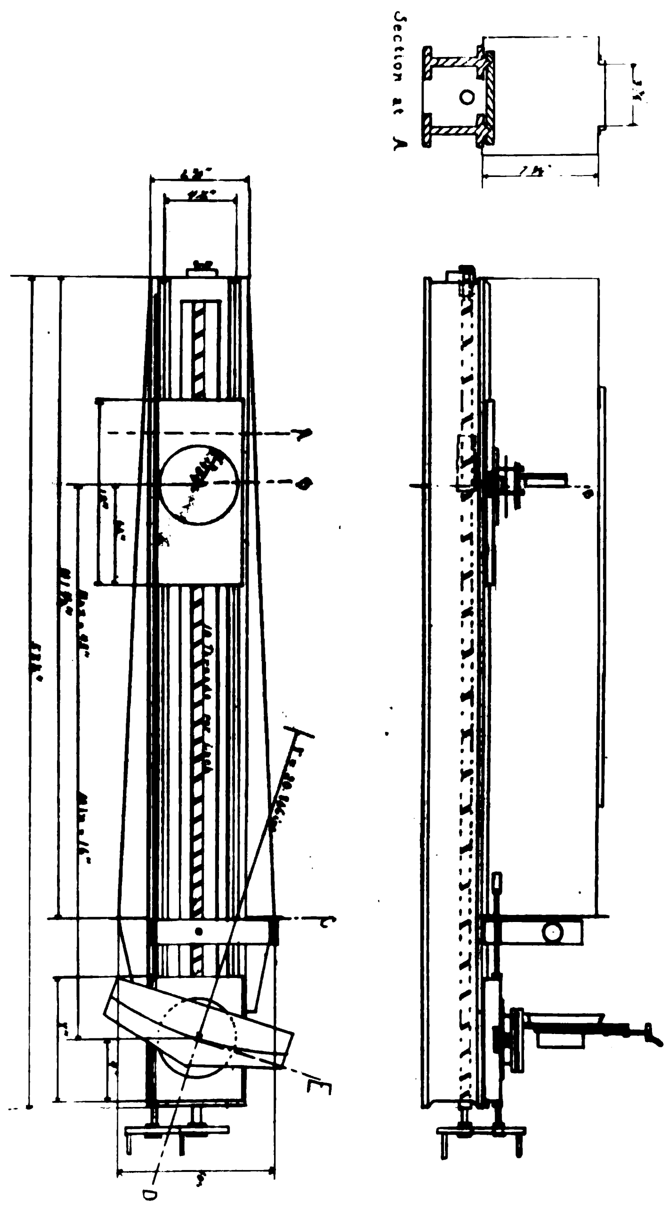
Actually this last may be accomplished in two ways. The slit may be mounted directly beneath the plate holder. (The disadvantage being that only one exposure may be obtained on any given plate as there is no opportunity to move the plate into successive positions without covering up the slit with the plate holder.) Or the slit may be mounted perpendicular to this optical path and just below the plane of the Rowland circle with a 45° totally reflecting prism at the foot of the perpendicular, and the optical path adjusted until it is the same length as in the previous condition. This is similar to the mounting used in the litrow type of prism spectrographs.

The distance between the grating and the plate holder must be capable of a wide range of literal adjustment and must be capable of reset positions quickly and easily. The maximum length must be the

*E. C. Baly--Spectroscopy Vol. 1--pp. 205-212 focal length of the grating, in this instance 106 cm. The minimum length will depend on the spectral order possible with the grating at hand. This one was constructed with a range of 42" to 16" from grating to plate. This adjustment is the length of the chord of the Rowland circle.

As the chord is changed in the Rowland circle the grating must remain tangent to the circle and the curve of the plate holder must always coincide with this circle. Therefore, rotational motion must be given to change from one part of the spectrum to another and from one order to another. This will amount to a right handed motion of one and a corresponding left handed motion of the other, of equal amounts.

The simplest support seemed to be a lathe bed, although a U beam or, even a flat plate could be machined as a track for the lateral movement of the grating carriage. This one is a wood turning, lathe bed 4' 5 3/16" long by 6 5/16" wide. The camera, slit, and grating are mounted on carriages machined to the ways of the lathe bed. The camera carriage is mounted permanently on one end of the bed since it receives the greatest mechanical strains during operation. The slit carriage clamps to the bed and may be changed at will by loosening two clamping screws. This carriage also supports the totally reflecting prism. The grating carriage is free to move laterally on the ways and is controlled by a screw the length of the bed with a pitch of 1/10 of an inch. The plan, elevation, and also a section are shown in Plate I.



Plan and Elevation of the Spectrograph

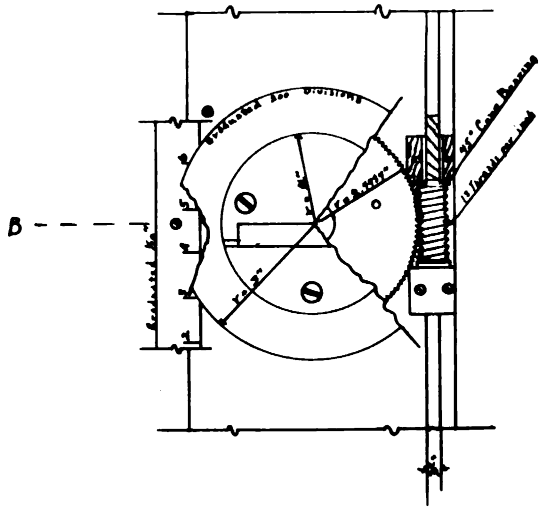
PLATE I

The grating carriage, the details of which are shown in Plate II, is of 3/8" rolled brass stock 5½" x 12". The V ways are cut lengthwise. In the upper side a circular recess is turned 4.8968 inches in diameter in which the worm gear rests. The center of this is cut and threaded for a 3/4" mounting stud. A recess is cut on one side for the worm. Cone bearings on either end of this worm hold it in position against the worm gear. A square shaft through the worm allows the longitudinal motion of the carriage. This worm and gear have a pitch of 1/13" R. H.

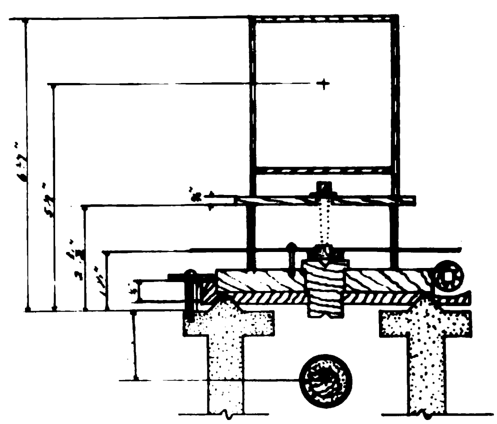
The diameter of the circular plate, 4.89", is such that 200 threads are cut in its periphery. Thus one complete revolution of the worm moves the worm gear $\pi/100$ radians, which is one division on the calibrated dial mounted just above the plate. The worm gear was cut with a standard 13 thread tap by constructing a jig to fit into the tool post of the lathe to carry the gear level with the centers and allow free rotation of the gear. The tap in the lathe will automatically feed the circular plate as it cuts the gear.

Just above this worm gear and supported by it is the circular scale 6" in diameter. Above this is the grating mounting, supported by three leveling screws, and held in place by a coil spring. The grating is capable of being tilted either forward and backward or to either side and its heighth is also controlled by these leveling screws. It may be given a slight rotational motion by two screws at the top of the mounting.

The carriage is connected to the screw by a four inch cast babbit nut linked with a flat spring. This suffices for the reset purposes required of this apparatus; but if direct measurements are necessary, a direct mounting should be used such as is used on comparator screws. Then by dividing the dial in 100 parts the move-



Plan at B



Section at B

Plan and Section of the Grating Carriage

PLATE II

ment could be read directly to 1/1000 of an inch.

The details of the camera and its carriage are shown in Plate III. The carriage is made from a rolled iron plate 3/4" thick, 6" x 8". A circular recess is also turned in this plate of the same diameter as that in the grating carriage, 4.89 inches. V ways are cut lengthwise of this plate. Both are cut deeper to compensate for its added thickness. The circular plate is cut to a worm gear the same as for the grating except that a left hand tap is used. This worm gear is held in place by a 3/4" stud screw into the iron plate. A steel ball in the center of this stud carries a brass bolt which supports the camera mounting plates. The lower plate is clamped to the worm gear by four studs, giving opportunity to level in either direction. The upper plate is fastened to the lower plate by means of the brass bolt supporting the camera and two circular ways bolted near either end of the lower plate with corresponding ways in the upper plate. These allow rotation of one plate with respect to the other which gives opportunity to correct for errors in the worm gears. Between these plates and fastened to the lower one is a 6" calibrated and verniered dial identical to the one used in the grating mounting. The upper plate is rotated over the lower one by means of a worm meshing in a rack near one end of these plates. The amount of rotation is read from the circular scale.

On the upper plate is mortised a 3/8" brass plate 12" wide and 9 11/16" high. This is so placed that the emulsion of the photographic plate in the plate holder is directly above the center of the two supporting bolts. This places the center of the photographic plate coincident with the center of the rotation of the camera.

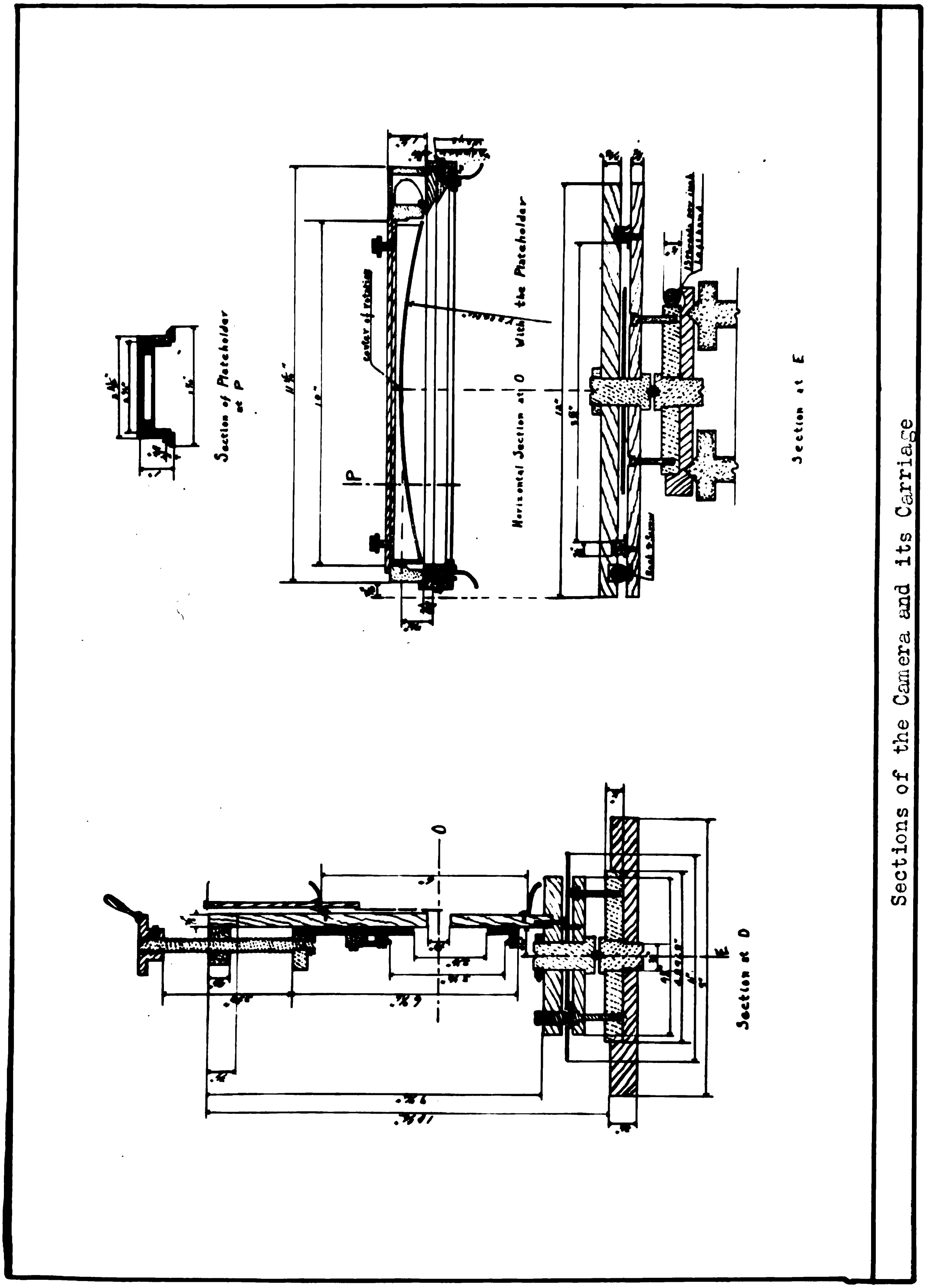

Sections of the Camera and its Carriage
Section at D
Section of Plateholder at P
Horizontal Section at O with the Plateholder
center of rotation
Section at E

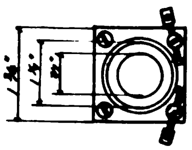
PLATE III

Hence any rotation of the camera alone should in nowise alter the focus at the center of the plate.

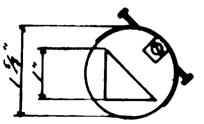
On this vertical plate in vertical ways, see section O Plate III is a carriage which supports the plate holder. This carriage is free to move through a vertical distance of 6 cm. and is controlled by a screw at the top. These ways are also high enough so that they give covering to the ends of the plate holder and with the upper and lower clamps furnish a complete light seal between the plate holder and its carriage.

The back of this carriage, except a small distance on each side which is left as a bearing surface is machined down about .008" to permit these surfaces to be painted a dull black which furnishes a very useable light seal. On the back of the camera a Z bar was formed into a square box 11½" x 6" over which the light tight cloth hood is fastened. This frame also contains ways whereby a mask can be lowered. This mask is suitably cut with horizontal slots of varying width which allow different widths to be exposed on the plate.

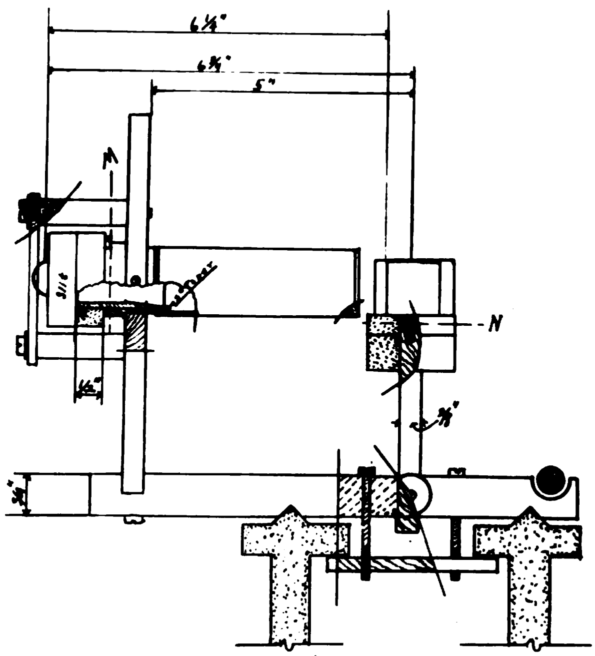
The slit mounting, details of which are shown in plate IV, consists of an iron bar 3/4" x 2" x 8" in which ways are milled so that it will fit rigidly on the lathe bed. One end extends 5½" from the center of the bed. It is held in place by a clamping plate directly beneath the ways of the bed, and secured by means of two clamping screws. 5" from the center of the center of the ways a mortice is cut so that a brass bar 3/8" thick will set vertically on this carriage. This bar carries the slit and its



Details at M



Plan at N



Section at C

The Slit Carriage

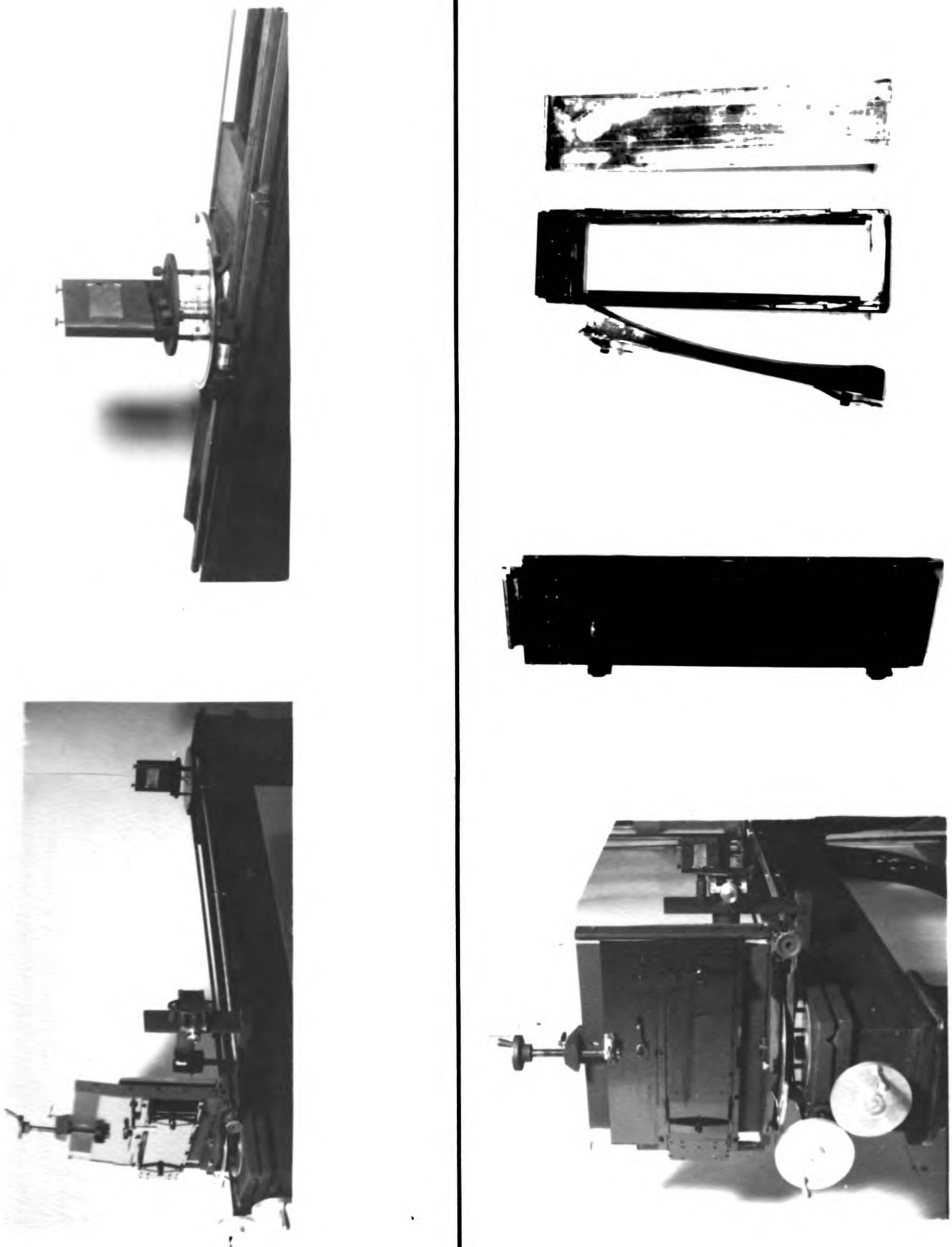
PLATE IV

mounting and shield. The mounting is made by taking a heavy 1" brass tube and fitting a brass collar to a press fit and then sweating the two together leaving ½" of the tube extending on one end to fit in the square block which backs up the slit. This block fits over this tube against the collar and is held in place by a ring nut countersunk flush with the square block. The block is held to the slit by means of four studs, two of which have holes drilled and tapped at right angles in their heads to carry adjusting screws. These adjusting screws face each other and engage pins set in the collar, thus controlling the rotation of the slit in its mount. This collar is turned to fit the hole in the vertical brass bar and to carry on its other end a 5/4" brass tube which acts as a shield to the pencil of rays from the slit to the prism.

At the center of the ways on the slit mounting carriage is a 5/16" hole with a permanent key mounted in one side of the hole and a set screw with knurled nut on the opposite side. A brass shaft with a keyway fits in this hole and carries at its upper extremity a double brass plate. The lower plate is fixed rigidly to the vertical support, the upper one is left free to turn as two screws arranged opposite in a slot in the upper disk engage a pin in the lower disk which extends into the slot of the upper disk. This upper disk carries the totally reflecting quartz prism. Thus we have two adjustments on this prism; one a rotational movement in the horizontal plane and the other a movement of translation along the axis of rotation.

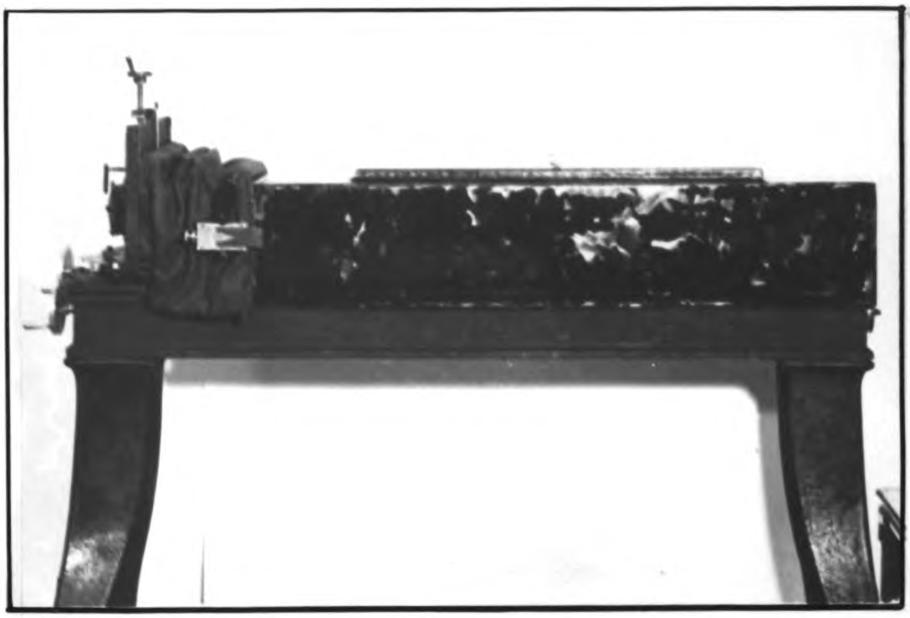
A hood covers the lower end up to the slit. This hood has a hand door in the top for convenience and is connected to the camera by means of a light tight cloth hood. The bottom of the lathe bed is covered with a piece of sheet iron. This allows the apparatus to be operated in a light room thus adding greatly to its adaptability and efficiency.

Plate V shows photographs of the various parts of the equipment and plate VI the finished spectrograph.



VIEWS OF THE APPARATUS

PLATE V



THE COMPLETED SPECTROGRAPH

PLATE VI

ADJUSTMENT AND OPERATION

To arrange the spectrograph to photograph any particular spectral region two major and one minor adjustments are necessary. The major adjustments consist of a lateral movement of grating with respect to plate and a rotational adjustment of grating and plate. The minor adjustment consists of a small additional rotation of the plate.

In this discussion the rotational motion "R" controlled by the left hand dial will be considered the independent variable and the other adjustments will be considered in respect to it. The rotational dial controls both the camera and the grating, giving to one a left hand and to the other a right hand motion simultaneously. This is accomplished by a left hand screw on the camera and a right hand screw on the grating. Each revolution of the screw imparts a rotation of $\pi/100$ radians, which is equivalent to one division of the graduated dial. There is approximately 1/4 turn of backlash in this train. Any difference in backlash between the two gears is eliminated by setting as the dial reading increases. The bearings on the screws are cones and can be adjusted if necessary.

The lateral adjustment is obtained by the central dial. There is about 1/6 turn of backlash in this adjustment but all settings are taken as the scale readings increase. Any lateral play in the screw may be eliminated by tightening the centering pin at the rear of the instrument.

A small knob at the right of the camera rotates the plate holder independently and can be used to apply the necessary correction to keep the plate on the Rowland circle. This correction is also read on the graduated dial.

When setting up the instrument the slit is set to give vertical lines on the plate. Then the grating is rotated by means of screws at the top of its mounting until the ends of the lines seem to be symmetrical. If the rulings of the grating and the slit are not optically parallel the lines will have a parallelogram shape caused by the successive images not exactly coinciding as  . The spectrum is brought into the slot in the camera by means of the three leveling screws on the grating carriage.

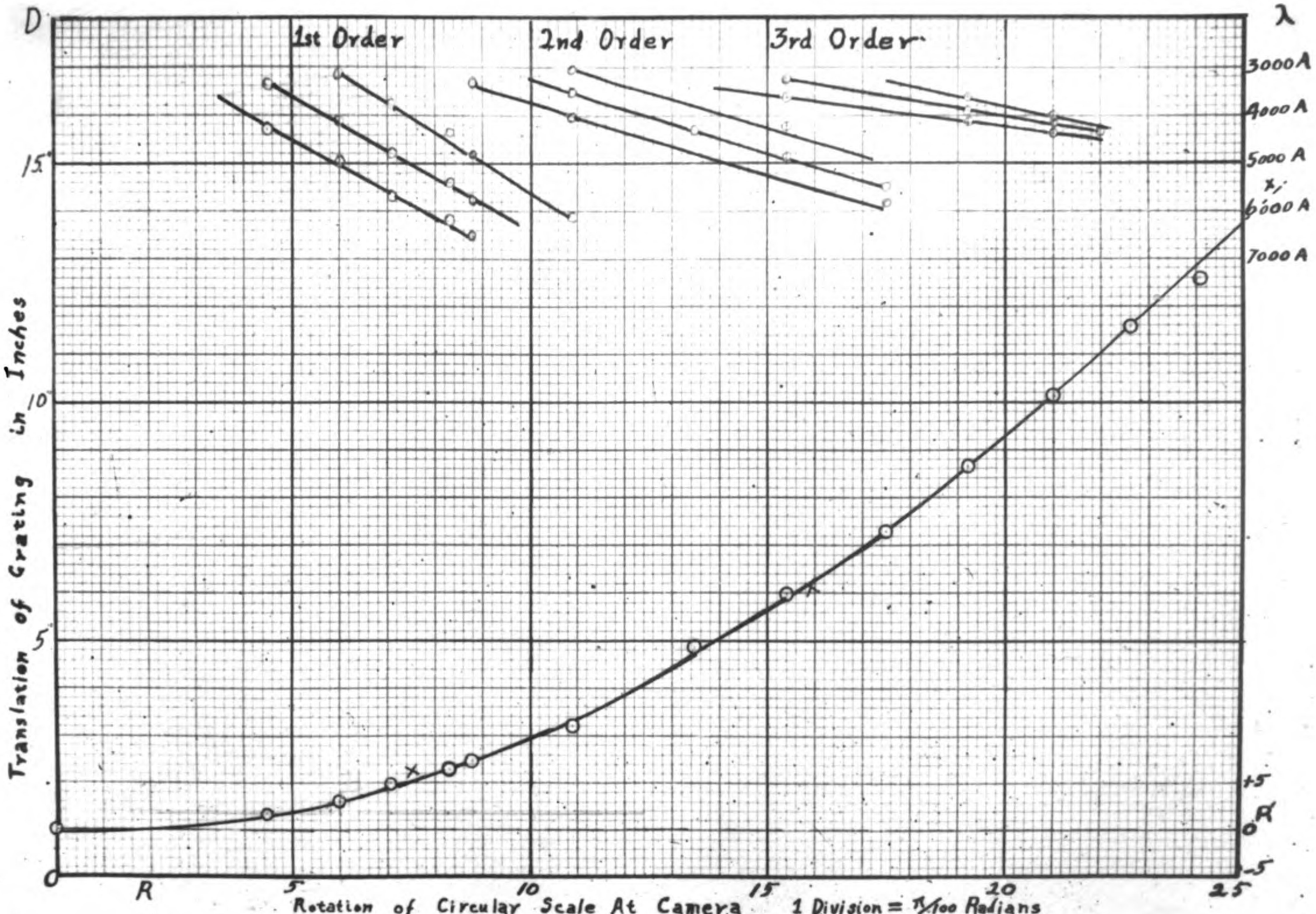
The mask may be set to give different widths of spectra across the plate.

The prism should be set so that the entering beam of light is normal to the longitudinal axis of the instrument. When the slit is opened and no condensing lens is used the pencil of rays form an outline of the slit which should center on the grating.

The curvature of the plate holder must be relatively high in order that the emulsion coincide with the Rowland circle. Extra thin glass plates have been tried with poor success. The necessary curvature breaks them. Films were used for the exposures for this paper.

Trial exposures have been taken of different spectral regions and the results correlated in Plate VII from which dial settings for any particular range may be obtained. At the top of the figure three shaded areas give the part of the spectrum covered by the plate at any setting of "R". The center line of each shaded part gives the approximate wavelength in Angstrom units at the center of the plate. The main curve gives the corresponding lateral setting for each rotational setting. A very interesting correlation should be pointed out, the circles, from which the curve is plotted, are from experimental results while the x's are the theoretically computed results from table 1.

Reset trials using this curve as a standard have given very favorable evidence of its reliability.



THE CALIBRATION CURVE

LIMITATIONS, ABERRATIONS, and RESOLVING POWER of this GRATING

Limitations

This instrument has very definite limitations, and some very definite advantages. The collodion of which the grating is made gives a sharp limit in the ultra violet at about 3100 A. It appears that below this limit a rapidly increasing amount of absorption takes place. The upper limit, as far as observable, is dependent only on the photographic emulsion available. However, suitable filters must be used to eliminate the overlapping higher order as illustrated by the overlapping of the shaded areas in Plate VII, and explained on page seven of this paper.

The rotation of the plate is limited to about $25\pi/100$ radians or 45° by the reflecting prism and its mounting. From Table 1 it is seen that the green line of iron $\lambda = 4359.757$ A. in the third order will be near the center of the plate at this limit. Further rotational adjustment is of no advantage with this instrument, however, as the imperfections of the grating are such as to give poor definition in the third order and, therefore, no advantage over lower orders. The reflecting prism and mounting could easily be moved if any advantage were to accrue.

Aberrations

Several aberrations should be mentioned. The central image appears as a sharp image of the slit with considerable diffused light on each side and with several false images symmetrically arranged. On plate VII a picture of this central image is shown. As a narrow mask was moved over the grating the intensity of these false images varied continously. The most probable explanation seems to be that small parts of this grating are acting independently as well as collectively to form various images. This may be due to uneven shrinkage of various parts of the collodion transfer. The diffused light, no doubt, comes from the dust on the surface of the collodion.

These false images carry over into the spectra and appear as light lines on one side of the parent line giving to the spectrogram the appearance of being out of focus.

Ghosts

In the ruling of a grating any periodic error in the ruling engine produces in the spectra from that grating false images of a line which are called ghosts. These by their nature are symmetrical with the parent line. They have been studied by Rowland, Anderson, Quincke, Pierce, and others and many of their causes have been analyzed.*

*-Chas. F. Meyer--The Diffraction of Light,-p. 173

Plate VIII gives a picture of the ghosts present near the mercury line 5460 A and the pair 5679 A and 5790 A. In order to photograph these the plate was exposed about 15 minutes under conditions, such that an exposure of 1 minute produced an over-exposed line. This plate shows that the ratio of intensity of parent line to ghost is high. So high, in fact, that only when dealing with faint lines near a very intense line is there any danger of mistaking them.

The only ghosts found are those which are commonly known as Rowland ghosts. They are caused by a periodic error in the screw of the ruling engine. They are symmetrical about the parent line and relatively close to it. Their relative intensity increases in the higher orders. However, this 5460 A line showed no ghosts in the second order after an exposure of 80 minutes. However, the second order shows slight ghosts after an exposure of 8 hours.

Astigmatism

The images formed by a grating are, in general, astigmatic.* That is, a concave grating produces a line image of a point source. Since a slit source is a succession of point sources the spectral lines will be a composite of superimposed lines. These lines when combined will form a line which decreases in intensity toward its ends.

This astigmatism has two serious disadvantages; 1) it decreases the intensity of any given line thus requiring longer exposures, 2) it prohibits the use of a mask in front of the slit to facilitate

*Chas. F. Meyer--The Diffraction of Light--p. 158

comparison spectra. The characteristics of the Eagle mounting are such that this astigmatism is considerably less than in the common mountings. It is about one half, in the first order, of that produced by the Rowland mounting. This mounting is sufficiently stigmatic that a wedge may be used in front of the slit (See Plate VIII) from the ultra violet through the green of the first order. For above the red of the first order and for other orders a mask, which may be adjusted easily without disturbing the camera, has been placed in front of the camera carriage. This facilitates the use of the instrument in comparison spectra work.

Resolving Power

The resolving power of the optical instrument is its ability to separate the images of two objects which are close together. In spectroscopy the resolving power is determined by the ability of a spectrograph to separate wavelengths that are nearly the same. It may be defined by the ratio $\frac{\lambda}{\Delta\lambda}$ where λ is the wave-length of either of a pair of lines which can just be resolved and $\Delta\lambda$ is the difference of their wavelengths.

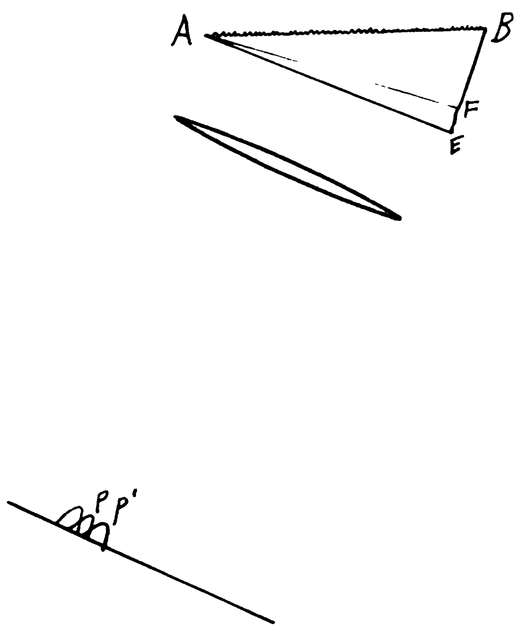


Figure 5

By measn of Figure 5 the relation of the resolving power to the constants of a plane grating may be developed. This result may then be applied to any grating. If AB is the grating surface having m lines and if n is the order of the spectra. Then BF must be equal to $mn\lambda$. This wave front will give rise to the diffraction pattern p, and the first minimum of the diffraction pattern will be given by the wavefront AE when EF $= \lambda$. Therefore, BE $= (mn\lambda + \lambda)$. A wavelength $\lambda' = \lambda + \Delta\lambda$ will give rise to a diffraction pattern p'. The wave front necessary to produce this pattern will be AE, and the increment of FE will be equal to $mn\Delta\lambda$. Therefore, BE will be equal to $(mn\lambda + mn\Delta\lambda)$. By equating these two values of BE it develops that,* $mn\lambda + mn\Delta\lambda = mn\lambda + \lambda$, or

(7) $$\frac{\lambda}{\Delta\lambda} = mn.$$

Which gives the theoretical resolving power of a grating spectrograph as dependent only on the trial total number of lines of the grating and the order. For a prism instrument the resolving power

*-Chas. F. Meyer--The Diffraction of Light--page 198.

is given by the formula,*

$$\frac{\lambda}{\Delta\lambda} = -t\,\frac{\Delta\nu}{\Delta\lambda} \qquad (8)$$

where t is the thickness of the prism at its base, and ν is the index of refraction of the material of the prism for the particular region of λ. $\frac{\Delta\nu}{\Delta\lambda}$, which is the dispersive power of the prism, varies for different wavelengths and various substa nces.

By equation 7 the theoretical resolving power of this grating is 50000 n, or approximately 50000 in the first order. From experimental results the two iron lines at $\lambda = 4934A$ are well defined at about 1/10 mm. separation on the plate. The resolving power is then $\frac{4934}{.675} = 7320$ which is about 1/6 of the theoretical. At $\lambda = 3402A$ two lines are well defined giving a resolving power of $\frac{3402}{.639} = 5330$. In the second order the iron lines at $\lambda = 4957$ are barely resolved which is equal to a resolving power of $\frac{4957}{.301} = 16400$. In comparison with these results, the Littrow, L-253, in this labratory, gives the following resolving powers in the same regions. The Littrow barely resolves two lines at $\lambda = 4919A$ and has a resolving power in this region of $\frac{4919}{1.51} = 3260$, while at $\lambda = 3402A$ it easily resolves .320A which is a resolving power of $\frac{3402}{.320} = 10,600$ approximately. These two lines give, in brief, the comparison of the resolving power of the two instruments. Below 4200A the Littrow has a greater resolving power than the grating in the first order. At 3700 A the dispersion of the Littrow and the grating in the first order are almost identical.

*Chas. F. Meyer—The Diffraction of Light—p. 204.

Above 4200A the dispersion of the quartz train rapidly decreases while that of the grating remains almost constant. The dispersion of this instrument in the visable region in the first order is such that this region covers more than a ten inch photographic plate. Therefore, for wavelengths in the visable and above, this grating has a definite superiority when compared with the Littrow. In the second order this resolution is approximately doubled.

Illustrative Spectra

Plate VIII is composed of photographic prints of various plates and illustrates some of the possibilities and limitations of the apparatus. Though the detail of the original is lost in a print much can be shown in this way.

"A" is a picture of the central image. The extraneous lines are very definite on the plate although they blend in the print.

"B" is the green line of Hg λ=5460A with its ghosts in the first order, and "C" the same line in the second order.

"D" is a photograph of the iron arc from 3200A to 4900A in the first order. #1 corresponds to λ=3399A , #2 to λ=4045A , and #3 to λ=4283A .

"E" is a photograph of the iron arc from 4800A to 7100A in the first order. As an illustration of the close proximity to linear dispersion even in this region the separation of the lines λ=4859A (1) and λ=5328A (#2) is 51 mm. giving 9.18 A/mm.

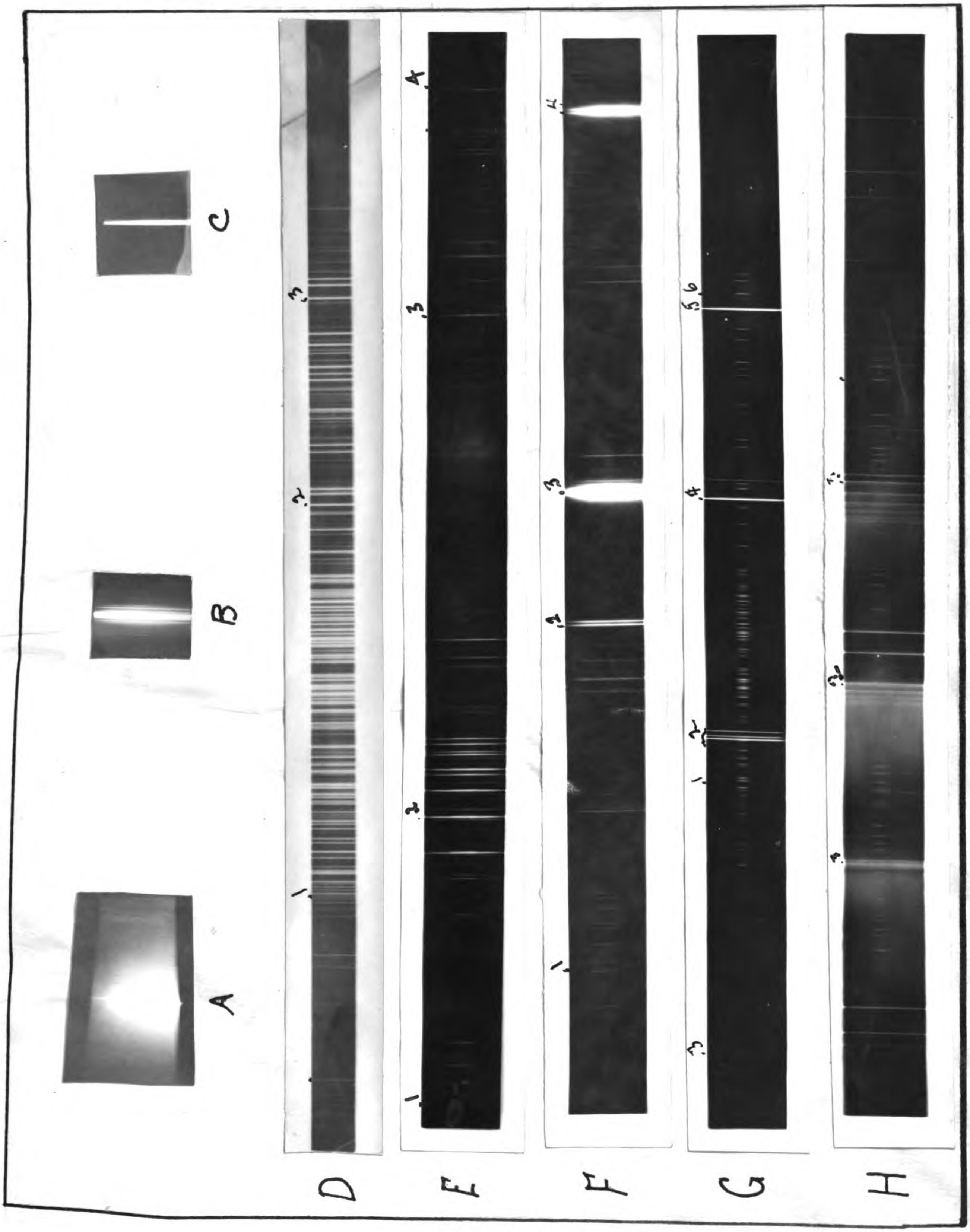
and the separation of the lines $\lambda = 5328$ and $\lambda = 6137A$. (#3) is 89 mm. which gives 9.09A/mm. and the separation of the lines $\lambda = 6137$ and $\lambda = 6494A$ (#4) is 40 mm. which gives 8.95A/mm.

In "F", lithium and potassium chlorides were used in the carbon arc and an iron comparison was placed by means of the mask. #1 is the iron line $\lambda = 5328A$. #2 is the sodium "D" lines, $\lambda = 5890A$ and 5896A. #3 is the lithium line $\lambda = 6103A$. #4 is the lithium line $\lambda = 6708A$ a doublet, which is resolved with this spectrograph.

In "G" the mercury arc was used and its spectra is shown in the region $\lambda = 3100A$ to $\lambda = 4300A$. The comparison is iron placed by means of the wedge in front of the list. The dispersion is almost linear, for from the triplet lines $\lambda = 3650A$, 3655A and 3663A to the pair $\lambda = 3131A$ and $\lambda = 3125A$ the distance is 57mm which gives a dispersion of 8.9A/mm. (See "E"). #1 $\lambda = 3581A$, #4 $\lambda = 4046A$, #5 $\lambda = 4350A$, #6 $\lambda = 4383A$.

"H" is a photograph of the cyanogen bands in the region $\lambda = 3300A$ to $\lambda = 4300A$. This was obtained by photographing a naked carbon arc.

1, 2 and 3 are band heads at $\lambda = 3590A$, $\lambda = 3883A$, and $\lambda = 4216A$ respectively. The comparison is iron.



VARIOUS SPECTRA

PLATE VIII

CONCLUSION

This instrument proves novel in several ways. The direct mechanical link between the grating and camera rotation has proved successful and is of great convenience in rapid resetting to previous values. The dispersion and resolving power in the visable and infra red is definitely much better than can be found in any glass or quartz instrument of an equal cost. It is easily portable. It can be used in a light room the same as a prism spectrograph. It is sufficiently stigmatic that weak sources may be used with good success. The ghosts are extremely weak compared to any parent line and should never offer any serious problem. The spectra in the first order is very near to a normal spectra, that is, the dispersion along the plate is almost a linear dispersion.

The diffused light from the grating is a problem and if an original could be obtained much better results would be expected. The threads of the worms and worm wheels would be better if made after the Acme type instead of the 45 type. The grating mounting could be improved by a provision for a rotational motion about the normal to the center of the grating.

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