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A NEW METHOD OF MEASURING THE TIMES AND EFFICIENCIES OF PHOTOGRAPHIC SHUTTERS.

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Read before the Optical Society on November 15th, 1906.

THE work on which the following paper depends was undertaken at the National Physical Laboratory, to provide a test for photographic shutters. The resulting apparatus has been used to measure the times of exposure given by several different types of shutters, and these actual times have ranged from one four-hundredth of a second to two seconds.

There seems to be no reason why much shorter times than one four-hundredth of a second should not be measured by the same means; but the shutters under observation in no case gave a more rapid exposure with the lens of the apparatus. When the time is longer than two seconds, or even one second, one can actually time the shutter with a stop watch, with quite sufficient accuracy.

The optical principles on which the method depend are first briefly explained. An electric lamp with a long straight filament is set up in a vertical position. By means of a lens, an image of the filament is formed. A shutter is put over the aperture of the lens, and if this shutter is set and released, the image of the filament is formed, and exists for just the time during which the shutter is open. We thus have to determine the time for which the image exists.

For this purpose a disc is mounted on a shaft, so as to be free to rotate. It is put in such a position that the image of the filament is formed on it. A radial slot is cut in this disc. The light from the point of the image which is formed at the slot, passes through the slot, and is visible from behind the disc.

Now let the disc be turned through an angle. If the image is still existing, the portion of it opposite the new

position of the slot is now visible from behind the disc. In fact, as the disc is turned, different portions of the image become visible. Now, suppose that by means of the shutter the image is only formed for a short period, and let the disc be rotated uniformly, assuming for the moment that it is crossed by the image, when the image is formed. Until the image is formed nothing is visible from behind the disc. As soon as the image is formed the portion opposite to the slot at once becomes visible from behind the disc, and other portions of the image are exposed in turn until the shutter closes, and the image ceases to exist.

It will be easily seen that different portions of the image are exposed, if the time for which the image is formed is lengthened or shortened. In fact, while the image exists, it is exposed at a definite *rate* by the slot in the rotating disc. That is the same thing as saying that a particular length of image is exposed when the image exists for a given time. From a measurement of this length of image we can infer the length of time for which the image exists. In this way we reduce the timing of the shutter to the measuring of the length of a strip of light.

In practice a disc having a number of slots is used; this being necessary to ensure that the image should be exposed, as above described, whatever the position of the disc at the moment at which the image is formed.

The essential features of the apparatus employed in carrying out the optical method just described, are:—

- (1) A lens of large aperture (say two inches) and short focal length (say five or six inches).
- (2) A source of light in the form of a long strip.
- (3) An opaque, circular disc, in which some radial slots are cut, mounted on a shaft which can be rotated at any speed within certain wide limits.
- (4) A mechanical device for releasing the shutter under test at a definite phase of the position of the disc.

In the apparatus, made at the National Physical Laboratory, an electric light—a “linolite”—with a long, straight filament is used as the source of light. An image of this is formed by the lens, which is put in a position so as to give unit, or somewhat greater, mag-

nification. The circular disc is placed in the image plane, and only those portions of the image which cross one or other of the slots in the disc can be seen by an eye placed behind the disc.

There are ten equidistant radial slots in the disc, and the image must be long enough to extend always across at least two of these; that is, it must subtend at the centre of the disc an angle equal to twice the angle between

FIG. 1.

two consecutive slots. When the disc is made to rotate, different parts of the image become visible; in fact, if the disc turn with constant angular speed, a definite amount of image becomes visible in a given time. The slots all extend between circles of $2\frac{1}{2}$ " and $4\frac{1}{2}$ " radius, respectively.

Fig. 1 shows the position of the image relatively to the ten slots 1—10. When viewed from behind the disc, the amount of image shown, while the disc turns until the slots have the positions indicated by the dotted lines, is

shown in fig. 2. To see this, it is best to put up a piece of ground glass, close behind the disc, on which the image may be formed. If we can observe the angle subtended at the centre of the disc by the amount of image exposed by any slot, and if we know the mean speed of the disc, we can infer the length of time taken by the disc in turning through this angle.

Now, suppose we rotate the disc at a known speed, and

FIG. 2.

for a short time allow the light from the source to pass through the lens, we can find this time by measuring the angular length of image. Let θ° be this angle, n the number of revolutions of the disc in one second, t the time in seconds for which the image is formed, we have the relation—

$$\frac{\theta}{360} = nt \text{ or } t = \frac{\theta}{360 n}$$

Now put up the shutter to be tested close in front of the lens. So long as the shutter uncovers any part of the lens, the complete image is formed; the lens having, if necessary, a stop placed in front of it to ensure this being the case. Thus, the time for which the image exists is the *complete* time of exposure given by the shutter over the lens aperture. This time is the " t " of the formula written above, and so can be determined by measurements of θ and n .

FIG. 3.

FIG. 4.

To measure the angle θ , the positions of the two ends of the portion of image exposed by one slot of the disc must be observed, and we must avoid certain of the portions of the image. Thus, in fig. 2 we may measure the

portions exposed by slots 1 or 2; but that exposed by slot 10 is, obviously, not complete, as for the first part of the motion of slot 10 no exposure occurs. So it is a safe rule always to measure an inner portion of the image.

The image only exists for a short time—the time t —and it is, of course, impossible during this time to make observations of both ends. The time for which any part of the image is visible is simply the time for which persistence of impression on the retina continues. This is probably about one twenty-fifth of a second. All that can be ascertained in this time is whether an end of a portion of image lies on a cross-wire, or not. So it is clear that more than one observation is required.

If, by hand, we set and release the shutter more than once, the appearance of the image is in each case different. Fig. 3 shows three such different appearances. The positions we wish to measure vary on each setting and release of the shutter, though the whole angle subtended at the centre of the disc by each inner portion is every time the same, provided the shutter has a constant performance.

The several appearances shown in fig. 3 differ from each other, because the shutter in each case was released at random, as far as the angular position or phase of the disc was concerned. If the shutter is always released when the disc reaches a definite position, or is in a definite phase, the appearance of the image on the ground glass will, in each case, be the same. It is arranged for mechanically, in a manner to be described, that this shall always be the case. By this means the observer can have as many repetitions of the portion of image he wishes to measure as are necessary. All is now quite straightforward.

A piece of ground glass, with a cross-wire or line marked on it, is moved up and down in front of the image. It is adjusted after a few releases of the shutter to one end, P, of the image, P (fig. 3a), to be observed, and a reading on a suitably graduated scale is taken. The same is then done for the end Q, and the difference of the readings for P and Q gives the angular length of P Q; that is, θ . The speed of the shaft remains to be measured, and then t is known. The actual details for the measuring of θ are shown in fig. 7, and

described later. The whole process may be gone through very rapidly after a little practice.

When the exposure given by the shutter is anything shorter than one-twenty-fifth of a second, all the portion of the image exposed by one slot on account of its persistence on the retina, appears visible at the same time. This fact may be made use of to avoid measuring θ , and affords an alternative method of finding the shorter times of a shutter. The speed of the disc is increased until the image is *just* complete; *i.e.*, the portion exposed by one slot of the disc just joins up to the portion exposed by the adjacent slot. In this way the angle θ is known to be the angle between two consecutive slots in the disc. All that remains to be determined is the speed at which the disc is turning. However, there is some difficulty in adjusting the speed to just the right amount; and, of course, a number of releases of the shutter are wanted, with an increase of speed of the disc between each. Further, one has to be very careful not to increase the speed too much.

Fig. 4*b* shows the correct appearance of the image; but it is clear that the appearance is substantially the same if we speed up the disc further than the desired amount. One can make certain of not doing this by leaving a slight gap between the successive portions of image; when one is sure that the speed is not quite high enough. Or, it is possible, by continually moving the source of light, to make the image appear, as in fig. 4*a*, instead of fig. 4*b*. One can then be sure that the correct speed of rotation has been found. The shape of the curves in fig. 4*a* depends on the kind of motion given to the source. If this is moved with simple harmonic motion, these curves are portions of sine curves plotted against a tangent scale of abscissas.

At best it is rather difficult to see certainly when the image becomes complete, or nearly so, since the break may come at any position, and the continued straining to see if the breaks are just present or have just disappeared is very tiring to the eyes. For a few observations the method is sometimes useful, for times shorter than one-twenty-fifth of a second.

The appliance, with mechanical release of shutter, has been found much superior in this and other respects. It has been used successfully for finding various times of

exposure ranging from two seconds to one-four-hundredth of a second; the times being those given by one or other of several different types of shutters, including a focal plane shutter. It will be seen that the method does not depend on the period of persistence on

FIG. 5.

FIG. 6.

the retina, and so is applicable to times shorter than one-twenty-fifth of a second.

As far as I have been able to ascertain, all shutters may be released by a small motion of some accessible part. In many cases there is a trigger, while in others

a ratchet has to be released. In the mechanical device, above alluded to, for releasing the shutter at a definite phase of the revolving disc, a cam K (see fig. 5) is mounted on the same shaft which carries the disc, but at the end of the shaft remote from the disc. A system of bars, A B C D E B, is freely jointed at the corners B, C, D, E. Near B a bar F G is rigidly fixed to the bar A B C in a direction perpendicular to A B, and this bar F G works against the cam K. The bar B E is fixed to the bed plate of the whole apparatus. One end of a strong spring is attached to the bar A B at A, and this keeps F G in contact with the cam K.

The cam is of such shape that when the shaft has turned to a certain position, the arm F G drops over the abrupt angle of the cam, owing to the tension of the spring attached at A. This causes the bar C D to move upwards, sufficiently nearly in a straight line in a direction along its own length.

The bar C D has a long slot cut in it, and a bolt passing through this at M clamps the bar L M in any convenient position. It will be seen that the point L of the bar L M has adjustments in any desired directions in the plane B C D E, by compounding a motion of M along the slot, and a twist of the whole bar L M about M. A screw passes through the bar L M at L in a direction normal to the plane B C D E, and gives an adjustment in this direction. By these adjustments the end of this screw is brought into gear with the shutter release, and the upward motion of the rod C D then serves to release the shutter. This motion can be regulated to suit the particular shutter under test.

With the mechanism so far described the release of the shutter would take place at each revolution of the shaft. This was found to be very inconvenient when high speeds of shutter were being dealt with, as there was not sufficient time, after setting the shutter, to get ready to observe the image. To evade this, a little catch P Q (figs. 5 and 6) was made to hold back the bar F G, except when release was wanted. P Q is pivoted at O, and the end P is placed opposite the core of an electromagnet R. A little spring keeps it up against the bar F G, except when the electromagnet is in action, that is, when the key switch S is down.

The electromagnet is put at such a distance that it

exerts a force sufficient to overcome the little spring alone, but not this spring and the friction force between Q and F'G. Thus it is only when the cam has lifted F'G clear of Q that the catch Q is drawn aside by the electromagnet. This takes place when the portion opposite to the sharp angle of the cam K is in contact with F'G, so that the arm F'G is free to follow the cam when the angle turns round to G.

By the means just described the shutter may be set,

FIG. 7.

and the release can be made by pressing down the switch S, as soon as the observer is ready to make a setting for the end of the visible image.

Several ways have been thought of, and tried, for holding the shutter in position. It seems best to actually fasten the shutter down by screws to a wooden support with an aperture in it. This support is attached to the lens holder, and the shutter is brought as close as possible to the lens.

It has been found convenient in practice to work with

two images. A second source may be arranged for by putting up a second lamp, or two reflected images of one lamp may be used. This double source, however formed, is made such that the images formed by the lens are about one inch apart. Each image is observed from behind the rotating disc. One is formed on a strip of ground glass, and the other is used for "end" settings.

Fig. 7 shows the arrangement. The lines A B, A' B' represent the two images. A' B' is received on the strip of ground glass G G. Part of the image A B is observed on a small piece of ground glass, fixed at the end of a short tube, shown in fig. 7 as a circle C. The tube is mounted in a slide E, which moves up and down the bar H K. The ground glass on C has a line marked on it pointing to S, and the slide D E fixed to C, ensures this line always passing through S. On E is fixed a pointer P, and the angular position of the line on C is read by means of P on a properly graduated scale. The graduations give the position in decimals of a complete revolution.

Thus if the bar is set so that the line in C corresponds successively with the two ends of the visible image, the difference of the two readings gives the decimal of 360° subtended at S by the visible image, *i.e.*, it gives the fraction $\theta/360$ which came in the original formula, $t = \theta/360 n$. It only remains to divide this by n , the number of revolutions per second of the disc, to find t the time of the shutter exposure.

In considering the quantity $\theta/360$, it is clear that θ cannot be measured in the way described if it exceed $360^\circ/m$, where m is the number of slots in the disc. On the other hand greater percentage accuracy of setting can be made, when θ is as large as convenient. It is best to arrange the speed of the disc so that θ is about two-thirds of the angle between consecutive slots of the disc.

The use of the second image A' B' is to enable the observer at once to form an idea as to whether the speed of rotation is suitable to the time of the shutter. He also can see about where the ends of the image are. The shutters dealt with were often widely different in actual performance from nominal performance, and the time engraved on the shutter did not give much idea as to what was a suitable speed for rotating the disc.

Remembering that times of exposure to be measured vary between wide limits (say two seconds to one-four-hundredth of a second) it will be seen that is very necessary to have a ready means of altering greatly the speed of the disc. At first this was attempted by driving the disc by an electric motor and altering the volts on the motor by means of a variable resistance. In this way the speed could be varied considerably, but not nearly enough. To meet the case it was necessary to have a pair of coned pulleys giving speed ratios of 10 to 1 and 1 to 10 at the two ends. These were not connected by the ordinary crossed belt, but by a method devised by the author.

FIG. 8.

A rubber ball, merely resting between the two cones, transmits the motion from one to the other. The ball can rapidly be moved from end to end of the cones, giving the desired speed change. With this arrangement the cones can be used down to extremely small radii, where it would be impossible to have a belt drive. Fig. 8 shows the appearance of the system.

This, then, completes the apparatus. The general appearance is shown in fig. 9. It will be well to consider

to what inaccuracy the method is liable. The distance between consecutive slots where the image A B is formed is about 5 cm., and observations are made on a length of $\frac{2}{3}$ (5) cm. It is quite easy to make a setting within 1 mm. at either end, so that we have an error of .2 cm. in $10/3$ cm., i.e., a 6 per cent. error. The finite width of the slots of the disc perhaps introduce a similar amount. In taking the speed of rotation an error of several per cent. may be expected, and variation of speed of the motor introduces still further error. On the whole the author is confident that there can in no case be an error of more than 20 per cent of the quantity measured. A great many readings have been taken, and repetitions quite justify this as an outside estimate of possible error.

FIG. 9.

In a few cases a shutter has on different occasions given results differing by more than 20 per cent., but this has only occurred when the shutter has been acting in a variable manner. Of course, it cannot be expected that a shutter should have precisely the same performance from day to day, and after further wear.

As indicated in the title, tests for efficiency have been made with a number of shutters. What has actually been measured is the length of time during which the

shutter is open beyond a certain amount. In the cases of shutters which open from the centre, the method followed was to put up a stop as near the shutter as may be, and shaped like the aperture of the shutter. The shutter had then to open beyond this aperture before any image was formed. The ratio of the area of this aperture to the aperture when the shutter was full open, gave the amount of lens uncovered, when the stop was removed.

Stops were made to eclipse about $\frac{1}{4}$, $\frac{1}{2}$, and $\frac{3}{4}$ of the aperture, and in each case these stops were of the shape of the shutter when open to an equal extent. After readings have been taken and reduced, with the various stops in the way, it is possible to draw an efficiency curve in which abscissas give time during which the shutter is open, and ordinates give the aperture beyond which the shutter was open for this time. The efficiency is given by the ratio of the mean abscissa to the greatest abscissa.

Measurements were made on a number of shutters to test the accuracy of the method. Several of these were old, and the experiments must not be looked upon in any way as tests of the type of shutter, as no special care was taken to secure representative shutters. The object of the investigation was to test the method of measurement and the possibility of applying it to shutters of various forms.

Results are given which were obtained from four shutters. Of these the first two were diaphragm shutters, and the others roller blind and focal plane shutters, respectively.

In the case of shutter No. 1, the actual readings taken are reproduced so as to illustrate the method in which results are arrived at. These are given in Table I. Column I. gives the nominal times of the shutter; column II. gives the reading for one end of image minus the reading for the other end, *i.e.*, the angle subtended at the centre of the disc by the visible portion of the image, in decimals of a complete revolution; column III. gives number of revolutions of the disc per second, usually measured over ten seconds; column IV. gives actual time of shutter, being $\text{II.} \div \text{III.}$

Two independent sets of readings, A and B, were taken for comparison.

A

TABLE I.

Nominal times.	Readings.	Revs. per sec.	Actual time.
1 ...	.142-.067	12	63
$\frac{1}{2}$...	.152-.066	19	45
$\frac{1}{5}$...	.145-.067	21	37
$\frac{1}{25}$...	.160-.068	34	27
$\frac{1}{50}$...	.132-.092	... 2.0	020
$\frac{1}{100}$...	.172-.116	... 3.6	0156

B

1 ...	.124-.066	09	64
$\frac{1}{2}$...	.138-.066	17	42
$\frac{1}{5}$...	.142-.067	22	35
$\frac{1}{25}$..	.142-.068	35	21
$\frac{1}{50}$...	.164-.110	... 3.0	0180
$\frac{1}{100}$...	.172-.113	... 3.4	0173

Here there seems to be good agreement of results. The worst difference is in the case of the $\frac{1}{25}$ second nominal, where it is 25 per cent. of the mean value of the two results. This is, no doubt, partly due to the performance of the shutter not being quite constant. But the amount by which some of the times differ from the nominal times is far greater than the amount which might be attributed to inaccuracy of reading. Thus the nominal $\frac{1}{50}$ is nearly correct, while the nominal $\frac{1}{25}$ is really about $\frac{1}{4}$.

When arrangements were being made for testing efficiency one of the leaves of this shutter was broken. This was afterwards replaced by a new leaf, after which the following results were found for the two fastest times. Three stops were made of proper shape, and these were placed close to the iris diaphragm. The three stops eclipsed $\frac{3}{4}$, $\frac{1}{2}$, and $\frac{1}{4}$ of the aperture respectively. The results are in—

TABLE II.

Nom. time.	Stop 3.	Stop 2.	Stop 1.	No stop.
$\frac{1}{50}$...	.0098 ...	.014 ...	.018 ...	.022
$\frac{1}{100}$...	.0102 ...	.014 ...	.017 ...	.021

The corresponding efficiency curves are shown in figs. 10a, 10b, the efficiencies working out to be .64 at $\frac{1}{50}$ th second, and .66 at $\frac{1}{100}$ th second.

Shutter No. 2. TABLE III.

Amount of aper. eclip. by stop.		.70		.47		.26		0	
		A	B	A	B	A	B	A	B
1/300	...	.0026	.0026	.0039	.0035	.0041	.0045	.0054	.0038
1/200	.	.0030	.0032	.0041	.0043	.0048	.0048	.0058	.0057
1/100	.	.0040	.0029	.0041	.0050	.0061	.0050	.0067	.0066
1/25	...	.0050	.0040	.0043	.0048	.0072	.0065	.0081	.0078
1/10	...	.0100	.0103	<u>.0235</u>	.0103	.0118 .0159	.0114	.0195	.018
$\frac{1}{4}$	...	.050	.037	.071	.042	.034 .050	.039	.064	—
$\frac{1}{2}$	...	.11	.09	.168	.102	.111 .149	.140	.157	.13
1	...	.21	.26	.224	.336	.247	.266	.296	—

Shutter No. 2.

The following Table III. shows the results found for shutter No. 2. Stops 1, 2, 3, were made of the proper shapes. Their areas were measured by planimeter, and were found to be .7, .47, .26 of full aperture, respectively. After one complete set of results (A) had been found, a second set (B) were taken for comparison, and two more sets (C and D) for full aperture taken at an entirely different time are shown for comparison with (A) and (B).

The A result for 1/10 with stop .47 is obviously due to either a misreading or a failure in the action of the shutter. The headings .7, .47, .26, 0 of the columns indicate the amount of aperture exposed for period of time indicated in the table.

TABLE IV.

MEANS OF TABLE III.

Aperture Eclipsed.	.70		.47		.26		0
1/300	.0026	...	.0037	...	.0043	...	.0046
1/200	.0031	...	.0042	...	.0048	...	.0056
1/100	.0035	...	.0046	...	.0056	...	.0063
1/25	.0045	...	.0046	...	.0069	...	.0077
1/10	.0102	...	.0103	...	.0130	...	.0192
$\frac{1}{4}$	.044	...	.057	..	.041	...	.062
$\frac{1}{2}$	.10	...	.135	...	.133	...	.146
1	.24	...	.28	...	.26	...	.30

In these results it will be noticed that from one second nominal to 1/100th nominal, the nominal times are longer than the actual times. Thus—

1 sec.	nominal	is really	1/3
$\frac{1}{2}$	"	"	1/7
$\frac{1}{4}$	"	"	1/14
1/10	"	"	1/50
1/25	"	"	less than 1/100

The 1/25 nominal is only 1.7 times as long as the 1/300 nominal.

The performance of the shutter when set at speeds of $\frac{1}{4}$, $\frac{1}{2}$, 1 sec. nominal does not seem to remain constant, and so the results worked out with a view to finding efficiencies at these speeds are contradictory.

The efficiency results for the faster speeds down to

1/10th nominal work out at 1/300, 68; at 1/200, 65; at 1/100, 64; at 1/25, 61; at 1/10, 55; showing a steady decrease of efficiency.

Roller Blind Shutter (No. 3).

In this shutter the lens aperture is exposed by a wide gap in the blind. Suppose d is the width of this gap and a the diameter of the aperture to be exposed, then the complete time of exposure is the time in which the blind moves a distance $d + a$. It is clear, then, that this time depends partly on the size of the lens aperture.

With this shutter two sets (I. II.) of readings were taken with the shutter working across an aperture of $1\frac{1}{2}$ inches. Results are shown in Table V.

TABLE V.					
Nom. Times.	I.		II.		Mean.
1/12 ..	.066	..	.059	..	.063
1/25 ...	.045	...	.046	} ...	.047
			.048		
1/35 ...	.037	...	.042	...	.040
1/50 ..	.0325	..	.036	...	.034
1/70 ..	.031	.	.032	..	.032

It will be seen that the agreement in the two sets of readings is fairly close.

In this shutter no correct statement of the time of exposure given can be made without at the same time the size of the lens aperture with which it is to be used. As before, if d is the width of the gap and a the diameter of the lens aperture, the shutter has to move through a distance $d + a$ while the lens is partially or wholly uncovered. It is clear that if a is altered the time of exposure is also altered. The most natural statement seems to be the time of the shutter in exposing a point. As d is large compared with a , we can assume some mean velocity v of the shutter without making much error. Then the time t with aperture of diameter a is given in terms of T the time over a point by rela-

$$\text{tion } t = \frac{d+a}{d} T.$$

Focal Plane Shutter (No. 4).

In testing this, the shutter was placed close to the lens, and the time of exposure given by the shutter with slit

of width d when passing over an aperture of width a was found. This is the same thing as the time for slit of width $d + a$ to pass over a point, if we assume uniform velocity over this small width. From this was inferred the time taken by a slit of width 1 cm. to pass a point.

Six sets of readings were taken: two (A, B) for a point near edge of the plate which would first be exposed; two (C, D) for a point near centre of the plate; and two (E, F) for a point near the edge of the plate, which would last be exposed. From the results it is possible to notice the changing speed of the shutter as it crosses the plate.

The results are in Table VI.

TABLE VI.

Setting.	A	B	C	D	E	F
1. ...	.0132	.0126	0113	.0107	0084	.0088
2. ...	.0120	.0105	.. .0064	.0078	.. .0061	.0075
3. ..	.0095	.0087	.. .0059	.0069	0053	.0061
4. ...	.0082	.0084	0056	.0066	0049	.0051
5. ...	.0078	.0077	0047	.0052	0045	.0044

Column I. gives the setting of the shutter which was used, and the remaining columns give corresponding times. Pairs of readings A B, C D, E F, were taken for comparison, to see that the differences found for different positions was larger than that due to inaccuracy of reading. Comparing A with B, C with D, E with F, we see that in general the agreement is fairly close, and that the difference between the various pairs is a real one. This is put in a more convenient form in Table VII., where means of A and B, C and D, E and F, are given; also, the nominal times of the shutter.

TABLE VII.

Setting.	I. Edge first exposed.	II. Middle.	III. Edge last exposed.	Nominal times.
1. ..	.0129	0110	.. .0086	... 1/50
2. ...	.0113	0071	0068	... 1/100
3. ...	.0091	. .0064	.. .0057	... 1/150
4. ...	.0083	0061	.. .0050	... 1/200
5. ...	.0078	0050	0045	... 1/250

It is clear that in position I. the shutter has not attained its full speed, at any of the settings; and with the spring at its weakest, setting No. 1, the full speed is not reached even by position II. This is also the case to a less extent with the other settings, but it is not supposed that the figures given have sufficient accuracy to distinguish certainly between .0050 and .0045, though the uniform run of the figures rather supports this view.

Between Columns I. and II. the difference is quite beyond the difference possible through error of reading, etc.

Some visual methods have been used for shutter tests in which a lens has not been employed to form an image of the various objects observed. In two of these the

$E = .64$

FIG. 10A.

$E = .66$

FIG. 10B.

shutter to be tested has been held close up to the eye. A little consideration will show that this cannot give a correct result except in certain cases. If the shutter is one which opens from the centre and then closes towards the centre the method may be correctly employed if the eye is placed so that it can see the object to be observed as soon as the shutter is very slightly open.

But a roller blind shutter is not correctly dealt with in this way. For, if the eye is placed at the centre of the aperture, it is only when the shutter has uncovered half the aperture that the eye can see the object to be observed; and after the shutter, when closing, has covered half of the aperture, nothing can be seen.

In other words the time which could be measured by this means would be the time for which a single point

TABLE VIII.—Showing ratio of actual times to nominal times.

Nominal time.	1	1/2	1/4-1/5	1/8-1/12	1/16-1/25	1/32-1/40	1/50	1/64-1/80	1/100	1/150	1/200	1/250-1/300
.63	.87	1.8	—	6.0	—	.95	—	1.6	—	—	—	—
.30	.29	.25	.19	.18	—	—	—	.63	—	—	1.1	1.3
1.2	1.4	2.9	—	7.8	—	1.2	—	1.7	2.7	2.0	—	—
1.0	1.5	2.4	—	6.0	—	.75	—	1.3	2.0	1.6	—	—
—	94	1.6	—	7.3	—	.46	—	1.1	1.6	—	—	—
1.6	2.3	2.8	4.3	2.1	1.7	—	1.1	1.6	—	—	—	—
—	—	—	1.3	1.1	1.4	—	2.6	—	—	—	—	—
—	—	—	.76	1.2	1.4	1.7	2.2	—	—	—	—	—
—	—	—	—	—	—	.43	—	.68	—	.86	1.0	1.1

(placed where the eye is) receives light through the shutter. On the assumption of any law of velocity of the shutter blind it would be possible to deduce the time over a lens of given aperture.

In other papers on shutter testing results have been published which show that the shutters considered differ very widely in nominal and actual performance. And the same feature is very noticeable in the shutters with which the author has had to deal. In the following table (VIII.) the results of a large number of his tests on different shutters are collected. The entries made represent the ratio of actual time to nominal time. Each horizontal row refers to one shutter. The headings of the columns give a small range of time in which the nominal time of the shutter is included. In the case of two of the shutters which have a certain nominal time in common, one shutter gives an exposure of forty-three times the length of exposure given by the other. But the table explains itself.

SIR WILLIAM ABNEY said the apparatus they had had the advantage of seeing before the paper was read, was very beautiful in design, and, so far as his knowledge went, was novel. It seemed to him to have been worked out with very great skill and care, and he was surprised at its accuracy and the small differences there were in the two or three readings in succession. He was glad that Mr. Hunter had called attention to the actual times and the nominal times, as no one knew, perhaps, better than he, that the ratios of the times put on shutters were in many cases absolutely fictitious. As a rule, the speeds merely indicated that the plate was exposed for a longer or shorter time, and nobody who knew this would ever think of using the figures marked on the shutters. That, at any rate, was his experience—he would mention no shutters and no names, but there were a great many sinners in that respect, but he had not the slightest doubt that they arrived at their figures by some means or another.

If they got one of the instruments now shown they would, at all events, have the correct nominal exposures to go by. A good deal of experimental work had been carried out by amateurs in measurements in which they had taken for gospel the makers' times of exposure. This was unfortunate, as it rendered such work of but

little use. Of course one had to recollect that with shutters the actual exposures might vary, for anybody who had used a shutter in which thin plates of ebonite formed a part would know that the exposures varied very considerably.

There was one shutter he had in mind with regard to which he could say the times had varied between $1/100$ th of a second and about $1/12$ th of a second, though they were supposed to be the same. The difference was due to change of temperature and deposit of moisture. So that one must not blame the makers altogether. He would not make any further observations except to congratulate Mr. Hunter on the very efficient apparatus he had introduced, and he hoped it would be found useful to the manufacturers of different kinds of shutters.

MR. CONRAD BECK said that some years ago he noticed that a certain shutter put on a certain camera was marked $1/100$ th, which a year before had been marked $1/50$ th, and without any very apparent change, the next year it was marked $1/150$ th. He was bound to say that he wondered where it was going to stop. At that time he commenced a scheme by which he tested customers' shutters for fourpence each, and he tested nearly 6,000.

In the course of this work, they got some extremely interesting information. He certainly could endorse everything Mr. Hunter had said as to the question of accuracy of speeds of shutters; at the same time he was bound to say there were many ways of looking at it. For instance, if a shutter opened from the centre and closed to the centre, the exposure which was required to be given, according to exposure tables, would not be in the same ratio to the total time the shutter was open as that required by a focal plane shutter. Consequently, there were two methods of defining the rapidity of a shutter, one of which had reference to the amount of light admitted into the camera and regulated the exposure necessary, the other had reference to the period during which a hand camera could be held steady, and to the movement of a quick moving object being photographed, and he thought there was some difficulty in expressing the speeds of shutters for that reason.

It was the simplest, and perhaps the more practical and certain method of expression, to state the actual period during which the shutter opened the central por-

tion of the lens. Then, again, one had also to consider the size of stop or aperture of the lens which was going to be used. If the total time during which a shutter was open, modified by an efficiency co-efficient, were taken as the speed of a shutter this might be quite incorrect, because the shutter might have a full aperture of 1-inch on which the efficiency was calculated, whereas the lens used with it had perhaps an aperture of $\frac{3}{4}$ -inch. Mr. Hunter had been suggesting that his method was a fair test of a blind shutter, but it was not correct to take the total motion of the blind. A blind shutter working in front of the lens commenced by exposing one edge of the plate, the rest being in darkness, and this edge of the plate ceased to be illuminated some time before the shutter had completed its travel. Thus, a measurement giving the total travel of the blind did not give a correct measurement of the exposure at any one point of the photograph, and was not a useful mode of expressing the speed of that shutter. He merely raised those points with a view to showing that the question of expressing speed of shutters ought to be carefully discussed and set forth by some consulting body who would consider all those points, in order that some systematic method could be adopted. He thought there were two distinct points which every man wanted to know. Firstly, the speed of his shutter with reference to exposure. Secondly, how much the moving body would move during the exposure, and the probability of shaking the camera during the exposure. They were extremely difficult points, and it was very difficult to know what was the most convenient method of expressing the speed when two such dissimilar points had to be considered.

He thought Mr. Hunter was to be congratulated on his method of testing shutters—the change of speed and other details were ingeniously worked out. He must say that he should feel a great deal of satisfaction if, as a check to some of Mr. Hunter's results, they had one or two photographic tests—for instance, Sir William Abney's method—to test their accuracy. In starting any method, it was above all essential that there were no chances of errors creeping in. He was bound to say, judging from the average of his own results, he was a little suspicious as to whether Mr. Hunter's figures did

not give shorter exposures than should be the case. In a method he had himself adopted for testing shutters, which had to be a rapid method, the shutter was placed before the eye, a small stop being used and a series of bright spots rapidly uncovered by a revolving slit was observed.

Mr. Hunter's machine was a modification of the invention of Mr. Kershaw, of Leeds, which he thought was the most ingenious he had ever seen. That method was patented by Mr. Kershaw four or five years ago, and he used it for testing his focal plane shutters. For that purpose he did not think it could be much improved, and in discussing a question of this kind he thought credit should be given to Mr. Kershaw for his method.

SIR WILLIAM ABNEY wished to add one or two words in reference to the time of duration in the method he adopted himself—the photographic method. Of course he always used the method with the lens which was going to be used—not without a lens, although it could be measured without a lens—the photographic diagram had no possible meaning unless it gave the mean time of the exposure on the shutter with a certain stop. With the diagram method there was none of that uncertainty which Mr. Beck referred to. There was the time before them, and they could calculate it as they liked. With a focal plane shutter one could not judge of the ordinary rules of shutters, because they had only got to alter the slit, and they got as rapid an exposure of a certain portion of the plate as they liked. But where they had the shutters near the lens, the diagrams they got by the photographic method left no manner of doubt as to the speed obtained. Mr. Hunter had got approximately the total time a shutter was opened. He did not get the mean time, but he got his diagrams in a different way.

MR. PURSER said it would be a good thing if the speed of shutters could be accurately measured by such an instrument as that which Mr. Hunter had devised, but the question of more importance was the production of a shutter that would do credit to the measuring instrument. Manufacturers are quite conscious of the fact that the speeds of shutters are only approximately correct, and the production of an elaborate instrument for testing does not bring us any nearer the perfect shutter.

In the production of such an article there are so many factors that affect the constancy of the working parts, such as changes of temperature acting on the springs of the shutter blades, grit or moisture on the valves, etc.; that, in the absence of constancy, it was not much satisfaction for the photographer to know that some time in the dim and distant past his shutter had worked at correct speeds, because at the present time, under changed conditions, it was working quite differently.

In recording incidents referring to the inconstancy in the working of shutters and other factors, Mr. Purser humorously asked the question, "Did we want speeds in shutters, and are they of any use when we have got them?" He recently saw some photographs taken by a camera having a shutter working at nominal speeds of 1 to 1/100th of a second. They were hunting pictures with horses and dogs scampering across a field, and the photographer recorded the information that they were taken at 1/25th of a second. It was generally considered by the amateur photographer that in order to take pictures of animals moving at a rapid rate across the field of vision a speed of at least 1/300th of a second was necessary. He also remembered conversing with a gentleman who had promised to lecture at a local photographic society on "Exposures," and "Rapid *v.* Slow Plates."

Just two days previous to the lecture he purchased a packet each of extra rapid and ordinary plates and made a few exposures. On developing the plates under the same conditions he found precisely the same results, the negatives from the extra rapid plates being quite indistinguishable from those of the ordinary plates, notwithstanding the fact that the exposure given had been precisely the same. Whether this result was due to lack of constancy in the working of the shutter or to other causes is not recorded, but the incident goes to prove that where so many factors are unreliable it must be difficult to arrive at satisfactory results, and he thought that an elaborate method of testing of shutters could not be of any serious service to amateur photographers until such time as a shutter could be produced that would give constantly reliable speeds.

MR. ROSENHAIN said that he particularly admired the ingenious mechanical arrangements of Mr. Hunter's apparatus, and especially the change-speed gear; he only

wished it were possible to apply such a form of gear to the transmission of a considerable amount of power, but he understood from Mr. Hunter that there were very serious obstacles to its use, so that those who had looked at the gear and dreamt of noiseless motor cars should not be too sanguine. In the mechanism for releasing the shutter at the proper moment there seemed to him a slight duplication; could not the electro-magnet used to put the mechanism into action be employed to cause the release of the shutter directly?

Further, after looking at the very perfect arrangements of the apparatus, he (Mr. Rosenhain) was led to wonder that no greater degree of accuracy than that claimed by Mr. Hunter (20 per cent.) could be attained; on looking through the figures given in the paper, in fact, it appeared as though Mr. Hunter's claim were rather too modest. He supposed that the object would hardly justify such a refinement, but by the use of a chronograph, the speed of rotation of the disc, at all events, could be measured to a much higher degree of accuracy than the 6 per cent. mentioned in the paper. However, while he (Mr. Rosenhain) was thus asking for greater accuracy, others had said that no speed-testing of shutters was required at all—that these measurements were of no real value to the users of shutters. He did not at all agree with that; if he knew what certain shutters did under standard conditions, and how far they were liable to vary, that would be a means of discriminating between the good shutters and the bad, and would thus be the first step towards the attainment of the perfect shutter.

Even Mr. Hunter's results, as they stood, appeared to show that the roller-blind type of shutter was less liable to vary than the diaphragm shutters. As for the argument deduced from the fact that with the same exposure equally good results might be obtained upon fast and slow plates, that hardly bore on the question; they all knew that by suitable development good results could be obtained with enormous variations of exposure, but for that purpose it was desirable to know approximately what the exposure had been. Similarly as regards a hunting picture taken with an apparently abnormally long exposure, everything depended upon the point of view relatively to the motion of the animals; under

unfavourable conditions in this respect a sharp result could sometimes be obtained with relatively long exposures by a suitable movement of the camera during exposure. In any case, the first step towards scientific accuracy in photography was to have the means of knowing the actual duration of the exposure given in any particular case, and he thought they all felt that Mr. Hunter's apparatus would be of considerable service in that direction.

MR. HORACE BECK said that there was one question raised by Mr. Rosenhain on which he would like to say a word or two, namely, as to following an object by swinging the camera. He had found this a most satisfactory method, and by doing so he had taken photographs at an actual speed of about $1/100$ of a second of tobogganning on some of the ice runs, whereas by keeping the camera steady he required $1/500$ of a second to get equal sharpness of the moving object. In this case he had a specially speeded up shutter for the experiment.

Another point which arises is that if one is taking the total length of exposure in the method which Mr. Hunter is using, one takes it from the time the lens begins to uncover, and goes on to the time it is completely closed. In many shutters the rate of opening is a comparatively gradual one at starting, and it then opens more rapidly to a maximum, closing again more rapidly at first, and then more gradually. This applies particularly to any shutter in which a circular aperture is opened by means of a straight-edged plate. Thus, only a very small amount of light enters the camera at the time the shutter is beginning to open and just closing.

Supposing that in a correctly timed exposure the first and last $1/10$ th of the exposure do not give sufficient light to appreciably affect the plate. It can be calculated that in some shutters which, taken in Mr. Hunter's method, would show a certain speed, in actual practice would give results of 30 per cent. difference as far as movement of the object goes.

Another reason why one wanted correct speeds for photography was that when one was using a slow speed a person who had a good, steady hand, could hold a camera comparatively steady for a tenth of a second, and occasionally for longer, but with the ordinary per-

son it was perfectly certain, in the vast majority of cases, that if he had a shutter which, when set at the nominal $1/25$ th of a second, was really running at a third of a second, he could not help shaking the picture. Then, with reference to Mr. Hunter's actual instrument for testing, he thought it was an extremely ingenious arrangement, particularly the device of the rubber ball between the two cones.

He believed if Mr. Hunter wanted to apply it to greater power he could do so by putting a solid bicycle tyre in between, which would hang loosely on one cone. Then Mr. Purser raised another point, namely, the difference that occurred either by accident or malicious intent, owing to foreign matters getting into the shutters. Many of the shutters his firm had received for repairs were in such a condition that they reminded him of the "Mad Hatter's" watch in "Alice in Wonderland," for, when he complained of the treatment it had received, the March Hare replied, "but it was the best butter."

MR. CHALMERS said he was very much interested in Mr. Hunter's paper. As an easy means of measuring the speed of the disc and determining its constancy, the method described by Dr. Drysdale, in his paper on "Stroboscopy," read to the Optical Society some time back, might be useful. Mr. Hunter had encountered difficulties due to the necessity of setting on the two ends of a scale; a similar difficulty occurs in the "ophthalmometer," and is there obviated by the device of "doubling the image." This device would render the method independent of the constancy of the shutter, and thus enable it to be applied to test this constancy.

He thought that the ideal method of testing shutters would be one which gave an actual picture of the shutter at regular intervals during exposure. He, therefore, suggested the use of a photographic recording drum, on which images of the shutter were focused by the aid of a good lens. If the shutter were illuminated by intermittent light, pictures of the shutter at regular intervals could be obtained. As a preliminary test of the method he proposed using an alternate current arc with a period of $1/100$ th second.

He anticipated no serious difficulties for low speeds, but expected that it would be necessary to use a tuning

fork to obtain the required frequency for high speed shutters. This method should give the efficiency and time of the shutter for any aperture, and should be specially applicable to roller blind and focal plane shutters. The suggestion of Mr. Beck that not only the actual time of exposure, but also its value for use with exposure tables, should be given, was most valuable.

MR. H. S. RYLAND congratulated Mr. Hunter on his method of attacking a difficult problem. The chief source of inaccuracies appeared to him to be that the speed of the disc was not constant. This could be eliminated by a self-recording centrifugal speed indicator. Then the speed could be easily read at any moment, or a key could be arranged, so that when depressed (as it would be at the instant of taking a reading) it would mark the speed indicator band.

As to the need for a means of marking shutter speeds, that undoubtedly existed; but it was annoying when one had a shutter and could not tell the difference between 1 second and $1/50$ th of a second. With such delicate mechanism as they had in shutters, it would be almost impossible to keep the speeds constant, but one did expect the ratios between the various marked speeds to be constant. The shutter should, he thought, be graduated for total time it is open, and its efficiency given at the aperture for which it was marked.

The PRESIDENT observed that except in gathering up the threads of the discussion he did not think he had anything to say before Mr. Hunter replied to the specific points raised. There was one thing borne in on his mind, namely, that in this matter they had one which should be considered by the Optical Standards Committee, as they had ample scope. He thought, however, that they had an agreement at the moment by which they had arranged that they would not interfere with photographic standards. Whoever undertook the work would find there were a great many controversial points, through all the intermediate stages, until they could decide on a standard nomenclature, and the degree of accuracy with which the numerical interpretation could be obtained and recorded.

Mr. Hunter's Reply.

MR. HUNTER, in reply to the various questions, said, as to what was the proper time to engrave on a shutter,

it seemed to him there was little doubt that it was the time for which an image of outside objects was formed by a lens, when the shutter was put close up to the lens, and released. One time which was of importance was the extreme time for which the photographic plate was exposed to light, which was the time during which an image was formed. To know the exposure, of course, it was necessary also to find the efficiency of the shutter. But what he called the time of the shutter gave correct information as to how far the position of a moving object would change during the time the shutter was open.

Of course, before knowing the performance of a shutter it was necessary to find the efficiency. From readings taken with apparatus described it was possible to plot an efficiency curve which gave the state of the shutter at any instant between its opening and closing. This curve was virtually the same as those given by Sir William Abney's method, and the method of finding points on the curve was applicable to all forms of shutter.

With regard to Mr. Conrad Beck's remarks, he (Mr. Hunter) had seen Mr. Kershaw's patent. The apparatus described in it seemed so different from his (Mr. Hunter's) own that he had made no reference to it. As far as he remembered, in this arrangement the shutter was held close to the eye, and a light was observed through the shutter and the radial slots of a disc. No image was formed or used as in the arrangement described that evening. As previously pointed out, the method was applicable only to periods shorter than that of persistence of impression on the retina. His (Mr. Hunter's) method and apparatus may be used in conjunction with a camera to make a photographic test. If it was considered that the visual method was in need of checking this could be done. A visual method, however, was considered more suitable on two accounts: (1) that it could be more rapidly carried out, and (2) that difficulties of getting sufficiently strong illumination would not occur.

It had been suggested that speeds in shutters were scarcely any use, and that a shutter was bound to vary widely in performance from day to day, owing to wear, or to dirt getting on the moving parts. If this was so it would be better not to mark times on the shutter at all.

It was no use saying a shutter gave a hundredth of a second if it really gave a tenth of a second. He (Mr. Hunter) had heard of the use of a rubber tyre between two cones, mentioned by Mr. Horace Beck, for a speed change mechanism. But to his mind it had not the same advantages as the mechanism with rubber ball between two cones. In this case the normal reaction required to give sufficient friction was automatically supplied, while in the bicycle tyre method it had to be specially applied. Greater accuracy of measuring the speed of the disc of the apparatus might be useful, and for this purpose a stroboscopic method would, doubtless, be very satisfactory; or, possibly, the continuous speed recorder suggested by Mr. Ryland.