EXPERIMENTAL STUDY OF THE RELATION BETWEEN INTERMITTENT AND NONINTERMITTENT SECTOR-WHEEL PHOTOGRAPHIC EXPOSURES

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ABSTRACT

This investigation on the effects of intermittent sector-wheel photographic exposures was prompted by data obtained some years ago which were not in agreement with the results of other investigators. It is the accepted view that, compared with a continuous exposure, intermittance always causes a loss in photographic effect. The data shown here prove that the effect may be either a gain, a loss, or zero, dependent on the illumination.

The illumination appears to control certain properties of the latent image not heretofore shown. When the latent image is formed by illumination above a certain level for the particular emulsion used, a growth of the latent image after exposure is found, and with the illumination below this level a fading of the image results.

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I. INTRODUCTION

It has long been known that photographic exposures given in regular installments do not show, on development, the same photographic action as an equal single or nonintermittent exposure. The discovery of this effect is attributed to A. and L. Lumière, 1881. Studies of its nature and magnitude have been made by a number of investigators, notably Abney (1),[1] Englisch (2), Schwarzschild (3),

[1] The figures given in parentheses here and throughout the text relate to the reference numbers in the bibliography given at the end of this paper.

Sheppard and Mees (4), Renwick (5), Howe (6), Jones (7), and others. Their data show it to be dependent upon three factors—First, the ratio of the exposure period to the rest period; second, the quantity of light received at each installment; and third, the illumination. It is important to note that in all cases the intermittent exposures are reported to be less in effect than the continuous. In those few cases where the data have indicated otherwise the contradiction is generally ascribed to experimental error.

A knowledge of the errors introduced by intermittent exposure is important—First, from its bearing on latent image theory; second, because of the general use of rotating sector-wheel sensitometers of the intermittent type.

In connection with some previous work (8) where a sensitometer of the intermittent type was employed, a short series of tests was made to evaluate the errors arising from the intermittence. Of five types of emulsions tested at that time (Seed Graflex, Seed 30, Seed 26, Seed 23, and Seed process) only one, the Seed process, agreed with the accepted view that intermittence reduces the photographic effect; the others showed a greater density resulting therefrom.

The new sensitometer recently described (9) having the necessary degree of precision, a thorough investigation of the effect of intermittence has been carried out, the results of which support and illuminate those from the earlier series of tests.

II. GENERAL PROCEDURE

1. SENSITOMETER DETAILS

The new instrument, though designed primarily for nonintermittent work, can also be used to give intermittent exposures to better advantage than the older machine because of the extended range of known speeds of the sector wheel available. Another advantage is that the plates may be exposed at will on either their upper or lower halves, without removal from the plate holder. The automatic timing device which controls the electric shutter, used on the older machine, was incorporated in the new one. This device may be set to hold the shutter open for any predetermined number of revolutions of the sector wheel. By a double-throw switch, which when thrown one way connects this device with the shutter circuits and when thrown the other way disconnects it, the sensitometer becomes intermittent or nonintermittent as desired.

Of the four sector wheels with which the sensitometer is equipped, one only, which has 13 apertures or steps, was used throughout this investigation. The total exposure range covered by the apertures in this wheel is from 1 to 256. The largest aperture is 180°, while the smallest is 0.703°. The aperture ratio, 2/3 power of 2, gives a

distinct advantage over the usual power-of-two steps for precision in determining the characteristic curves.

All exposures were made with one lamp and filter giving light of 5,325° K. color temperature. Of the four different illuminations used on the plates those of 4 candle meters and 1 candle meter were procured by varying the distances of the light source, while 0.1 and 0.02 candle meter were obtained by using two calibrated ground-glass screens. These screens are each composed of two pieces of ground glass with a diaphragm between which varies the intensity by limiting the aperture. (This procedure does not appreciably change the color of the light.) The screens were calibrated photographically in the sensitometer at the distances from both the lamp and the test plates used in the experiments. While this calibration is not exact, the effective photographic intensity varying somewhat with the plates used, it is sufficiently close for the work in hand, since, as will be seen, the method used makes it unnecessary to know the exact value of the illumination.

2. PREPARATION OF TEST PLATES

All plates were of the commercial 5 by 7 inch size. These were cut in one operation, by a special plate-cutting machine, into seven parts, giving five which are $1\frac{3}{32}$ by 5 inches, the two end strips being discarded. The plates after cutting are removed intact—that is, not broken apart—painted on the glass side with a black shellac mixture to prevent halation, and then dried in a ventilated closet. After drying they are broken apart and loaded into the plate holders, each having three pockets. In all experiments three kinds of plates were exposed in each holder; for example, "A" plates in the upper pocket, "B" plates in the center pocket, and "C" plates in the lower pocket. Since practically every experiment was made with eight holders, this gave 24 test specimens for each designated experiment.

To avoid mixing or losing identity of developed test plates the specimens often appearing to be exactly alike, an identifying mark is automatically recorded on the plate. On the upper edge of each plate-holder pocket there is a small projection so placed that its mark (see fig. 1) is made on the exposed square, the number of which corresponds to the plate-holder number. Similarly the location within the square determines whether the plate occupied the upper, the central, or lower pocket. For permanent identification, test numbers were written in ink on the emulsion side.

In numbering the plate holders by apertures the longest exposure was chosen for No. 1 because this end of the plate always received sufficient exposure to permit the use of these identifying marks. It should be understood, however, that aperture numbers given in the

tables are in the reverse order, No. 1 being the shortest exposure and 13 the longest.

3. METHODS OF EXPOSING TEST PLATES

Two methods were tried for studying the effects of intermittent exposure.

(1) The intermittent and nonintermittent exposures were made on separate test plates and developed together. From each set of data a characteristic curve was constructed and the two compared with each other in regard to difference in gamma, speed, and shape. This proved unsatisfactory because the observed differences were in some cases equaled or exceeded by the experimental errors, caused chiefly by irregularities of emulsion and development.

(2) Both intermittent and nonintermittent exposures were made on adjacent parts of the same plate and the entire set developed together. The results proved much more reliable. By comparing adjacent parts of the same plate lack of exact duplication of coating and irregularities of development are minimized; and, furthermore, greater precision in the photometric measurements of density is obtained by observing merely the difference in density between the two kinds of exposures, not the actual densities.

Following the procedure outlined in the second method the nonintermittent exposures were made, without exception, on the upper half of each test specimen. The lower half was given either no exposure or the equal intermittent exposure. The number of interruptions varied from 1 (2 exposures) to 127 (128 exposures) in power-of-two steps. Those plates which received only the nonintermittent exposures were used simply to determine the characteristic curve of the emulsion.

4. DEVELOPMENT OF PLATES

It is generally recognized that a good portion of the difficulties met with in sensitometry arises from unequal development of different plates in the same developing bath and even of the different parts of the same plate. Several methods of stirring the developer or agitating the plates in it were tried without marked improvement. Developing in trays and agitation of the developer by rocking proved no better. By far the best results were obtained with the "brush method," recommended by Clark (10).

In this the 24 exposed plates were placed in a single metal rack, as seen in Figure 1. Thus all of the plates of a single test were handled as a unit. These were developed in a tray in which the developer was maintained by a water bath at a constant temperature of 20° C. During development (four minutes) the plates were brushed in two directions with a 3-inch camel-hair, rubber-bound brush.

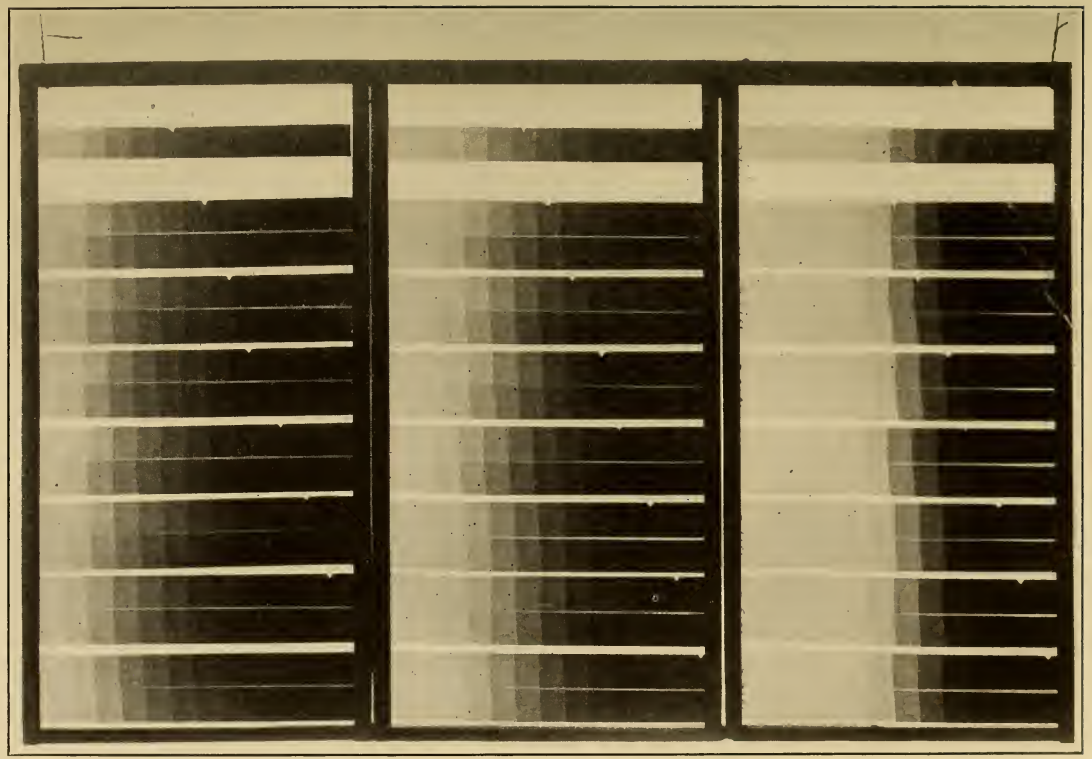

Fig. 1.—*Method of developing 24 test specimens (8 each of 3 kinds) as a single unit*

The reference marks for identification of each plate are clearly shown

Following development they were rinsed in dilute acetic acid and fixed in the usual acid hyposolution. Pyro soda developer[2] of normal tray strength, without bromide, was used in all cases.

After fixing and washing, the black shellac backing on the plates was softened by swabbing with a tuft of absorbent cotton wet with alcohol, and the plates returned to the water. One plate at a time was then taken and the shellac backing scraped off with a small sharp-cornered piece of wood (the edge of a wooden photo clip).

To facilitate drying and to prevent the appearance of watermarks the emulsion was wiped with the edge of the hand until all of the surface water was removed. The glass side was then wiped dry with a towel and the plates dried in a gentle stream of air at room temperature.

5. DENSITY MEASUREMENTS

The densities were measured with a Martens polarization photometer. The illumination for this purpose is diffuse, the light being reflected from a ground opal surface which constitutes the bottom of a box, opposite sides of which consist of ground-glass windows. Outside of each of these windows is a lamp serving as the source of illumination. These lamps are so placed that each illuminates equally both fields of the photometer. Any change in the brightness of a lamp affects equally both fields, hence causes no photometric error.

With this apparatus one beam of light passes through the density square to be measured and the other through the fog strip. Thus the density values given have the fog subtracted. In cases where both halves of the plates are exposed the density values given are their difference. This latter case, of course, applies to those where intermittent and nonintermittent exposures are made on adjacent parts of the same plate. *In the records, the nonintermittent exposure is taken as the standard, so that absence of sign indicates the intermittent exposure density to be the greater, while a minus sign shows it as the smaller.*

Density values exceeding 1.80 were, for the sake of accuracy, always measured with a plate of accurately known density inserted over the fog strip and its value added to the observed difference. This procedure furnished good results for densities as high as 3.5.[3]

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[2] Developer formula:

(*a*)	Water	cubic centimeters	1,000
	Potassium metabisulphite	grams	12
	Pyro	do	60
(*b*)	Water	cubic centimeters	1,000
	Sodium sulphite, dry (hydrometer test 55°)	grams	90
(*c*)	Water	cubic centimeters	1,000
	Sodium carbonate, dry (hydrometer test 40°)	grams	75

(To develop, take 1 part each of (*a*), (*b*), and (*c*) and 8 parts of water.)

[3] It is of interest to state that a group of plates measured in contact with ground opal glass in another laboratory gave densities in agreement with the values obtained with this apparatus.

In general, all densities were measured twice. Occasionally there appeared in plotting the curves one or more erratic values. The entire strip was thereupon examined and remeasured, with the result that either an error of reading was detected or the cause of the discrepancy, such as pinholes or other defects, discovered.

III. CHARACTERISTIC DATA OF EMULSIONS USED

Three emulsions, Seed 30, Seed 23, and Seed process, were selected as being representative of widely different types. These plates had been on hand for some time, and although not fresh, were in good condition. They were chosen because they were well seasoned and stable. These emulsions are referred to throughout as A, B, and C, respectively. All plates of the same kind had the same emulsion number though not all were from the same box.

As mentioned before, three plates, one of each kind, were exposed simultaneously. In all cases plate A was placed in the top pocket, B in the central, and C in the lower one of the holder. In each group the data presented for A, B, and C plates belong to that particular set of exposures; that is, they are not in any case taken from the same emulsion in a duplicate experiment.

Experiment 1 consists of a series of nonintermittent exposures made according to Table 1 under an illumination of 1 candle meter.

TABLE 1.—*Exposure data, experiment No. 1*

Plate-holder numbers	Number of exposures	Seconds per revolution of sector wheel	Plate-holder numbers	Number of exposures	Seconds per revolution of sector wheel
1	1	1	5	1	16
2	1	2	6	1	32
3	1	4	7	1	64
4	1	8	8	1	128

The plates were developed as described above, the developing time being, however, five minutes instead of four.

The step exposures given by the sector-wheel apertures are in the ratio of 2/3 power of 2 (that is, log E changing by steps of 0.20), but the exposures for each group of plates (indicated by plate-holder numbers) are in power of two steps. This is made clear by the data arrangement in Tables 2, 3, and 4. In the first column is given the log of the exposures, product of illumination by time; the next column the density values of the corresponding strips in the eight different plate holders; and in the last column the mean densities for each exposure value.

As was to be expected, these tables show for the same exposure value no regular differences with the different apertures of the sector wheel. From the mean densities the corresponding characteristic curves (fig. 2) were drawn. The A plates have no true straight-line section—a fact shown as well in all of the other curves obtained with this emulsion. This is not believed to be characteristic, however, of all Seed 30 plates, but only of this particular emulsion. Plates B and C are considered normal material with curves having the usual form.[4] These data demonstrate incidentally, though not conclusively, what we consider to be the effects of uneven thickness of the emulsion layer. Were the emulsion perfectly uniform and

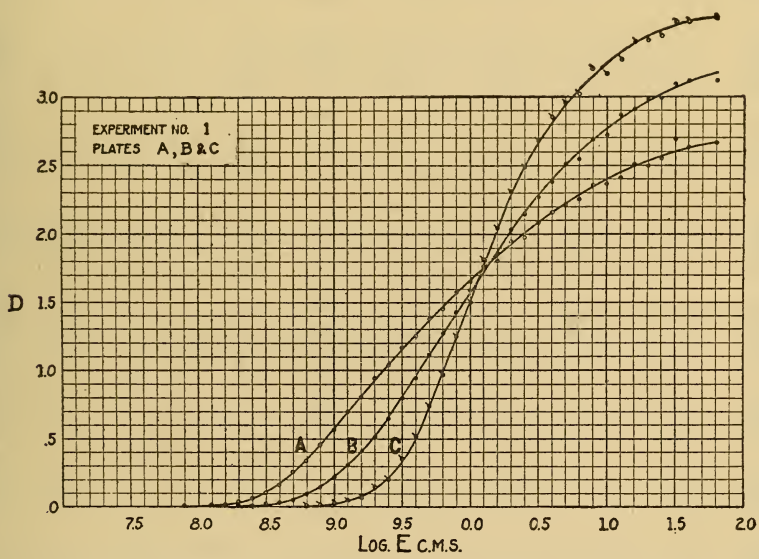

FIG. 2.—*Characteristic curves of the three emulsions used in studying the effect of intermittent exposures*

the density measurements exact, the scattering of the points off the smooth curve would be much the same at all parts. Here all three emulsions show much greater scattering at the higher densities, which is consistent with the assumption that irregularities become most prominent where the major portion of the silver halide in the emulsion is used. Allowance should be made in this case, however, for these values at the ends of the curves not being the means of as many separate densities as those in the central part.

[4] The middle section of a characteristic curve is ordinarily referred to as the straight line section and is usually so drawn, as are the curves B and C. If the plotted points be sufficiently close together, few, if any, emulsions will show a true straight-line section.

TABLE 2.—*Densities for continuous exposures, experiment No. 1, plates A*

[Illumination, 1 candle meter]

Log E	Plate-holder number—								Mean
	1	2	3	4	5	6	7	8	
7.29	0.00								
7.39									
7.49	.00								
7.59		0.00							
7.69	.00								
7.79		.00							
7.89	.01		0.00						0.005
7.99		.00							
8.09	.02		.01						.015
8.19		.01		0.02					.015
8.29	.05		.02						.035
8.39		.07		.06					.065
8.49	.11		.09		0.12				.105
8.59		.17		.17					.170
8.69	.26		.24		.28				.260
8.79		.33		.35		0.33			.335
8.89	.47		.44		.48				.465
9.00		.57		.58		.56			.570
9.10	.72		.66		.71		0.71		.700
9.20		.80		.83		.80			.810
9.30	.95		.91		.96		.93		.940
9.40		1.02		1.04		1.03		1.05	1.03
9.50	1.17		1.15		1.18		1.17		1.17
9.60		1.24		1.27		1.24		1.25	1.25
9.70	1.41		1.34		1.38		1.39		1.38
9.80		1.46		1.46		1.44		1.45	1.45
9.90			1.59		1.58		1.58		1.58
0.00		1.70		1.63		1.63		1.65	1.65
0.10			1.78		1.78		1.76		1.77
0.20				1.83		1.79		1.80	1.81
0.30			1.98		1.94		1.93		1.95
0.40				2.02		1.97		1.96	1.98
0.50					2.11		2.05		2.08
0.60				2.21		2.15		2.11	2.16
0.70					2.29		2.16		2.22
0.80						2.27		2.23	2.25
0.90					2.40		2.30		2.35
1.00						2.41		2.34	2.37
1.10							2.41		2.41
1.20						2.58		2.45	2.51
1.30							2.50		2.50
1.40								2.55	2.55
1.50							2.69		2.69
1.60								2.63	2.63
1.70									
1.80								2.67	2.67

Table 3.—Densities for continuous exposures, experiment No. 1, plates B

[Illumination, 1 candle meter]

Log E	Plate-holder number—								Mean
	1	2	3	4	5	6	7	8	
7.29	0.00								
7.39									
7.49	.00								
7.59		0.00							
7.69	.00								
7.79		.00							
7.89	.00		0.00						
7.99		.00							
8.09	.00		.00						
8.19		.00		0.00					
8.29	.01		.00						0.005
8.39		.01		.00					.005
8.49	.03		.01		0.01				.017
8.59		.03		.02					.025
8.69	.06		.04		.05				.050
8.79		.10		.10		0.09			.093
8.89	.16		.14		.14				.146
9.00		.20		.24		.21			.216
9.10	.32		.29		.31		0.31		.307
9.20		.40		.43		.39			.406
9.30	.53		.49		.52		.51		.512
9.40		.64		.67		.64		0.65	.650
9.50	.80		.82		.79		.78		.797
9.60		.94		.96		.92		.93	.937
9.70	1.16		1.09		1.10		1.12		1.12
9.80		1.28		1.30		1.27		1.25	1.27
9.90			1.41		1.45		1.43		1.43
0.00		1.61		1.62		1.56		1.56	1.59
0.10			1.71		1.78		1.75		1.75
0.20				1.90		1.84		1.86	1.87
0.30			1.99		2.07		2.03		2.03
0.40				2.15		2.13		2.13	2.14
0.50					2.28		2.27		2.27
0.60				2.45		2.34		2.34	2.38
0.70					2.50		2.53		2.51
0.80						2.57		2.52	2.54
0.90					2.65		2.73		2.69
1.00						2.75		2.70	2.72
1.10							2.87		2.87
1.20						2.93		2.89	2.91
1.30							2.98		2.98
1.40								2.99	2.99
1.50							3.10		3.10
1.60								3.12	3.12
1.70									
1.80								3.12	3.12

TABLE 4.—*Densities for continuous exposures, experiment No. 1, plates C*

[Illumination, 1 candle meter]

Log E	Plate-holder number—								Mean
	1	2	3	4	5	6	7	8	
7.29	0.00								
7.39									
7.49	.00								
7.59		0.00							
7.69	.00								
7.79		.00							
7.89	.00		0.00						
7.99		.00							
8.09	.00		.00						
8.19		.00		0.00					
8.29	.00		.00						
8.39		.00		.00					
8.49	.00		.00		0.00				
8.59		.00		.00					
8.69	.00		.00		.00				
8.79		.00		.01					0.005
8.89	.01		.00		.01				.007
9.00		.01		.03					.020
9.10	.04		.03		.05		0.03		.038
9.20		.06		.08		0.08			.073
9.30	.15		.12		.15		.14		.140
9.40		.21		.20		.22		0.16	.197
9.50	.37		.34		.36		.35		.355
9.60		.51		.51		.51		.52	.512
9.70	.82		.70		.71		.74		742
9.80		.99		.97		.95		.98	.972
9.90			1.23		1.25		1.25		1.24
0.00		1.56		1.49		1.46		1.50	1.50
0.10			1.82		1.82		1.78		1.81
0.20				2.07		2.03		2.03	2.04
0.30			2.36		2.34		2.22		2.31
0.40				2.58		2.48		2.42	2.49
0.50					2.72		2.64		2.68
0.60				3.00		2.80		2.75	2.85
0.70					3.00		2.93		2.96
0.80						3.01		3.04	3.02
0.90					3.25		3.15		3.20
1.00						3.18		3.16	3.17
1.10							3.27		3.27
1.20						3.46		3.34	3.40
1.30							3.41		3.41
1.40								3.43	3.43
1.50							3.54		3.54
1.60								3.54	3.54
1.70									
1.80								3.58	3.58

IV. COMPARISON OF INTERMITTENT AND NONINTERMITTENT EXPOSURES

In experiment 2 two exposures, one intermittent and the other nonintermittent, were made as described on adjoining parts of the same plate. In both, the same angular aperture of the sector wheel gave identical exposures to the two adjoining squares, one without interruption, the other divided into a number of equal parts (2 to 32). The continuous exposure was made on the upper half of the plate and followed by the equal intermittent exposure on the lower half.

Table 5 gives a record of the exposure conditions for experiment 2 made with an illumination of 4 candle meters, the results being given in Tables 6, 7, and 8. In the latter the first column indicates the aperture number of the sector wheel, No. 1 being the smallest and No. 13 being the largest; the second column (log E) gives the logarithm of the exposure in candle meter seconds; the third (D) gives the densities of the nonintermittent exposures; while in the next five columns, headed, respectively, by the number of exposures, are the density differences between the two kinds of exposures. The ninth column gives the mean density difference of the 8, 16, and 32 exposures, the reason for which is discussed below. The last column shows the effective exposure ratios:

$$\frac{E \text{ int.}}{E \text{ cont.}} = \frac{\text{intermittent exposure}}{\text{nonintermittent exposure}}$$

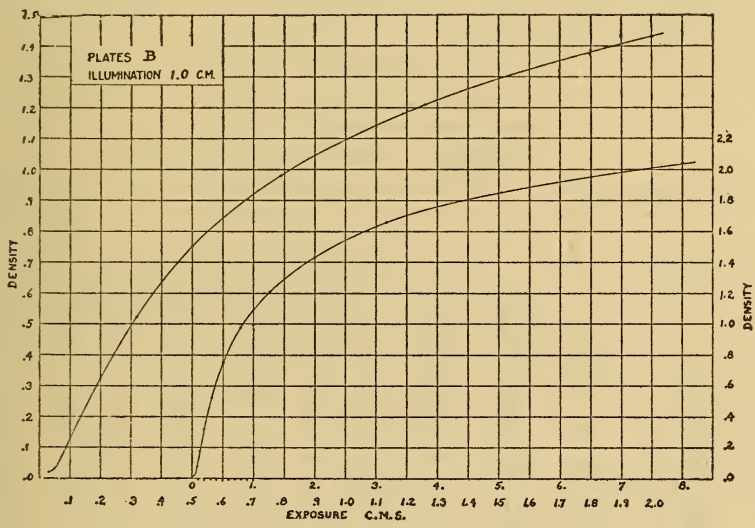

Fig. 3.—*Characteristic curves plotted with exposures as abscissas (not log exposures) used to obtain the ratio* $\frac{E \text{ int.}}{E \text{ cont.}}$

To obtain these the characteristic curve for the nonintermittent exposure was plotted (fig. 3) on a large scale, using exposures (not log exposure) as abscissas and densities (D) as ordinates. The corresponding mean density differences for 8, 16, and 32 were added to this nonintermittent density and the exposure on the characteristic curve corresponding to the intermittent density thus found, obtained as the "intermittent exposure." In the graph, the upper curve is the short exposure portion of the lower curve drawn on a larger scale.[5]

[5] For example, let the nonintermittent density =0.75 (from exposure of 0.50 candle meter second), the density difference =0.05. The sum 0.80 is the intermittent density. From the graph, density 0.80 corresponds to an exposure 0.55 candle meter second, hence

$$\frac{E \text{ int.}}{E \text{ cont.}} = \frac{0.55}{0.50} = 1.10$$

TABLE 5.—*Exposure data, experiment No. 2*

[Illumination, 4 candle meters]

Plate-holder number	Nonintermittent: Upper half of test plate		Intermittent: Lower half of test plate	
	Number of exposures	Sector-wheel speed (seconds per revolution)	Number of exposures	Sector-wheel speed (seconds per revolution)
1	1	4	2	2
2	1	4	4	1
3	1	4	8	½
4	1	4	16	¼
5	1	4	32	⅛
6	1	4	16	¼
7	1	4	32	⅛
8	1	4	----------	----------

TABLE 6.—*Experiment No. 2, plates A*

[Illumination, 4.0 candle meters]

Aperture step number	Nonintermittent		Number of exposures (density differences)						$\frac{E \text{ int.}}{E \text{ cont.}}$
	Log E	D	2	4	8	[1] 16	[1] 32	Mean of 8–16–32	
1	8.49	0.03	0.01	0.02	0.03	0.04	0.05	0.040	1.29
2	8.69	.12	.02	.03	.06	.08	.09	.077	1.28
3	8.89	.28	.03	.06	.09	.11	.12	.107	1.32
4	9.09	.47	.01	.05	.07	.11	.12	.100	1.31
5	9.29	.64	.00	.04	.07	.10	.12	.097	1.33
6	9.49	.80	−.01	.03	.05	.09	.11	.083	1.25
7	9.69	.97	−.03	.02	.05	.07	.09	.070	1.23
8	9.89	1.12	−.03	.02	.05	.07	.08	.067	1.22
9	.10	1.27	−.02	.01	.03	.04	.06	.043	1.16
10	.30	1.41	−.03	.00	.03	.03	.05	.037	1.12
11	.50	1.55	−.03	.00	.00	.02	.04	.020	1.07
12	.70	1.68	−.03	.00	.00	.01	.03	.013	1.05
13	.90	1.81	−.03	.00	.00	.00	.02	.007	1.02
Mean	-------	-------	-------	-------	-------	-------	-------	-------	1.202

[1] Means of two sets.

TABLE 7.—*Experiment No. 2, plates B*

[Illumination, 4.0 candle meters]

Aperture step number	Nonintermittent		Number of exposures (density difference)s						$\frac{E \text{ int.}}{E \text{ cont.}}$
	Log E	D	2	4	8	[1] 16	[1] 32	Mean of 8-16-32	
1	8.49	0.00	0.00	0.00	0.01	0.01	0.01	0.010	1.42
2	8.69	.02	.00	.01	.02	.02	.02	.020	1.40
3	8.89	.05	.00	.03	.03	.05	.05	.043	1.32
4	9.09	.14	−.01	.03	.07	.09	.08	.080	1.30
5	9.29	.30	−.01	.05	.08	.12	.12	.107	1.30
6	9.49	.50	−.02	.06	.09	.13	.14	.120	1.27
7	9.69	.74	−.03	.05	.09	.12	.13	.113	1.23
8	9.89	.98	−.04	.05	.09	.11	.11	.103	1.23
9	.10	1.21	−.04	.04	.06	.10	.09	.083	1.18
10	.30	1.45	−.05	.03	.04	.08	.08	.067	1.14
11	.50	1.68	−.07	.03	.03	.06	.05	.047	1.10
12	.70	1.93	−.10	.01	.01	.04	.04	.030	1.14
13	.90	2.09	−.10	.00	.00	.02	.02	.013	1.04
Mean									1.236

[1] Means of two sets.

TABLE 8.—*Experiment No. 2, plates C*

[Illumination, 4.0 candle meters]

Aperture step number	Nonintermittent		Number of exposures (density differences)						$\frac{E \text{ int.}}{E \text{ cont.}}$
	Log E	D	2	4	8	16	32	Mean of 8-16-32	
1	8.49	0.00							
2	8.69	.00							
3	8.89	.00	0.00	0.00	0.00	0.00	0.00	0.000	
4	9.09	.03	−.01	−.01	.00	.00	.00	.000	1.00
5	9.29	.09	−.03	−.01	−.01	.00	−.01	−.007	.97
6	9.49	.27	−.03	−.02	−.01	.00	.00	−.003	1.00
7	9.69	.58	−.02	.03	.03	.03	.04	.033	1.04
8	9.89	1.01	−.02	.03	.04	.05	.06	.050	1.05
9	.10	1.44	−.02	.03	.05	.06	.08	.063	1.06
10	.30	1.85	−.04	.02	.03	.05	.05	.043	1.07
11	.50	2.15	−.06	−.01	.00	.03	.03	.020	1.04
12	.70	2.36	−.09	.00	.00	.02	.01	.010	1.01
13	.90	2.52	−.07	−.01	−.02	.01	.00	−.003	.99
Mean									1.023

The results shown in Tables 6, 7, and 8 are represented in Figures 4, 8, and 12. Curve 1 is the nonintermittent characteristic curve plotted with density as ordinates and log E as abscissas. Curve 2 is the mean density difference of the 8, 16, and 32 exposures plotted on 10 times the ordinate scale of curve 1. Curve 3 (dashed), the algebraic sum of 1 and 2, is the intermittent curve.

Experiments 3, 4, and 5 differed from 2 only in the illuminations employed, namely, 1.0, 0.1, and 0.02 candle meters, respectively, in place of 4 candle meters. The exposure data and results of these three experiments are given in Tables 9 to 20, and graphically represented in Figures 5 to 7, 9 to 11, and 13 to 15.

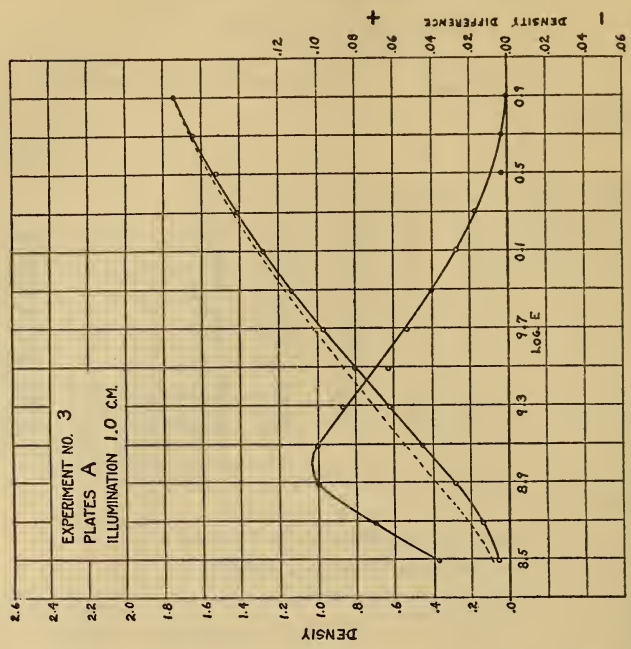

FIG. 5.—*Effect of intermittent exposures on Seed 30 plates at an illumination value of 1.0 candle meter*

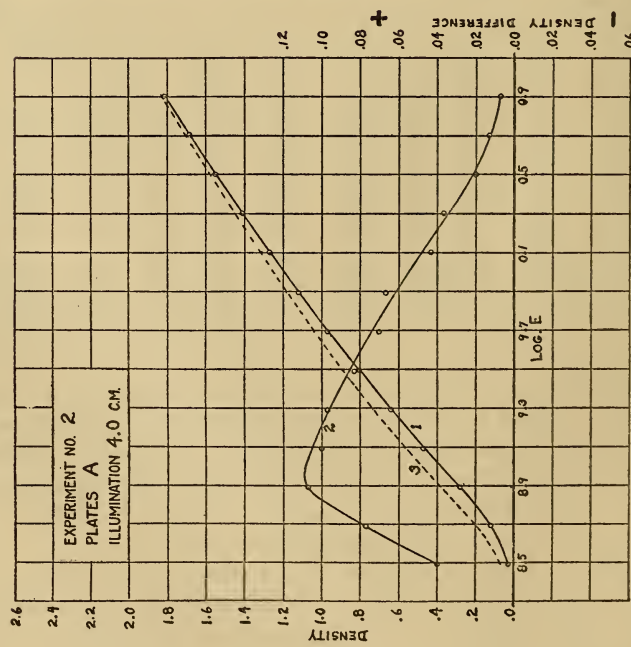

FIG. 4.—*Effect of intermittent exposures on Seed 30 plates at an illumination value of 4.0 candle meters*

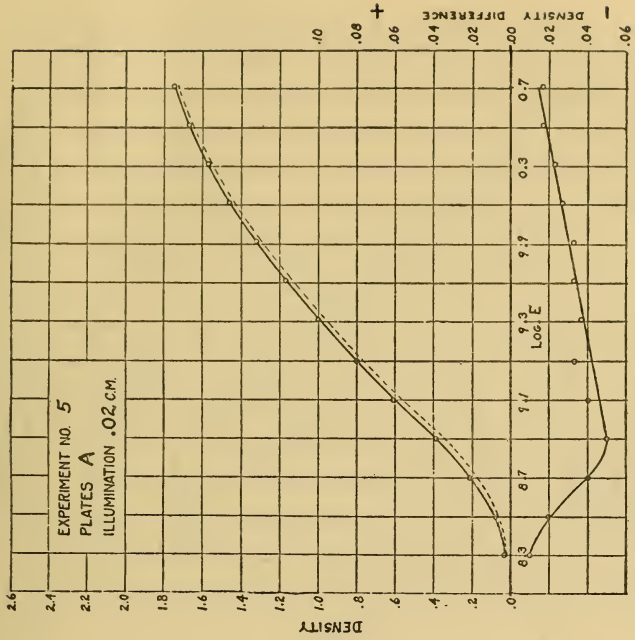

FIG. 7.—*Effect of intermittent exposures on Seed 30 plates at an illumination value of 0.02 candle meter*

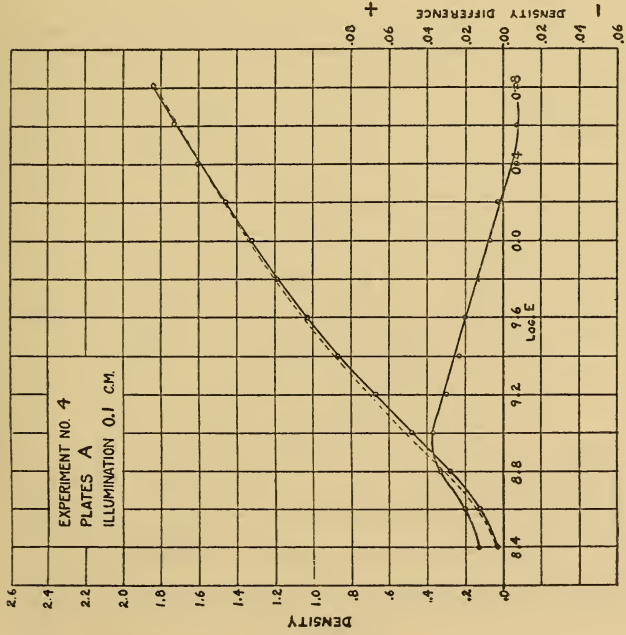

FIG. 6.—*Effect of intermittent exposures on Seed 30 plates at an illumination value of 0.1 candle meter*

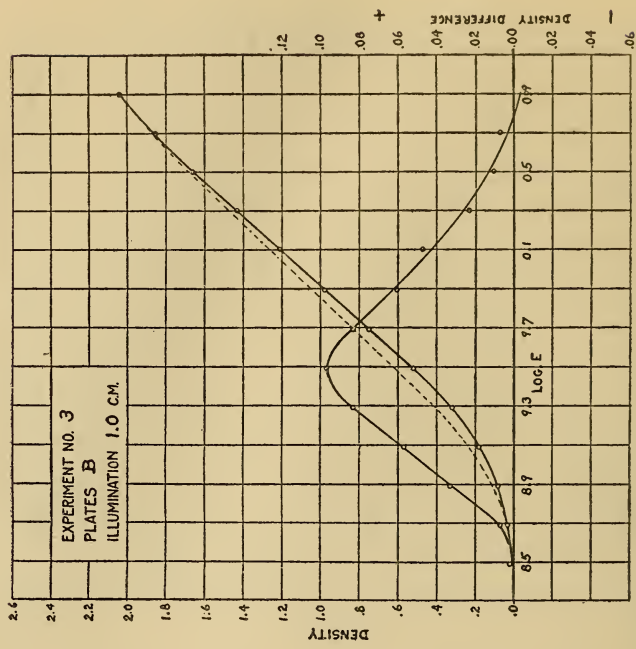

FIG. 9.—*Effect of intermittent exposures on Seed 23 plates at an illumination value of 1.0 candle meter*

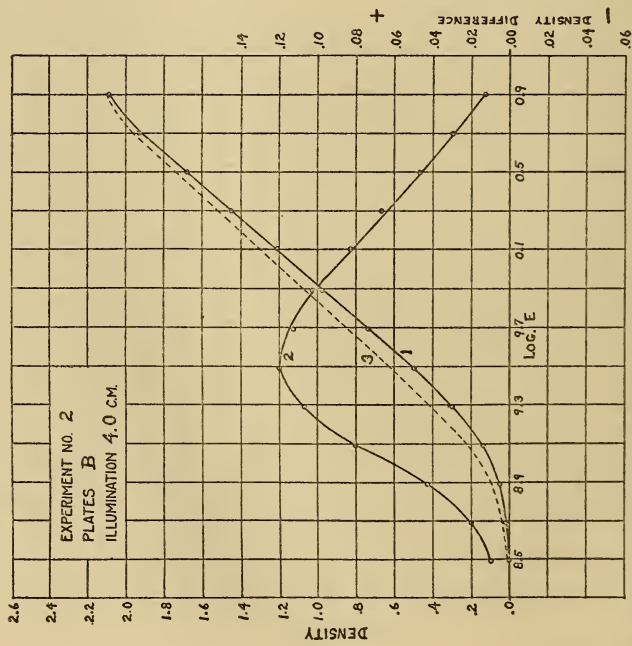

FIG. 8.—*Effect on intermittent exposures on Seed 23 plates at an illumination value of 4.0 candle meters*

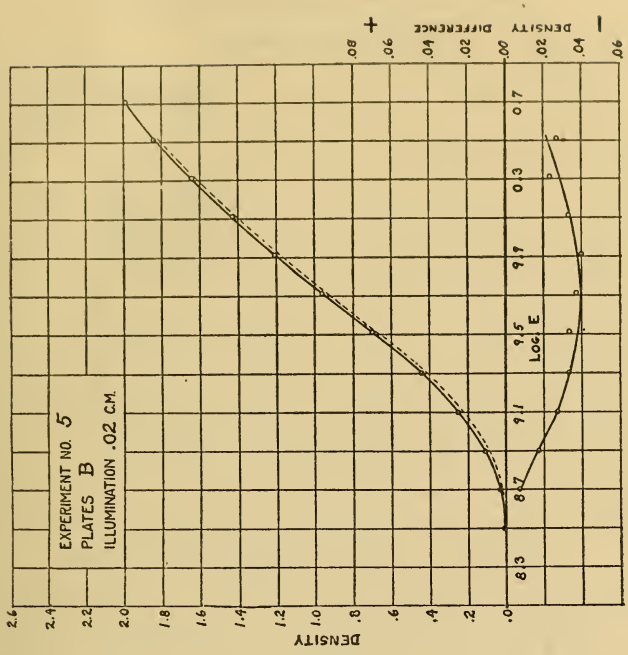

FIG. 11.—*Effect of intermittent exposures on Seed 23 plates at an illumination value of 0.02 candle meter*

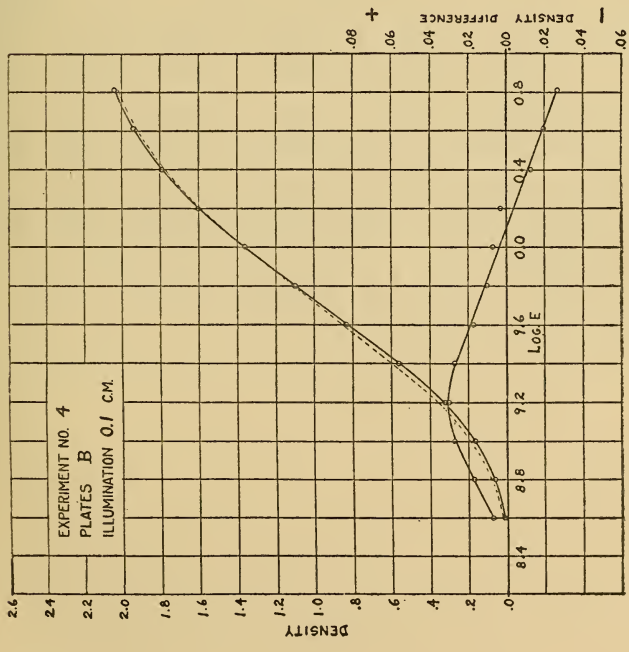

FIG. 10.—*Effect of intermittent exposures on Seed 23 plates at an illumination value of 0.1 candle meter*

TABLE 9.—*Exposure data, experiment No. 3*

[Illumination, 1 candle meter]

Plate-holder number	Nonintermittent: Upper half of test plate		Intermittent: Lower half of test plate	
	Number of exposures	Sector-wheel speed (seconds per revolution)	Number of exposures	Sector-wheel speed (seconds per revolution)
1	1	16	2	8
2	1	16	4	4
3	1	16	8	2
4	1	16	16	1
5	1	16	32	½
6	1	16	64	¼
7	1	16	128	⅛
8	1	16		

TABLE 10.—*Experiment No. 3, plates A*

[Illumination, 1.0 candle meter]

Aperture step number	Nonintermittent		Number of exposures (density differences)								$\frac{E \text{ int.}}{E \text{ cont.}}$
	Log E	D	2	4	8	16	32	64	128	Mean of 8–16–32	
1	8.49	0.06	0.00	0.01	0.02	0.04	0.05	0.06	0.05	0.037	1.32
2	8.69	.14	.00	.03	.05	.08	.08	.12	.11	.070	1.30
3	8.89	.28	.00	.05	.08	.10	.12	.14	.14	.100	1.32
4	9.09	.45	−.01	.05	.08	.10	.12	.15	.15	.100	1.33
5	9.29	.62	−.01	.03	.06	.09	.11	.14	.13	.087	1.27
6	9.49	.80	−.03	.01	.03	.07	.09	.12	.12	.063	1.19
7	9.69	.97	−.03	.01	.03	.06	.07	.11	.11	.053	1.16
8	9.89	1.13	−.05	−.01	.02	.05	.05	.09	.09	.040	1.12
9	.10	1.28	−.06	−.01	.01	.04	.03	.07	.08	.027	1.09
10	.30	1.41	−.06	−.01	.00	.04	.01	.05	.06	.017	1.06
11	.50	1.52	−.06	−.02	−.01	.02	.00	.04	.05	.003	1.01
12	.70	1.64	−.06	−.02	.00	.01	.00	.02	.03	.003	1.01
13	.90	1.74	−.04	−.02	.00	.00	.00	.00	.01	.000	1.00
Mean											1.17

TABLE 11.—*Experiment No. 3, plates B*

[Illumination, 1.0 candle meter]

Aperture step number	Noninter-mittent		Number of exposures (density differences)								$\frac{E \text{ int.}}{E \text{ cont.}}$
	Log E	D	2	4	8	16	32	64	128	Mean of 8-16-32	
1	8.49	0.02	−0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.000	-------
2	8.69	.03	−.01	.00	.00	.00	.02	.03	.02	.007	1.02
3	8.89	.08	−.02	.00	.03	.03	.04	.06	.05	.033	1.20
4	9.09	.18	−.01	.01	.05	.06	.06	.09	.09	.057	1.21
5	9.29	.32	−.01	.02	.06	.09	.10	.13	.15	.083	1.22
6	9.49	.52	−.01	.03	.07	.10	.12	.15	.17	.097	1.22
7	9.69	.75	−.02	.03	.07	.09	.09	.15	.17	.083	1.18
8	9.89	.98	−.05	.01	.05	.07	.06	.13	.15	.060	1.15
9	.10	1.21	−.07	.01	.03	.06	.05	.09	.14	.047	1.10
10	.30	1.43	−.09	−.01	.01	.03	.03	.07	.09	.023	1.05
11	.50	1.66	−.10	−.02	−.01	.03	.01	.06	.07	.010	1.02
12	.70	1.85	−.10	−.01	−.02	.03	.01	.03	.04	.007	1.00
13	.90	2.04	−.07	−.02	−.03	.01	.00	.03	.01	−.007	.98
Mean	------	------	------	------	------	------	------	------	------	------	1.11

TABLE 12.—*Experiment No. 3, plates C*

[Illumination, 1.0 candle meter]

Aperture step number	Noninter-mittent		Number of exposures (density differences)								$\frac{E \text{ int.}}{E \text{ cont.}}$
	Log E	D	2	4	8	16	32	64	128	Mean of 8-16-32	
1	8.49	------	------	------	------	------	------	------	------	------	------
2	8.69	------	------	------	------	------	------	------	------	------	------
3	8.89	------	------	------	------	------	------	------	------	------	------
4	9.09	0.03	−0.01	−0.02	0.00	−0.01	−0.01	−0.01	−0.01	−0.007	0.96
5	9.29	.11	−.03	−.02	−.02	−.02	−.03	−.02	−.02	−.023	.90
6	9.49	.26	−.04	−.01	−.01	−.01	−.03	−.01	−.01	−.017	.96
7	9.69	.53	−.05	−.02	−.02	−.01	−.03	−.02	.00	−.020	.98
8	9.89	.90	−.05	.00	.01	.01	.01	.02	.05	.010	1.01
9	.10	1.38	−.05	−.01	.01	.02	.00	.03	.05	.010	1.01
10	.30	1.85	−.05	−.01	.01	.02	.02	.03	.06	.017	1.02
11	.50	2.17	−.06	−.02	.00	.01	.00	.02	.04	.003	1.01
12	.70	2.38	−.09	−.04	.00	.01	−.01	.01	.01	.000	1.00
13	.90	2.53	−.08	------	.00	.00	−.01	−.01	.00	−.003	.99
Mean	------	------	------	------	------	------	------	------	------	------	0.984

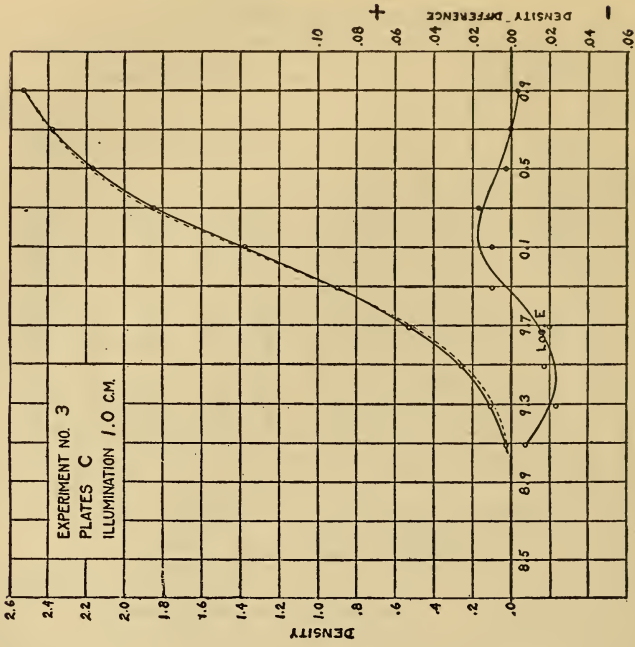

FIG. 13.—*Effect of intermittent exposures on Seed process plates at an illumination value of 1.0 candle meter*

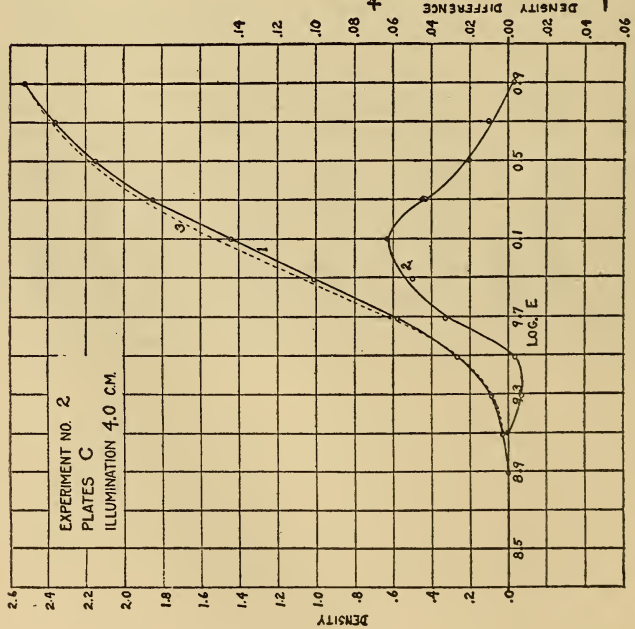

FIG. 12.—*Effect of intermittent exposures on Seed process plates at an illumination value of 4.0 candle meters*

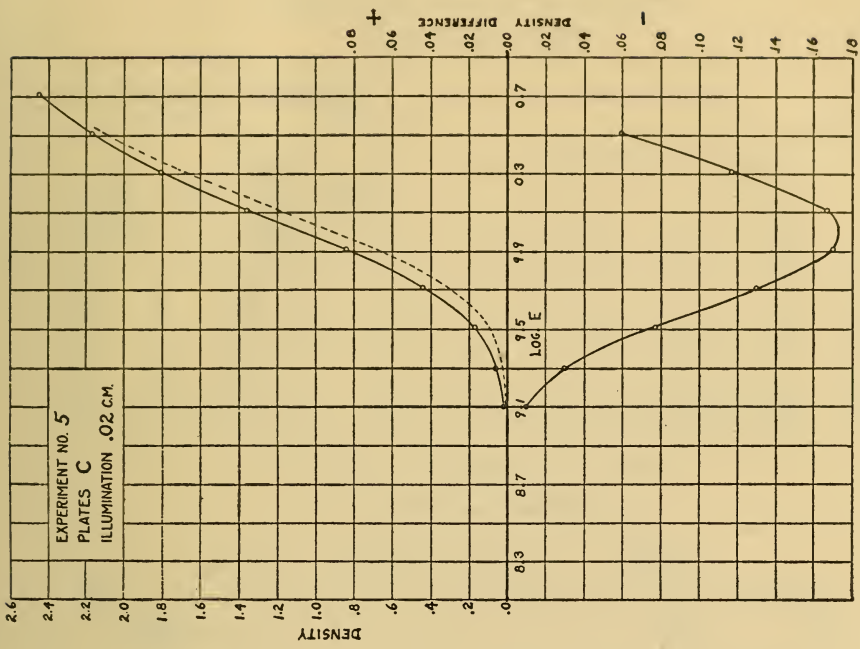

FIG. 15.—*Effect of intermittent exposures on Seed process plates at an illumination value of 0.02 candle meter*

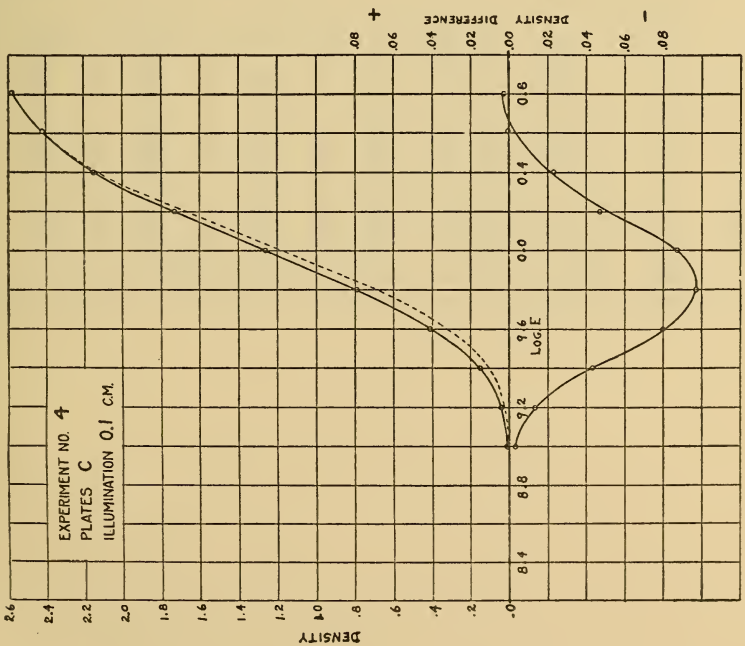

FIG. 14.—*Effect of intermittent exposures on Seed process plates at an illumination value of 0.1 candle meter*

TABLE 13.—*Exposure data, experiment No. 4*

[Illumination, 0.1 candle meter]

Plate-holder number	Nonintermittent: Upper half of test plate		Intermittent: Lower half of test plate	
	Number of exposures	Sector-wheel speed (seconds per revolution)	Number of exposures	Sector-wheel speed (seconds per revolution)
1	1	128	2	64
2	1	128	4	32
3	1	128	8	16
4	1	128	16	8
5	1	128	32	4
6	1	128	64	2
7	1	128	128	1
8	1	128		

TABLE 14.—*Experiment No. 4, plates A*

[Illumination, 0.1 candle meter]

Aperture step number	Nonintermittent		Number of exposures (density differences)								$\frac{E \text{ int.}}{E \text{ cont.}}$
	Log E	D	2	4	8	16	32	64	128	Mean of 8–16–32	
1	8.40	0.03	−0.01	−0.01	0.01	0.01	0.02	0.02	0.02	0.013	1.04
2	8.60	.12	−.01	−.01	.00	.02	.04	.04	.06	.020	1.10
3	8.80	.28	−.01	−.01	.01	.03	.06	.07	.06	.033	1.11
4	9.00	.48	.02	.00	.02	.03	.06	.07	.07	.037	1.08
5	9.20	.67	.02	.00	.01	.04	.04	.06	.07	.030	1.06
6	9.40	.87	.03	.00	.01	.04	.02	.05	.06	.023	1.07
7	9.60	1.03	.03	.01	.01	.05	.00	.03	.05	.020	1.05
8	9.80	1.19	−.03	.00	.00	.05	−.01	.03	.03	.013	1.04
9	.00	1.32	−.03	−.01	.00	.03	−.01	.01	−.01	.007	1.02
10	.20	1.46	−.03	−.02	.00	.02	−.01	.01	−.02	.003	1.01
11	.40	1.60	−.01	−.03	−.01	.00	−.01	.00	−.02	−.007	.97
12	.61	1.73	.00	−.02	.00	−.01	−.01	.00	−.03	−.007	.96
13	.81	1.84	.00	−.01	−.01	−.01	.00	−.01	−.03	−.007	.96
Mean											1.03

TABLE 15.—*Experiment No. 4, plates B*

[Illumination, 0.1 candle meter]

Aperture step number	Noninter-mittent		Number of exposures (density differences)								$\frac{E \text{ int.}}{E \text{ cont.}}$
	Log E	D	2	4	8	16	32	64	128	Mean of 8–16–32	
1	8.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000	-------
2	8.60	.01	−.01	−.01	.00	.01	.01	.00	.01	.007	1.08
3	8.80	.06	−.01	−.01	.01	.02	.02	.01	.03	.017	1.09
4	9.00	.16	−.03	−.01	.02	.03	.03	.03	.05	.027	1.10
5	9.20	.32	−.03	.00	.01	.04	.04	.05	.07	.030	1.07
6	9.40	.56	−.04	.00	.00	.03	.05	.06	.06	.027	1.10
7	9.60	.83	−.04	.00	−.01	.03	.03	.03	.05	.017	1.03
8	9.80	1.10	−.05	−.01	−.02	.03	.02	.01	.03	.010	1.02
9	.00	1.36	−.05	−.01	−.03	.03	.02	.01	.02	.007	1.01
10	.20	1.60	−.05	−.02	−.02	.02	.01	.00	.01	.003	1.01
11	.40	1.79	−.05	−.03	−.03	.00	−.01	−.02	.00	−.013	.96
12	.61	1.94	−.06	−.04	−.03	−.01	−.02	−.03	−.01	−.020	.93
13	.81	2.04	−.05	−.03	−.03	−.02	−.03	−.03	−.03	−.027	.87
Mean	------	------	------	------	------	------	------	------	------	------	1.02

TABLE 16.—*Experiment No. 4, plates C*

[Illumination, 0.1 candle meter]

Aperture step number	Noninter-mittent		Number of exposures (density differences)								$\frac{E \text{ int.}}{E \text{ cont.}}$
	Log E	D	2	4	8	16	32	64	128	Mean of 8–16–32	
1	8.40	0.00	------	------	------	------	------	------	------	------	-------
2	8.60	.00	------	------	------	------	------	------	------	------	-------
3	8.80	.00	------	------	------	------	------	------	------	------	-------
4	9.00	.01	0.00	0.00	0.00	0.00	−0.01	−0.01	−0.01	−0.003	-------
5	9.20	.04	.00	−.01	−.01	−.01	−.02	−.03	−.02	−.013	0.89
6	9.40	.15	−.01	−.03	−.03	−.05	−.05	−.05	−.04	−.043	.89
7	9.60	.41	−.03	−.04	−.06	−.09	−.09	−.09	−.09	−.080	.89
8	9.80	.79	−.06	−.05	−.07	−.12	−.10	−.12	−.12	−.097	.91
9	.00	1.26	−.07	−.03	−.04	−.11	−.11	−.12	−.12	−.087	.92
10	.20	1.73	−.08	−.01	.00	−.07	−.07	−.08	−.09	−.047	.95
11	.40	2.15	−.08	−.02	.00	−.03	−.04	−.05	−.05	−.023	.98
12	.61	2.42	−.08	−.02	.00	.01	−.01	−.03	−.04	.000	1.00
13	.81	2.58	−.08	−.02	.00	.01	.00	.00	−.01	.003	1.01
Mean	------	------	------	------	------	------	------	------	------	------	.93

TABLE 17.—*Exposure data, experiment No. 5*

[Illumination, 0.02 candle meter]

Plate-holder number	Nonintermittent: Upper half of test plate		Intermittent: Lower half of test plate	
	Number of exposures	Sector-wheel speed (seconds per revolution)	Number of exposures	Sector-wheel speed (seconds per revolution)
1	1	512	2	256
2	1	512	4	128
3	1	512	8	64
4	1	512	16	32
5	1	512	32	16
6	1	512	64	8
7	1	512	128	4
8	1	512		

TABLE 18.—*Experiment No. 5, plates A*

[Illumination, 0.02 candle meter]

Aperture step number	Nonintermittent		Number of exposures (density differences)								$\frac{E \text{ int.}}{E \text{ cont.}}$
	Log E	D	2	4	8	16	32	64	128	Mean of 8–16–32	
1	8.30	0.03	−0.01	−0.01	−0.01	−0.01	−0.01	0.00	0.00	−0.010	
2	8.50	.08	−.02	−.02	−.02	−.02	−.02	−.01	.00	−.020	0.91
3	8.70	.21	−.03	−.03	−.04	−.04	−.04	.00	.00	−.040	.88
4	8.90	.39	−.04	−.05	−.06	−.05	−.04	−.01	.01	−.050	.91
5	9.10	.61	−.05	−.03	−.05	−.04	−.03	−.01	.01	−.040	.93
6	9.30	.80	−.05	−.01	−.04	−.03	−.03	−.01	.00	−.033	.93
7	9.51	1.00	−.05	.00	−.05	−.03	−.03	−.02	−.01	−.037	.92
8	9.71	1.17	−.05	−.01	−.05	−.03	−.02	−.02	−.01	−.033	.91
9	9.91	1.32	−.06	−.04	−.04	−.03	−.03	−.02	.00	−.033	.90
10	.11	1.46	−.05	−.06	−.03	−.02	−.03	−.01	.00	−.027	.92
11	.31	1.57	−.04	−.05	−.03	−.01	−.03	−.01	−.01	−.023	.90
12	.51	1.67	−.04	−.05	−.02	.00	−.03	−.03	.01	−.017	.93
13	.71	1.75	−.04	−.03	−.01	−.01	−.03	−.03	.00	−.017	.89
Mean											.91

TABLE 19.—*Experiment No. 5, plates B*

[Illumination, 0.02 candle meter]

Aperture step number	Noninter-mittent		Number of exposures (density differences)								$\frac{E \text{ int.}}{E \text{ cont.}}$
	Log E	D	2	4	8	16	32	64	128	Mean of 8–16–32	
1	8.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000	--------
2	8.50	.01	.00	.00	.00	.00	.00	.00	.00	.000	--------
3	8.70	.03	−.01	−.02	−.01	.00	−.01	−.01	.00	−.007	0.94
4	8.90	.11	−.03	−.03	−.02	−.01	−.02	−.01	−.01	−.017	.91
5	9.10	.25	−.05	−.05	−.03	−.02	−.03	−.01	−.01	−.027	.91
6	9.30	.44	−.05	−.05	−.04	−.03	−.03	−.02	−.01	−.033	.93
7	9.51	.70	−.05	−.05	−.04	−.02	−.04	−.03	−.02	−.033	.95
8	9.71	.96	−.05	−.04	−.04	−.01	−.06	−.02	−.03	−.037	.95
9	9.91	1.21	−.07	−.04	−.04	−.01	−.07	−.03	−.03	−.040	.92
10	.11	1.43	−.08	−.04	−.03	−.01	−.06	−.03	−.03	−.033	.94
11	.31	1.64	−.09	−.05	−.01	−.02	−.04	−.03	−.03	−.023	.96
12	.51	1.84	−.11	−.05	−.01	−.03	−.04	−.03	−.01	−.027	.94
13	.71.	1.99	−.12	(1)	(1)	−.03	(1)	(1)	−.01	(1)	--------
Mean	-------	-------	-------	-------	-------	-------	-------	-------	-------	--------	.93

[1] Defective plates.

TABLE 20.—*Experiment No. 5, plates C*

[Illumination, 0.02 candle meter]

Aperture step number	Noninter-mittent		Number of exposures (density differences)								$\frac{E \text{ int.}}{E \text{ cont.}}$
	Log E	D	2	4	8	16	32	64	128	Mean of 8–16–32	
1	8.30	-------	-------	-------	-------	-------	-------	-------	-------	--------	------
2	8.50	-------	-------	-------	-------	-------	-------	-------	-------	--------	-------
3	8.70	-------	-------	-------	-------	-------	-------	-------	-------	--------	--------
4	8.90	-------	-------	-------	-------	-------	-------	-------	-------	--------	--------
5	9.10	0.02	−0.01	−0.01	−0.01	−0.01	−0.01	−0.01	−0.01	−0.010	0.79
6	9.30	.06	−.03	−.02	−.03	−.03	−.03	−.04	−.03	−.030	.75
7	9.51	.17	−.05	−.05	−.07	−.06	−.10	−.09	−.09	−.077	.75
8	9.71	.44	−.08	−.09	−.12	−.12	−.15	−.17	−.15	−.130	.83
9	9.91	.84	−.11	−.11	−.15	−.16	−.20	−.22	−.19	−.170	.84
10	.11	1.36	−.10	−.13	−.13	−.16	−.21	(1)	−.18	−.167	.86
11	.31	1.81	−.12	−.08	−.10	−.10	−.15	(1)	−.12	−.117	.89
12	.51	2.17	−.12	−.06	−.03	−.05	−.10	(1)	(1)	−.060	.93
13	.71	2.45	−.11	−.04	−.03	(1)	(1)	(1)	−.03	--------	--------
Mean	-------	-------	-------	-------	-------	-------	-------	-------	-------	--------	.88

[1] Defective plates.

From experiments 2, 3, 4, and 5 it is seen that the effect of intermittent exposure depends upon at least four factors, namely, the illumination, the number of interruptions, the length of the rest periods or the ratio of the rest period to exposure period, and the value of the exposure. That the intermittent exposure may result in a gain instead of a loss has not been heretofore brought out. That this is real seems beyond doubt; furthermore it is not a property peculiar to the above emulsions (see below), as others are found to

show the same effects. Additional proof is furnished by the regularity with which the effect varies with the illumination as seen in Figure 16, in which the mean ratio is plotted against the logarithm of the illumination. In this figure the dashed straight lines are inserted for comparison.

It will also be noted that the density differences for those plates receiving as low as two exposures (one interruption) are in nearly

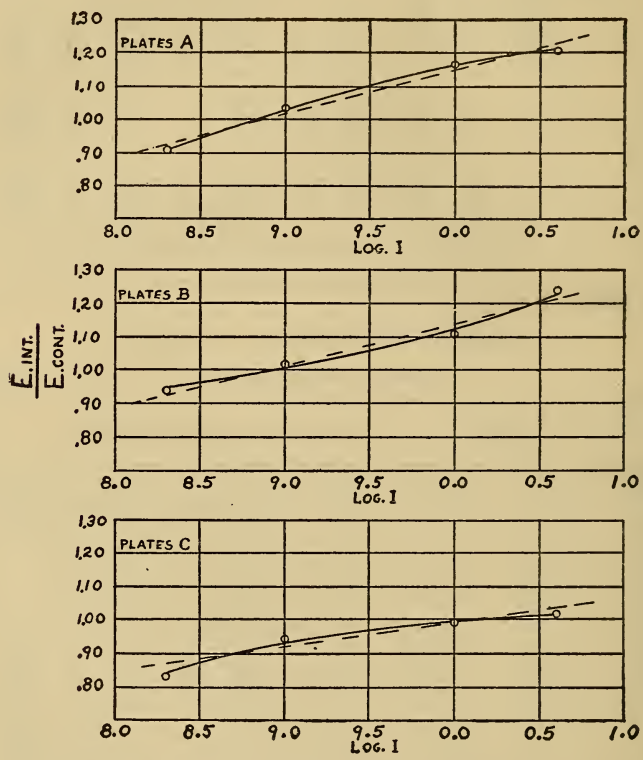

FIG. 16.—*Curves showing the regularity with which the intermittency effect varies with illumination*

every case observed as negative values; that is, the intermittent exposure is less effective than the equal continuous exposure.

To simplify the comparison of the density differences obtained at the four intensity levels the 8, 16, and 32 exposures were averaged and these results used in plotting the curves given. This was considered permissible in that the effects vary quite regularly in direction and magnitude with intermittence. In addition, the average should, in a measure, increase the accuracy of the plotted data.

Inspection of Tables 6 to 20 shows an effect which progresses regularly with the number of interruptions at any given intensity

level and also with change of intensity at any given number of interruptions. Space does not permit presenting a complete set of curves, so those for a single intensity level (1.0 candle meter) were selected (figs. 17, 18, and 19).

V. INFLUENCE OF THE SECTOR-WHEEL APERTURE

In the foregoing experiments, all similar exposures at a given illumination were made with the same apertures of the sector wheel. The influence of the aperture size or ratio of rest period to exposure period was thus kept constant in each experiment for each exposure value. The following test (experiment 6) was performed to bring out the effect of the rest periods. The number of interruptions and the illumination were maintained constant and the total exposure time varied. By this procedure several equal exposures were made with different apertures of the sector wheel, according to the plan of Table 21.

The corresponding density measurements are found in Tables 22, 23, and 24. In these, as before, the first column gives the logarithm of the exposure, the second the nonintermittent density, and the other seven the measured density difference between the intermittent and nonintermittent exposure. The 13 values in each of these columns correspond to the 13 steps in the sector wheel, the first value being from the smallest aperture and the last from the largest.

TABLE 21.—*Exposure data, experiment No. 6*

[Illumination, 1.0 candle meter]

Plate-holder number	Nonintermittent: Upper half of test plate		Intermittent: Lower half of test plate	
	Number of exposures	Sector-wheel speed (seconds per revolution)	Number of exposures	Sector-wheel speed (seconds per revolution)
1	1	2	16	1/8
2	1	4	16	1/4
3	1	8	16	1/2
4	1	16	16	1
5	1	32	16	2
6	1	64	16	4
7	1	128	16	8
8	1	16		

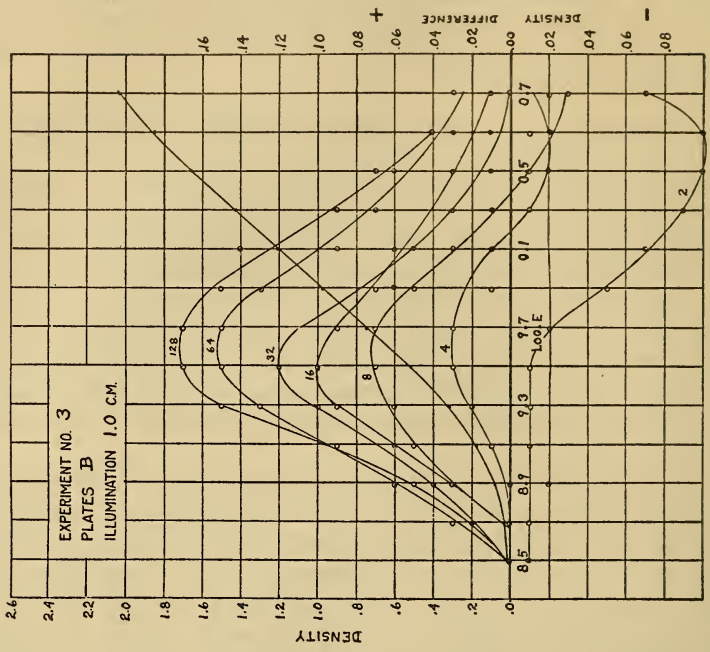

FIG. 18.—*A family of curves showing the effect of intermittency on Seed 23 plates*

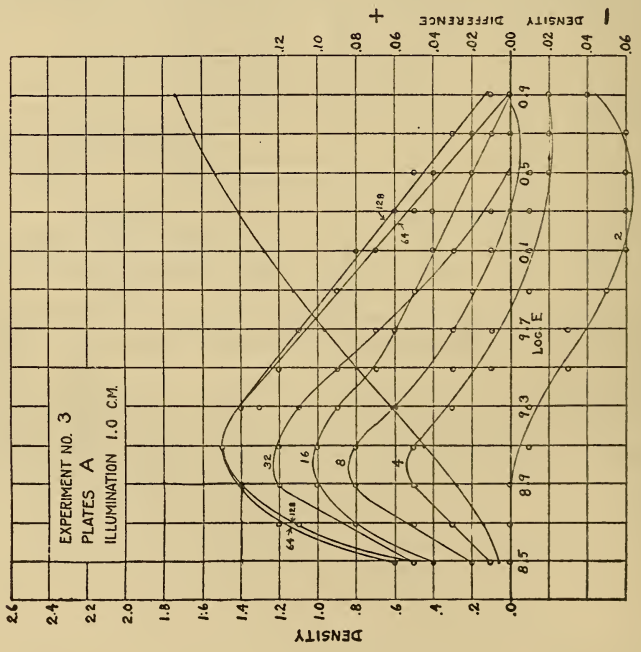

FIG. 17.—*A family of curves showing the effect of intermittency on Seed 30 plates*

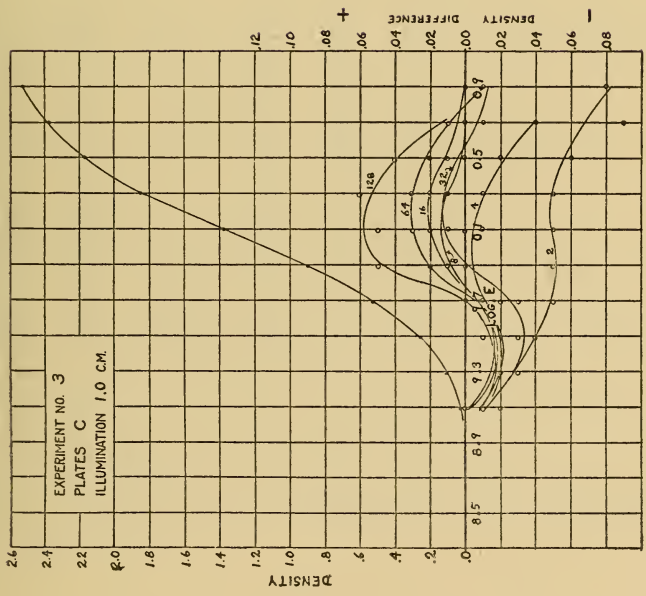

FIG. 19.—*A family of curves showing the effect on intermittency on Seed process plates*

TABLE 22.—*Experiment No. 6, plates A*

[Illumination, 1 candle meter]

Log E	8	1	2	3	4	5	6	7
7.60		0.00						
7.70								
7.80		.00						
7.90			0.00					
8.00		−.01						
8.10			.00					
8.20		.00		0.01				
8.30			.01					
8.40		.01		.02				
8.50	0.05		.03		0.04			
8.60		.03		.04				
8.70	.15		.05		.06			
8.80		.05		.06		0.08		
8.90	.31		.06		.08			
9.00		.04		.07		.10		
9.10	.49		.06		.09		0.12	
9.20		.03		.05		.11		
9.30	.66		.05		.08		.12	
9.40		.00		.05		.12		0.11
9.50	.84		.04		.06		.10	
9.60		−.01		.04		.12		.11
9.70	1.00		.03		.06		.08	
9.80		−.01		.03		.12		.09
9.90	1.15		.03		.05		.06	
0.00		−.01		.01		.11		.08
0.10	1.29		.01		.04		.03	
0.20				.00		.09		.03
0.30	1.41		.00		.03		.03	
0.40				.00		.06		.06
0.50	1.51				.02		.03	
0.60				.00		.03		.05
0.70	1.61				.00		.02	
0.80						.00		.03
0.90	1.68				−.01		.03	
1.00						−.01		.03
1.10							.03	
1.20						−.02		.03
1.30							.03	
1.40								.03
1.51							.00	
1.61								.02
1.71								
1.81								.01

TABLE 23.—*Experiment No. 6, plates B*

[Illumination, 1 candle meter]

Log E	8	1	2	3	4	5	6	7
7.60		0.00						
7.70								
7.80		.00						
7.90			0.00					
8.00		.00						
8.10			.00					
8.20		.00		0.00				
8.30			.01					
8.40		.00		.00				
8.50	0.01		.02		0.01			
8.60		.01		.00				
8.70	.03		.03		.01			
8.80		.02		.02		0.04		
8.90	.07		.04		.03			
9.00		.03		.04		.05		
9.10	.15		.05		.06		0.09	
9.20		.04		.06		.08		
9.30	.32		.07		.10		.09	
9.40		.04		.09		.12		0.12
9.50	.53		.09		.13		.11	
9.60		.02		.09		.12		.13
9.70	.76		.08		.12		.11	
9.80		.01		.08		.12		.13
9.90	.99		.06		.09		.09	
0.00				.06		.09		(1)
0.10	1.24		.05		.06		.08	
0.20				.03		.06		.11
0.30	1.47		.03		.04		.07	
0.40				.01		.05		09
0.50	1.69				.04		.06	
0.60				(1)		.04		.08
0.70	1.89				.02		.05	
0.80						.02		.06
0.90	2.04				.00		.03	
1.00						.01		.08
1.10							.02	
1.20						.01		(1)
1.30							.01	
1.40								.04
1.51							.02	
1.61								.04
1.71								
1.81								.03

[1] Defective plate.

TABLE 24.—*Experiment No. 6, plates C*

[Illumination, 1 candle meter]

Log E	8	1	2	3	4	5	6	7
7.60		0.00						
7.70								
7.80		.00						
7.90			0.00					
8.00		.00						
8.10			.00					
8.20		.00		0.00				
8.30			.00					
8.40		.00		.00				
8.50	0.00		.00		0.00			
8.60		.00		.00				
8.70	.00		.00		.00			
8.80		.00		.00		0.00		
8.90	.01		.00		.00			
9.00		.00		.00		−.01		
9.10	.04		.00		−.01		0.00	
9.20		.01		.01		−.03		
9.30	.12		−.01		−.02		−.01	
9.40		.01		−.01		−.02		−0.02
9.50	.29		−.01		−.02		−.01	
9.60		.01		−.01		.00		−.01
9.70	.57		−.01		.02		−.01	
9.80		−.01		−.01		.05		.03
9.90	.95		.00		.01		.01	
0.00		−.04		.01		.05		.05
0.10	1.43		.00		.02		.05	
0.20				.01		.09		.08
0.30	1.85		−.01		.04		.02	
0.40				.00		.07		.08
0.50	2.15				.02		−.02	
0.60				−.02		.03		.05
0.70	2.36				.01		−.05	
0.80						−.01		.05
0.90	2.61				.00		−.05	
1.00						−.06		.03
1.10							−.03	
1.20						−.08		.01
1.30							−.03	
1.40								.01
1.51							−.02	
1.61								(1)
1.71								
1.81								(1)

[1] Defective plate.

By counting from the top the number of the sector-wheel step is obtained. The approximate ratios of the rest period to the exposure for each step of the sector wheel in these experiments are as follows:

Sector-wheel step [1]	Rest period / Exposure period	Sector-wheel step [1]	Rest period / Exposure period
1	511	8	19
2	322	9	12
3	202	10	7
4	127	11	4
5	80	12	2
6	50	13	1
7	31		

[1] The calibration of the sector-wheel apertures is given in B. S. Sci. Paper No. 511, p. 357, Table 4. The apertures of this sector wheel are cut to high precision.

The corresponding curves are shown in Figures 20, 21, and 22. These are identified by Nos. 1 2, 3, etc., corresponding to the plate-holder numbers given in the previous tables. A distinct and fairly regular variation in the intermittency effect is exhibited by these graphs. The changes in the density difference with an increase of rest period is quite marked. The progressive change of shape of the curves also resembles, to a marked degree, that caused by varying the number of interruptions in experiment 3. These data seem to indicate that the change in the silver halide caused by light (formation of latent image) continues for a period after the exposure has stopped.

A last test with these emulsions (experiment 7) was performed to determine the effect of longer rest periods than were given in experiment 6. In this the intermittent exposures were made as before (16 exposures), except that the exposure was omitted during certain revolutions of the sector wheel; thus the rest periods were greatly increased. Table 25 makes this clear.

The exposures, taking place during every eighth, sixteenth, and thirty-second revolution of the sector wheel, were obtained by using the auxiliary shutter wheel described in B. S. Sci. Paper No. 511, p. 362, together with the timing device mentioned above. The results are given in Tables 26, 27, and 28 and curves in Figures 23, 24, and 25. As seen by comparing curves 1, 2, 3, and 4 of each figure, the longer rest periods have but little additional effect on the A and B plates except in the high densities, and there the density appears to gain slightly with an increase in the rest period. The C plates show, on the other hand, the same effect for the high densities and the opposite effect, a distinct loss in the lower part of the characteristic curve with an increase of the rest period.

TABLE 25.—*Exposure data, experiment No. 7*

[Illumination, 1 candle meter]

Plate-holder number	Nonintermittent: Upper half of test plate		Intermittent: Lower half of test plate	
	Number of exposures	Sector-wheel speed (seconds per revolution)	Number of exposures	Sector-wheel speed
1	1	16	16	1 revolution per second, exposed every revolution.
2	1	16	16	1 revolution per second, exposed every eighth revolution.
3	1	16	16	1 revolution per second, exposed every sixteenth revolution.
4	1	16	16	1 revolution per second, exposed every thirty-second revolution.
5	1	16		

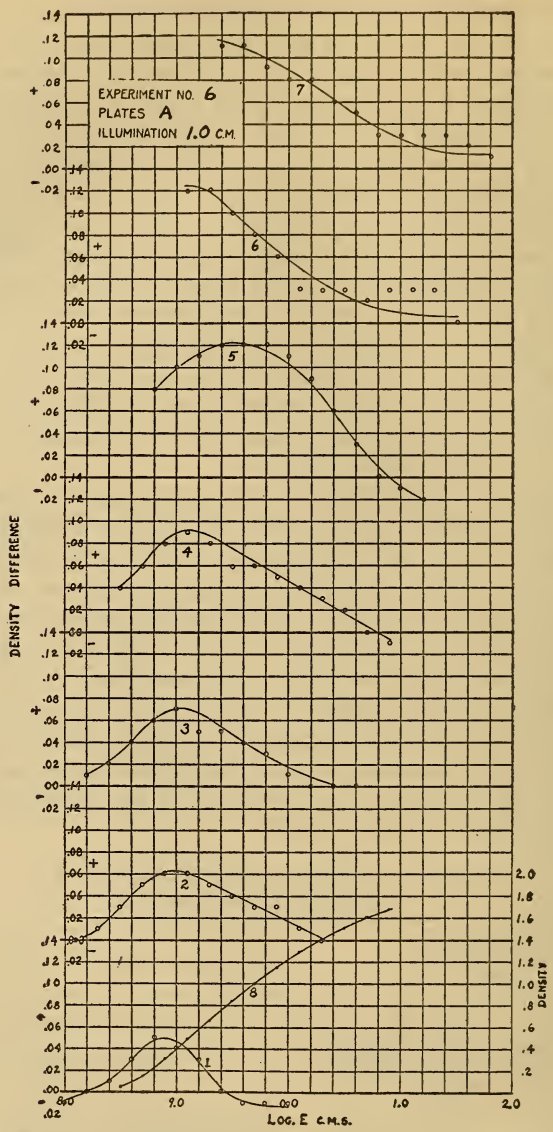

FIG. 20.—*Progressive change in the intermittency effect with increased rest period between exposures on Seed 30 plates*

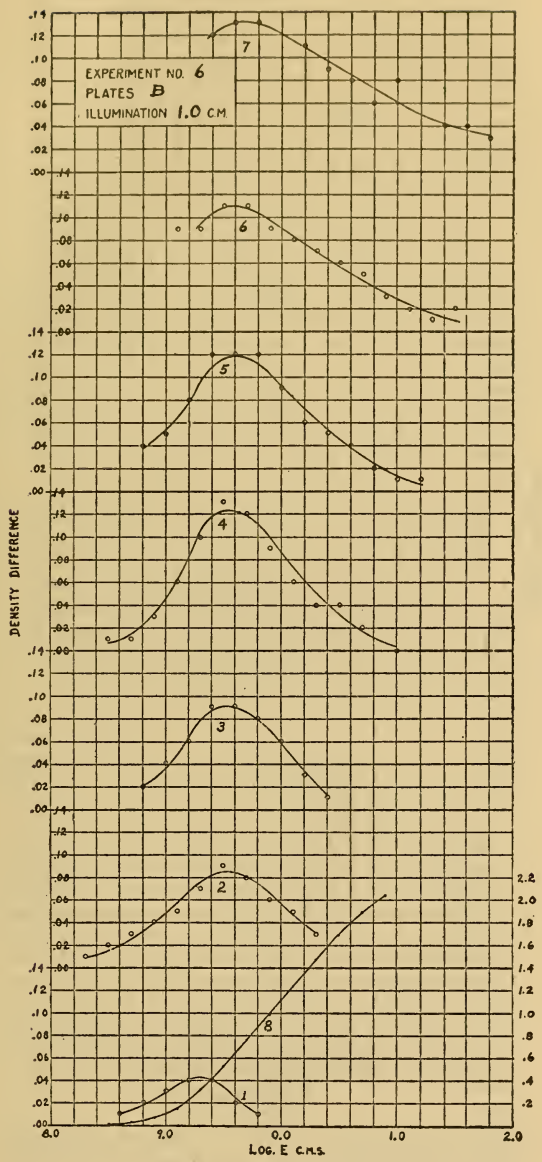

FIG. 21.—*Progressive change in the intermittency effect with increased rest period between exposures on Seed 23 plates*

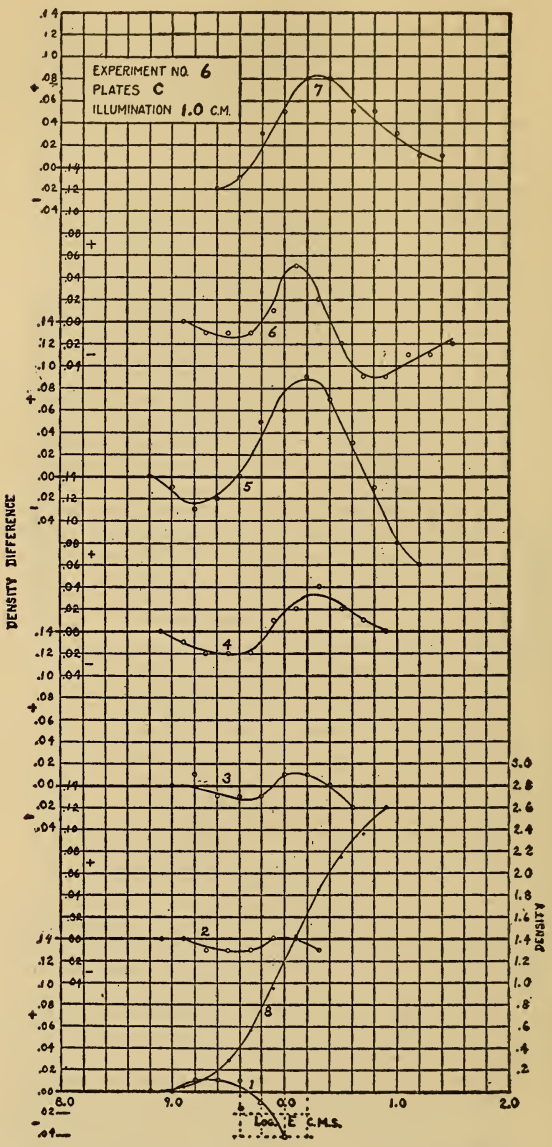

FIG. 22.—*Progressive change in the intermittency effect with increased rest period between exposures on Seed process plates*

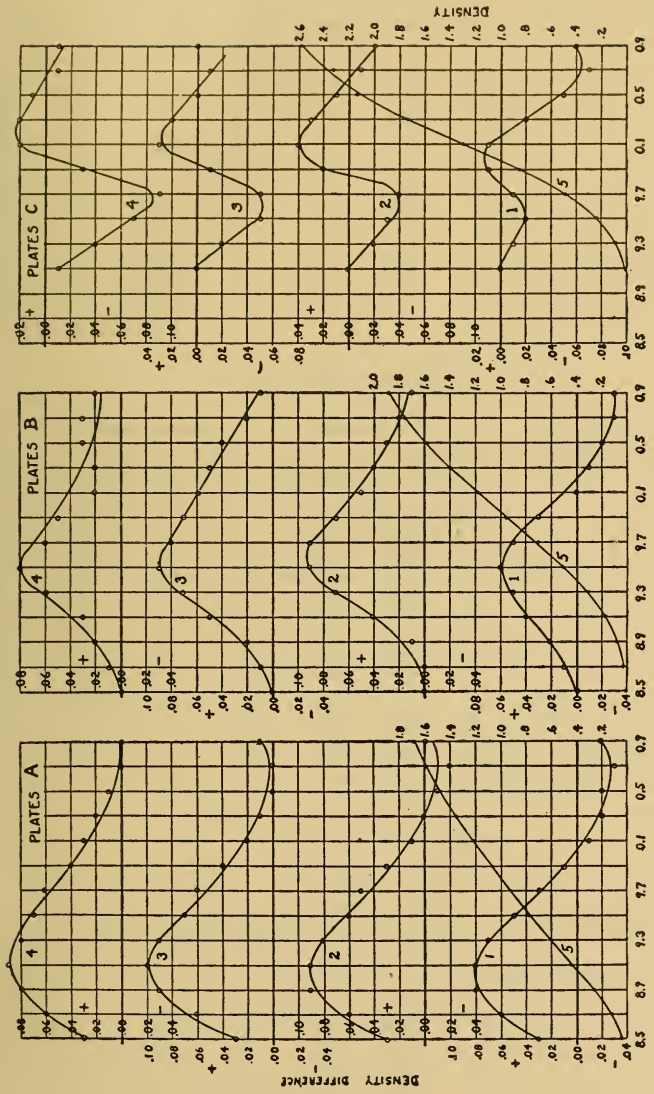

FIG. 23

FIG. 24

FIG. 25

Curves obtained by further increasing the length of the rest periods between exposures

TABLE 26.—*Experiment No. 7, plates A*

[Illumination, 1 candle meter]

Aperture step number	Log E	Density	Density differences			
		Holder No. 5	Holder No. 1	Holder No. 2	Holder No. 3	Holder No. 4
1	8.50	0.05	0.03	0.03	0.03	0.03
2	8.70	.12	.06	.06	.06	.06
3	8.90	.26	.08	.09	.09	.08
4	9.10	.45	.08	.09	.10	.09
5	9.30	.60	.07	.08	.09	.08
6	9.50	.78	.05	.06	.07	.07
7	9.70	.92	.03	.05	.06	.06
8	9.90	1.07	.01	.03	.04	.04
9	.10	1.21	−.01	.01	.02	.03
10	.30	1.35	−.02	.00	.01	.02
11	.50	1.47	−.02	−.01	.00	.01
12	.70	1.57	−.03	−.02	.00	.00
13	.90	1.69	−.02	.00	.01	.00

TABLE 27.—*Experiment No. 7, plates B*

[Illumination, 1 candle meter]

Aperture step number	Log E	Density	Density differences			
		Holder No. 5	Holder No. 1	Holder No. 2	Holder No. 3	Holder No. 4
1	8.50	0.01	0.00	0.00	0.00	0.00
2	8.70	.03	.01	.00	.01	.01
3	8.90	.08	.02	.01	.02	.02
4	9.10	.17	.04	.04	.05	.03
5	9.30	.31	.05	.07	.07	.06
6	9.50	.51	.06	.09	.09	.08
7	9.70	.71	.05	.09	.08	.06
8	9.90	.96	.03	.07	.07	.05
9	.10	1.18	.00	.05	.06	.02
10	.30	1.40	−.01	.04	.05	.02
11	.50	1.58	−.02	.03	.04	.03
12	.70	1.76	−.03	.02	.02	.03
13	.90	1.89	−.03	.01	.01	.02

TABLE 28.—*Experiment No. 7, plates C*

[Illumination, 1 candle meter]

Aperture step number	Log E	Density	Density differences			
		Holder No. 5	Holder No. 1	Holder No. 2	Holder No. 3	Holder No. 4
1	8.50	----------	----------	----------	----------	----------
2	8.70	----------	----------	----------	----------	----------
3	8.90	----------	----------	----------	----------	----------
4	9.10	0.02	0.00	0.00	0.00	−0.01
5	9.30	.09	−.01	−.02	−.02	−.04
6	9.50	.24	−.02	−.03	−.05	−.07
7	9.70	.49	−.01	−.04	−.05	−.09
8	9.90	.85	.01	.02	−.01	−.03
9	.10	1.30	.01	.04	.03	.02
10	.30	1.74	−.02	.03	.02	.02
11	.50	2.14	−.05	.01	.00	.01
12	.70	2.33	−.07	−.01	−.01	−.01
13	.90	2.58	−.06	−.02	.00	−.01

VI. INTERMITTENT EFFECTS ON OTHER EMULSIONS

Similar intermittency effects were found with other types of plates, three of which are reported under experiment 8. These plates, Eastman D. C. Ortho., Eastman 33, and Seed 26X, indicated as D, E, and F, respectively, were exposed as in Table 9. The first two emulsions were very fresh; and the last, though not fresh, was in good condition. In this experiment the development was carried out in a tank using core racks, so were not brushed. The developer was metol hydroquinone with bromide. Figures 26, 27, and 28 give the nonintermittent characteristic curves and the mean density differences for the 8, 16, and 32 exposures. The curves of Figures 26 and 27 are specially interesting in that they show two maxima. Of these, plate D is double coated, two emulsions with different speeds; while plate E, though single coated, is apparently a mixture of two emulsions.

VII. GENERAL DISCUSSION

The data given under experiments 1 to 7 are representative of three times as many observations made on the three emulsions selected for the crucial part of this investigation. The density values were in all cases measured at least twice, necessitating for this part of the work alone, more than 14,000 observations.

Considering the number of independent variations in the imposed conditions there does not seem to be the remotest chance that the observed effects are caused by systematic errors in the sensitometer. It is of interest in this connection to note that in one of Schwarzschild's experiments with intermittent exposures (Table, p. 94) he gives a series of results which show both types of intermittency effect found in this work. Schwarzschild did not believe it possible for the intermittent exposure to give a greater density than the equal continuous exposure, so he ascribed his results to "errors in experiment."

It was noticed that in the warm weather (absolute moisture content of the air higher) the magnitude of the intermittency effects were slightly greater than the results shown here—obtained in September and the first week in October. Some differences may be seen when the curves of experiment 2 are compared with curve 4 of experiment 6, and curve 1 of experiment 7, in which the exposure conditions were identical. These are believed to be due, in part, to the variations of humidity, or moisture content, of the emulsions on different days, although plates were exposed only in fair weather.

The most interesting fact brought out by the investigation is that the intermittent exposures may, under certain conditions, exceed the nonintermittent exposures in photographic effectiveness. The mag-

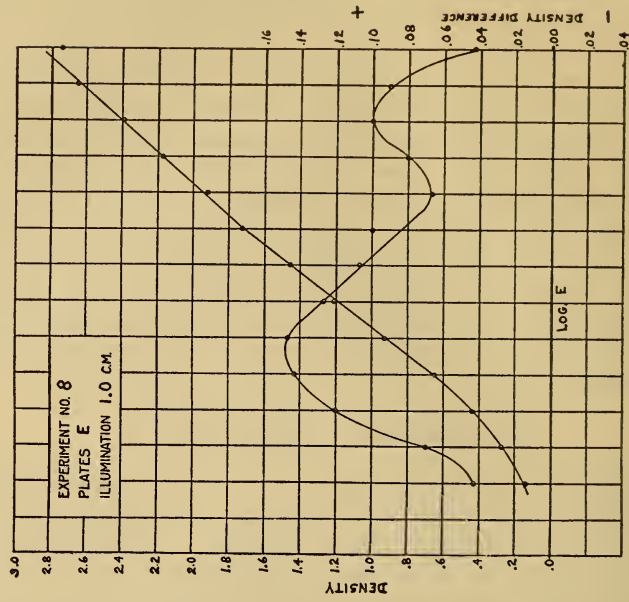

FIG. 27.—*Intermittency effects on Eastman 33 plates*

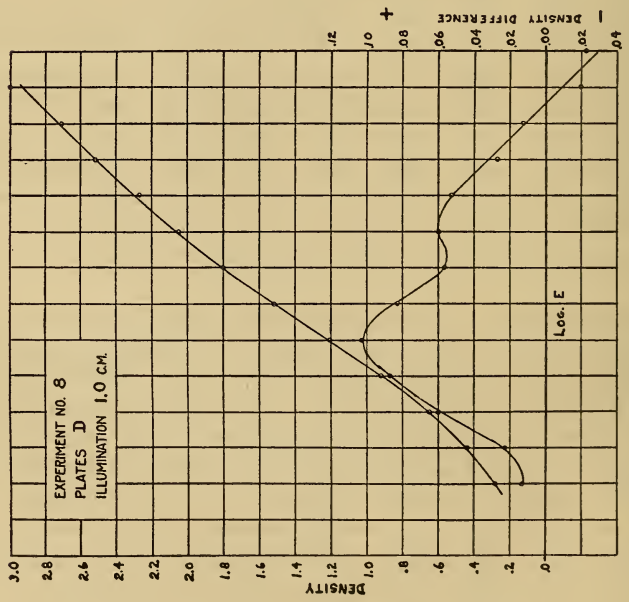

FIG. 26.—*Intermittency effects on Eastman D. C. Ortho. plates*

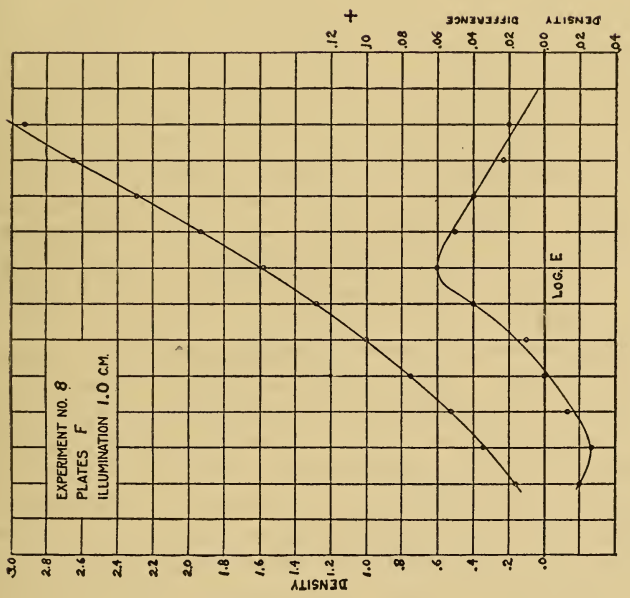

FIG. 28.—*Intermittency effects on Seed 26X plates*

nitude and direction of sector-wheel intermittency errors are found to vary with different emulsions, with illumination, with the total exposure, with the number of parts into which the exposure is divided, and with the length of the rest periods between exposures. In many cases the maximum effect appears to take place at the lower end of the straight-line portion of the characteristic curve when a single effect is prominent and at both ends when both a gain and a loss occur in the same curve.

The C plates (Seed process) exhibit two opposite effects that are well marked. In experiment 7 the longer rest periods caused an additional loss in the lower part of the curve and a gain in the upper part of the curve. This result is also confirmed by the shapes of the density difference curves of experiments 2 and 3 (figs. 12 and 13). In these the loss of the "toe" and the gain of the "shoulder" suggests that two effects are present, namely, a continuation of the latent image formation and a fading of the image. Both are probably present in all parts of the curve, the fading being a maximum in the "toe" and the growth a maximum in the "shoulder." With lower intensities of the light, the fading action is the greater throughout the length of the characteristic curve. The variation from the lowest intensities to the highest suggests that with intensities higher than 4 candle meters the growth would probably exceed the fading in all cases.

Accepting the results of these experiments as reliable, an explanation must be sought. The following analysis is based on the conclusion that the latent image is modified by the simultaneous presence of two opposing influences, namely, (1) a fading of the latent image after exposure and (2) a growth of the latent image after exposure. Both of these being distinctly accentuated by intermittence but only slightly by long rest periods indicate that the two actions are a maximum at the instant the exposure ceases and decrease rapidly from that time. The factors governing the magnitude and the rate of decay of these actions vary with the emulsion. The variation with illumination indicates that with a given intermittent exposure (1) a growth of the latent image results when the illumination exceeds a certain value dependent upon the emulsion and (2) a fading of the latent image results when the illumination is less than this value.

In other words, the latent image has properties peculiar to the method and factors involved in its formation, such that when formed at a lower rate than the normal reaction rate of the emulsion, fading takes place, while, conversely, with higher rates a growth is obtained.

With illuminations above the critical value for the emulsion the intermittent exposure image is greater than would be the case if the

same intensity of light were allowed to fall upon the emulsion continuously for an equal time. Under these conditions we have the growing image for each exposure and the density obviously increasing with the number of exposures. With illuminations below the critical value for the emulsion the latent image fades and the fading effect is accentuated by each interruption. The separate fading and growing effects both probably decrease exponentially so that the resultant effect of each interruption is the difference between two exponential functions, hence there should be a limit to the effect caused by increasing the number of interruptions for the same exposure.

Applying these principles to the case of an emulsion of finite thickness, we have, in the formation of the image, light absorbed by the silver halide (11), (12); consequently its intensity diminishes as it proceeds through the emulsion layer. With illuminations higher at the surface, but deeper in less than the critical value, a combined type of image (fading and growing) should be formed.

The characteristic curve of a photographic emulsion furnishes in reality the latent image existing at the end of the exposure, as modified, of course, by fading or growth before development and by the usual factors of development. When the density is plotted with exposure as abscissas as in Figure 3, it represents the growth of the latent image with time, if the exposure was made under constant illumination. From the variable slope of this curve it is evident that as the image is built up the rate of formation changes.[6] If the illumination were doubled and the exposure time halved, or vice versa, we know from the failure of the reciprocity law that the curve would not be exactly the same as before. The reaction velocity between light and silver halide depends upon the illumination, but is only approximately proportional to it. Were it exactly proportional there would be no failure of the reciprocity law. Kron (13) found that each emulsion had an optimal illumination. The reaction between light and silver halide was most efficient at a particular value of the illumination and above or below this optimal value a loss in photographic effect was found. This loss became greater the further the illumination departed from the critical value.

The data presented here appear to support the above interpretation of Kron's reciprocity work. With a particular value of the illumination and fixed intermittence conditions, exposures may be selected which give approximately equal effects with intermittence and nonintermittence. This illumination differs with different

[6] Objection might be raised to this interpretation on the ground that density is a logarithmic quantity so should not be proportional to exposure. This objection may be answered by stating that the mass of silver comprising the developed image is directly proportional to the density, the photometric constant being $P=0.0103$, approximately, per 100 cm ^{2}. Thus if density is replaced by quantity of silver per unit area, the shape of the curve would be the same.

emulsions. When it is in excess of the optimal value the halide may be temporarily supersaturated and the reaction continue after exposure until equilibrium is established. With it less than the optimal value, the reaction does not proceed at a rate normal for the emulsion, and at the conclusion of the exposure retrogression takes place until equilibrium is established.

The presence of both fading and growth of the latent image indicates rather strongly that the reaction between light and silver halide is not a single step or simple conversion into what we call latent image, but that an intermediate condition exists between the first effects of light and the latent image proper. The time element found in the phenomena fortifies this view

It may be that the first product of the reaction is in a nascent form which under continued influence of light completes the reaction and forms the latent image. If, however, during this process, the light be extinguished, the nascent product, left in the dark, in part returns to its former state and in part completes the reaction, the degree of each depending upon the illumination used.

VIII. SUMMARY

A comparison of sector-wheel intermittent and equal nonintermittent exposures shows that the difference varies with the emulsion used, the illumination, the number of interruptions, and the rest periods between.

When the illumination is above a certain level a greater effect results from the intermittent exposure, and, conversely, for lower intensities a loss is obtained. The gain or loss, as the case may be, is accentuated by intermittence.

The following analysis of the observed facts is offered: After extinguishing the illumination the latent image is subject to modification by two opposing influences, one tending to intensify it, the other to fade it—both rapidly decreasing with time. At the higher illuminations the resultant effect is a growth in density; at the lower, fading results. When the exposure is intermittent each interruption adds a part to the total growth or diminution of the image, but it is readily appreciated that, as the rest periods shorten, the change introduced by each interruption should diminish. Consequently, there should be a limit to the modification which an increase in the number of interruptions can cause.

This indirect experimental evidence of the presence of the two opposing influences lends definite support to the view that the reaction between light and silver halide in the formation of the latent image is not confined to a single step.

In conclusion, the writer desires to express his indebtedness to Paul T. Howard and Daniel Aronowsky for their assistance in the experimental work.

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