LICK OBSERVATORY BULLETIN

NUMBER 449

THE PHOTOMETRY OF LINES IN THE SOLAR SPECTRUM

By

C. D. SHANE

Any adequate interpretation of astronomical spectra must be based largely on the accurate wave-lengths and intensities of their component lines. Wave-length determinations are made by well known methods which in most cases yield results of satisfactory accuracy. Less progress has been made in the measurement of line intensities. It is my purpose here to develop a method by which the distribution of light intensity within a solar line may be measured accurately and to test this method by applying it to certain lines.

Existing determinations of intensity have been made primarily by eye estimates on some arbitrary scale adopted by the observer. Such estimates amount to little more than arranging the lines in the most obvious order, which may have some physical significance. It is possible in some cases to interpret this significance, as was shown by Russell, Adams and Moore¹ in their calibration of the Rowland scale in terms of the relative numbers of atoms acting in a given time. The further work of Russell and Adams² in applying the calibration to stellar line intensities has amply demonstrated the value of the method. There are, however, certain limitations to this procedure. We must consider not only the total intensity but also the distribution of intensity within the line if we hope to gain much quantitative knowledge of the physical conditions that govern the processes of absorption and emission.

The necessity for such measures has been generally recognized in recent years. Absorption line profiles in the solar spectrum have been determined by Unsöld,³ Plaskett,⁴ von Klüber,⁵ Minnaert,⁶ Woolley⁷ and no

doubt others. All of these observers have used the same general method; namely, the photometric measurement of high dispersion solar spectrograms by the use of suitable intensity standards impressed on the individual plates. It is generally admitted that this process may be considerably affected by systematic errors especially when applied to any but the strongest solar lines.

The sole purpose of this investigation was to develop a method of determining the profile of an absorption line, freed as far as possible from systematic errors. Observational methods were employed which resulted in reduced systematic errors, and corrections for these were determined and suitably applied in the calculations. The measured lines were selected entirely on a basis of their convenience in testing the method and are of no particular astrophysical significance. It will be noted that in some cases the observations are not well adapted to their purpose. This arose from the circumstance that when the observations were made, a method of reduction was contemplated which differed greatly from that finally adopted. While the preliminary nature of the work should be fully recognized, it is hoped that this new approach to the subject will be of assistance to those who pursue investigations of the same character.

The contents of the paper will now be briefly summarized. Observations of line profiles were made both in the ordinary way and from spectrograms crossed by interference fringes. A method is developed for correcting these observations by the use of an integral equation of the first kind. It is shown how this may be solved indirectly and the corrected profiles derived. The kernel of the integral equation represents the distribution of monochromatic light on the spectrogram. Since the kernel appropriate to the interferometer spectrograms is more strongly concentrated near its maximum value than is the ordinary kernel, it is evident that this observational procedure has the greater inherent accuracy.

¹ *Contr. Mt. Wilson Obs.* No. 358, 1928.

² *Contr. Mt. Wilson Obs.* No. 359, 1928.

³ *Ap. J.*, **69**, 209, 1929; *Zeit. f. Phys.*, **46**, 765, 1928.

⁴ *Mon. Not.*, **91**, 870, 1931.

⁵ *Zeit. f. Phys.*, **44**, 481, 1927.

⁶ *Zeit. f. Phys.*, **45**, 610, 1927.

⁷ *Contr. Mt. Wilson Obs.* No. 413, 1930.

Observations of six lines were made both without the interferometer and with the interferometer using different separators. The photometry of the plates and the determination of the systematic errors are considered in detail. The method of reduction referred to above is applied and the results tabulated. The intensities deduced from the different observational procedures are in virtual agreement. Since the systematic errors enter differently into each group of observations, it appears that they have been largely eliminated.

In conclusion a number of improvements in observational technique are suggested which became evident in the course of the present study, and a program of further work is indicated.

THEORETICAL DEVELOPMENT

If photographic plate transmissions at all positions in a spectrum line are converted into light intensities expressed as a function of the position on the plate measured in Angstrom Units, the function is known as the "observed profile" of the line. The observed profile fails to represent the true distribution of intensity because of errors inherent in the spectrograph and in the photographic plate. The "reduced profile" is the result of correcting the "observed profile" for the systematic errors. Except where accidental errors of observation are involved, the reduced profile represents the true intensity distribution in the line.

I shall first discuss the sources of systematic error and then develop a method for their elimination.

The systematic errors which merit consideration in the present study may be classified in the following somewhat arbitrary manner:

(a) Finite resolving power of the spectrograph. This involves the theoretical resolving power, small optical imperfections, and whatever deviations from perfect focus may exist.

(b) Finite spectrograph slit width.

(c) Linear scattering of light in the direction of dispersion. This effect is plainly visible with most grating spectrographs when one views a bright solar spectrum near the limit of the visible region. A band of visible light lacking Fraunhofer lines appears as a continuation of the spectrum in the region of the ultra-violet or infra-red.

(d) Rowland ghosts.

(e) General scattering of light in all directions in the spectrograph.

(f) Astigmatism in the optical system. Astigmatism does not affect profiles measured in the usual way nor does it enter appreciably into those obtained from interference spectrograms, but it does influence the visibility of the fringe system.

(g) Reflections and scattering of light in the photographic plate.

(h) Grain of the photographic emulsion. This is essentially a finite resolving power of the photographic plate.

(i) Eberhard effect.

Errors (a) to (g) inclusive have one important property in common: they provide blackening of the plate at a position corresponding to any wave-length λ by light of wave-length different from λ . Hence in making an empirical determination of the errors from photographs, it is sufficient to find a general resultant of these seven errors. To a sufficient degree of accuracy, error (h) will appear in this resultant, while (i) will be partially included. Error (i) may be minimized by using a suitable developer.

The problem of finding the true profile from the observed profile must be solved indirectly. To calculate the actual amount of the systematic errors, we require a previous knowledge of the true profile. We cannot tell how much light of wave-length λ was scattered to a given point on the plate unless we know the total amount available for scattering. The solution of the problem consists in finding a profile from which we calculate the systematic errors and thus reproduce the observed profile within the limits of its accuracy.

The relation between the observed and reduced profiles may be expressed by means of a definite integral.

Let λ be a wave-length of light. Light of wave-length λ is diffused to some extent over all parts of the plate, but at one position on the spectrogram, its effect has a principal maximum. Let l be a position on the spectrogram measured on a scale such that at the principal maximum of λ , $l = \lambda$. Let $I(\lambda)d\lambda$ be the intensity of light between wave-lengths λ and $\lambda + d\lambda$ which is transmitted through the spectrograph.

A fraction K of $I(\lambda)d\lambda$ will affect the plate at position l . K is a function of λ and l having the following properties: (1) $\int_0^\infty K d\lambda = 1$. (2) By definition of l , K as a function of λ has a maximum at $\lambda = l$. (3) It decreases steadily toward zero as $|\lambda - l|$ increases except for small subsidiary maxima due to ghosts. (4) Unless the optical parts of the spectrograph are notably defective or in poor adjustment, K as a function of λ is nearly symmetrical about $\lambda = l$, except perhaps where $|\lambda - l|$ is large and K is therefore small. These considerations suggest that K be written $K[l, (\lambda - l)]$. The dependence on l apart from $(\lambda - l)$ is small so that over a limited range of l , no more than one or two hundred Angstrom Units, K may in practice be treated as a function of $(\lambda - l)$ alone.

The contribution of $I(\lambda)d\lambda$ toward blackening the plate at position l is $K(\lambda - l)I(\lambda)d\lambda$ and the total effective light, called $J_0(l)$, is

$$J_0(l) = \int_0^\infty K(\lambda - l)I(\lambda)d\lambda \quad (1)$$

$J_0(l)$ taken across a spectrum line is therefore the observed profile of the line. It will be expressed in units of the adjacent continuous spectrum so that just outside the limits of the line, $J_0(l)=1$. The reduced profile of the line is $I(\lambda)$, where λ ranges over the same values as l .

If $J_0(l)$ and $K(\lambda-l)$ are known, $I(\lambda)$ may be determined by solving the integral equation (1). $K(\lambda-l)$ is known as the kernel of the integral equation and will be referred to by that name. The kernel describes mathematically the resultant of the systematic errors. Its empirical determination is a lengthy process, but if the conditions are kept nearly constant over a series of observations, a single determination of $K(\lambda-l)$ is sufficient.

Equation (1) can be transformed so as to make unnecessary any detailed knowledge of the kernel except for small values of $|\lambda-l|$.

$$J_0(l) = \int_0^{l-\epsilon} K(\lambda-l) I(\lambda) d\lambda + \int_{l+\epsilon}^{\infty} K(\lambda-l) I(\lambda) d\lambda \\ + \int_{l-\epsilon}^{l+\epsilon} K(\lambda-l) I(\lambda) d\lambda$$

The sum of the first two terms on the right hand side will be denoted by S_0 . S_0 is commonly termed the "scattered light." Then

$$J_0(l) - S_0 = \int_{l-\epsilon}^{l+\epsilon} K(\lambda-l) I(\lambda) d\lambda \quad (2)$$

If ϵ be taken sufficiently large, ($\epsilon=1\text{\AA}$ is suitable for all but the strongest solar lines), S_0 is practically independent of l . This follows from the fact that $K(\lambda-l)$ is small for $|\lambda-l| > 1\text{\AA}$, and the importance of the term S_0 depends principally on the long range of integration. As l varies so as to move the range of integration across the spectrum, changes in the integrand arise from varying positions of the absorption lines with reference to l , but the localized nature of these changes renders them unimportant. If l varies by as much as $200\text{\AA}$, we should of course consider the necessity for a new determination of S_0 . When we know the numerical value of S_0 , a detailed description of $K(\lambda-l)$ is unnecessary except for values of $(\lambda-l)$ between $+\epsilon$ and $-\epsilon$.

The solution of equation (2) for $I(\lambda)$ is accomplished as follows: A first approximation to $I(\lambda)$ called $I_1(\lambda)$ is obtained by estimation. By mechanical integration calculate for five or six suitably chosen values of l

$$J_{01}(l) - S_0 = \int_{l-\epsilon}^{l+\epsilon} K(\lambda-l) I_1(\lambda) d\lambda$$

The curve of residuals

$$J_0(l) - J_{01}(l) = \int_{l-\epsilon}^{l+\epsilon} K(\lambda-l) [I(\lambda) - I_1(\lambda)] d\lambda$$

is plotted and we now estimate a curve $I(\lambda) - I_1(\lambda)$, from which the values are substituted in the right hand side of the above equation. The integrations are again performed and the results should equal the values of $J_0(l) - J_{01}(l)$. If not we proceed to a third approximation. When one has had a little experience in making the estimates, the residuals after the second approximation seldom exceed .005, which is well within the observational errors. The reduced profile thus obtained satisfies the observations to the desired degree of accuracy. To force a closer agreement would involve unnecessary labor.

Observed profiles are customarily obtained directly by the photometry of high dispersion spectrograms. A method is introduced here which involves the measurement of spectrograms crossed by fringes formed with a Fabry and Perot etalon interferometer. In this case the observed profile is plotted from intensity measures of the fringe maxima. This procedure reduces the effect of the systematic errors, and since it presents some novel features, it will be discussed rather fully.

If light giving a continuous spectrum be passed first through an etalon interferometer and then through a lens so placed as to focus parallel light on the slit of a spectrograph, the resulting spectrum will in general be crossed by approximately parabolic fringes. Figure 1 is the reproduction of a spectrum formed in this way using a narrow spectrograph slit. A linear section taken parallel to the direction of dispersion consists of essentially monochromatic dots whose positions on the spectrogram correspond to their wave-lengths. The dots are monochromatic in proportion to the resolving power of the interferometer which depends upon two factors; the separation of the plates, and their reflecting powers. If high resolving power is obtained by a large separation of the interferometer plates, the dots may lie too close together to be well resolved by the spectrograph. On the other hand the resolving power may be increased by heavily silvering the plates, provided the light source is sufficiently intense. We may thus obtain a series of very nearly monochromatic dots that fall within the limits of the line. Owing to the curved form of the fringes, a dot can be found at any desired wave-length by choosing a suitably placed linear section of the spectrum. If the interferometer had infinite resolving power and if the systematic errors previously discussed were inappreciable, the intensities thus obtained would represent the true intensities. Neither of these conditions is realized in practice so that the profiles derived are to be regarded as observed profiles subject to correction by equation (2) used with a modified kernel. The advantage of this method lies in the smaller difference between the observed and reduced profiles than is the case with the usual method. As will be shown presently, this is due to a stronger concentration of the modified kernel near $\lambda=l$ than of the ordinary kernel.

The mathematical treatment is fairly simple. From the well known theory of the etalon interferometer the intensity of the fringe system in wave-length λ is given by

$$I'(\lambda) = R[(\lambda - \lambda_0), \theta] I(\lambda), \quad (3)$$

where

$$R[(\lambda - \lambda_0), \theta] = \frac{(1-r)^2}{1+r^2-2r \cos\left(\frac{2a \cos \theta}{\lambda} 2\pi\right)} \\ = \frac{(1-r)^2}{1+r^2-2r \cos\left(2\pi n \frac{\lambda - \lambda_0}{\lambda_0}\right)} \text{ (approximately).}$$

r = the geometrical mean reflecting power of the interferometer plates.

a = the linear separation of the plates.

θ = the angle which the light beam makes with the normal to the plates. The fringe curvature is produced by the variation of θ along the spectrograph slit.

$\lambda_0 = \frac{2\pi a \cos \theta}{n} = a$ wave-length on a fringe maximum.

n is a large positive integer. It is usually chosen so that $\left| \frac{n(\lambda - \lambda_0)}{\lambda_0} \right| < 1$ and is called the order of interference in wave-length λ_0 .

Equation (3) is theoretically incomplete through the omission of a factor depending on the absorption of light in the silver coatings of the interferometer plates. This factor is unimportant for the present purpose because it affects all wave-lengths in essentially the same ratio. Nor is any account taken of imperfections and lack of parallelism in the interferometer plates. With a good instrument in proper adjustment these are negligible. Finally it should be noted that r is itself a slowly varying function of λ . While not strictly accurate, it is sufficient in practice to use for each limited region of the spectrum a constant value of r corresponding to that particular region.

The light traversing the spectrograph is distributed according to $I'(\lambda)$ so that if $J'(l, \theta)$ be the light intensity affecting the plate at l ,

$$J'(l, \theta) = \int_0^\infty K(\lambda - l) R[(\lambda - \lambda_0), \theta] I(\lambda) d\lambda \quad (4)$$

The determination of an observed profile by measuring only points in the fringe maxima has been described. An equation relating this observed profile to the reduced profile can be derived from (4) if θ is so restricted that λ_0 always falls at l . It is evident from the relation, $\lambda_0 = \frac{2\pi a \cos \theta}{n}$, that for a suitable n , λ_0 can be made equal to l by properly choosing θ . Using these restricted

values of θ , $J'(l, \theta)$ and $R[(\lambda - \lambda_0), \theta]$ may be written $J(l)$ and $R(\lambda - l)$. $J(l)$ represents the observed profile determined from fringe maxima.

$$J(l) = \int_0^\infty K'(\lambda - l) I(\lambda) d\lambda \quad (5)$$

where

$$K'(\lambda - l) = K(\lambda - l) R(\lambda - l)$$

$K'(\lambda - l)$ is the modified kernel. It is more strongly concentrated near $(\lambda - l) = 0$ than is $K(\lambda - l)$, since both $K(\lambda - l)$ and $R(\lambda - l)$ have maxima at this point. This means that the observed profile determined with the interferometer is more nearly equal to the reduced profile than that determined in the usual way. The resulting $I(\lambda)$ is also increased in accuracy as the smaller total effect of the errors renders uncertainties in the kernel of less importance.

Equation (5) can be put in the same form as (2).

$$J(l) - S = \int_{l-\epsilon}^{l+\epsilon} K'(\lambda - l) I(\lambda) d\lambda \quad (6)$$

where

$$S = \int_0^{l-\epsilon} K'(\lambda - l) I(\lambda) d\lambda + \int_{l+\epsilon}^\infty K'(\lambda - l) I(\lambda) d\lambda$$

S bears a simple relation to S_0 of equation (2). Both S and S_0 represent scattering to distances at least as great as ϵ . The scattered light is essentially proportional to the average intensity of the spectrum. Let J_0 be the intensity of the continuous background on the ordinary spectrograms. When an interferometer is introduced, J_a' represents the average intensity taken across the fringe system where there are no absorption lines, and J the intensity of the fringe maxima. Then

$$\frac{S}{J_a'} = \frac{S_0}{J_0}$$

whence

$$S = S_0 \frac{J_a'}{J_0} \quad (7)$$

The units are always chosen so that both J_0 and J equal 1.

$$\text{Therefore } S = S_0 J_a' \quad (8)$$

S being measured in units of J . Errors in the determination of S_0 are thus reduced in forming S , since $J_a' < 1$.

The solution of equation (6) for $I(\lambda)$ is accomplished by the same methods of estimation and substitution that were described in connection with equation (2).

It is desirable as a check to have a method of finding observed profiles which will give reduced profiles as sensitive as possible to errors in $K(\lambda - l)$. Such a method consists in measuring the minima of the fringe system instead of the maxima. It possesses disadvantages

exactly corresponding to the advantages in the measurement of maxima. The modified kernel is less instead of more strongly concentrated about $(\lambda-l)=0$ than is $K(\lambda-l)$, whence any errors in determining $K(\lambda-l)$ will produce magnified errors in $I(\lambda)$. The occasional use of this third method is of value as a check since we may form some idea as to the accuracy of our $K(\lambda-l)$ by comparing reduced profiles of the same line derived by all three methods.

APPLICATION TO SOLAR LINES

All portions of the discussion which refer to securing and reducing the observations are included in this part of the paper. Following a description of the instruments used and of the observational procedure, the method of reduction is treated in considerable detail. This involves the photometric standardization of the plates, the evaluation of the scattered light and of the kernel for $|\lambda-l| \leq 1\text{\AA}$, and the determination of the profiles. Finally the results are briefly discussed.

Instruments and observations. Through the kindness of Director Walter S. Adams, instruments of the Mount Wilson Observatory were made available to me for securing observations during the summer months of 1929 and 1930.

The thirty-foot vertical Littrow spectrograph of the Snow telescope was used throughout. This was provided with a Michelson plane grating containing five inches of rulings with 15,800 lines to the inch. The photographs were made in the second order giving a scale value at $\lambda 5550$ of 0.863 $\text{\AA}$ per mm. Direct reflections from the lens surfaces were eliminated by placing an occulting bar at right angles to the grating rulings just above the lens, and an occulting spot in a suitable position at some distance above it. Scattered light was minimized by using simultaneously yellow and green color filters, which rather effectively limited the light entering the slit to the green portion of the spectrum.

An interferometer arranged with auxiliary lenses as described by Burns⁸ was used in conjunction with the spectrograph. It was provided with glass plates of excellent quality and with three invar separators of thicknesses 2.6 mm, 5 mm and 10 mm. The geometrical mean reflecting power of the two silvered plate surfaces was measured in light of wave-length 5550 $\text{\AA}$ both before and after the series of observations, yielding values of 42.9% and 43.7% respectively. The adopted value of the reflecting power was 43%. To avoid undue heating effects, the color screens were placed in front of the interferometer, and all solar radiation not necessary to fill the optical system was eliminated by means of diaphragms.

⁸ *Publ. Allegheny Obs.*, 6, 105, 1925.

The photographs were made on Wratten M plates. These plates possess all of the requirements for successful photographic photometry; namely, adequate color sensitivity, fine grain, uniformity over a given plate, and large scale. The rather high degree of contrast was minimized by using a soft metol hydroquinon developer. Development was conducted at a constant temperature of 65° for three minutes, the plate being brushed continually during the process to secure uniformity of action.

The Zeiss microphotometer belonging to the Physics Department of the University of California was used for the photometry of the plates. The stability and sensitivity of this instrument were quite sufficient to meet the exacting requirements of the interferometer spectrograms. In every case it was possible to use a microphotometer slit so narrow that no correction of the measures for slit width was required. The smallest slit used covered an area 0.3 mm $\times$ 0.015 mm on the plate, yet even with the small amount of light thus admitted, a deflection of over 60 mm was obtained on the recording film. When using the photometer at high sensitivities, it was found that the deflection was not very closely proportional to the intensity of light falling on the photoelectric cell. For this reason every set of runs on a given plate was accompanied by calibration runs using the same instrumental adjustments. This procedure eliminated any errors that might have arisen from the non-linear relation between light intensity and electrometer deflection.

The spectrograms used in the present discussion are listed in Tables Ia and Ib. Table Ia contains a record of plates secured for such special purposes as determination of scattered light, wedge calibration, etc. In Table Ib are listed the plates used in determining the profiles. These plates incidentally provided data for the determination of $K(\lambda-l)$ between $\lambda=l-\epsilon$ and $\lambda=l+\epsilon$.

TABLE Ia

Plate No.	λ Central	Subject	Purpose
116	5550	Sun with wedge and sectors (9° and 36°)	Calibration of wedge
119			
154			
155			
122	5550	Sun with wedge and diaphragm over grating	Check on wedge calibration
157			
149a	5550	Wedge and Dunham's standards	Check on wedge calibration
149b			
159	5550	Sun	General scattered light
161	5219	Sun with neodymium chloride cell	Linear scattering
160	5461	Hg. arc	Ghosts and scattered light

TABLE Ib

Plate No.	Slit width	Exposure time	Interferometer separator
93	.03 mm	12 ^s	No int.
94	.03	16 ^s	No int.
165	.05	80 ^s	No int.
138	.18	120 ^s , 45 ^s	2.573 mm
139	.18	150 ^s , 60 ^s	2.573
128	.05	15 ^m	4.983
151	.08	15 ^m , 6 ^m	4.983
146	.06	10 ^m , 4 ^m	10.032
147	.06	10 ^m , 4 ^m	10.032
150	.06	20 ^m , 8 ^m	10.032

All plates were taken with $\lambda 5550$ central.

The slit length for plates 93, 94 and 165 was 3.3 mm, while for the remaining plates it was 30 mm.

Where two exposure times are shown for a plate, half of the slit length was exposed for each of the two times, thus giving two spectra of different densities.

Photometric standardization. The spectrograms were standardized photometrically by exposing a portion of each plate to the solar spectrum taken through a photographic step wedge placed immediately in front of the slit. The wedge consisted of a fine grained photographic plate which had been darkened by exposure in fifteen steps, each of 2 mm width, so as to give approximately a constant ratio of transmissions for the successive steps. The extreme ratio between the clearest and the blackest steps was about 11:1.

It was necessary that the wedge be calibrated with reference to the particular spectrograph and wavelength for which it was used. A preliminary calibration was made by measuring the transmissions through the different steps of the wedge directly with the microphotometer. This was then corrected by photographing the solar spectrum through the wedge with the light reduced artificially in a known ratio. In order to secure an accurately known intensity ratio, two brass disks were prepared in each of which five equally spaced sectors were cut. In one the sector angles were 36° and in the other they were 9° , so that the first transmitted exactly four times as much light as the second. Either could be rotated centrally in the beam of parallel light between the celostat and the concave mirror which formed the solar image on the slit. In this position the disk served effectively as a rotating diaphragm over the grating and thus permitted non-intermittent light to strike the photographic plate. The five equally spaced sectors in each disk smoothed out the periodic light fluctuations which a single sector would produce due to the rectangular form of the grating and to the occulting bar over the lens. Photographs of the solar spectrum at $\lambda 5550$ were made through the wedge in its two opposite orientations with each sector, care being taken that all exposure times should be the same. The mean plate transmission for each step with the wedge direct and reversed was then measured. The logarithms of these quantities were plotted as abscissae against the loga-

rithms of the wedge transmissions as ordinates, and smooth curves drawn through the plotted points. If the calibration were correct, the abscissae corresponding to equal ordinates on the curves for the 9° and 36° sectors should differ by log 4.00. Actually they were found to differ by a constant amount but this was log 4.10. The preliminary values of the wedge constants were adjusted so as to make this constant difference log 4.00, and these corrected quantities were adopted as final.

In the above discussion it was assumed implicitly that the only variations in intensity across the spectrum were due to the wedge. This is not entirely correct. The slit when used with the wedge was 3.0 cm long as compared with a solar image of about 15 cm diameter. Although the central portion of the solar disk was used, its variation of brightness over this range resulted in an appreciably non-uniform illumination of the slit. In addition the slit may have been slightly narrower at one end than at the other, and finally the optical system was not equally filled by light from all points on the slit. The linear portion of the intensity variation across the spectrum was sufficiently eliminated by using the wedge in direct and reversed positions. The non-linear portion was determined by photographing the spectrum without the wedge and determining photometrically its intensity distribution perpendicular to the direction of dispersion. From this it was found necessary to apply certain small corrections to all measures of points depending on their distance from the center of the spectrum.

The calibration of the wedge was checked in two different ways. The first was by diaphragming the grating. A metal plate containing eight holes of equal size was laid over the grating and two series of exposures on the Sun were made with eight, four, and two holes uncovered. Wedge exposures with the full grating aperture were also impressed on the plates. The intensities of the exposures with the diaphragm were then measured, using the previously determined wedge constants. If there were no errors of any kind, the ratios of measured intensities for the three diaphragms should have been 4:2:1. The measures for the two plates gave 4.23:1.97:1.00 and 4.16:2.06:1.00 respectively. The test is only approximate since the grating surface is neither uniformly bright nor is it uniformly illuminated by light from the slit. Moreover, changes in atmospheric transparency during the progress of the exposures would introduce some errors. It suffices, however, to indicate that the calibration involves no large errors. A better test was afforded by comparing the wedge standards with the monochromatic aperture standards devised by Dr. Dunham. Plates 149a and 149b were exposed to both sets of standards. Assuming the derived values of the wedge constants, the relative areas of the apertures were determined by measuring the intensities of

the images formed by the light passing through them. These photometric values are compared with the measured values in Table II.

TABLE II

Measured	Photometric Mean of 149a and 149b	% Error
1.000	1.014	+1
.699	.686	-2
.494	.485	-2
.357	.353	-1
.250	.253	+1
.185	.183	-1
.116	.124	+7
.087	.085	-2

The close agreement of five individual photometric determinations for the seventh aperture suggests strongly that the measured value may be in error. The general comparison indicates that the two quite independent methods of standardization are in essential agreement. When values for the wedge constants have been determined, the photometry of the spectrograms is accomplished by the usual method and need not be described here.

In determining the scattered light, it was necessary to make measures over a range of intensities greater than 11:1, the range of the wedge. In such cases, exposures of different lengths were made on the plate and converted into a scale of relative intensities for the same exposure time by means of the Schwarzschild exponent ($p=0.85$), determined empirically.

Scattered light. In the determination and use of the kernel, ϵ was chosen as 1.0A. S_0 was therefore the integrated effect of the kernel at all distances $|\lambda-l| > 1.0A$, and may be properly termed the "scattered light." The process of finding S_0 involves the evaluation of three quantities; first, the general scattering of light in all directions in the spectrograph and on the plate (errors (e) and (g)); second, the linear scattering in the direction of dispersion (error (c)); third, the Rowland ghosts (error (d)).

The general scattering was determined from a number of strong overexposures of the Sun (plate 159). The darkening of the plate, which was evident on either side of the spectrum, fell off gradually as the distance from the spectrum increased and, in its denser portions, faint continuations of the absorption lines were visible. It is apparent from this that the effect of selective diffusion, perpendicular to the direction of dispersion, is superposed upon the general scattering. This selective diffusion may be classed as astigmatism (error (f)). It was determined independently by measuring the extensions of an over-exposed image of the green mercury line (plate 160). In the case of a line image there is no appreciable general scattering and the measures represent almost entirely the effect of astigmatism. These

values were then deducted from the photometric measures of the darkening made on plate 159. The resulting mean value of the general scattering was 0.050, expressed in units of the intensity of the continuous spectrum. These observations were made with a slit 30 mm long. Since the general scattering is approximately proportional to the slit length, its value may be determined for any plate by multiplying .050 by the ratio, slit length/30 mm.

The linear scattering was measured directly on a number of strong exposures of the green mercury line (plate 160). The darkening was measurable in the region $1A < (\lambda-l) < 10A$ and yielded a value of .024. Beyond 10A the exposure was not sufficient to darken the plate measurably, and the integrated effect to infinity was determined by the following indirect method: A number of different exposures of the solar spectrum were made with an absorption cell of neodymium chloride before the slit (plate 161). In the center of the broad absorption region at $\lambda 5219$, a band of light resembling a continuous spectrum is visible, but the solar absorption lines are completely absent. This band of light is, of course, due to the linear scattering reinforced by the general scattering. A photometer run was made across the center of this band at right angles to the direction of dispersion. Within the limits of the spectrum this gave a value of the combined linear and general scattering, while on either side, only the latter was present. From these values the ratio, linear to general scattering, was found to be 0.123. Assuming that this ratio holds for all $|\lambda-l| > 1A$, we calculate the linear scattering to be $.123 \times .050 = .006$. This assumption of a constant ratio is certainly inaccurate near $\lambda=l$, but the total effect is less than one per cent and the order of magnitude is probably correct. Combining this value with the direct measure of 0.024, we calculate the linear scattering to be 0.030.

The Rowland ghosts in general reinforce the linear scattering by an amount equal to the sum of their intensities. This quantity was calculated from the photometry of plate 160. The ghosts were readily observed in the continuous band of scattered light flanking the central image, and their intensities were found to total 0.012. If in the solar spectrum a ghost of an absorption line falls within the limits of a photometrically measured line, the quantity 0.012 is slightly reduced. However, since the strongest single ghost was only 0.005, it is clearly legitimate to assume that the effect comes from the continuous spectrum.

It is now possible to give a formula for S_0 that will be applicable to all spectrograms of the series discussed here:

$$S_0 = 0.050 \frac{L}{30} + 0.042, \quad (9)$$

where L is the slit length in mm.

The kernel for $|\lambda-l| \leq 1A$. Four conditions were available for the evaluation of the kernel in this range. The first was a numerical value for $K(\lambda-l)$ at $|\lambda-l| = 1A$. The other three were provided by the measured ratios of maximum to minimum intensity in the fringe systems formed with the three interferometer separators.

Direct photometric measures were made across an overexposed image of the green mercury line (plate 160). It was found by trial that the intensity distribution for $|\lambda-l| \geq 1A$, could be well represented by integrating $K(\lambda-l) = .01(\lambda-l)^{-1.7}$ over the width of the mercury line image. Full account was taken of the two principal satellites of the line though their presence introduced some numerical complications and rendered it impossible to determine $K(\lambda-l)$ for $|\lambda-l|$ less than $1A$. The first condition is therefore $K(1) = .01$.

The intensity ratios, formed after deducting the scattered light, were applied to the determination of $K(\lambda-l)$ in an indirect manner. Measures of these ratios, which will be called γ , were made and compared with values computed on the basis of an assumed kernel. These values failed to agree by amounts depending on errors in the provisional $K(\lambda-l)$. By successive trials a $K(\lambda-l)$ was found which brought the observed and computed γ 's into accord.

The observed intensities were measured at the center of the fringe system, ($\theta=0$), in a region free from absorption lines. The mean γ 's, corrected for S , are tabulated in the third column of Table III.

TABLE III

Interferometer separator	Mean slit width	Mean γ Obs.	γ_1 Computed	γ_2 Computed
2.6 mm	.18 mm	3.67	3.58	3.64
5.0	.06	3.14	2.88	3.25
10.0	.06	1.93	1.51	1.85

The computed γ 's were derived from equation (4). It was convenient to choose $\theta=0$, as this largely eliminated any error caused by astigmatism in the spectrograph. Let l_0 be the position of a fringe maximum at λ_0 , and l_1 be the position of a minimum at $\lambda_0 \left(1 + \frac{1}{2n}\right)$.

The ratio γ may then be written

$$\gamma = \frac{\int_{l_0-1}^{l_0+1} K(\lambda-l_0) R(\lambda-\lambda_0, 0) d\lambda}{\int_{l_1-1}^{l_1+1} K(\lambda-l_1) R(\lambda-\lambda_0, 0) d\lambda}$$

R is essentially a separate function of $(\lambda-\lambda_0)$ for each interferometer separator, while $K(\lambda-l)$ remains the same except for the effect of slit width.

The steps in determining $K(\lambda-l)$ which gave suitable values of γ were as follows:

(1) If the spectrograph had zero slit width and gave the theoretical resolving power, and if the plate pos-

sessed neither errors (g) nor (h), the central portion of $K(\lambda-l)$ would approximate a Gaussian error curve falling to half its maximum value at $|\lambda-l| = .02A$. One effect of the various errors is to widen the central portion of the curve. Therefore the first estimate, $K_1(\lambda-l)$ was a curve resembling a Gaussian error curve but falling to half its central value at $|\lambda-l| = .04A$. The outer portions were raised so as to run smoothly through $K(1) = .01$, which point was previously determined.

(2) A γ was calculated for each separator and is entered in column four.

(3) An inspection of these values suggested that the central portion of the kernel should be more strongly concentrated, always of course keeping $K(1) = .01$. A new estimate was made on this basis and the γ 's computed. These are recorded in column five. The agreement was considered to be within the limits of observational error so the second estimate was adopted as final.

Table IV contains $K(\lambda-l)$ and $K'(\lambda-l)$ tabulated as functions of $|\lambda-l|$ for different slit widths and interferometer separators.

With the interferometers of 5 mm and 10 mm separation, it is evident that $K'(\lambda-l)$ for maxima is much more strongly concentrated near $(\lambda-l)=0$ than is $K(\lambda-l)$. This illustrates the advantage of using the interferometer in securing purity of spectrum. On the other hand the concentration for the 2.6 mm separator is apparently diminished, but this is due entirely to the large slit width used. No interferometer spectrograms were secured with the 2.6 mm separator and a slit sufficiently narrow to render them suitable for profile determinations, an observational deficiency which arose from the preliminary nature of the work.

The determination of the kernel described above corresponds to the determination of instrumental constants in any observational problem and when once accomplished, need not be repeated as long as the conditions of observation remain approximately the same.

Determination of the profiles. Since the present observations were made solely as a test of the method, the lines to be measured were chosen on the basis of a suitable intensity range and of freedom from complications due to close neighboring lines. Six lines were selected ranging in wave-length from 5528A to 5579A and in Rowland intensity from 1 to 8. Each line was measured on plates taken without the interferometer and on interferometer spectrograms taken with separations of 5 mm and 10 mm.

The photometry of the plates taken without the interferometer involves only well known procedures and need not be described here. The measurement of the interferometer spectrograms, however, presents some points of difficulty and will be discussed in detail.

We denote by abscissae, x , and by ordinates, y , distances parallel and perpendicular respectively to the

Fig. 1. Solar spectrum with interference fringes; 5 mm separator

Fig. 2. Detail of fringe system, reproduced from pencil sketch

TABLE IV

$ \lambda - l $	K($\lambda - l$) Slit 0.000	K($\lambda - l$) Slit 0.033	K'($\lambda - l$) max. Slit 0.180 2.6 mm	K'($\lambda - l$) max. Slit 0.063 5.0 mm	K'($\lambda - l$) max. Slit 0.063 10.0 mm	K'($\lambda - l$) min. Slit 0.076 10.0 mm
0.00	12.7	12.1	7.8	15.5	20.4	7.6
0.01	12.0	11.4	7.8	14.2	16.1	7.3
0.02	9.8	9.6	7.4	10.6	9.2	6.7
0.03	7.2	7.2	6.8	6.8	4.7	5.6
0.04	4.6	4.8	5.9	4.0	2.5	4.6
0.05	2.6	2.8	4.9	2.1	1.3	3.3
0.06	1.2	1.5	3.9	1.0	0.6	2.5
0.07	0.6	0.8	3.0	0.5	0.4	1.8
0.08	0.4	0.4	2.0	0.2	0.2	1.0
0.09	0.3	0.3	1.2	0.1	0.2	0.5
0.10	0.3	0.3	0.8	0.1	0.1	0.6
0.125	0.25	0.25	0.19	0.06	0.20	0.86
0.150	0.21	0.21	0.08	0.04	0.39	0.96
0.175	0.18	0.18	0.06	0.04	0.15	0.63
0.200	0.15	0.15	0.04	0.04	0.06	0.30
0.225	0.12	0.12	0.03	0.05	0.04	0.16
0.250	0.11	0.11	0.02	0.06	0.04	0.12
0.275	0.09	0.09	0.02	0.10	0.08	0.08
0.300	0.08	0.08	0.02	0.12	0.15	0.06
0.35	0.07	0.07	0.02	0.04	0.02	0.06
0.40	0.06	0.06	0.01	0.02	0.05	0.12
0.45	0.05	0.05	0.02	0.01	0.08	0.21
0.50	0.03	0.03	0.02	0.01	0.01	0.08
0.60	0.02	0.02	0.04	0.04	0.06	0.02
0.70	0.02	0.02	0.01	0.01	0.01	0.03
0.80	0.01	0.01	0.01	0.00	0.00	0.03
0.90	0.01	0.01	0.00	0.01	0.02	0.02
1.00	0.01	0.01	0.00	0.01	0.01	0.01

direction of dispersion. The microphotometer runs were made so as to cross the center of the given line at different ordinates and in a direction at right angles to the fringes. The runs were short, each one being merely sufficient to cross the line and one or two fringes outside its limits. The rather small inclination of the fringes to the spectrum lines at the points measured, combined with the shortness of the runs, made it possible to treat all points on a given run as having the same ordinate for the microphotometer slit center. For the same reason distances along the run were treated as abscissae. Figure 2 shows the detail of the fringe system in the neighborhood of a line, with the paths of the runs indicated by a, b, etc. The intensity curve for each run is displaced in x by an amount dependent upon the change in y . In order, therefore, to reduce the different microphotometer runs to the same scale in x , a relation between x and y must be established. Let $x = ay^2$ be the equation of a fringe. a is the product of the wave-length and a constant determined empirically for each plate. The y for each run was measured and the corresponding x calculated. With these data it was possible to combine all the runs pertaining to one line into a single curve. When a maximum falls in a region of steep intensity gradient, as on the side of a spectrum line, it suffers a displacement in position. In such cases the photometric

measures were made not at the apparent maximum, but at the undisplaced position interpolated from neighboring maxima outside the limits of the line.

Since an extremely narrow microphotometer slit was used, no appreciable error was introduced by light integrated across the fringe falling on the photoelectric cell. The finite length, however, admitted light of different intensities and in effect gave a section integrated along the fringe. It was necessary, therefore, to reduce the microphotometer measures to their values on the assumption of a zero slit length. The problem is mathematically the same as that of correcting for finite slit width, so it was possible to use the formula given for that purpose by von Klüber.⁹

The measures of the fringe maxima were converted into intensities by means of calibrations impressed on each plate. A scale was used such that the intensity just outside the line was unity. By plotting intensities against l , the observed profile, $J(l)$, was obtained. In no case was there evidence of asymmetry in the lines. A more accurate $J(l)$ could therefore be obtained by plotting all points on one side of the line center, thus in effect assuming symmetry. The subtraction of S and the successive estimates of $I(\lambda)$ were carried out

⁹ *Zeit. f. Phys.*, 44, 481, 1927.

as described in the theoretical development, to a point where the maximum residual was not more than 0.005. $I(\lambda)$ was finally multiplied by a constant chosen to make its value unity outside the limits of the line. Figure 3 shows the successive steps in the graphical procedure. In the case of each plate, separate reductions were made as far as the determination of $J_0(l)$ or $J(l)$. Beyond this point it was the general practice to combine all values of $J_0(l)$ for a given line into a mean function

Fig. 3. Graphical procedure in determining $I(\lambda)$

and to effect the reduction to $I(\lambda)$ by using average values of S_0 and $K(\lambda-l)$ appropriate to the plates used. The functions, $J(l)$, obtained from all plates with the same interferometer separators were treated in a similar manner.

Tables Va to Vf contain the collected results. The first column gives the distance from the center of the absorption line at which its intensity is recorded. The second, third, and fourth columns record respectively

TABLE Va
 $\lambda 5538.524$ Fe. ROWLAND INTENSITY 1

Distance from center in A.U.	No interferometer 93, 94, 165	5 mm separator 128, 151	10 mm separator 146, 147, 150	Mean
0.00	.62	.59	.61	.61
0.02	.68	.68	.67	.68
0.04	.77	.79	.80	.79
0.06	.87	.89	.92	.89
0.08	.95	.94	.96	.95
0.10	.99	.97	.97	.98
0.125	1.00	.99	.99	.99
0.150	1.00	1.00	1.00	1.00

TABLE Vb
 $\lambda 5543.946$ Fe. ROWLAND INTENSITY 2

Distance from center in A.U.	No interferometer 93, 94, 165	5 mm separator 128, 151	10 mm separator 146, 147, 150	Mean
0.00	.47	.48	.44	.46
0.02	.49	.50	.48	.49
0.04	.64	.62	.65	.64
0.06	.78	.76	.80	.78
0.08	.90	.92	.92	.91
0.10	.95	.97	.97	.96
0.125	.99	.99	.99	.99
0.150	1.00	1.00	1.00	1.00

TABLE Vc
 $\lambda 5569.633$ Fe. ROWLAND INTENSITY 6

Distance from center in A.U.	No interferometer 93, 94, 165	5 mm separator 128, 151	10 mm separator 146, 147, 150	Mean
0.00	.24	.21	.19	.21
0.02	.25	.24	.20	.23
0.04	.34	.33	.34	.34
0.06	.46	.46	.54	.49
0.08	.60	.62	.64	.62
0.10	.71	.75	.70	.72
0.125	.80	.82	.79	.80
0.150	.86	.85	.87	.86
0.175	.90	.89	.92	.90
0.200	.93	.92	.94	.93
0.250	.96	.97	.97	.97
0.300	.98	.99	.98	.98
0.400	.99	1.00	1.00	1.00

(a) 5539 Å

(b) 5544 Å

(c) 5570 Å

(d) 5579 Å

(e) 5576 Å

(f) 5528 Å

Fig. 4. Profiles plotted from mean intensities in Table V

TABLE Vd

 $\lambda 5578.731$ Ni. ROWLAND INTENSITY 1

Distance from center in A.U.	No interferometer 93, 94, 165	5 mm separator 128, 151	10 mm separator 146, 147, 150	Mean
0.00	.50	.48	.48	.49
0.02	.54	.55	.52	.54
0.04	.69	.67	.66	.67
0.06	.81	.79	.81	.80
0.08	.93	.93	.93	.93
0.10	.98	.99	.97	.98
0.125	1.00	1.00	.99	1.00

TABLE Ve

 $\lambda 5576.101$ Fe. ROWLAND INTENSITY 4

Distance from center in A.U.	No interferometer 93, 94, 165	5 mm separator 128, 151	10 mm separator 146, 147, 150	Mean
0.00	.25	.27	.24	.25
0.02	.26	.29	.28	.28
0.04	.43	.39	.40	.41
0.06	.58	.52	.58	.56
0.08	.71	.71	.74	.72
0.10	.81	.83	.83	.82
0.125	.88	.89	.91	.89
0.150	.93	.94	.95	.94
0.175	.96	.96	.97	.96
0.200	.97	.98	.98	.98
0.250	.99	1.00	1.00	1.00

TABLE Vf

 $\lambda 5528.420$ Mg. ROWLAND INTENSITY 8

Distance from center in A.U.	No interferometer 93, 94, 165	5 mm separator 128, 151	10 mm separator 146, 147, 150	Mean
0.00	.18	.15	.15	.16
0.02	.21	.20	.17	.19
0.04	.25	.26	.24	.25
0.06	.31	.34	.32	.32
0.08	.39	.41	.41	.40
0.10	.48	.48	.49	.48
0.15	.66	.66	.67	.66
0.20	.77	.78	.77	.77
0.25	.84	.84	.85	.84
0.30	.88	.88	.89	.88
0.40	.94	.92	.94	.93
0.50	.96	.95	.96	.95
0.60	.97	.97	.98	.97
0.70	.98	.98	.99	.98
0.80	.99	.99	.99	.99
0.90	.99	.99	1.00	.99
1.00	1.00	1.00	1.00	1.00

the intensities derived from plates taken without the interferometer and with the interferometer using separators of 5 mm and 10 mm. The fifth column is the mean of the three preceding.

A close agreement between the intensities recorded in the second, third, and fourth columns is apparent. Since the systematic errors listed in the introduction enter differently into each of these results, it is quite evident that they have been to a considerable extent eliminated by the present method of reduction.

The method was subjected to a severe test by applying it to the measures of minima instead of maxima. In this case small errors in the kernel should give greatly magnified errors in the resulting intensities. Table VI gives the profile of $\lambda 5576$ determined by this method on two plates in comparison with its mean profile taken from Table V.

TABLE VI

Distance from center in A.U.	Mean from Table V	5 mm separator Plate 151	10 mm separator Plate 150	residuals
.00	.25	.19	.23	-.01
.02	.28	.20	.29	.00
.04	.41	.39	.44	
.06	.56	.59	.58	+.01
.08	.72	.75	.72	
.10	.82	.85	.85	+.04
.15	.94	.98	.96	+.02
.20	.98	1.00	.98	+.01

From the agreement of the profiles it is quite evident that errors in the determination of the kernel are not large. Any such errors would be greatly magnified when applied to minima and thus give results highly discordant with those obtained by the other methods. The residuals in $J(l)$ left after solution for $I(\lambda)$ are given for plate 150. Owing to the very diffused nature of the modified kernel in this case, it was impossible to reduce the residuals further without introducing large abrupt fluctuations in $I(\lambda)$. With the less diffused kernel of the smaller separator, no residual was greater than .01.

Figure 4 shows the profiles of the six tabulated lines plotted from the mean intensities.

It will be remembered that this undertaking was of an experimental nature and that the observational yield is therefore fragmentary. The following generalizations are made with this full understanding and they are offered for substantiation rather than acceptance.

1. The profiles are rather sharply curved at their minima.
2. Wings begin to appear in lines of Rowland intensity 5 or 6.
3. The maximum slope in each line is practically constant over a considerable distance.
4. Lines of intensity 1 to 4 inclusive have approximately the same maximum slope (7% per .01A). For stronger lines the slope decreases with increasing intensity.

A number of possible improvements in observational technique became apparent in the course of measuring and reducing the spectrograms. Some of these are so obvious that they would surely have been incorporated in the original observations had I contemplated the method of treatment finally adopted. Greater accuracy would result from (1) the elimination of the Eberhard effect, (2) the decrease of accidental errors in the photometry, (3) a more accurate determination of the kernel, and (4) a greater concentration of the modified kernel near $(\lambda - l) = 0$.

The Eberhard effect can be greatly reduced by the use of certain special developers. However, these are somewhat difficult to use, and this preliminary survey scarcely seemed to require such a refinement.

Undoubtedly accidental errors in the photometry were enhanced by the use of a photographic wedge for calibration. Its darkened surface was, of course, granular in structure which made the calibrations impressed on the spectrograms somewhat irregular. This resulted in a rather large scattering of points from which the calibration curves were determined, thus increasing the uncertainty of the curves themselves. Suitable wedges could probably be made by depositing evaporated metal on glass, or commercial wedges of neutral tinted glass could be used.

The kernel would be improved principally by obtaining a better value for the linear scattering. The residual intensity in the center of a black artificial absorption line of 2A or 3A width, should give the linear scattering very accurately. Two methods of producing such a line seem promising. The first involves the use of crystals of certain rare earth salts placed before the spectrograph slit. When kept at low temperatures, these crystals produce fairly sharp absorption lines in the visual region of the spectrum. The crystal should, of course, be of such thickness that only a negligible amount of light is transmitted at the wave-length of the line. The second method utilizes a double spectrograph somewhat similar to a monochromator. Two identical spectrographs are placed with their focal planes in contact. One is rotated into such a position that it exactly integrates the light analysed by the other. An absorbing strip can be placed in the focal plane in a position to remove light of any desired wave-length. The light emerging from the slit of the second spectrograph would thus have a black absorption line corresponding to the position of the strip. This emergent light can be focused on the slit of the solar spectrograph and the scattered light measured as before.

The detailed values of the kernel should also be found, as Unsöld¹⁰ has suggested, by measuring photometrically plates of monochromatic emission lines. I feel that this

method is not so reliable as the determination from interference fringes, but it is simple in application and should certainly be used as a check.

The modified kernel can be more highly concentrated near $(\lambda - l) = 0$ by reducing the general scattering and by increasing the resolving power. General scattering is reduced by the use of a shorter spectrograph slit. With the interferometer, it is necessary only to use a slit of such length that, on the spectrogram, a given fringe traverses a distance, $\Delta\lambda$, along the spectrum equal to the interval between fringes. The resolving power is best increased by depositing highly reflecting coats of silver on the interferometer plates. A limit is set by the amount of light available but probably reflecting powers of at least 65% could be used.

An application of the procedures outlined here will undoubtedly give more reliable profiles. A conservative estimate indicates that their accuracy should be at least doubled.

At the present time the requirements of theory do not justify the labor involved in determining accurate profiles for a very large number of solar lines. Advances in observational technique would probably render the work obsolete before its completion. Nevertheless some kind of a survey is desirable, not only to provide data for lines of particular interest but also to seek empirical relations between the profiles of the lines and the physical conditions governing their formation.

The interferometer method is laborious and its advantage lies solely in the accuracy of the results. However, a relatively small number of determinations would serve as standards from which profiles found by the more usual methods could be corrected. It is estimated that one hundred lines, suitably distributed in wave-length and intensity, would suffice as standards for the region 3900A to 7000A. The profiles of these standard lines could then be redetermined by simple photometry, and a correction curve obtained for each, based on the difference between the accepted profile and the one thus observed. This same correction curve could be applied with small error to the profiles of all lines, agreeing approximately in wave-length and intensity distribution, observed under the same conditions as the standard line. This involves relatively little labor and the number of additional lines thus included compensates for the small errors which are introduced into their profiles by this method of standards. The question arises as to the lower limit of intensity observable by the interferometer method. If the approximate constancy in slope of the straight portions of the profiles noted for lines between intensities 1 and 5 continues to smaller intensities, the absolute accuracy of the determinations should be unaffected by the faintness of the lines. If, however, faint lines are much deeper in proportion to width than the stronger ones, the profiles would be less reliable owing

¹⁰ *Ap. J.*, **75**, 106, 1932.

to the increased importance of the kernel. There seems to be no reason why lines at least as faint as intensity 0 should not be reliably measured.

The courtesy of Director Walter S. Adams of the Mount Wilson Observatory who granted me the facilities for securing these observations is most gratefully acknowledged. It is also a pleasure to thank Dr. Edison Pettit and other members of the staff for their generous technical advice and assistance. Professor

Elmer E. Hall, Chairman of the Physics Department of the University of California, has permitted me unlimited use of the Zeiss microphotometer belonging to that department, and I am deeply indebted to him.

MOUNT WILSON OBSERVATORY,
BERKELEY ASTRONOMICAL DEPARTMENT.

July, 1932.

Issued November 16, 1932.