INVESTIGATIONS ON THE REFLECTION AND TRANSMISSION CHARACTERISTICS OF PHOTOGRAPHIC PLATES

Thesis by

Daniel Brent McRae

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ABSTRACT OF CONTENTS

A method is described for measuring the reflection and transmission of light by a photographic plate under conditions similar to those met in the ordinary use of the plate. The essential features of the work are the use of photographic methods of measurement and the development of a null method of working which eliminates from the discussion the characteristic curve of the plate, the degree of development or contrast, and which requires as a final step only a single measurement of the transmission of an optical wedge at some chosen point.

A complete series of measurements was carried thru on several boxes of Eastman 40 plates, all of the same emulsion number. The measurements were made using white, blue, green and red light.

It was found that for blue light the plate reflected 25%, transmitted 9%, and absorbed 66%. The reflection and transmission losses increased rapidly with increasing wavelength. The effect of exposure time on reflection and transmission was investigated, and no change was found in these factors over considerably greater lengths of time than any of the exposures used in this work.

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I. INTRODUCTION

When considering the processes taking place during the illumination of a photographic plate it is necessary to be able to determine the energy absorbed and its relation to the number of grains made developable, or the density produced on development. Several workers have carefully measured the energy incident on the plate and the effect produced, but before we can say just how much of this incident light is actually absorbed by the silver halide grains we must make a correction for the part which has been reflected from the surface, and for the part which has been transmitted without affecting the emulsion.

One or two of the workers referred to have attempted to measure these very important factors, but in other cases the question of reflection and transmission has been treated lightly or ignored altogether.

Nutting[1] determined the diffuse transmission and reflection for Seed 23, Seed 30, and lantern plates, using white light, and making measurements at various angles. He found 57% of the incident light was reflected and 35% transmitted, leaving only 8% to be absorbed. We may doubt the applicability of his data to the conditions under which photographic plates are generally used as his method was a visual one, and probably gives the values of transmission and reflection for a wavelength to which his plates were very insensitive.

Eggert[2] and Noddack in their work on the quantum efficiency of the photographic plate used an integrating method. They placed the plate between the two halves of a closed box lined with thermocouple elements, allowed monochromatic light to fall on the plate thru a small opening and measured the current produced by the thermocouples on the two sides of the plate. Their results for two brands of plate available in Germany are given in Table I.

Helmick[3] made rough determinations, chiefly for ultraviolet light. He dissolved the emulsion from commercial film (brand not specified) and recoated it on quartz plates. Using a copper arc as a light source, he reflected the light from the coated quartz plate onto the slit of a spectrograph. Several exposures were also made with the light falling on the slit directly with diaphragms giving relative light intensities of 1, 1/10, and 1/100. An analogous procedure was used for transmissions. By a comparison of the number of lines appearing on the various plates he estimated that the reflection lay between 6.5% and 8%, while the transmission was less than 1% for the region from 2100 Å to 5200 Å.

Huse[4] is reported as having determined the transmissions of a number of commercially available plates for white light and for the three principal colors. As the reference to his publication was not given, the author is unable to comment on his method. His results as taken from a table in Ross' book appear in Table II.

In view of the lack of extensive work in this field it was thought worth while to make some measurements on commercial types of plates and to carry thru a complete set of both transmission and reflection measurements on the same batch of plates. For this purpose

TABLE I

Reflection, Transmission and Absorption of Plates

According to Eggert and Noddack

	Fast Plate			Process Plate		
(Å)	R	T	A	R	T	A
6150	55 %	30	15	59	29	12
5460	57	25	18	61	24	15
4900	51	23	26	60	20	20
4360	28	9	63	41	11	48
4050	18	6	76	23	8	69
3650	8	2	90	12	4	84

R is percent of reflection

T is percent of transmission

A is percent of absorption by difference

TABLE II

Transmission of Plates According to Huse

Plate	Transmissions in %			
	White	Blue	Green	Red
Seed 30	22	8	39	41
Seed 23	18	8	32	39
Seed Process	34	11	40	36
Seed Lantern	41	25	43	44
Standard Orthonon	13	--	26	30
W+W Panchromatic	10	5	12	23

several boxes of Eastman 40 plates, Emulsion No. 2637, were obtained and used in the following work. It was originally hoped to carry thru similar measurements on several different typical emulsions but the time available proved too short.

II. DESCRIPTION OF LIGHT SOURCE AND PHOTOMETER USED IN FINAL EXPERIMENTS

A. The Lamp and Lamp Housing.

The light source used consisted of a 3.8-volt flashlight lamp which was run at slightly less than normal brilliancy by an Edison storage battery with a milliammeter and rheostat to control the current.

Figure 1 shows the lamp and accessories. This lamp was mounted in a Brownie safelight lamp housing by means of an adapter socket. The usual colored screen in the front of the box was replaced by a pair of fine ground glass sheets with the ground surfaces together. Between these was sandwiched a piece of thin copper foil having a number of 3/8-inch holes punched thru it. By means of using copper sheets with different numbers of holes the light intensity could be varied as desired, and as a 3/8-inch hole happened to have very nearly 1% of the total area of the front of the lamp house, it was a convenient way of roughly estimating the extent of any variations made. It was found that a ten-hole diaphragm gave a convenient light intensity and this diaphragm was retained throughout the experiments. Exposures were made by closing and opening a small knife switch. Timing was done with a stop watch and after a little practice it was found possible to get considerable accuracy by this means, especially since most of the exposures were 15-30 seconds or more in length. A small red light furnished illumination to read the milliammeter and stop watch.

Fig. 1

B. Calibration of Lamp.

The candle power of the exposure lamp in its housing and with the ten-hole diaphragm in place exactly as it would be in use, was determined by means of a Leeds and Northrup bench photometer with direct reading scale which is installed in the Electrical Engineering Department of the Institute. A slowly rotating lamp calibrated by the Bureau of Standards (Standard Lamp No. 2435) was used as a primary standard. The mean horizontal candle power of this standard was 32.3 when running on 110.0 volts, D.C.

The exposure lamp was too weak for direct comparison with the primary standard, so it was necessary to prepare an intermediate standard. This consisted of a 10-watt tungsten filament lamp operated at 80.0 volts. The direct reading scale gave the candle power of the intermediate standard as 32.3/13.65 = 2.37 c.p. This was still too bright, so an absorbing screen was prepared consisting of a uniformly fogged photographic plate.

Placing this between the primary standard and the photometer head, balance was obtained with a reading of 0.91 as against 13.65 with the screen not present. The transmission of the screen then is

$$K = \frac{0.91}{13.65} = 0.0667$$

The intermediate standard with the addition of this screen then has an effective candle power of 2.37 x 0.0667 = 0.158 c.p. This will subsequently be referred to as standard X. The exposure lamp was mounted on a bar in such a manner that it moved with the photometer head and remained at a fixed distance of 157 cm. from the screen in the photometer head.

This distance was chosen because it was the distance from the lamp to the plate when making transmission measurements. With this arrangement the direct reading scale could no longer be used and it was necessary to measure the distance from standard X to the photometer screen. The mean of several determinations gave this distance as 166.8 cm. The candle power of the exposure lamp with the ten-hole diaphragm in place was therefore

$$0.158 \times \left(\frac{157.0}{166.8}\right)^2 = 0.140 \text{ c.p.}$$

The filament current was 0.280 amperes whereas operation at the rated voltage of the lamp requires 0.300 amperes. The filament temperature was determined by means of an optical pyrometer and was found to be about 2200° Absolute. Some difficulties had formerly been met when attempting to operate filaments at their rated voltage, because they would sometimes burn out at very inconvenient times. With lowered filament current no further difficulty was had.

C. Description of Photometer.

All density measurements were made by means of a Marten's type polarization photometer (Franz Schmidt and Haensch No. 180). This was mounted as shown in Figure 2. The light source was a 100-watt light placed in a box. Over the top of the light was a plate of opal glass covered with black paper in which had been cut two apertures of 3 x 9 mm. Each aperture corresponded to one of the two holes in the photometer, i.e. to one of the two light beams entering the photometer. The holes were carefully cut to as near the same size as possible and the final adjustment for equality of the energy coming thru the holes was made by slightly shifting the lamp underneath until the two fields matched.

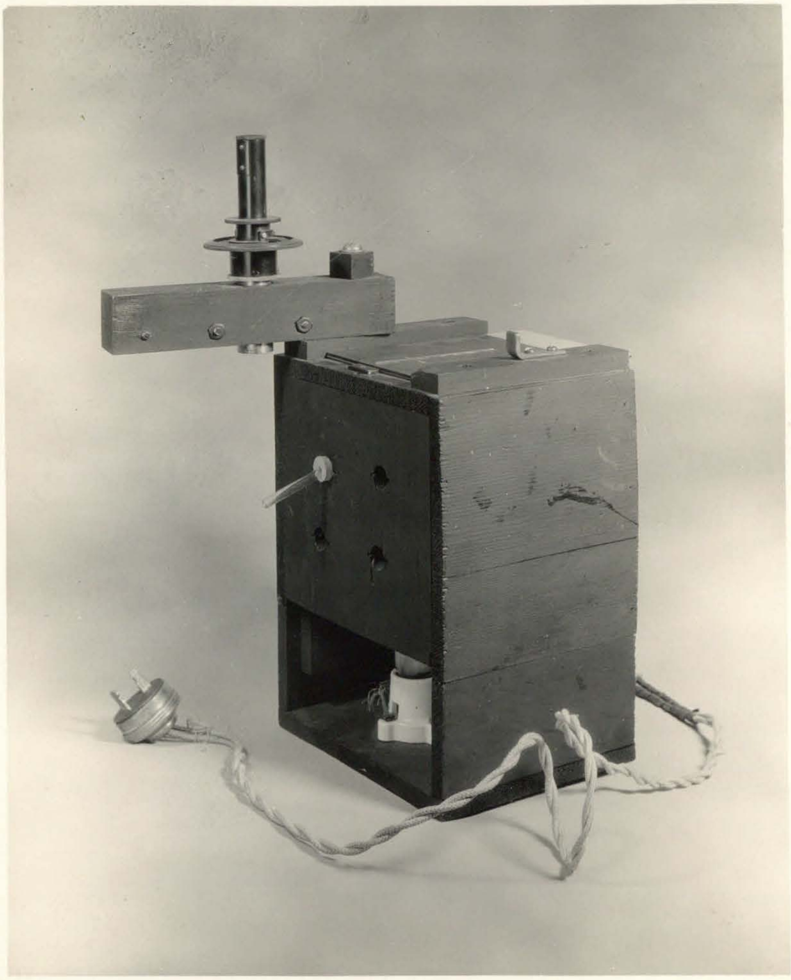


Fig. 2. Photometer.

A swinging support allowed the photometer to be swung out of the way while placing plates in position and then be quickly swung back to the correct place.

D. Methods of Photometry.

This instrument was especially convenient when picking out spots of equal density on two plates, as the photometer is first set for equality of the fields, and then one plate is placed over each aperture on the opal glass, with the emulsion side down. Then one or both plates may be slid along until the fields again match.

When measuring densities, one makes use of the fact that this type of instrument operates according to the tangent squared law. That is to say, when the fields are equalized by turning the upper Nicol, then

$$\frac{I_R}{I_L} = \tan^2 \theta$$

where I_R = intensity of beam coming thru right-hand aperture

I_L = intensity of beam coming thru left-hand aperture

θ = angle thru which Nicol is turned as read on instrument scale

If the plate to be measured is placed over the left-hand aperture, the right-hand aperture being left free, then after equalizing the fields

$I_R = I_o$ = light falling on plate

$I_L = I_T$ = light transmitted by plate

Then the opacity of the plate is

$$O = \frac{I_o}{I_T} = \tan^2 \theta$$

and the density is by definition

$$D = \log_{10} O = \log \tan^2 \theta$$

To save the labor of calculation a curve was plotted on a large scale from this equation, with values of D as ordinates and values of θ as abscissae, from which the photometer readings could be immediately converted to densities.

The maximum sensitivity is found at $\theta = 45°$, and it is therefore advantageous to use a supplementary known density of nearly the same value as the one to be measured over the right-hand aperture. Furthermore, it was found when measuring densities greater than 1.0 that these high densities in the case of photographic plates, at least, caused considerable scattering which resulted in low density readings. A supplementary density over the right-hand aperture was quite necessary to compensate for this. A series of 7 supplementary densities were therefore prepared by fogging photographic plates, and by a process of comparing each with the next higher they were found to have the densities, 0.163, 0.330, 0.630, 1.138, 1.776, 2.415, and 3.052. These values were rechecked from time to time and were found to remain quite constant. Measurements made in this way, of course,give only the difference in density of the two plates, so it is necessary to know the value of the supplementary density before we can obtain the density of the plate.

The plates used were Eastman 40 and Wratten and Wainwright Panchromatic. They were developed in Eastman D-11 developer for five minutes at approximately 20°C. To insure even development the plates were brushed during development, and when two or more plates belonged to a single experiment they were developed together in a large tray. A fresh portion of developer was used each time, and was then discarded.

III. THE MEASUREMENT OF TRANSMISSION

A. The Plate Holder and Exposing Screen.

The apparatus used to hold the plate is shown in Figure 3. Four narrow strips, which for convenience happened to be glass, form a rectangular enclosure into which a 3 1/4" x 4 1/4" plate can be dropped. Along the left side of this enclosure the bounding strips have been made thicker in order to hold also a 1 1/8" x 4 1/4" strip lying on top of the first plate. This is the plate whose transmission is to be tested, and is hereafter designated as the transmitter. The plate lying underneath receives the radiation transmitted by the top plate and may conveniently be called the receiver.

The right-hand two thirds of the receiver plate is exposed thru a strip of optical wedge which may be seen in Figure 3a fastened over a slot in the exposure screen S. When screen S is turned down, as in Figure 3b, the slot, which has a width of 1.5 cm., allows a strip to be exposed extending across the plates from left to right. The wedge has now heen brought into place over the right-hand part of the receiver. The exposure screen slides in the channel formed by the two rows of nails and by bringing stop T successively against the four nails on the right, four different strips can be exposed on one plate. A piece of ground glass rests on the shoulders, G - G. If the ground glass is not used, then the part of the receiver which lies under the wedge receives light which is nearly parallel, while that part lying under the transmitter receives diffuse light. With the ground glass in place both parts receive the same type of light, as it has all been diffused. It will be shown later that it is desirable to make the exposures with diffueed light.

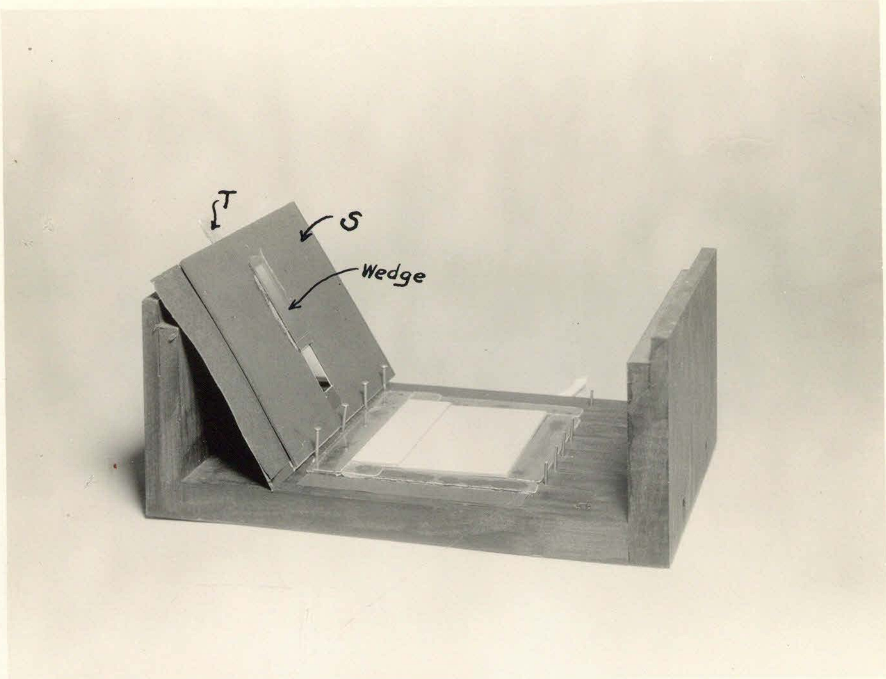


Fig. 3a.

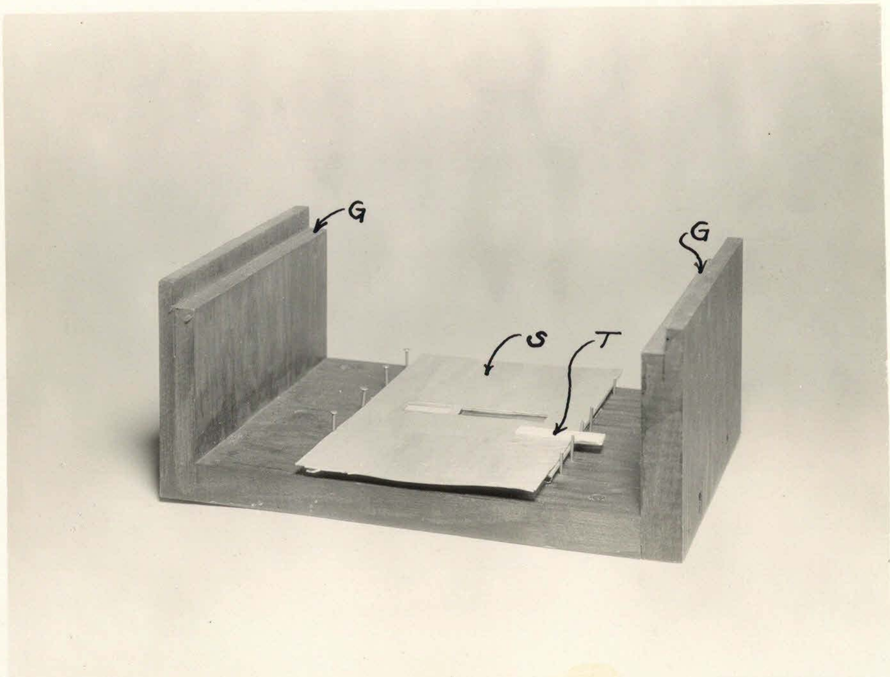


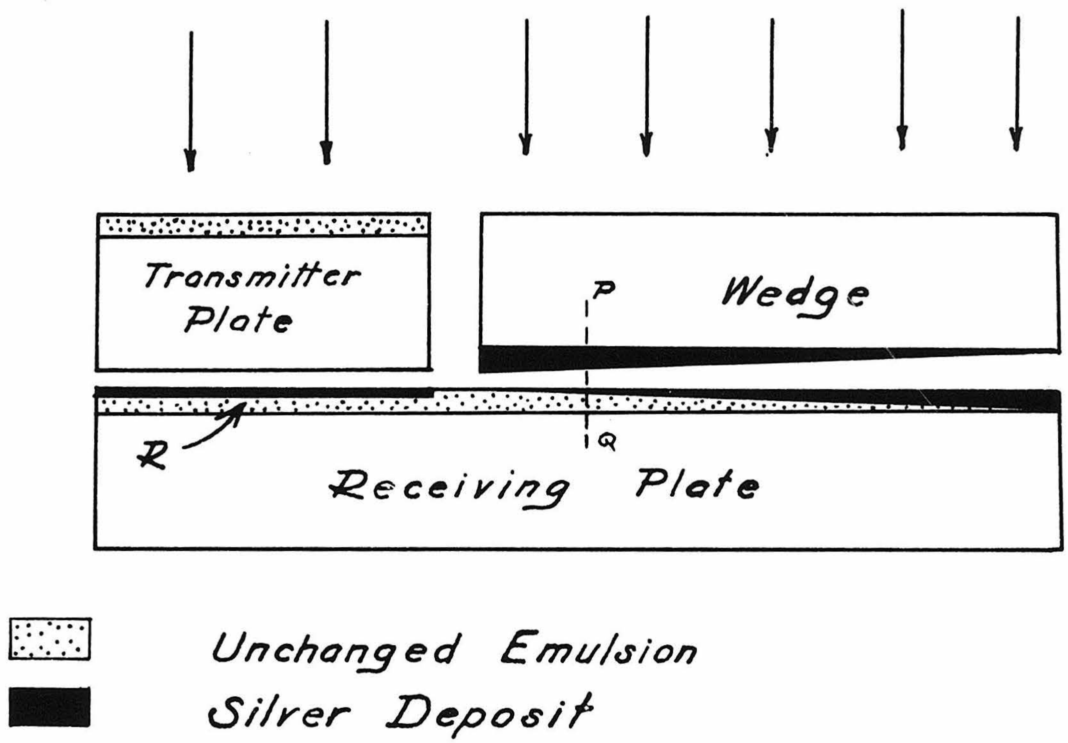
Fig. 3b.

B. Method of Making a Transmission Measurement.

Figure 4 shows diagrammatically what happens in making a transmission measurement. Light of equal intensity falls on the transmitter and on the wedge. Part goes thru the transmitter and produces a more or less dense silver deposit on the receiver. Under the wedge a silver deposit of varying density is formed. These deposits appear, of course, only after the plate has been developed.

Now by means of the photometer we pick out a place, Q, where the wedge image has the same density as some average spot, R, in the deposit under the transmitter. Next we find the spot P on the wedge corresponding to Q. The wedge density at P is then measured and is taken to be equal to the transmission of the plate being tested, since they have produced identical images under the same conditions of exposure, development, etc.

Fig. 4. Section on line O-O of Fig 3b.



C. Results of Transmission Measurements.

1. Measurements on Eastman 40 Plates with Parallel and Diffused Light.

Table III shows a series of runs with an Eastman 40 plate as transmitter and receiver, and with a filament current I = 0.280 amp. Strips A, B, C, etc. refer to the various strip exposures made by moving the exposure screen, S, in Figure 3b, to its various positions over one or more plates. E is the exposure time in seconds. D_L is the developed density of the lower or receiving plate in the region under the transmitter plate, e.g., at R in Figure 4. D_U is the developed density of the upper or transmitter plate. D_{wedge} is the wedge density at Point P, Figure 4. T is the transmission of the wedge at this point and is obtained from the relation

$$D = \log \frac{1}{T}$$

T is then also equal to the transmission of the plate being tested, by the argument already advanced.

We thus obtain for the average transmission a value of 14.6%, if we exclude the two measurements made with no ground glass, that is, with parallel light. These two values are seen to be a little higher than the corresponding values for diffuse light. To determine whether or not this difference is real or accidental a series of similar runs was made without using the ground glass and an average value for T was found to be 15.7%. This increase can be accounted for if the wedge has a slightly greater transmission for diffuse than for parallel light. For suppose we replace the parallel light in Figure 4 by diffuse light. If the wedge has increased transparancy, then the points P and Q will be shifted to the left. When the transmission of the wedge is measured

TABLE III

Eastman 40 transmitter
Eastman 40 receiver

$I = 0.280$ amp.

Strip	E	D_L	D_U	D_{wedge}	T	Remarks
A	$7\frac{1}{2}$	0.185	0.823	0.832	(14.7)%	without ground glass
B	$7\frac{1}{2}$	0.151	0.747	0.878	13.3	with ground glass
C	15	0.277	0.980	0.830	14.8	" " "
D	30	0.467	1.268	0.830	14.8	" " "
E	60	0.769	1.468	0.750	(17.8)	without ground glass
F	60	0.721	1.441	0.830	14.8	with ground glass
G	120	0.929	1.745	0.830	14.8	" " "
H	240	1.142	2.038	0.823	15.1	" " "
					avg. 14.6%	excluding the two runs without ground glass.

in the photometer, however, under the same conditions as before, a smaller value for T will be found.

It will be remembered that the value of T was actually the measured transmission of the wedge at point P, so that by changing from parallel to diffuse light we have decreased the value of T, which was the effect experimentally obtained.

Now it is well known that the silver image of a developed photographic plate is considerably more transparent to diffuse light than to parallel light, owing to scattering. The wedge used in this work was made by copying another wedge by means of a photographic plate and consequently would be subject to exactly this increased transparency to diffuse light.

It seems probable that the diffused light measurements are the ones we want for two reasons:-

First, the measurement of the density of the wedge at point P is made in the photometer by the use of diffused light; consequently exposure should be made by the same type of light.

Second, before the light passing thru the transmitter falls on the receiver it has become highly diffused, and it would seem desirable to also diffuse the light falling on the receiver under the wedge. The wedge will not produce much diffusion itself so we must put in a ground glass. Opal glass would no doubt be still better but would increase the exposure times to undesirable lengths.

2. Effect of Exposure on Transmission.

It might be expected that the transmission of a plate would depend on the length of time it had been exposed to light. It would be a serious difficulty if the transmission changed greatly during the time that the plates were being exposed to light for the purpose of measuring the transmission. No evidence of such a change was found with any of the exposures used in this work. In Table III the exposures range from $7\frac{1}{2}$ seconds to 240 seconds, but the corresponding values of T show no definite trend which could be correlated with the exposure.

Table IV gives further evidence that there is no appreciable change in transmission during any kind of normal exposure. Another lamp was used in place of the calibrated one usually used. This extra lamp was run at a current of 0.320 amp. instead of the 0.280 at which the usual calibrated lamp was run. This current raised the candle power from 0.158 to about 0.486. The treatment proved destructive and the filament burned out when only one reading had been obtained on the bench photometer, so its calibration may be somewhat inaccurate. The chief point of interest, however, is that there is no evidence of changed transmission with this light even up to 1088 seconds.

TABLE IV

Eastman 40 transmitter
Eastman 40 receiver

$I = 0.320$

Strip	E	D_L	D_U	D_{wedge}	T	Remarks
F	4	0.308	1.278	0.981	10.5	with ground glass
G	8	0.541	1.629	0.979	10.5	" " "
H	16	0.792	1.921	0.980	10.5	" " "
I	16	0.861	1.951	0.981	10.5	" " "
J	32	1.010	2.216	1.010	9.8	" " "
K	64	1.290	2.506	1.010	9.8	" " "
L	128	1.549	2.935	1.041	9.1	" " "
M	136	1.664	2.718	0.920	12.0	" " "
N	272	1.876	3.169	0.960	11.0	" " "
O	544	2.146	3.482	1.004	9.9	" " "
P	1088	2.415	3.660	1.049	8.9	" " "
				Avg.	10.2%	

3. The Effect of Wavelength on Transmission.

Transmissions were determined for red, green, and blue light by the use of the standard Wratten A, B, and C tricolor filters. They were used in the form of gelatine films placed between the ground glasses in the front of the lamp housing and in contact with the copper foil diaphragm.

The results appear in Tables V-VII showing that the transmission is much larger for the long wave lengths than for the blue to which the plate is chiefly sensitive. The only departure from the usual procedure was the use of Wratten and Wainwright Panchromatic plates for the receiver instead of Eastman 40's, and in the case of the C filter it was found necessary to increase the light intensity by making the distance of the light from the plate 157/4 or 39.25 cm.

TABLE V

Transmission with "A" Filter (red)

Eastman 40 transmitter
Wratten and Wainwright Panchromatic receiver

Strip	E	D_L	D_U	D_{wedge}	T	Remarks
A	15 sec.	0.620	no	0.371	42.5 %	I = 0.280, D = 157 cm.
B	30 "	1.188	trace	0.360	43.7	"
C	1 min.	1.798	of	0.350	44.7	"
D	2 "	2.288	image	0.381	41.6	"
E	4 "	2.747	on	0.362	43.5	"
F	8 "	3.175	upper	0.367	43.0	"
G	16 "	very high	plate	--	--	"
H	32 "	very high		--	--	"
				avg.	43.2 %	

TABLE VI

Transmission with "B" Filter (green)

Eastman 40 transmitter
Wratten and Wainwright Panchromatic receiver

Strip	E	D_l	D_U	D_{wedge}	T	Remarks	
A	$7\frac{1}{2}$ sec.	1.381	0.550	0.405	39.2%	I = 0.280,	distance = 39.25 cm.
B	15 "	2.016	0.830	0.476	33.4	"	"
C	30 "	2.567	1.078	0.476	33.4	"	"
D	1 min.	3.152	1.290	0.443	36.1	"	"
E	15 sec.	0.185	0.121	0.439	36.4	"	distance = 157.0 cm.
F	30 sec.	0.367	0.183	0.490	32.4	"	"
G	1 min.	0.780	0.342	0.472	33.8	"	"
H	2 "	1.295	0.578	0.476	33.4	"	"
I	4 "	1.803	0.829	0.476	33.4	"	"
J	8 "	2.291	1.089	0.481	33.1	"	"
K	16 "	2.692	1.295	0.440	36.4	"	"
				Ave.	34.6%		

TABLE VII

Transmissions with "C" Filter (blue)

Eastman 40 transmitter
Wratten and Wainwright Panchromatic receiver

Strip	E	D_L	D_U	D_{wedge}	T	Remarks
A	30 sec.	0.295	1.378	0.990	10.2 %	I = 0.280, distance = 39.25 cm.
B	1 min.	0.481	1.610	1.092	8.1	" "
C	2 "	0.878	1.936	1.070	8.5	" "
D	4 "	1.327	2.288	1.030	9.3	" "
E	8 "	1.409	2.634	1.018	9.6	" "
F	18 "	1.838	3.100	1.030	9.3	" "
G	32 "	2.206	very high	1.040	9.1	" "
H	64 "	2.477	very high	1.070	8.5	" "
				Ave.	9.1%	

IV. THE MEASUREMENT OF REFLECTION

A. Description of Apparatus.

1. Plateholders and Exposing Devices.

Figures 5a and 5b show the apparatus used for measuring reflection. Figure 5a shows the reflector plate, P, in the sliding plate carriage, C, and the optical wedge, W, in its position covering the slot, L. The light enters through the opening O at the top. S is a screen which is placed over plate P, allowing light to fall on the latter only thru the slot in S. Screen S thus plays a role analogous to that of the screen, S, seen in Figure 3, and which was used in the transmission experiments. The principal difference is that whereas in Figure 3b the plate remains stationary and screen S moves to four definite positions, in Figure 5b screen S remains fixed, while plate P is moved to four different positions by means of the sliding carriage, C, actuated by push rod, N. At K is placed a spring-actuated ball check, which snaps into four shallow depressions on the top of rod N. The click can be distinctly heard and felt, and makes it possible to move the plate to its different positions with ease and certainty even in the dark.

Figure 5b shows screen, S, and the receiving plate, R, in place. Plate R slides smoothly between the guide rails, G, and over the surface of wedge W, which is set flush with the surrounding surfaces. Plate R can be brought into four definite positions by means of push rod M and ball check J. A shifting fork, F, on the upper end of rod M, engages the edge of the plate to push the plate upwards. It slides downward by gravity. Cover B swings down to prevent extraneous light from reaching plate P, and pressure pad E serves to improve the contact between the wedge and plate.

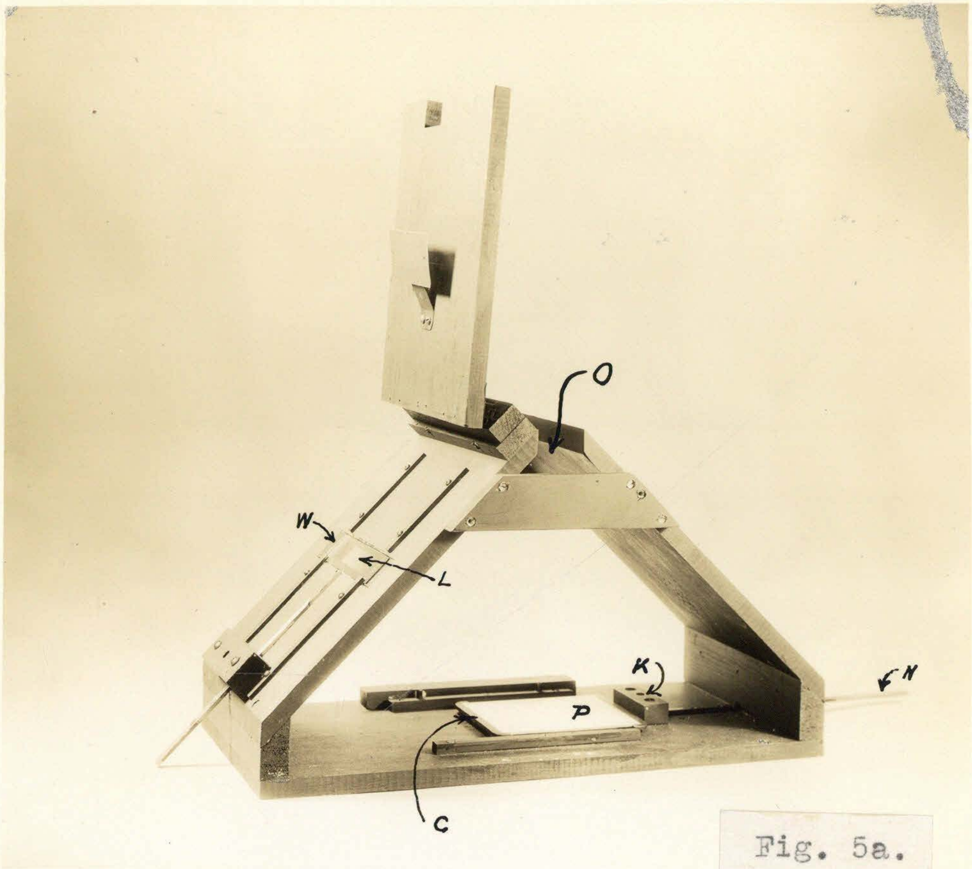


Fig. 5a.

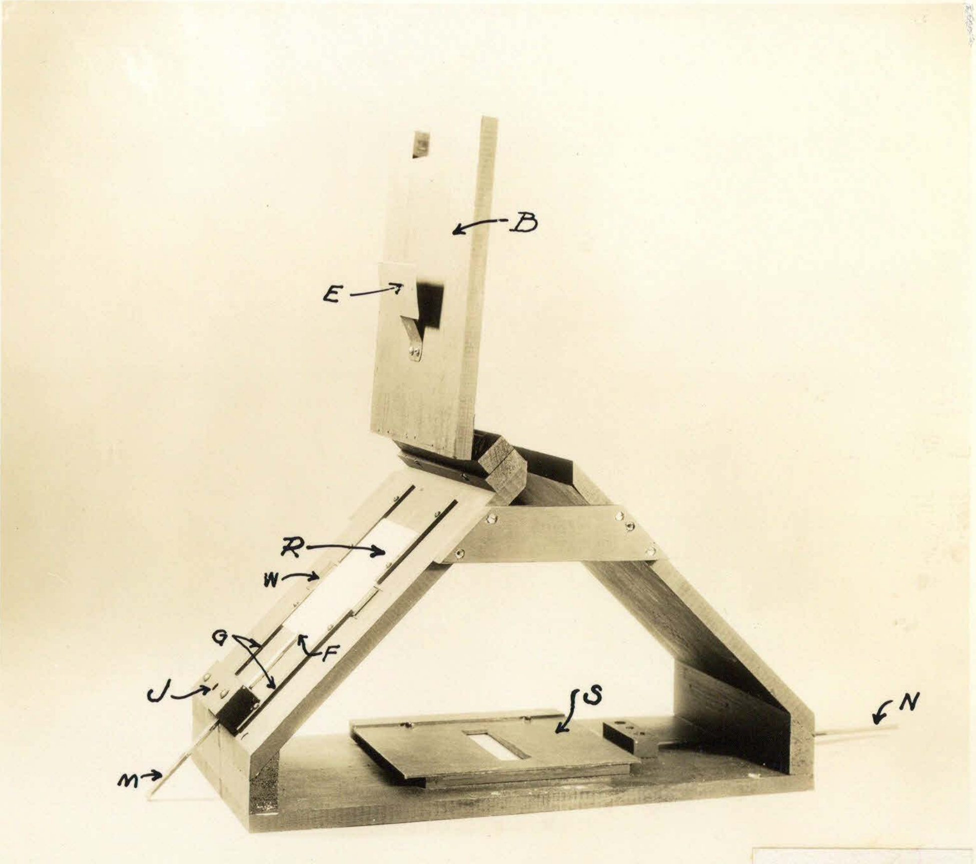


Fig. 5b.

Several stops and diaphragms which serve to define the light beam falling on P, and to intercept stray light have been omitted for the sake of clearness. The distance from plate P to plate R is $6\frac{1}{2}$ inches, and the light passing thru slot L, onto plate R, is light which has fallen normally on plate P, and has then been diffusely reflected at an angle of 45°. If the distance from P to R could have been made less, the exposures would have been decreased, but the angle of reflection would have been a less definite quantity, and it would have been impossible to slide plate R into its upper position without cutting into the light beam.

2. Preparation and Calibration of Standard Reflecting Plate.

For this experiment it was necessary to compare the diffuse reflection from the photographic plate, with that from a diffuse reflector whose reflecting power or albedo is known. A piece of solid opal glass of the same size as a plate (3 1/4" x 4 1/4") was ground on one side with No. 100 "Crystolon" abrasive powder until a uniform matt surface was obtained. This was compared with a calibrated plate of the same type belonging to the Electrical Engineering Department.

The Martens polarization photometer was clamped so it pointed downwards at an angle of 45°, then the two plates to be compared were laid on the table so that one of them appeared in the left field of the photometer and the other in the right field. Light was allowed to fall normally on the plates and a photometer reading was taken with the plates in this position and another with the plates interchanged. The two readings differed slightly showing that the illumination of the plates was not quite equal. Adjustments of the light were made until the two readings checked.

The ratio of the brightness of the calibrated plate to that of the new plate was then found to be 1.00 : 0.98 at this particular angle. The total reflecting power of the calibrated plate was 0.80 and this gives for the total reflection of the new plate 0.80 x 0.98 = 0.78 if we assume the distribution curves for reflected light have the same shape for both plates. The plate thus standardized with a reflection of 78% will be known simply as the standard reflector. It was cleaned frequently with soap, water and a mild cleansing powder to keep it in good condition.

B. Method of Making a Reflection Measurement.

The method of making a reflection measurement is illustrated in Figures 6a and 6b. Two separate exposures are required to get one reflection measurement. First the photographic plate to be tested is placed under screen S (Figure 5), a definite exposure is given, and the light reflected at an angle of 45° is received on plate R, where it produces a certain density. The set-up is then changed to that shown in Figure 6b. The standard reflector is placed under screen S, and a fresh plate R' is used to receive the radiation. In this experiment a wedge, W, is placed in front of R', thus producing a graded series of densities on R'. At some point along R' the density will be the same as the density of R. The wedge density at this point is measured. The transmission T of the wedge at this point when multiplied by 0.78, gives the reflecting power of the photographic plate. The illumination over plate R is not quite uniform but falls off toward the ends. This makes it essential to observe two rules when measuring the densities of R and R'.

1. Two points of equal density must be picked out.
2. These points must be at the same distance from the end of the strip.

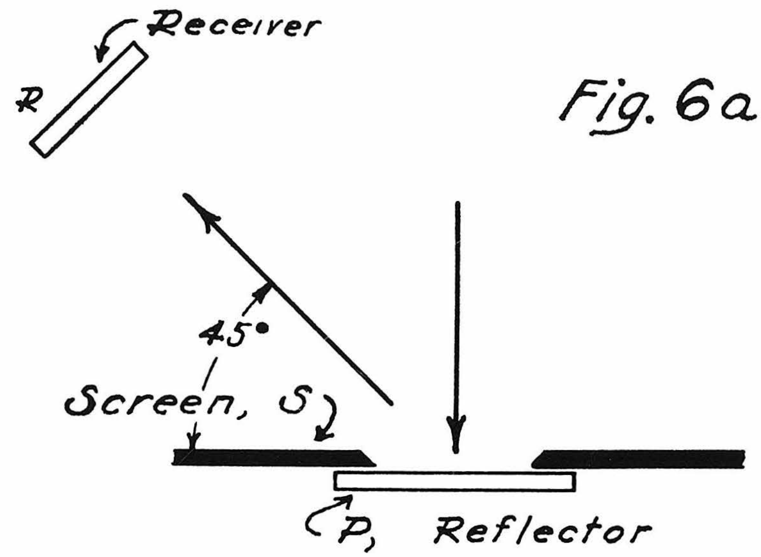

Receiver
R
45°
Screen, S
P, Reflector

Fig. 6a

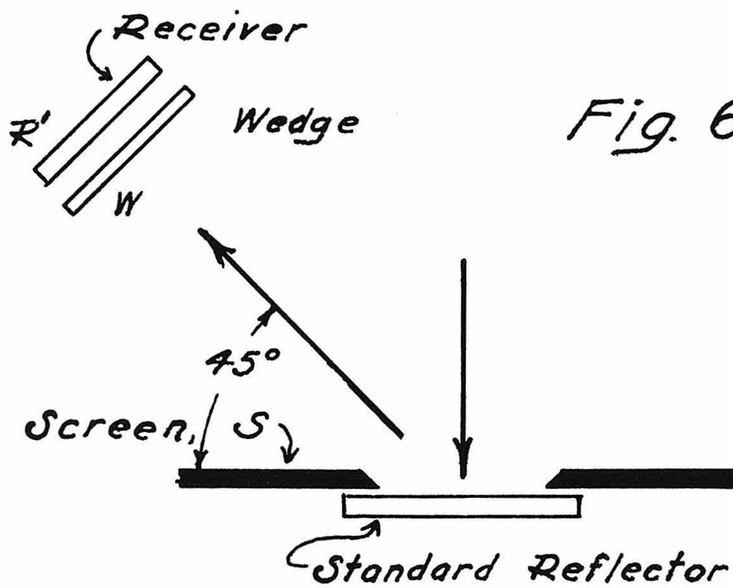

Receiver
R'
Wedge
W
45°
Screen, S
Standard Reflector

Fig. 6b

The measurement is easily carried out by adjusting the photometer fields for equality, then placing R under one side and R' under the other side of the photometer, and sliding them along together until the fields again match. The required point on R' having been determined, the density of the corresponding point on the wedge can be measured.

Since the two plates are not exposed simultaneously care must be taken that the exposure time and lamp filament current are the same for both. The two exposures are made on adjacent strips of the same receiver plate, and thus we are assured of having the same emulsion characteristics and the same degree of development.

C. Results of Reflection Measurements.

1. Measurements on Eastman 40 Plate.

In the following experiments the distance from lamp to plate was 39.25 cm. Table VIII shows the results of a run using Eastman 40 plates both as the reflector and receiver. In the third and fourth column the particular reflecting and receiving plates used are specified. E-40 means an Eastman 40 plate, while S signifies the standard reflector. In the column headed "Wedge" the presence or absence of a wedge in front of the receiving plate is recorded. D_W and T_W are the density and transmission of the wedge, while R is the reflecting power of the plate being tested and is given by

$$R = 0.78\ T_W$$

TABLE VIII

I = 0.280 amp.

Strip	E	Reflector	Receiver	Wedge	D_W	T_W	R
A	1	E-40	E-40	no	0.442	36.2	28.2 %
B	1	S	"	yes			
C	2	E-40	"	no	0.442	36.2	28.2
D	2	S	"	yes			
E	4	E-40	"	no	0.448	35.6	27.8
F	4	S	"	yes			
G	8	E-40	"	no	0.442	36.2	28.2
H	8	S	"	yes			
						Avg.	28.1%

2. The Effect of Exposure Time on Reflection.

In the transmission experiments no change of transmission with increasing exposure time was found. Referring to Figure 6, we see that a large amount of energy must fall on plate P in order that sufficient shall reach R to produce an image, and it might be expected that this would affect the reflection from P during the course of an exposure. To test this each of a series of eight plates was placed in position at P, and given exposures to the light as normally used. These exposures varied from 3 minutes to 128 minutes. Each of these pre-exposed plates was then treated in the usual way and its reflection measured using an exposure time of 2 minutes. Table IX shows the results and indicates no tendency of reflection to change with any of the exposures used in this work.

TABLE IX

Eastman 40 reflector
Eastman 40 receiver
I = 0.280 amp.

Strip	E min	D_W	T %	R %	Previous exposure of reflector
B-C	2	0.406	39.3	30.6	3 min.
D-C	2	0.380	41.7	32.5	4
E-F	2	0.412	38.8	30.2	4
G-H	2	0.378	41.9	32.7	8
I-J	2	0.377	42.0	32.8	18
K-L	2	0.480	33.1	25.8	32
M-N	2	0.407	39.2	30.6	64
O-P	2	0.430	37.2	29.0	128
			Avg.	30.5%	

3. The Effect of Wave Length on Reflection.

The reflection for red, green, and blue light was determined by the use of Wratten A, B, and C filters in front of the lamp house. Wratten and Wainwright Panchromatic plates were used to receive the reflected light, otherwise there was no departure from the usual procedure. The results are shown in Tables X, XI, and XII.

TABLE X

"A" filter (red)
I = 0.280 amp.

Strip	E (min)	D_W	T_W %	R %
A-B	1	0.130	74	57
C-D	2	0.150	71	55
E-F	4	0.110	77.5	60
G-H	8	0.110	77.5	60
			Avg.	58%

TABLE XI

"B" filter (green)
I = 0.280 amp.

Strip	E (min)	D_W	T_W	R
A-B	2	0.150	71	55
C-D	4	0.130	74	58
E-F	8	0.130	74	58
G-H	16	0.130	74	58
			Avg.	57%

TABLE XII

"C" filter (blue)
I = 0.280

Strip	E (min)	D_W	T_W	R
A-B	11	0.590	25.7	20.0
C-D	20	0.443	36.1	28.2
E-F	41	0.508	31.1	24.2
G-H	80	0.472	33.8	26.4
			Avg.	24.7%

V. SUMMARY AND DISCUSSION

Collecting and averaging the data obtained in Sections III and IV, we obtain Table XIII, which shows what becomes of the light which falls on an Eastman 40 plate, the absorptions having been obtained under the condition that

$$\text{reflection} + \text{absorption} + \text{transmission} = 100\%$$

The obtaining of -1% for absorption of red light indicates, of course, that the measurements contain some inaccuracies. High precision is not claimed for these results, but it is thought that they represent to a fair degree of accuracy the conditions found in the ordinary use of the photographic plate. In interpreting these results it should be remembered that in the white light exposures the receiving plate was an Eastman 40, and not a panchromatic plate.

The reason for the use of the Eastman 40 in this case is that it was desired to investigate the reflection and transmission characteristics of the plate for that band of wavelengths to which the plate is chiefly sensitive. When "white light" (i.e., light from a tungsten filament burning at lowered voltage) is reflected from a plate there will be a preponderance of the longer wavelengths. To investigate the reflection of that band of wavelengths to which the reflecting plate was sensitive, we might use a filter passing only that band as we did for the three primary colors, but the simplest solution is to use for the receiver another plate of the same kind. Perhaps the the description of the light as "The Actinic Band" in place of "White" might be advisable.

TABLE XIII

Disposal of Light Falling on Eastman 40 Plate

Color of light	Reflected	Transmitted	Absorbed	
Red	58%	43%	-1%	W+W Pan. Receiver
Green	57%	35%	8%	"
Blue	25%	9%	66%	"
"White"	29%	15%	56%	Eastman 40 Receiver

The results seem to show that on this type of plate, at least, the incident light is absorbed with pretty fair efficiency if it is of a wavelength which can be absorbed by the silver halide, while of the other wavelengths, reflection and transmission account for practically the entire incident energy. In other words, the plate wastes very little of any incident energy which it is capable of using. We are speaking now of efficiency as being synonymous with the disappearance of radiant energy within the boundaries of the plate. In other words, we have shown that the energy is used up, but have not said anything about whether it is used to the best advantage. It would be very interesting to make further measurements on this same type of plate after bathing in dyes which sensitize for different regions of the spectrum.

It is claimed by the author that these measurements have the advantage of being made under conditions which approach those occurring in normal photographic exposure, and that they give valuable information regarding the over-all behavior of the plates which is difficult to obtain from discussions and experiments involving the refractive indices and other characteristics of the separate components of the emulsion.

The principal feature of the work is the use of a null method of making the measurements. At no time are any direct measurements of anything necessary until the final step when the transparency of the wedge is measured in the photometer and used directly as a transmission or multiplied by the factor 0.78 to give a reflection.

Thus there is avoided all discussion of the characteristics of the sensitive material and all calculations. The only precaution necessary is that the two comparison plates must be developed evenly and to the same degree, which is easily done, they being generally two portions of the same plate. In the reflection measurements the photographic plate is compared simply and directly with a plate of known reflection. The assumption is involved that if the photographic plate and the standard plate have the same intensity reflected diffusely at 45°, then the total diffuse reflection is equal. This, of course, is probably not quite true, but it is thought to be a fair approximation, as it would be the case if both plates were perfect diffuse reflectors.

APPENDIX A

PRELIMINARY EXPERIMENTS ON THE TRANSMISSION OF PHOTOGRAPHIC PLATES

1. Exposure of a Plate Backed by a Mirror.

Before a decision was reached regarding the best method to use in measuring transmissions, some preliminary experiments were made to try out various ideas which presented themselves. The first of these was an attempt to measure the transmission of a plate by allowing the transmitted light to fall on a mirror from which it was reflected back again thru the plate. It appeared possible then from a knowledge of the characteristic curve of the plate and of the reflecting power of the mirror to correlate the extra density produced by the return of the light thru the plate with the amount of light transmitted by the plate.

Figure 7 shows the arrangement used. A piece of silvered glass mirror was laid down on a table. A strip of black paper and one of white paper were pasted lengthwise along the mirror, leaving a strip of uncovered mirror between them. Each strip was about 3/4 of an inch wide. On top of this a photographic plate was laid with the emulsion down, i.e., against the paper strips. By means of a sliding sheet of cardboard a series of geometrically increasing exposures ranging from 5 seconds to 160 seconds was impressed on the plate in the form of strips running at right angles to the paper strips. One end was left unexposed to serve as a fog strip.

The plate was developed and the densities of the eighteen rectangles ~~was~~ were measured by means of the Marten's polarization photometer. The densities thus obtained were plotted against the common logarithms of the corresponding exposures according to the usual method of plotting H and D curves.

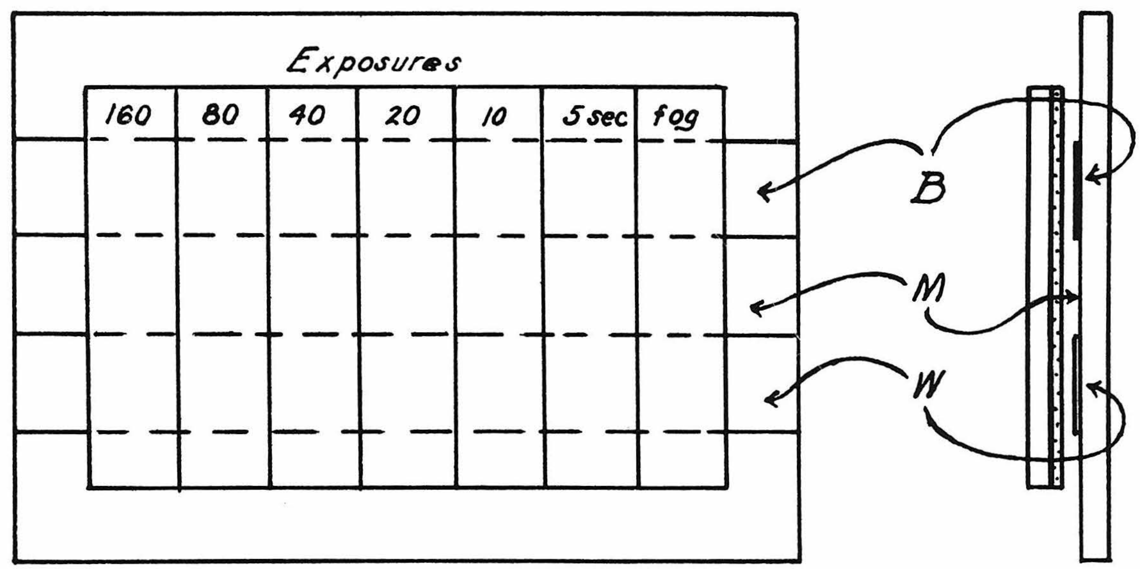


Fig. 7

B - black paper
W - white paper
M - bare mirror

Tables XIV and XV show the densities measured on the developed plates, together with the exposures received. Figures 8 and 9 show this data plotted as H and D curves. It will be seen that the densities of the mirror-backed plate are considerably higher than those of the plate backed by the black paper for equal exposure. Densities corresponding to the white paper backed plate are but slightly lower than for the mirror and have not been plotted.

If, however, on curve B, we give an exposure which is sufficiently greater than the exposure given on curve M, then it will be possible to obtain equal densities on the two plates. The amount by which log E must be increased is easily seen to be the quantity marked δ. Denoting the exposure required on the black paper backed plate and the mirror backed plate in order to get equal densities by E_B and E_M respectively, we have:-

$$\log E_B = \log E_M + \delta$$

or

$$\log E_B = \log (E_M \times \log^{-1} \delta)$$

so

$$E_B = E_M \times \log^{-1} \delta$$

and

$$\frac{E_B}{E_M} = \log^{-1} \delta$$

In the two cases just investigated, the values shown in Table III were obtained and can be used to calculate the transmission of the plates.

TABLE XIV

Eastman Regular Lantern Plate

E	log E	D_B	D_M	D_W
5	0.699	0.152	0.217	0.183
10	1.000	0.340	0.433	0.400
20	1.301	0.661	0.780	0.756
40	1.602	1.068	1.236	1.221
80	1.903	1.521	1.717	1.709
160	2.204	2.057	2.253	2.225

D_B signifies density above black paper

D_M signifies density above mirror

D_W signifies density above white paper

TABLE XV

Eastman 40 Plate

E	log E	D_B	D_M	D_W
1	0.000	0.000	0.000	0.000
2	0.301	0.000	0.000	0.000
4	0.602	0.000	0.005	0.000
8	0.903	0.000	0.032	0.010
16	1.204	0.036	0.092	0.071
32	1.505	0.111	0.210	0.188
64	1.806	0.258	0.367	0.360
128	2.107	0.420	0.529	0.544
256	2.408	0.584	0.691	0.716

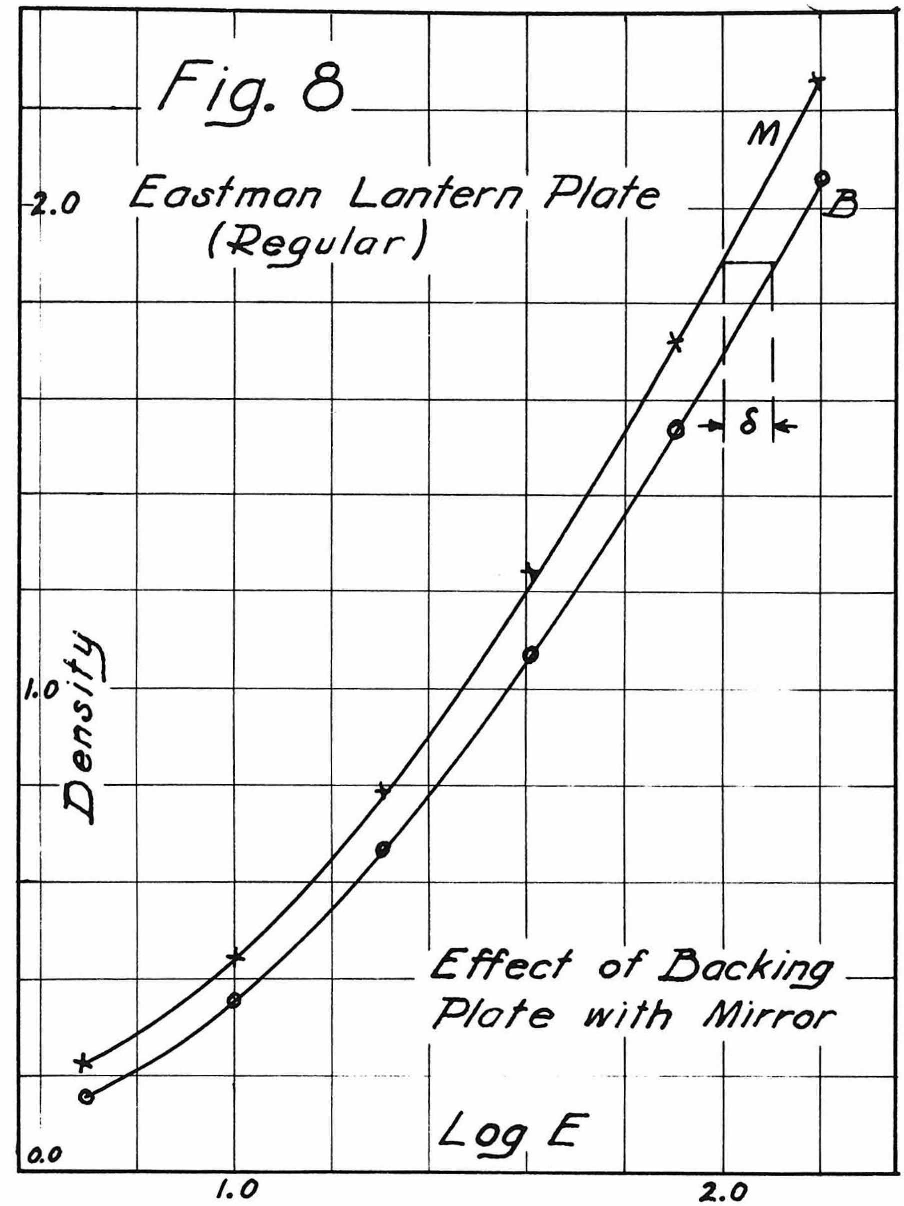


Fig. 8
Eastman Lantern Plate
(Regular)
M
B
δ
2.0
1.0
0.0
Density
Effect of Backing
Plate with Mirror
Log E
1.0
2.0

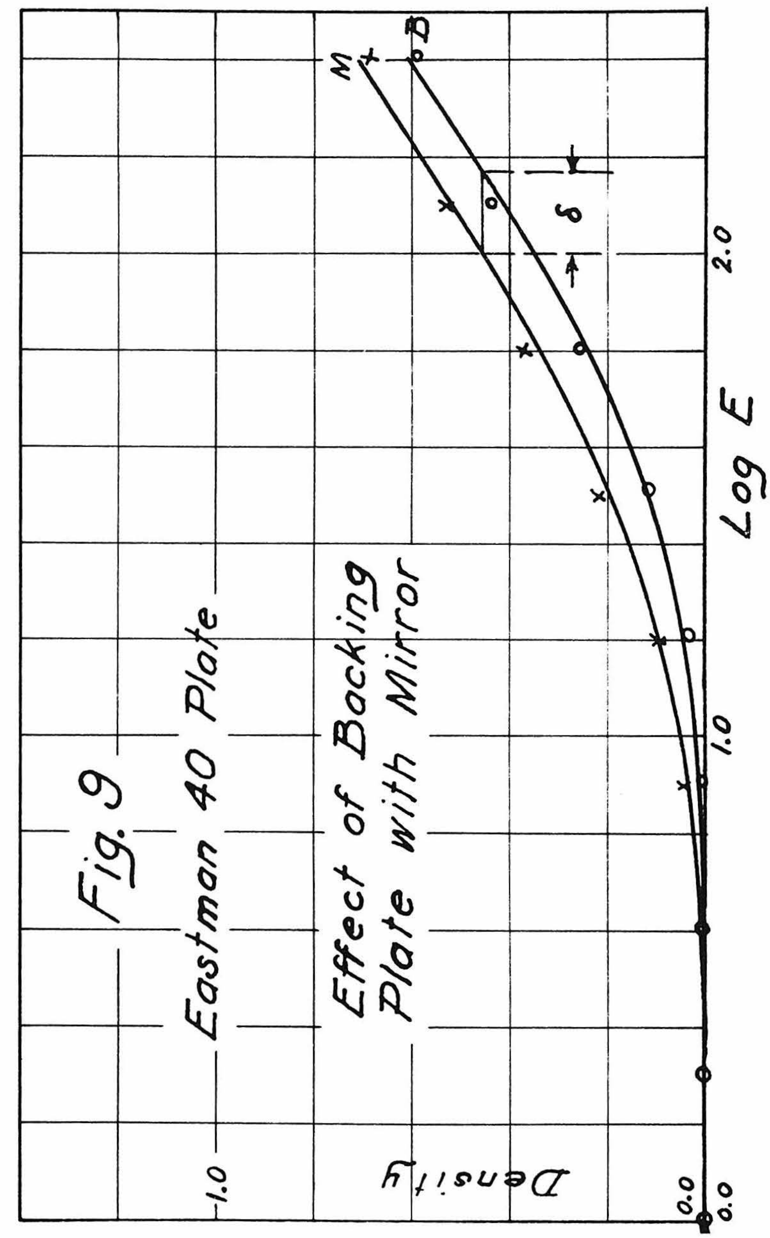


Fig. 9
Eastman 40 Plate
Effect of Backing Plate with Mirror
Density
Log E
1.0
0.0
0.0
1.0
2.0
M
D
δ

Let I_o = incident energy on plate

k_T = fraction of incident energy transmitted

R = reflection factor of mirror

also let B designate the plate backed by black paper

and M designate the plate backed by the mirror

The energy falling on both plates will be I_o.

An amount $I_o k_T$ passes thru plate M onto the mirror and of this an amount $I_o k_T R$ comes back, giving a total of $I_o(1 + k_T R)$ falling on plate M, whereas only the amount I_o acted on plate B. We may equate the ratio of these energies to E_B/E_M.

$$(1 + k_T R) = E_B/E_M$$

$$k_T R = E_B/E_M - 1$$

$$\text{and} \quad k_T = 1/R(E_B/E_M - 1)$$

Assuming R = 0.80, the values of k_T for the two types of plates have the values shown in the last column of Table XVI.

TABLE XVI

	δ	$E_B/E_M = \log^{-1}$	k_T
Lantern Plate	0.100	1.26	0.32
Eastman 40	0.170	1.48	0.60

The idea that an Eastman 40 plate should show a transmission of nearly twice that of a lantern plate, was startling and unbelievable, and led to the discovery of a fundamental error in the procedure, which might have remained undiscovered for some time had the values of k_T happened to come out in a more reasonable order.

The difficulty is that if an equal amount of energy falls on one plate from the front and on a similar plate from the back, i.e., thru the glass, the one exposed from the glass side will develop up to a much lower density than the other, no doubt owing to lack of penetration of fresh developer to the back of the emulsion. In this experiment the light traverses the plate first from back to front and after reflection from the mirror, falls on the plate from the front where it can now act much more advantageously than before. As a result the effect of the original light is lessened and that of the reflected light is exaggerated. As there seemed no good way of ascertaining exactly what had happened, the method was abandoned.

2. The Exposure of Two Superposed Plates.

An attempt was also made to place two plates with their emulsions in contact, giving to the combination a series of graduated exposures, and then comparing the densities produced on each. This method was subject to the same difficulties. If, however, each of the superposed plates is placed with the emulsion side up, then the light will pass through each one in the same direction, and we shall avoid the difficulty of which we have been speaking.

We still have a small error to consider, due to reflections between the plates. If light passes thru the first emulsion and falls on the second, a part will be reflected back to the first emulsion, and then back again to the second. It would seem that this would not be of serious magnitude however, except for work of high precision, and this effect has been neglected in the following experiments.

3. Final Method Used for This Work.

A further modification of the original idea made it possible to avoid the labor of plotting curves and improved the accuracy at the same time. Let us cut the upper plate of the pair in half and remove one of the halves. Then over the uncovered half of the lower plate place an optical wedge. Now expose this arrangement to a uniform light for the desired length of time, and develop the lower plate. We may now pick out a spot on the wedge image which has the same density as that produced under the plate being tested. The corresponding place on the wedge itself can then be located and its density measured. The transmission of the wedge at this point is equal to the transmission of the plate being tested.

This method does not require precise control of the exposure time and lamp filament current which would be necessary in the curve plotting method, and avoids arguments about development factor, the reciprocity law, and numerous other ills to which the photographic plate is heir. It was therefore adopted in all subsequent work reported in this paper.

APPENDIX B

TRANSMISSION OF EASTMAN SPEEDWAY PLATES

Some of the first transmission measurements using the wedge method described under Section III were made on Eastman Speedway Plates using a lamp filament current of 0.260 amp. The results obtained were not very consistent, a series of four runs giving the following values of transmission,

33.5%

6.5%

23.0%

30.0%

The plates fogged considerably during development and it was decided to adopt a cleaner working plate, namely the Eastman 40, for the investigation. Unfortunately timedid not permit of going back and clearing up the matter of the erratic behavior of the Eastman Speedway plates.

APPENDIX C

TRANSMISSION AND REFLECTION MEASUREMENTS AT VARIOUS LAMP VOLTAGES

Before starting the transmission measurements with the use of filters, some preliminary experiments were tried to see whether there was actually a change in transmission with changing wavelength. This was done by running the filament on reduced current, which shifted the wavelength of the light toward the red. The following average values were found for the transmission

I	T	E
0.280	15.0%	$7\frac{1}{2}$ sec - 240 sec
0.240	18.3	$\frac{1}{2}$ min - 16 min
0.180	20.2	15 min - 500 hours (estimated)

A very definite increase in transmission with wavelength is thus indicated. That the increase was no larger than here shown is probably due to the use of an Eastman 40 as the receiving plate. The Eastman 40 has practically no sensitivity for wavelengths greater than 5500Å. Furthermore, reducing the filament current is much more effective in cutting down the candle power than in shifting the wavelength of the maximum energy output, which in the case of a lamp filament is down in the red even with the highest filament currents. The relative exposure times required to get a series of analogous exposures with different filament currents may be of interest, and these are also included in the table under the heading, E.

An attempt was made to get a similar series of reflection measurements, but only those for currents of 0.280 and 0.240 amp. proved practical to run. They show an increase in reflection with a decreased filament current so far as they were carried out. The values obtained were:

I	R	E
0.280	28.1%	2 min - 1 hour
0.240	31.2%	8 min - 4 hours
0.180	——	4 hours - 8000 hours (estimated)

APPENDIX D

EXPERIMENTS WITH PLATES IN ELECTRIC FIELDS

Several experiments were performed during the early part of the investigation with the object of ascertaining whether an electric field has any influence on a photographic plate when acting by itself, and whether a plate behaves in the same way when exposed to light or when exposed to light and an electric field simultaneously.

A flat block of brass was placed under the center of a 3 1/4 x 4 1/4 Eastman 40 plate, the plate lying with its emulsion side up. At a distance of 9/16 inch above the plate a 1/8-inch aluminum rod was supported on fiber strips. A potential difference could be applied between the rod and the brass block, while the plate lay in the field between them. The plate could at the same time be illuminated by a light from above.

Before illuminating, a piece of black paper was laid over part of the surface of the plate in such a way as to obtain four well-defined regions, as follows:-

A. A region with no field and no light

B. A region with no field but with light

C. A region with a field but no light

D. A region with a field and with light.

Careful examination of these various regions after development failed to show any effect which could be attributed to the electric field. The field used was an alternating one of 50 cycles frequency and had a potential drop of up to 9000 volts over the 9/16 inch gap.

An interesting and curious effect was obtained when a plate to which a spark had jumped was subsequently exposed briefly to light over half its surface. Upon development the part not exposed to light showed a typical spark discharge image - a beautiful arrangement of curving and branching lines. Over the portion which had been exposed to light the spark image had been completely obliterated except for one or two of the strongest lines. The white light exposure was nowhere near great enough to cause overexposure. That the lines simply disappear becuase the whole plate has become darker is not the explanation either, for when a supplementary plate having a density equal to that of the light exposed side is placed over the spark image, the latter appears as distinct as ever, except that brighter light is needed to see it. The brighter light, however, reveals nothing on the light exposed side. The effect is probably allied to the Herschel effect, which has been receiving quite a little attention lately, and in which exposure of a plate to red light will remove images which have been previously formed by blue light. Indeed it is known to be a rather general effect that long wavelength radiation will often reverse an effect of a short wavelength. Why this is so is scarcely within the field of this paper, and in fact the reasons are not any too well known.

APPENDIX E

METHOD OF MAKING OPTICAL WEDGES

The wedges used in this work cannot be made of colored gelatine protected by the usual cover glass because it is necessary for the absorbing material of the wedge to be in fairly close contact with the emulsion of the receiving plate to avoid parallax effects. Unprotected gelatine wedges soon become covered with finger marks, scratches, etc., and it is necessary to have a cheap and easy method of renewing them.

A master wedge was prepared by casting gelatin, containing neutral gray coloring material, between two slightly inclined glass plates, according to the method of Goldberg.[6] Not having the dyes recommended by Goldberg a fair substitute was made by adding India ink to a 10% hot gelatin solution until about the right depth of color was reached. The brownish tinge of the India ink was neutralized by small additions of a blue dye purchased at Woolworth's 5-and-10-cent store and known as Tintex French Blue. The gelatin solution was filtered thru cotton while hot and the wedge cast. Very good wedges were produced after a few trials of the process.

This master wedge was then laid against an unexposed lantern slide plate and a print made. A large number of these photographic prints can be made quickly and cheaply, and can be cut up into various sized wedges for use as required. The copies can be made having a gradation which may be steeper or flatter than that of the original by simply varying the development time, while the minimum density will increase with the exposure. The copy wedges will not be linear, especially in the lower densities, but non-linearity was of no consequence in this work. It was also found somewhat difficult to get a good copy having a minimum of transmission of less than 10% and at the same time get a steep enough gradation so that positions could be accurately located.

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