Auteur ou collectivité : Deville, Edouard
Auteur : Deville, Edouard (1849-1924)
Titre : The theory of the screen in the photo-mechanical process

Adresse : Ottawa : John Durie & son ; Toronto : The Copp-Clark Co. ; London : Bernard Quaritch, 1895
Collation : 1 vol. (p. 29-61) ; 25 cm
Cote : CNAM-BIB 4 Tu 52 (P.3)
Sujet(s) : Procédés photomécaniques ; Photogravure
Note : Extrait de "Transactions of the Royal Society of Canada", second series, 1895-1896, vol. I, section III.
Recueil factice intitulé "Métrophotographie" ayant probablement appartenu à Aimé Laussedat, la table des pièces étant écrite de sa main, et utilisé comme outil de travail pour ses publications.
Langue : Anglais

Date de mise en ligne : 03/10/2014
Date de génération du PDF : 28/9/2017

Permalien : http://cnum.cnam.fr/redir?4TU52.5

FROM THE TRANSACTIONS OF THE ROYAL SOCIETY OF CANADA

SECOND SERIES—1895-96

VOLUME I. SECTION III.

MATHEMATICAL, PHYSICAL AND CHEMICAL SCIENCES

THE THEORY OF THE SCREEN

IN THE

Photo-Mechanical Process

By E. DEVILLE

SURVEYOR-GENERAL OF CANADA

FOR SALE BY

JOHN DURIE & SON, OTTAWA; THE COPP-CLARK CO., TORONTO
BERNARD QUARITCH, LONDON, ENGLAND

1895

IV.—*The Theory of the Screen in the Photo-mechanical Process.*

By E. DEVILLE.

(Read May 17, 1895.)

I. THE SHADOW OF THE SCREEN.

Although comparatively new, photo-engraving, or the "half-tone process," as it is popularly called, has grown so rapidly that it has now become an important branch of the printing trade. An investigation of its theory may therefore prove of interest.

The object of the process is to break the continuous tones of an original into equivalent tones consisting of white and black dots suitable for printing in the typographic press. For this purpose, the original is copied in the camera, but a short distance in front of the sensitive plate a screen is inserted consisting of minute opaque and transparent figures; it is adjusted to project a diffused shadow over the plate, the light being strongest under the transparent parts and weakest under the opaque parts, with varying degrees of intensity between. Whatever may be the subsequent operations, the result, if they have been properly performed, is that all parts of the print corresponding to those parts of the photographic plate which have received less than a certain amount of illumination are covered with ink, while for all parts which have received more than the said amount of illumination the surface of the paper is left bare. Illumination means here the product of the intensity of light by the time of exposure.

The first question that arises is this: How does the illumination vary within the shadow of the screen?

In copying a subject in the camera, the aperture of the lens' diaphragm may be taken as the source of illumination; seen from a point of the photographic plate, its whole surface appears evenly illuminated, if the subject is properly focussed, the illumination being proportional to the intensity of the light sent by the corresponding point of the subject.

Let *ABCD*, Fig. 1, be the diaphragm, and *MM* the plane of the sensitive plate. For a screen, let us take a single opaque figure, *LL*. There is, on the plate, a certain space, *MM*, outside of which the whole of the diaphragm is visible and the illumination uniform. There is another space, *NN*, inside of which the diaphragm is invisible and where the illumination is zero: this is the shadow proper. In the space inside of *MM* and outside of *NN*, a portion only of the diaphragm is visible, and the illumination varies according as the diaphragm is more or less covered by the opaque figure, LL, of the screen: this is the penumbra. Designating by I the illumination outside of MM, and by q the fraction of the diaphragm visible from a point T of the plate, the illumination i at T is:

$$i = qI.$$

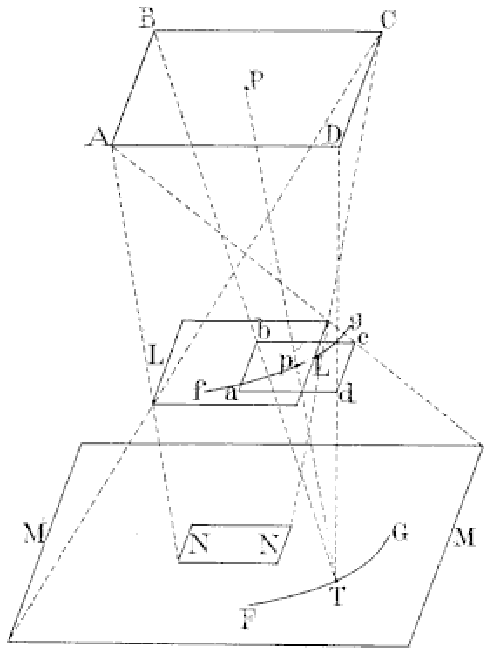

FIG. 1.

The uncovered portion of the diaphragm is found by projecting, on the plane of the screen, the perspective, *abcd*, of the diaphragm seen from T. The planes of the diaphragm and screen being parallel, the figure *abcd* is similar to $ABCD$, and the portion of *abcd* which is outside of the opaque figure LL, bears to the whole surface, *abcd*, the same ratio as the uncovered portion of the diaphragm bears to the whole surface, $ABCD$. The visible fraction of the diaphragm is thus ascertained by finding the fraction of the diaphragm's perspective not covered by the opaque part of the screen.

A line, FG, on the surface of the plate, such that from every one of its points the same fraction of the diaphragm is visible, is a line of equal illumination. When T is displaced along this line, the uncovered portion of the diaphragm may change its shape, but its area remains constant.

Let P be the centre of the diaphragm and p its perspective on the plane of the screen, T being the point of sight. When T moves along FG, p describes another curve, fg, which is the perspective of FG, seen from P. The screen and plate being parallel, these curves are similar, and any relation existing between the curves described by p holds good for the curves described by T. In process work, the distance from the diaphragm to the plate is so large compared to the distance from the screen to the plate, that these two sets of curves are practically equal. It will be assumed hereafter that they are exactly equal, but this is done merely for the sake of simplicity, as the relations which we will find are independent of this assumption. According to this, instead of determining the lines of equal illumination on the plate, it will be sufficient to calculate the curves described on the screen by the perspective of P when the visible portion of the diaphragm remains constant.

We will commence with the simplest case, that of the chess-board screen with square diaphragm, and we will suppose both to be so adjusted that the perspective of the diaphragm fits as shown in *ABCD*, Fig. 2. the diagonals of the perspective being equal and parallel to the sides of the squares of the screen.

Let I be the illumination when the whole of the diaphragm is visible, as in Fig. 2, and designate by $2a$ the side of a square of the screen; the area of the diaphragm's perspective is:

$$2a^2.$$

Now displace the perspective by moving the point of sight on the plate, and take O as origin of the co-ordinates. OX and OY as the axes. The centre of the perspective comes in P, Fig. 3, its co-ordinates being x

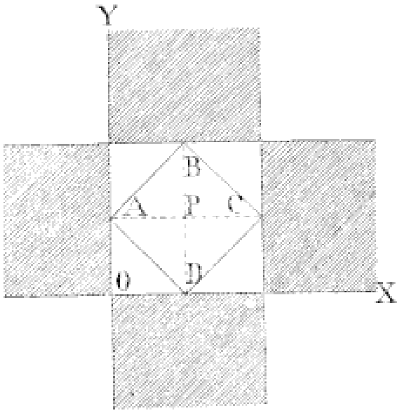

FIG. 2.

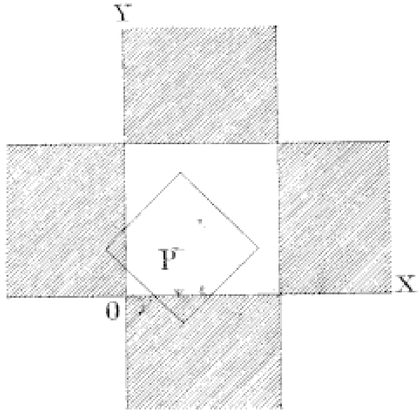

FIG. 3.

and y. The whole surface of the diaphragm has ceased to be visible: two corners are cut off by the opaque squares of the screen. The area of one corner is:

$$(a - x)^2,$$

and the area of the other:

$$(a - y)^2.$$

So the visible portion of the diaphragm is:

$$2a^2 - (a - x)^2 - (a - y)^2.$$

and the illumination:

$$i = I\left[\frac{2a^2 - (a - x)^2 - (a - y)^2}{2a^2}\right]$$

from which we obtain:

$$(a - x)^2 + (a - y)^2 = 2a^2\left(1 - \frac{i}{I}\right). \qquad (1)$$

The curve of equal illumination is therefore a circle, having its centre in the middle of the transparent square of the screen. The relation holds good so long as the portions cut off from the diaphragm are right angle triangles; that is, so long as P remains within the square, $ABCD$, Fig. 2. When outside, as in Fig. 4, the visible portion of the diaphragm becomes

$$a^2 + 2xy,$$

and the illumination,

$$i = I\left(\frac{a^2 + 2xy}{2a^2}\right);$$

hence:

$$xy = a^2\left(\frac{i}{I} - \frac{1}{2}\right). \qquad (2)$$

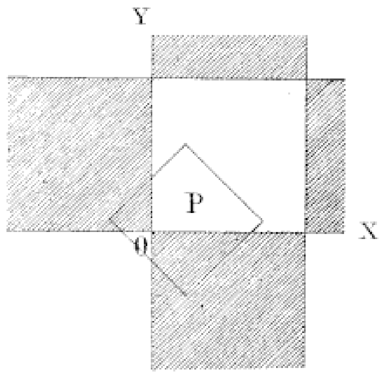

FIG. 4.

The curve of equal illumination is an hyperbola, with the sides of the transparent square as asymptotes.

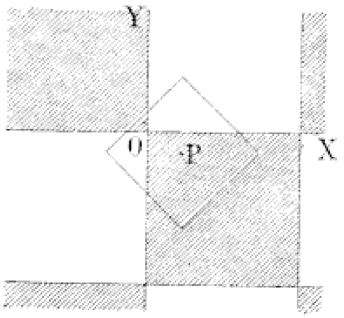

FIG. 5.

This last formula does not change when P comes into the opaque square, as in Fig. 5; the curve of equal illumination is still an hyperbola, with the axes of co-ordinates as asymptotes. But, when the visible portion of the diaphragm is reduced to two right angle triangles, as in Fig. 6, the curve again becomes a circle. For the area of this visible portion is in that case:

$$(a - x)^2 + (a + y)^2,$$

and the illumination:

$$i = I\left[\frac{(a - x)^2 + (a + y)^2}{2a^2}\right],$$

hence:

$$(a - x)^2 + (a + y)^2 = 2a^2\frac{i}{I}. \qquad (3)$$

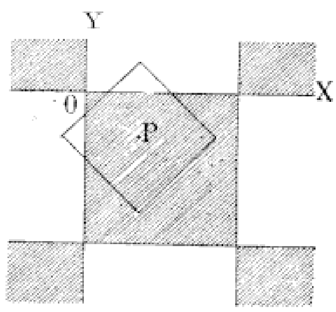

FIG. 6.

The centre of these circles is the middle of the screen's opaque square; as in the transparent square, the curves of equal illumination are circular so long as P is within the square formed by joining the middle of the sides of the opaque square.

When i is equal to one-half of I, the line of equal illumination coincides with the sides of the screen's squares.

The curves are plotted in Fig. 7 for values of $\frac{i}{I}$, increasing in arithmetical progression from $\frac{1}{20}$ to 1.

If we take for i that critical amount of illumination which is just sufficient to prevent the deposit of ink on the corresponding part of the print, the curves of Fig. 7 indicate the shape of the dots. They are black dots under the opaque square of the screen, and white dots under the transparent square. For $\frac{i}{I} = \frac{1}{2}$, they become alternate black and white squares, the print being an exact copy of the screen. We will call this the middle tone of the print.

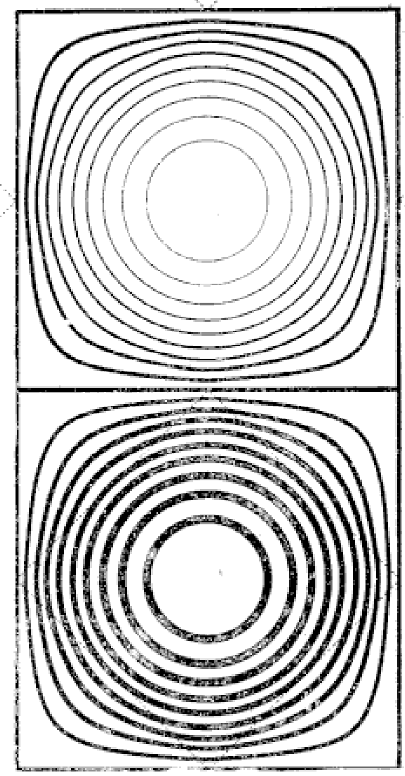

Fig. 7.

A cross-lined screen, in which the opaque and transparent lines are of equal width gives precisely the same curves as the chess-board screen. The screen and diaphragm must be adjusted to fit as shown in Fig. 8; this condition is fulfilled when the distance, f, from the screen to the plate is:

$$f = \frac{F}{n\,\Delta}, \qquad (4)$$

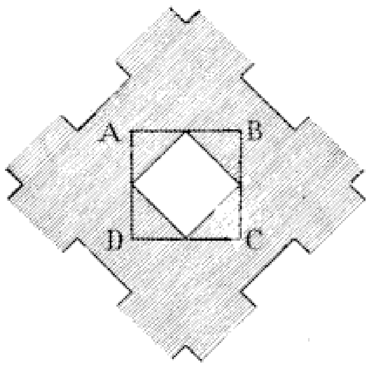

Fig. 8.

F being the distance from the plate to the diaphragm, n the number of the screen's lines to the inch, and Δ the diagonal of the opening in the diaphragm. We will see later on that this is also the proper adjustment when the transparent and opaque lines of the screen are not of equal width.

With this screen, we take D, Fig. 8, for origin of co-ordinates, DA and DC as axes, and we call $2a$ the distance from the centre of the transparent square to the centre of the intersection of the opaque lines. The equations of the curves of equal illumination are precisely the same as for the chess-board screen. The lines of the cross-lined screen are shown dotted in Fig. 7.

There are three important differences to be noted in the behaviour of the chess-board and cross-lined screens.

1st. The squares of the print's middle tone are, with the chess-board screen, equal and parallel to the squares of the screen. With the cross-lined screen, they are turned around 45° with reference to the lines of the screen, and their area is double the area of the transparent squares.

2nd. The aperture of the diaphragm with the cross-lined screen is twice as large as with the chess-board screen, but the exposure is the same for both, because there is never more than one-half of the aperture visible from the plate through the cross-lined screen.

3rd. The relative positions of the diaphragm and of the screen's squares for one of the screens are inverted with the other screen. With the chess-board screen, the diaphragm's perspective is inscribed in the square of the screen; with the cross-lined screen, it is the square of the screen which is inscribed in the diaphragm's perspective. The characteristics of the two screens seem to be due to this inversion. Thus the effect on the dots produced by increasing the width of the transparent lines in the cross-lined screen is obtained with the chess-board screen by increasing the size of the diaphragm. With the chess-board screen, a modification in the shape of the diaphragm's aperture would require a cross-lined screen with transparent figures of the same shape, to produce the same dots.

The two screens do, however, behave exactly alike when the cross-lined screen is used in connection with a diaphragm consisting of one or more pairs of equal apertures, preferably a single pair. This screen then transforms itself, so to speak, into a chess-board screen. The distance between the centres of the components of a pair is:

$$e = \frac{F}{nf\sqrt{2}}. \qquad (5)$$

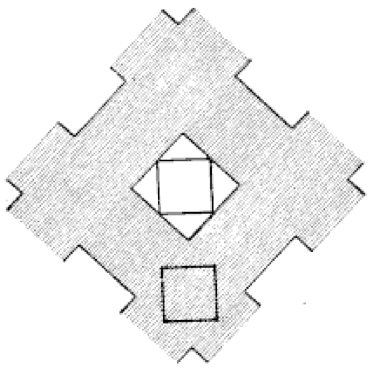

Fig. 9.

A double square diaphragm must fit as in Fig. 9 to correspond to the arrangement shown in Fig. 2.

The double aperture produces twice as many dots as the single aperture; in the shadows, there is a white dot under the middle of each transparent square, and another white dot under the intersection of the opaque lines. The squares of the print's middle tone are no longer turned around 45°: they are equal and parallel to the squares of the screen. All this can be verified by calculating the curves of equal illumination, in the same manner as we have already done, and as the matter is quite simple, it is unnecessary to say anything further about it.

Reverting to Fig. 7, it has been explained that the curves are lines of equal illumination, the value of $\frac{i}{I}$ changing by $\frac{1}{20}$ from one curve to the next one. Under the centre of the transparent square the illumination is I; at the first curve or circle it is reduced to $\frac{19}{20}$ of I; at the next curve to $\frac{18}{20}$ of I, and so on till the last circle under the opaque square, where it is $\frac{1}{20}$ of I. Under the centre of this square it becomes zero. Thus each curve is the limit of the space or surface which has received an illumination not less than the fraction

$$q = \frac{i}{I}$$

of the original intensity.

It will be shown further on that for copying from negatives and for making vignetted screens, this space or surface must be proportional to q.

The table underneath of the areas of Fig. 7 shows that this condition is not fulfilled by the square diaphragm and the screens employed; the small dots, black and white, are too small, and the larger ones, near the middle tone, change too rapidly.

q	Area.	q	Area.	q	Area.	q	Area.
0·05	0·0393	0·30	0·2373	0·55	0·5986	0·80	0·8430
0·10	0·0785	0·35	0·2826	0·60	0·6648	0·85	0·8812
0·15	0·1188	0·40	0·3352	0·65	0·7174	0·90	0·9215
0·20	0·1570	0·45	0·4014	0·70	0·7627	0·95	0·9607
0·25	0·1963	0·50	0·5000	0·75	0·8037	1·00	1·0000

It will be observed that errors are equal for dots of same size, whether black or white; in other tables we will only give the areas of the white dots.

The circular dots can, with the chess-board screen, be made perfectly exact by a diaphragm of proper shape, but the discrepancy near the middle tone cannot be removed entirely, although it may be reduced as much as desired.

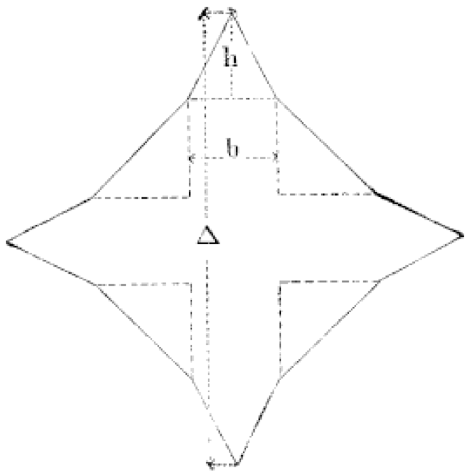

Fig. 10.

The general shape of diaphragm indicated by theory is one involving two separate exposures, and is shown in Fig. 10. It consists, for the first exposure, of a square of which the corners are cut off and replaced by triangles.

Designating by h the height of a triangle, by b the base, and by m the ratio between the second and the first exposure, we must have :

$$h = \frac{1}{2} b \, (m + 1) \qquad (6)$$

The length of b is given by the equation :

$$b = \frac{\Delta}{m + 2} \left[1 - \sqrt{1 - \left(\frac{4}{\pi} - 1 \right) \left(\frac{2}{m} + 1 \right)} \right] \qquad (7)$$

in which Δ is the diagonal of the figure and π the ratio of the circumference to the diameter. The first exposure is given through the whole aperture; the second one through the central cross shown by broken lines on the figure.

It would unduly expand the limits of this paper to give the full theory of this diaphragm, and it is quite sufficient for our purpose to calculate the curves which it gives, without inquiring any further.

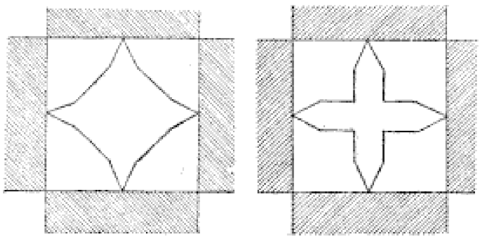

Fig. 11.

This diaphragm is adjusted so that its perspective will fit in the squares of the screen as in Fig. 11. The aperture of Fig. 10 is calculated for equal exposures; the value of b is :

$$b = 0{\cdot}192 \, \Delta.$$

The calculated curves are shown in Fig. 12. The smaller dots still are circles; the larger ones are composite curves, consisting of arcs of circles, ellipses and hyperbolas. Their areas are given hereunder.

q	Area.	q	Area.
0·05	0·05	0·30	0·2921
0·10	0·10	0·35	0·3349
0·15	0·15	0·40	0·3794
0·20	0·20	0·45	0·4386
0·25	0·25	0·50	0·50

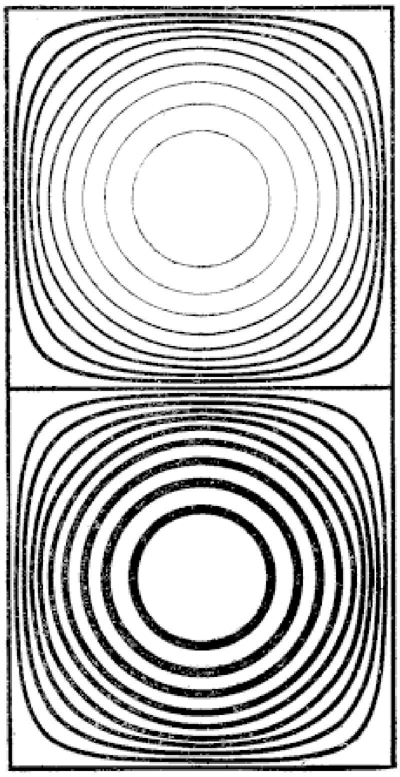

Fig. 12.

The first five dots are circles: their areas are absolutely correct. The square of the middle tone is, of course, correct. The errors in the remaining four dots are very much reduced.

The perfection of this result may be improved by increasing the ratio between the second and the first exposure and modifying the shape of the aperture accordingly, the only limit being the length of exposure which the operator is willing or can afford to give. It is unnecessary to add that the order of the exposures is immaterial; they may commence with the cross and end with the whole figure.

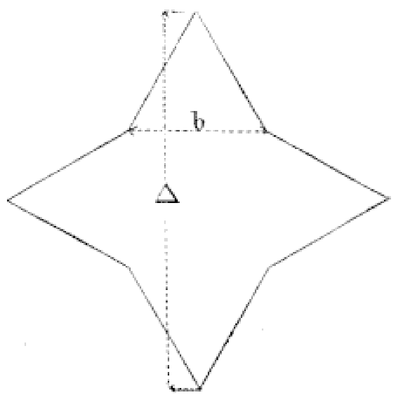

FIG. 13.

The cross exposure may be made less than the one with the whole figure, but only up to a certain point. The point is reached when the quantity under the radical in (7) becomes equal to zero. When the calculations are made, it is found that the figure assumes the shape of a star, like Fig. 13. The whole figure and the inner cross being now identical, there is no longer any necessity for two separate exposures. The value of b, which is the side of the square formed by joining the four inner angles of the star, is:

$$b = 0{\cdot}363\ \Delta,$$

Δ being the diagonal of the star. The height of the triangles forming the four wings is:

$$h = 0{\cdot}318\ \Delta.$$

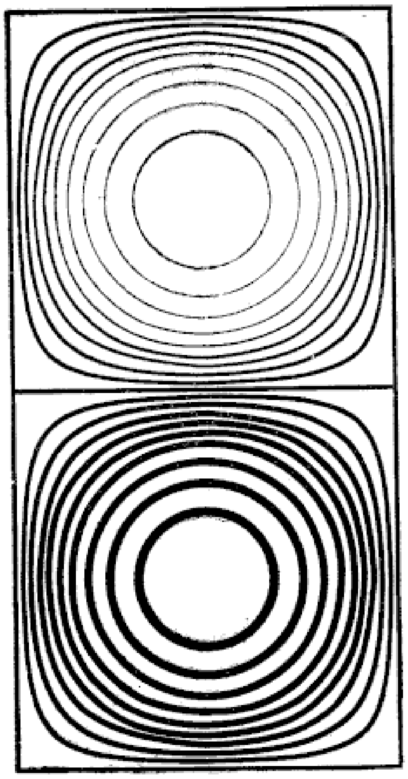

FIG. 14.

The dots produced by this aperture are given in Fig. 14. The smaller ones still are circles, the larger ones being bound by arcs of circles, ellipses and hyperbolas. Their areas are :

q	Area.	q	Area.
0·05	0·05	0·30	0·2836
0·10	0·10	0·35	0·3235
0·15	0·15	0·40	0·3689
0·20	0·1990	0·45	0·4215
0·25	0·2437	0·50	0.50

The three smaller dots, which are circles, are correct. The error for the other dots, although larger than with the two separate exposures, is small, and I believe that this shape of aperture will answer all practical purposes.

As already explained, any shape of diaphragm suitable for a chess-board screen is adapted to the cross-lined screen by using pairs of apertures, the distance between the components of a pair being given by (5), but it is necessary to have a screen in which the opaque and transparent lines are of equal width. Correct gradation cannot be produced with a cross-lined screen by means of a diaphragm having a single aperture.

II. Copying from Positives.

The object of the photo-mechanical process is to produce a print which will be an exact copy of the original. Before proceeding further we must define what an exact copy is in this particular case.

A print is an exact copy of the original when any tone of the print and the tone of the original which it represents, send out or reflect light of equal intensity.

In an original on white paper, a tone is produced by a semi-opaque film. The incident light has to pass through this film a first time before reaching the underlying surface of the paper, and is partly absorbed on the way. The remainder is reflected and diffused by the paper, after which it has to pass a second time through the film, where it is again partly absorbed. What is left is the light sent out by the tone in question; it varies, according to a certain law, with the opacity of the film.

In a half-tone print made with black ink on white paper, the incident light falling on the ink is, we will assume, entirely absorbed; that falling on the white surface is reflected and diffused, the intensity of the light sent out being proportional to the percentage of white paper in the tone—that is, proportional to the area of the white dots.

Let L be the intensity of the light sent out by the pure white paper: the intensity for the middle tone of the print is $0{\cdot}5\ L$, because one-half of the surface is covered by ink. Reducing the white dots to one-half of the middle tone squares, the intensity becomes $0{\cdot}25\ L$, because three-quarters of the surface are covered with ink. With black dots of this size, the intensity is $0{\cdot}75\ L$, because three-quarters of the surface are bare.

I assume that black ink does not reflect any light; this is not quite true, but is sufficient for our purpose. I find from photometric measurements on a good half-tone print, that the intensity of the light coming from the ink is only $\frac{1}{50}$ of the intensity for the white paper; this quantity is so small that we may neglect it.

Screens and diaphragms adjusted as we have seen would give very bad results in copying from positives. An investigation of the matter shows that the illumination is too small in the central parts of the dots, black and white, while it is excessive on the edges of the squares of the middle tone. With the cross-lined screen, for instance, it would be necessary to give a supplementary illumination under the central part of the transparent squares, for improving the shadows, and under the intersection of the opaque lines, for improving the lights. This is done for the lights by making the transparent lines of the screen wider than the opaque lines. Fig. 15 shows a screen in which the transparent lines are double

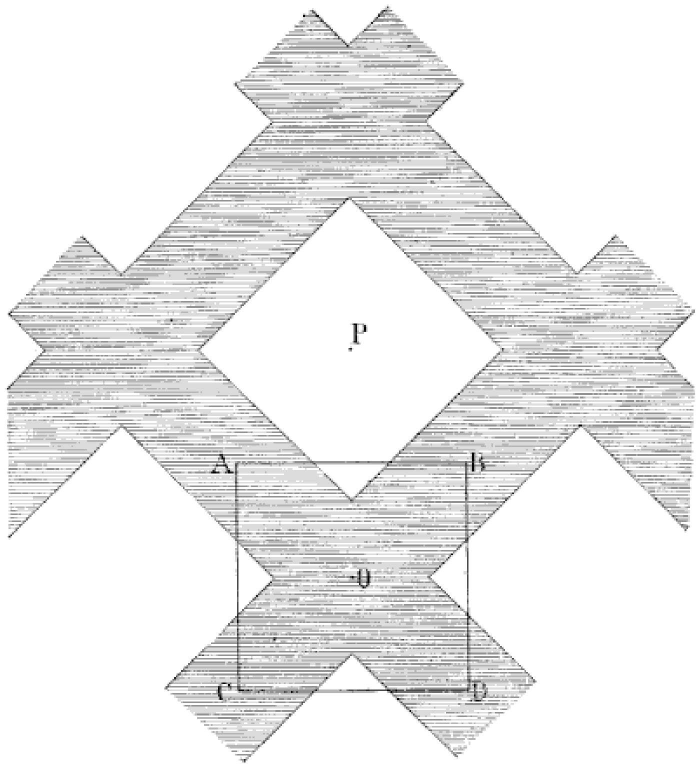

FIG. 15.

the width of the opaque lines; the perspective of the square diaphragm is adjusted over the intersection of the opaque lines, AC being equal to PO. With the screen made of lines of equal width, the diaphragm, in this position, was entirely hidden by the opaque lines: now, there are four triangular portions visible from the plate which give under O a certain amount of supplementary illumination, the effect of which is to improve the high lights. The shadows, however, are injured in proportion as the lights are improved.

I have now to explain why the diaphragm must be adjusted as in Fig. 15; this necessitates a digression.

The grain which we have been considering so far is one consisting of isolated black and white dots; only in the middle tone do the dots come into contact, and then only at one point, the corner of the squares. It must not be supposed that any screen or any diaphragm produces a grain of this kind; on the contrary, it is the exception and not the rule. It is not obtained with other screens than the cross-lined and chess-board, and even then, not without precise adjustment of diaphragm and screen. The general form of grain is reticulated; the small dots may or may not be isolated, but the larger ones are connected, the black ones by thin black lines, or the white ones by thin white lines. These thin lines have an ill effect on the printing qualities of the block; the black ones spread and the white ones clog in printing. Being so thin, they are liable to break in development and to cause uneven tints. These lines do not appear or disappear gradually; while the dots are still a considerable distance apart, a very slight change of illumination causes the connecting lines to shoot out between them. This sudden accession to the area of the dots destroys the continuity of the gradations.

The adjustment given in Fig. 15 produces a print of which the middle

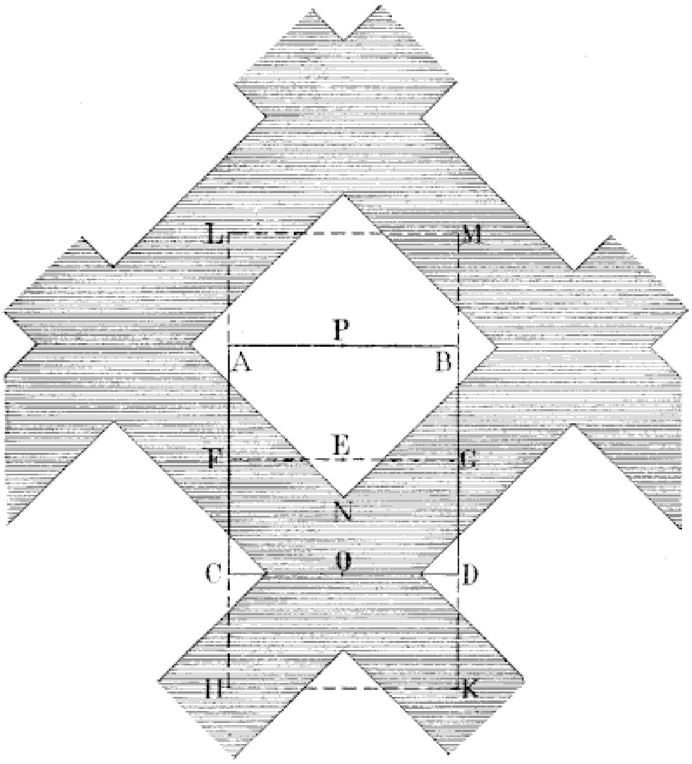

Fig. 16.

tone consists of equal black and white squares. To prove this, move the perspective of the diaphragm to the position *ABCD*, Fig. 16; the visible portion is:

$$S = (a + b)^2,$$

a being one-half of *PO* and b the distance *EN*. Moving now the centre *E* of the perspective around the squares *FLMG* and *HFGK*, it is found that the area of the visible portion remains constant. The sides of the squares being lines of equal illumination, these squares are the dots of the print's middle tone. The construction of the curves for any other dots shows that they are not connected.

With a larger or a smaller diaphragm, *FG* and the other sides of the squares cease to be lines of equal illumination; there are, therefore, no dots of that shape in the print, and its middle tone no longer consists of equal black and white squares. The construction of the curves shows that the larger dots are connected. Too small a diaphragm gives con-

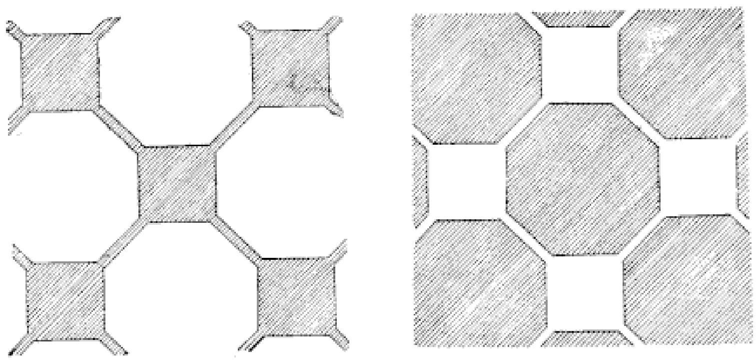

FIG. 17.

nected black dots; one too large gives connected white dots. Both are illustrated in Fig. 17 for diaphragms much out of adjustment. With better adjustment the effect would be less marked.

Let us now take an original made with black ink on white paper. To be an exact copy the print must be formed of tones equivalent to those of the original. Where the pure white of the paper is preserved in the original, black dots must be absent in the print. Here we meet a difficulty: the dots in the engraved block are in relief and the depressions between them are very shallow. If more than a few dots are omitted, there is nothing left to support the inking-roller, which is pressed against the bottom of the depressions and the print is not clean. Consequently, unless the extent of the high lights be very small, we cannot produce a print which will be an exact copy of the original; the high lights, instead of being pure white, must be a tone consisting of black dots, which may, however, be as fine as it is possible to print. We will consider the case where the extent of the high lights is so small that the dots can be omitted.

Let L be the intensity of the light coming from the pure whites of the original: leaving out the screen, the illumination received by the photographic plate at a point corresponding to the pure white is CL, C being a constant depending upon the length of exposure, aperture of diaphragm, etc. The intensity for any other tone of the original may be represented by pL, p being a fraction smaller than one; it causes an illumination of the plate equal to CpL. Now insert the screen; the aperture of the diaphragm, of which the full area R was formerly visible from the plate, is partly hidden by the opaque lines of the screen, leaving only the portion r uncovered. The illumination becomes:

$$i = CpL \frac{r}{R},$$

or, if we designate by Q the largest portion of the diaphragm's aperture visible through the screen, and by q the fraction thereof visible from the particular point of the plate under consideration:

$$i = CpL \frac{Qq}{R}.$$

We can take for i the critical amount of illumination which determines the formation of the dots; it is approximately what Messrs. Hurter and Driffield call the "*inertia*" of the plate. The outlines of the dots will then be the curves for which the uncovered fraction of the diaphragm is:

$$q = \frac{iR}{CpLQ}. \qquad (8)$$

For $p = 1$, that is, for the pure whites, the illumination at the darkest point, O, of the plate (Fig. 15) must not be less than i, otherwise a black dot would be found in the print. It must not be more than i, because a tone, pL, of the original, less bright than pure white, would be represented by pure white in the print. It must, therefore, be equal to i. As the value of q for this point, O, is $\frac{4b^2}{Q}$, we must have:

$$\frac{4b^2}{Q} = \frac{iR}{CLQ}.$$

Introducing this value in equation (8), it becomes:

$$q = \frac{4b^2}{pQ}. \qquad (9)$$

We now have only to calculate by means of equation (9) the value of q for each tone p of the original, and, with these values of q, to plot the curves of equal illumination in the same way as we did before. They are represented in Fig. 18 for values of p increasing in arithmetical ratio from $\frac{1}{20}$ to 1, and for a screen in which the opaque lines are one-half the width of the transparent lines; these lines are shown dotted in the figure. The values of q are given hereunder.

p	q	p	q	p	q	p	q
1·00	0·143	0·70	0·204	0·40	0·357	0·10	1·429
0·95	0·150	0·65	0·220	0·35	0·408	0·05	2·857
0·90	0·159	0·60	0·238	0·30	0·476	0·00	∞
0·85	0·168	0·55	0·260	0·25	0·572		
0·80	0·179	0·50	0·286	0·20	0·714		
0·75	0·191	0·45	0·317	0·15	0·952		

For $p = 1$, q is $\frac{1}{7}$ or 0·143.

As p decreases, q increases, slowly at first and more rapidly after, until the value of 1 is reached for $p = 0{\cdot}14$. This value of q, representing the full effective aperture of the diaphragm, it follows that the illumination is insufficient to produce white dots for tones of the original less bright than $0{\cdot}14\ L$; they are represented by solid black in the print.

The smaller black dots are circles; their equation is:

$$(a - x)^2 + (a - y)^2 = \frac{2}{q} a^2 \left(\frac{1}{p} - 1\right).$$

The larger dots are bound by composite curves; their equations are somewhat complicated, but it is always possible to construct the curves of any diaphragm by points. The diaphragm is placed in a number of

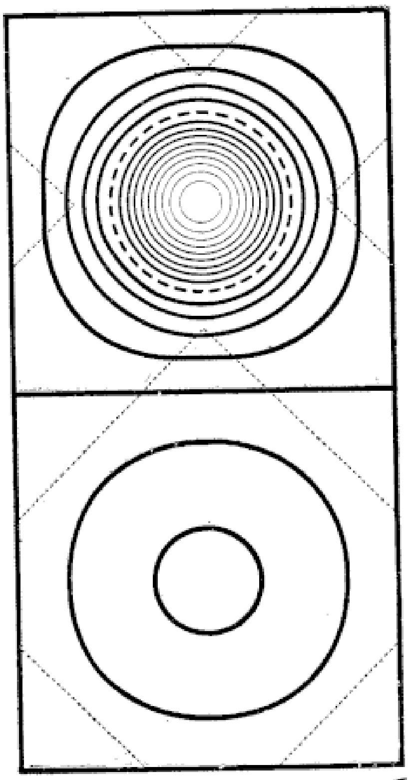

Fig. 18.

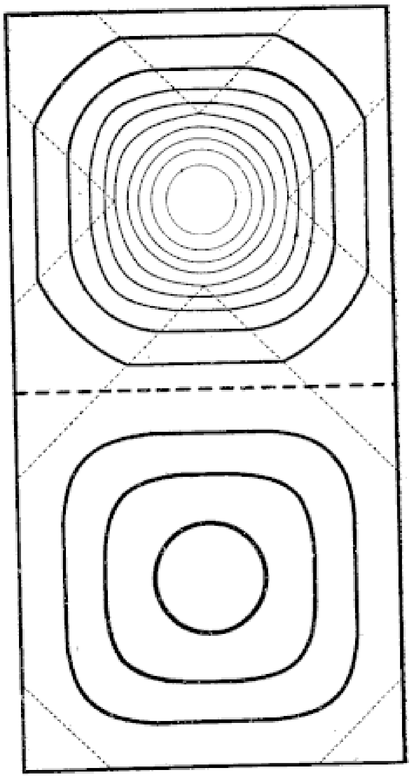

Fig. 19.

different positions over the screen, and its visible area measured for each position. The curves of equal illumination are then interpolated between the points so determined.

It is at once seen how imperfect the print is. The area of the white dots should be proportional to p and the area of the black dots to $1 - p$; that is, they should be like the dots of Figs. 12 and 14. Instead of this, we see that the original tone, $0{\cdot}5\ L$, which is one-half the brightness of the white paper, is represented in the print by the black dot shown by a broken line in Fig. 18; it ought to consist of equal black and white squares. The original tone, 0·25 *L*, which is one-quarter the brightness of white paper, is represented by equal black and white squares, which are one-half the brightness of white paper. In the deep shadows, the dots disappear altogether and detail is entirely lost.

In actual practice the result is slightly different. A shorter exposure is given in order to produce fine black dots in the high lights, and all the black dots are slightly enlarged. The light tones are improved, but there is a corresponding loss in the shadows where more white dots disappear.

The proportion between the opaque and transparent lines of the screen may be varied. As the width of the opaque lines decreases, the light tones of the print are improved; the dark ones become worse. Fig. 19 illustrates an extreme case, the proportion between the transparent and opaque lines being 3·415. The light tones are very much improved, and the original tone, 0·5 *L*, is correctly represented by equal black and white squares, but all the original tones less bright than 0·33 *L* are translated into solid black. From the foregoing we may conclude that an original in which the dark tones predominate must be copied with a screen having wide opaque lines, while a subject in which light tones predominate is better translated by a screen having thin opaque lines. I am inclined to believe that the opaque lines should not be much more than one-half and not much less than one-third the width of the transparent lines.

A larger diaphragm than the correct size, or, what is the same thing, adjusting the screen further away from the plate, produces approximately the same effect as a screen with thinner opaque lines; the opposite effect is produced by a smaller diaphragm or by placing the screen closer to the plate. An examination of a number of good prints shows that this mode of adapting their screen to the character of the original is resorted to by some of the best operators, but it must be used sparingly, because it is apt to produce reticulation. A reference to Fig. 15 shows what is taking place. With the larger diaphragm, the four triangular portions which are lighting the point *O* under the opaque lines, are increased in area, precisely as they would be if the opaque lines were thinner, while with the smaller diaphragm their area is reduced as it would be by wider opaque lines.

We already know that with the chess-board screen we must look to changes in the size of the diaphragm to produce the effect of unequal ruling of the cross-lined screen. An increase in size, as in Fig. 20, produces illumination at *O* under the centre of the centre of the opaque square by the four uncovered corners of the diaphragm. Making the area of these four corners one-eighth of the total area of the aperture gives the dots of Fig. 18; the dots of Fig. 19 are obtained by a still larger diaphragm, the four uncovered corners

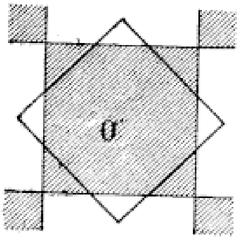

FIG. 20.

being one-quarter of the whole aperture. But we now have a resource which was not available with the cross-lined screen: we can change the shape of the aperture. Fig. 21 represents a diaphragm producing

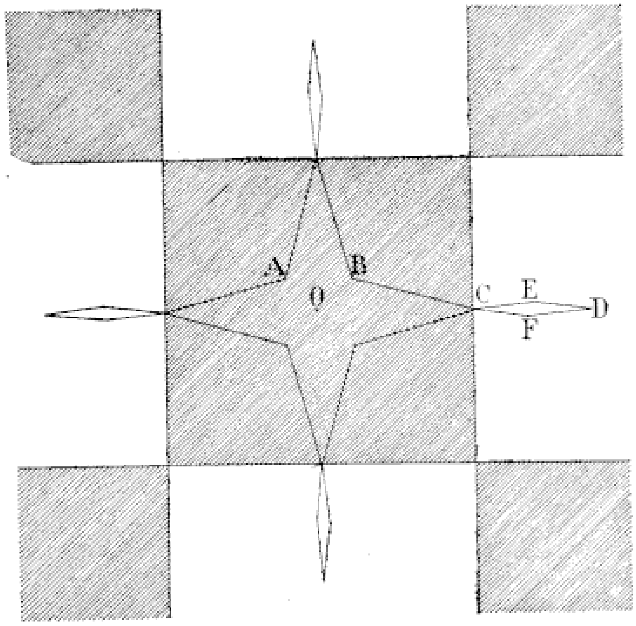

Fig. 21.

the effect of a cross-lined screen in which the transparent lines are double the width of the opaque lines. The dimensions are:

$$AB = \frac{7}{32} \Delta .$$

$$CD = \frac{25}{64} \Delta .$$

$$EF = \frac{1}{25} \Delta .$$

The dots of this diaphragm are given in Fig. 22; a comparison with Fig. 18 shows a very great improvement. The light tones are fairly translated; the dots are only a trifle too small, but the gradation is good. The light shadows are not quite so good, but much better than with the cross-lined screen; there is no improvement in the deep shadows. This diaphragm requires two and one-half times the exposure of the square diaphragm. Its rapidity may be increased by making the arms of the inner star less pointed and increasing proportionately the width, EF (Fig. 21), of the extensions, but that makes all the black dots smaller and the print less perfect. It is quite easy to devise other shapes of diaphragms. One is given in Fig. 27; the apertures are not so elongated as in Fig. 21, but it has the drawback of requiring very accurate adjustment.

The shorter diagonal of the rhombus-shape extensions is 0·19 of the diagonal of the central square; the longer diagonal of the rhombus is twice the length of the shorter one. Each of the smaller squares is equal to one-quarter of the area of the central square. The dots produced by this diaphragm are approximately those of Fig. 22.

A method much in vogue among operators consists in giving the exposure through several square diaphragms of various sizes. With a chess-board screen, the procedure may be as follows:

The first or preliminary exposure is given through a diaphragm AB, Fig. 23, placed at a distance, OP, from the optical axis of the lens equal to the diagonal of the aperture. The length of this diagonal is deduced from equation (16). The purpose of this exposure is to give the illumination which is lacking under the centre of the opaque squares of the screen. The illumination due to this diaphragm is maximum under the centre of these squares, while it is null under the centre of the transparent squares. The preliminary exposure should be just sufficient to give a trace of the highest lights, if the plate were fully developed and intensified.

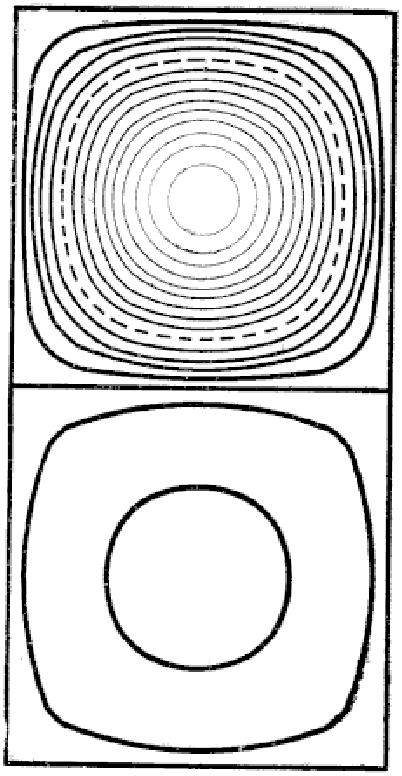

Fig. 22.

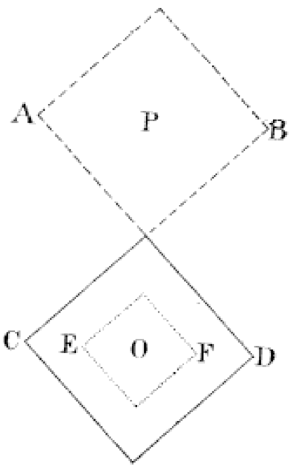

Fig. 23.

The main exposure is given through the diaphragm CD, equal to AB, and placed in the centre of the lens; it is equal to two and a half times the preliminary exposure. This exposure determines the size of the dots in the lights, but the shadows are still very imperfect. If the plate were now developed and a block made, the middle tone of the print would be found to represent the tone, 0·57 L, of the original; all tones less bright than 0·4 L would come out as solid black.

For improving the shadows a supplementary exposure is given with the diaphragm EF, the diagonal of which is equal to one-half of CD. This exposure is from ten to fifty times the preliminary exposure; the longer it is, the greater is the range of tones reproduced by the print. It has no effect on the lights. Making it eighteen times the preliminary exposure gives approximately the dots of Fig. 22. The middle tone of the print represents the tone, 0·25 L, of the original; the shadows less bright than 0·14 L come out as solid black. In other words, the range of tones reproduced is from $\frac{1}{7}$ L to L. Designating by k the supplementary exposure, the range of the print is from

$$\frac{1}{\frac{k}{4} + 2{\cdot}5} \text{ to } 1.$$

For instance, a supplementary exposure equal to thirty times the preliminary one gives a range from $\frac{1}{10}$ to 1.

We can now understand better the mode of action of the diaphragms of Figs. 21 and 27. In both, the equivalent of the preliminary exposure is given through the rhombus-shape extensions at the corners. The supplementary exposure in Fig. 27 is given through the four smaller squares; in Fig. 21 it results from the star-shape of the main aperture. The preliminary and main exposures, in the method described above, may be replaced by a single exposure through the central part of the diaphragm of Fig. 27.

The gradations may be improved by substituting for the original a sheet of white paper during part of the supplementary exposure. Let us assume that the original is on white paper and that the highest lights are represented by the pure white. After the preliminary and main exposures let us give a supplementary exposure of 4 on the original, then substitute the sheet of white paper and give an exposure of 2. The range of tones reproduced by the print is from $\frac{1}{7}$ L to L, as in the example cited above, but the middle tone now represents the tone 0·33 L of the original, instead of 0·25 L as formerly. That is a very great improvement. On the other hand, the total exposure which, by the first method, was 21·5 times the preliminary exposure, is reduced to 9·5, less than one-half of what it was before.

The methods which we have described are all more or less imperfect. Theoretically the correct method, which involves two separate exposures, is as follows:

1st. Expose, without the screen, on the original, which we will assume again to be on white paper, and time the exposure so that if the plate were then fully developed and intensified, it would just show a trace of the highest lights of the original. The size and shape of the diaphragm are, of course, immaterial, but for the sake of simplicity in the explanations, we use the same diaphragm as in the second exposure.

2nd. Cover the original with a sheet of white paper, remove the plate-holder to the dark room, insert the screen, and give a second exposure, equal to the first one, on the sheet of white paper, using the star diaphragm of correct size (Fig. 13). If this exposure were given alone, and the plate fully developed and intensified, the negative would show an extremely fine opaque dot under the centre of each transparent square of the screen. After receiving the two exposures, the negative is developed and the usual operations follow.

Using the same notation as before, the first exposure has caused an illumination, at any particular point of the plate, equal to

$$pL.$$

The second exposure gives the illumination,

$$qL,$$

so that the total illumination at the point of the plate under consideration is

$$pL + qL.$$

The outlines of the dots are the curves for which

$$pL + qL = i,$$

or

$$p + q = \frac{i}{L}.$$

L is the illumination produced, during the first exposure, by the highest lights of the original; it is also the illumination under the centre of the transparent squares during the second exposure. In both cases we have so timed the exposures that L is just sufficient to produce printing density on the negative. But that is precisely the definition of i; therefore

$$L = i,$$

and the equation of the dots becomes:

$$p + q = 1.$$

This equation means that the tone, pL, of the original is represented by dots, from the outlines of which the fraction $1 - p$ of the diaphragm is visible. We have seen, in the first part of this paper, that the areas of these dots are practically correct.

The first exposure may be given with any kind of diaphragm, and must be just sufficient to impress on the plate the highest lights of the original, whether on white paper or not.

The second exposure can be given on any uniform source of illumination, provided it is so timed as to just produce printing density under the centre of the transparent squares of the screen. If white paper be used, it is preferable to place it out of focus, so that the grain of the paper may not show. Each of these exposures can be timed very accurately with trial plates—a most important consideration.

We will see later on that the second exposure alone produces a vignetted screen. The mode of action in the process last described, therefore, consists in impressing, before development, a vignetted screen upon the negative.

Unfortunately the exposure on white paper obliterates, to some extent, the image in the shadows, and increases the difficulty of obtaining sharp dots with clean edges. In that respect the process is much inferior to those which we will now investigate. It has the advantage of requiring a very short exposure.

III. Copying from Negatives.

Exposure through a negative gives a transparency or positive; the interposition of the screen does not modify this relation. What is to be done with the dotted transparency does not come within the scope of this paper. Whether a negative is to be made from it, or whether, by some peculiar process, the engraved block is to be made directly from the transparency, I will leave for others to decide.

To understand what is to follow, I must give briefly Messrs. Hurter and Driffield's definitions of a perfect negative; for further explanations I refer to their original paper.[1]

The opacity of a film is the reciprocal of the number expressing the fraction of the incident light which emerges from the film. An opacity of ten lets one-tenth of the light pass, stopping nine-tenths of it. An opacity of two lets one-half of the light pass. An opacity of one does not stop any light; it is perfect transparency. The density is the logarithm of the opacity.

Two opacities, O' and O'', put together form an opacity, O, equal to the product of O' and O''. Two densities, D' and D'', produce a density, D, equal to the sum of D' and D''.

In a perfect negative the opacities are proportional to the light intensities by which they were produced. These opacities or densities are reached at a certain stage of development; with a shorter or longer development, a density, D, becomes αD, α being the "development factor."

Let L be the highest light intensity of the original, and ML the corresponding opacity of the negative. Another tone pL, of the original, is represented in the negative by the opacity MpL, and the light transmitted is $\frac{1}{MpL}$. We now place this negative in front of the camera and

[1] "Photo-chemical Investigations, and a New Method of Determination of the Sensitiveness of Photographic Plates," by Ferdinand Hurter, Ph.D., and N. C Driffield—Journal of the Society of Chemical Industry, May 31, 1890.

copy it through a screen. The illumination i of the plate is, we have seen, proportional to the intensity of the light transmitted through the negative and to the area of the fraction q of the diaphragm not hidden by the screen.

$$i = \frac{Nq}{MpL},$$

N being a constant. We may take for i the value of the illumination on the outlines of the dots and calculate q:

$$q = \frac{MpLi}{N}. \qquad (10)$$

Assuming again that the tone L of the subject is to be represented by pure white paper in the print, there must be no black dot when p is equal to one, and consequently the illumination under the centre of a transparent square, where the light is given by the full effective aperture Q of the diaphragm, must be equal to i, or:

$$1 = \frac{MLi}{N}.$$

Introducing this value in equation (10), it becomes

$$q = p \qquad (11)$$

This equation means that any tone pL of the original is transformed into dots, from the outline of which the fraction p of the diaphragm is visible.

For correct representation, the area of the white dots must be proportional to p, and the area of the black dots to $1 - p$; therefore the area of the curves of equal illumination must be proportional to q under the opaque squares of the screen, and to $1 - q$ under the transparent squares. Such curves are given by the chess-board screen and the single or double exposure diaphragms described in the first part of this paper. The dots are shown in Figs. 12 and 14, and are practically correct.

The negative must be what is termed a "soft" one, and must be produced by full exposure and short development. It should be much less dense than for printing by contact.

The formulæ indicate that there are white dots in the deepest shadows of the print; there is no solid black. In theory this is absolutely correct, because the clear glass of the negative does not indicate absence of light in the subject, but only an illumination less than the inertia of the plate on which the negative was made. We must remember, however, that we have assumed the ink to be perfectly black, which is not the case; we should therefore close the white dots in the deepest shadows. With a negative of average density, these dots are below printing size; they do not appear in the print; with a thinner negative it is sufficient to use a diaphragm very slightly larger than the correct size.

The easiest way of making the transparency is to employ one of the enlarging and reducing cameras which have a partition in the middle, carrying the lens, and one of the ends arranged to receive the negative. The ordinary copying board is covered with white paper and set some distance away from the negative; it is lighted, as usual, by electric light or otherwise. With a negative of proper density, the exposure need not be excessive, although longer than with the process as now worked.

It is possible to employ an arrangement like the enlarging lantern, provided the source of light be of the right kind. It must be a surface of uniform illumination; the lime-light or the arc-light will not do. Incandescent gas-light may answer the purpose. After focussing, and before exposing the plate, the condenser should be carefully adjusted. This may be done by marking, with ink or pencil, on a piece of white cardboard, the outline of the diaphragm's aperture and inserting it in the diaphragm's slot. The condenser and light are now moved until the image of the latter is formed on the cardboard; it must fully cover the diaphragm's aperture and be perfectly uniform. If it were otherwise, the shape of the dots would be governed, not by the diaphragm, but by the shape of the light.

IV. Copying through Vignetted Screens.

The screens which we have been investigating consist of opaque and transparent parts; a vignetted screen is semi-opaque over its whole surface, and divided into minute zones of varying degrees of opacity. This screen must be placed in contact with the photographic plate; its use is therefore restricted to dry plates.

It may be made to copy from an original or transparency, or from a negative; from a practical point of view, the first case is the only one to be considered.

In copying from the original, the screen is placed as usual in the camera, but in contact with the plate; the shape of the diaphragm is immaterial, and so is its size, provided it is not too large. A transparency may be copied in the camera or in a printing frame. The arrangement of the camera should be something like that described for copying from negatives, with the exception that any illuminant is suitable; the arc light would answer the purpose admirably. For the printing frame, the transparency is stripped and placed between the plate and the screen. Exposure must not be given to diffused light, but to light emanating from a point, like an arc light; the frame must be kept in the same position during the whole exposure. The theory is identical for the camera and for the printing frame; we will investigate the latter only.

In a perfect transparency, the opacities are inversely proportional to the light intensities which they represent. Let L be the greatest light intensity of the subject, and pL another tone, O_o and O, the opacities by which they are represented; we must have

$$\frac{pL}{L} = \frac{O_o}{O},$$

or

$$p = \frac{O_o}{O}$$

and

$$D - D_o = -\log. p,$$

D and D_o being the densities of the transparency which represent the light intensities pL and L. In a transparency developed more or less than required to produce a perfect one, the last equation becomes:

$$D - D_o = -\alpha \log. p, \qquad (12)$$

α being the development factor.

A vignetted screen is produced by exposing a photographic plate to illumination which varies in amount at different points of the plate. Let l be the greatest illumination of this plate, and ql another illumination. The opacities o_1 and o produced, being proportional to the light intensities, we have:

$$\frac{ql}{l} = \frac{o}{o_1},$$

or

$$q = \frac{o}{o_1},$$

and

$$d_1 - d = -\log. q,$$

d_1 and d being the densities of the screen produced by the light intensities, l and ql, the development factor being one. With another factor, β, the equation becomes:

$$d_1 - d = -\beta \log. q. \qquad (13)$$

We place this screen and the transparency in the printing frame, and through both give the proper exposure to the plate. The negative is developed, the engraved block made and the print struck off as usual. The final result is that wherever the sum of the superposed densities of the transparency and screen has been greater than a certain density, M, there is ink on the print, and wherever this sum is less than M, the white paper of the print is left bare; the outlines of the dots are, therefore, the lines for which we have:

$$D + d = M. \qquad (14)$$

This density, M, is the one which lets through just that critical amount of illumination which was stated to be about equal to the inertia of the plate, and which is the illumination on the outlines of the dots.

Assuming, as before, that the highest light, L, of the subject, for which the density of the transparency is D_o, must be represented by pure white in the print, we must have

$$D_o + d_1 = M,$$

d_1 being the greatest density of the screen. Combining with (14), there comes

$$D - D_o = d_1 - d.$$

Replacing both members of this equation by their values from (12) and (13), we obtain:

$$-\alpha \log. p = -\beta \log. q.$$

This equation is satisfied by:

$$\alpha = \beta,$$

and

$$p = q. \qquad (15)$$

The first relation shows that the development factors of the transparency and screen must be equal; a strongly developed transparency requires a strongly developed screen.

The second relation means that the outline of the dot by which the tone pL of the subject is represented, is the line of the screen which received the illumination pl while the screen was being made. In order to produce a correct print, the surface inclosed by this line must be proportional to p for the white dots, and to $(1 - p)$ for the black dots. We know that this is approximately the result of an exposure behind a chess-board screen through a star or double exposure diaphragm; we are, therefore, able to make vignetted screens possessing the gradations required to produce exact copies of an original. For this purpose we expose a photographic plate on a piece of white paper placed out of focus, the diaphragm and screen being adjusted as explained in the first part of this paper.

The theory for copies in the camera is so much like the theory for contact copies in the printing frame, that further explanations are not needed.

The vignetted screen having to be placed in contact with the photographic plate, its face cannot be protected by a glass cover; it can only be varnished. Very likely it will soon be scratched or damaged, and will have to be replaced frequently. The operator should have a set of screens of various densities to select from; light screens for light transparencies, and dark screens for intense transparencies. There does not appear to be any reason why every operator should not make his own vignetted screens; they are produced by operations with which he is familiar, and which do not present any special difficulty. The plate on which the screen is to be made is, we have seen, exposed behind a chess-board screen through a star or double exposure diaphragm. The correct exposure is ascertained by trial. After development the screen is found to consist of semi-transparent and semi-opaque dots alternately disposed; examining it under a moderately strong microscope, the central part of the semi-transparent dots must be thin, but not clear glass. The presence of minute spots of clear glass indicates under-exposure. Under a strong microscope it will be found that, even with correct exposure, there are very minute dots of clear glass in the centre of the semi-transparent dots; their size must be kept down by a full exposure. A screen not sufficiently developed does not reproduce the deep shadows; they come out solid black in the print, and the shadows are generally too dark. A screen too much developed gives a print in which the shadows are too light; there is no solid black. Under-exposure is indicated by the absence of the finest white dots in the print. A long exposure, within reasonable limits, gives a dense screen, but correct gradations; the only disadvantage is that it takes a long time to print. The collodion or emulsion must be of a kind giving soft negatives with good gradation. Special care must, of course, be taken to have the plate perfectly clean and everything in first class working order, so as to secure a screen free from defects.

In theory, the vignetted screen is the most perfect one for the photo-mechanical process, because correct prints may be obtained from thin or intense transparencies by using thin or intense screens, while in copying from a negative through a chess-board screen, the negative must be of right density to give a correct print.

V. The Diaphragms.

The proper shapes for the apertures in the diaphragms, or "stops," as they are more generally called, have been described in the course of this paper; we have now to consider their adjustment.

The square is the only shape adapted to the cross-lined screen with unequal lines; its adjustment has been given in equation (4):

$$f = \frac{F}{n\Delta}.$$

But this is not the proper way to use a cross-lined screen. Its opaque and transparent lines should be of equal width, and it should be employed with double aperture stops, so as to work like a chess-board screen. The adjustment of the diaphragm is then given by the formula:

$$f = \frac{F}{2n\Delta},$$

or

$$\Delta = \frac{F}{2nf}. \qquad (16)$$

The distance between the centres of the pair is:

$$e = \Delta\sqrt{2}.$$

The cross-lined screen, employed in this way, gives twice as many dots as otherwise ; a coarser ruling must be taken to obtain the same fineness of grain. If, for instance, it should be desired to have the grain of 150 lines to the inch, the screen for the double aperture should be ruled 106 lines to the inch. It must also be observed that, with the double aperture, the squares of the middle tone are not turned around 45° ; to keep them turned in the print as they now are, the ruling must be parallel to the sides of the screen, not to the diagonals. The double aperture diaphragm, illustrated in Fig. 29, is for screens so ruled.

The adjustment of the chess-board screen is the same as for the double aperture, and is given by equation (16), n being the ruling from which the screen is made and $\frac{1}{2n}$ inch the side of a square of the screen. In the aperture of Fig. 21, Δ is the diagonal of the inner star.

In equation (16) we have two variable quantities, Δ and f; the adjustment can therefore be made by changing the size of the diaphragm, or by changing the distance of the screen, or by both. So long as the product of Δ and f is equal to $\frac{F}{2n}$, it does not matter whether the diaphragm is small and the screen far from the plate, or the diaphragm large and the screen close to the plate ; the result is identical. In practice, there are many reasons why the diaphragm, and not the screen, should be made adjustable ; I will only give one. It is essential that the distance f from the screen to the plate be uniform throughout, and, being so very small, no adjustable arrangement can accomplish that satisfactorily.

The screen should be perfectly flat, and, for large sizes at least, nothing but plate glass should be used for the negative or transparency. The screen and plate should be separated by blocks of silver or glass, planed down to an accurate thickness, and they should be brought by pressure into close contact. This pressure must be applied to the edges and not to the centre of the plate.

I consider $\frac{1}{6}$ of an inch as being about the right distance between the plate and the screen. This allows a glass cover $\frac{1}{16}$ inch thick to protect the screen and leaves about $\frac{1}{16}$ inch between the face of the plate and the glass cover, which is quite enough.(*) It is this distance which I have adopted for the following classification.

All diaphragms, whether consisting of a single aperture, or of a pair of apertures, or of multiple apertures, and whatever their shapes may be, are included in one general series. In number zero of the series, the diagonal of the single aperture is one-quarter of an inch. There is an exception for the square diaphragm now in general use with cross-lined screens : for this shape or multiples of this shape, the diagonal of number zero is one-half inch. No smaller sizes are likely to be required for this process. The linear dimensions of the other diaphragms increase in geometrical

(*) In calculating the distance between the screen and the plate, the thickness of the glass cover must be counted at two thirds of its actual value, in order to allow for refraction through the glass. Thus the cover said to be 1/16 inch thick is really 3/32 inch thick.

progression from this size, the ratio being 1·05. Each diaphragm bears two numbers: the first one is the serial number and indicates the place of the diaphragm in the series; the second one is a number of inches which represents the extension of the camera to which it is adapted, when the screen used is ruled 100 lines to the inch or made from this ruling, and also when the distance from the screen to the plate is one-sixth of an inch. The camera extension is readily ascertained by nailing a yard measure on the tailboard and adjusting it to show the distance from the diaphragm to the plate. So, an operator using a screen of one hundred lines to the inch has only to select the diaphragm bearing the number of inches which, after focussing, he reads on the tailboard of the camera.

If the screen should not be ruled 100 lines to the inch, then, for 105 lines take the next smaller diaphragm of the series; for 110 lines, take two sizes smaller; for 116 lines, take three sizes smaller and so on. When the screen is 95 lines, take the next size larger; if 91 lines, take two sizes larger, etc. The classification of the screens is as follows:—

71	lines to	the inch is	. . . .	7 stops	coarse.
75	"	"	. . .	6	"
78	"	"	. . . .	5	"
82	"	"	. . .	4	"
86	"	"	. . . .	3	"
91	"	"	. . .	2	"
95	"	"	. . . .	1 stop	"
100	"	"	. . .	0	"
105	"	"	. . . .	1 stop	fine
110	"	"	. . .	2 stops	"
116	"	"	. . . .	3	"
122	"	"	. . .	4	"
128	"	"	. . . .	5	"
134	"	"	. . .	6	"
141	"	"	. . . .	7	"

The number of inches to be marked on each diaphragm is given by equation (16):

$$F = \frac{200}{6} \Delta.$$

For the exceptional square shape this number of inches is deduced from equation (4), and is only one-half of the above.

A screen ruled n lines to the inch requires a diaphragm in which the diagonal Δ' of the single aperture is such that:

$$\frac{\Delta'}{\Delta} = \frac{100}{n}.$$

The difference x of the serial numbers of the sizes Δ' and Δ is governed by the relation :

$$\left(1{\cdot}05\right)^{x} = \frac{100}{n},$$

or

$$n = \frac{100}{(1{\cdot}05)^{x}}.$$

The classification of screens given above was calculated by this formula.

The principle of this series is easy to understand. The idea is to have two numbers on each diaphragm, one, a number of inches, for adjusting it to the lens, and another one, the serial number, for adjusting it to the screen.

A full set of diaphragms for one lens and one screen consists of fourteen numbers ; they are taken from the general series and fitted to the lens. For more than one screen, there must be as many additional stops as between the coarsest and the finest screen. Thus for screens of 91 and 110 lines, the set consists of 14 + 2 + 2, or 18 diaphragms, because 91 lines is two stops coarse and 110 lines two stops fine.

Although the basis of this system is a distance of the screen of $\frac{1}{6}$ inch, the series may be used for any other distance, but with this difference, that the numbers on the diaphragms are for another screen than 100 lines. For instance with a distance of the screen of $\frac{1}{5}$ inch, the numbers correspond to a screen of 83 lines, and it is from it that the other screens have to be counted coarse or fine.

The illustrations represent the actual sizes of numbers of the series. Those who are familiar with the photo-mechanical process will find them somewhat smaller than the square stop to which they are accustomed, and may believe that they are proportionately slower. It is not so ; their rapidity must not be estimated from their comparative sizes. There are two reasons for this. The first one has already been stated ; as now used, there is always a portion of the square aperture hidden by the screen, while the full aperture of the new stops is, in most cases, effective. The second reason is that to obtain the same fineness of grain as at present, the new stops require a coarser screen which means a larger aperture. Where a longer exposure is required, it is, as in copying from negatives, by reason of the process and not on account of the sizes of the apertures.

The exposure can be reduced by the use of multiple apertures instead of single ones ; this can be done with any kind of screen. The exposure is reduced as many times as there are apertures in the diaphragm. It must be borne in mind that multiple apertures require great perfection in the screen and very accurate adjustments. For a double aperture, the screen must be three times more perfect and the adjustments three times more accurate to give as good a result as the single aperture. There is little doubt that the most perfect prints will be obtained with single apertures.

Fig. 24 is the square stop now used with cross-lined screens ruled diagonally.

Fig. 25 is the same stop with four square apertures, requiring one-fourth the exposure of the first one. The number of apertures may be

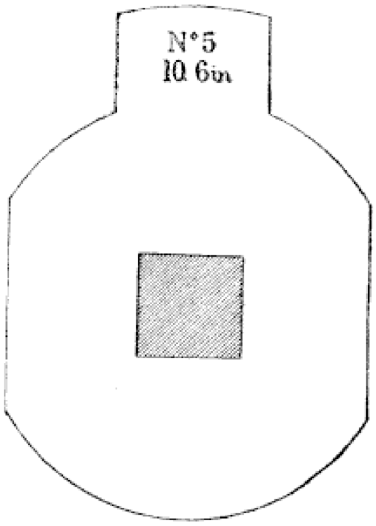

FIG. 24.

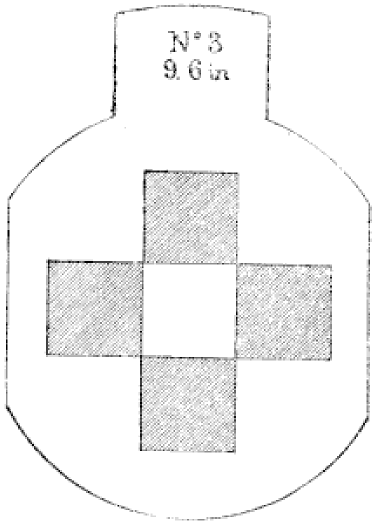

FIG. 25.

two, three, four, five or any other number; the rule is to dispose them like the squares of a chess board.

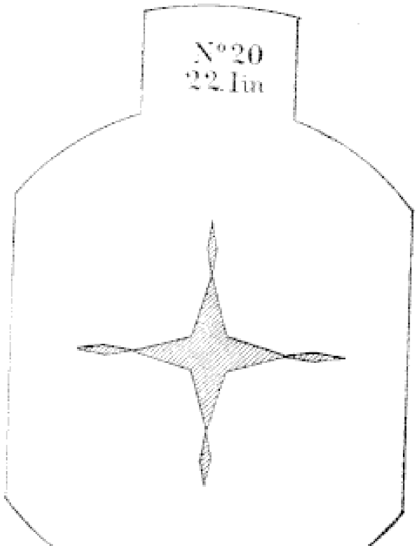

FIG. 26.

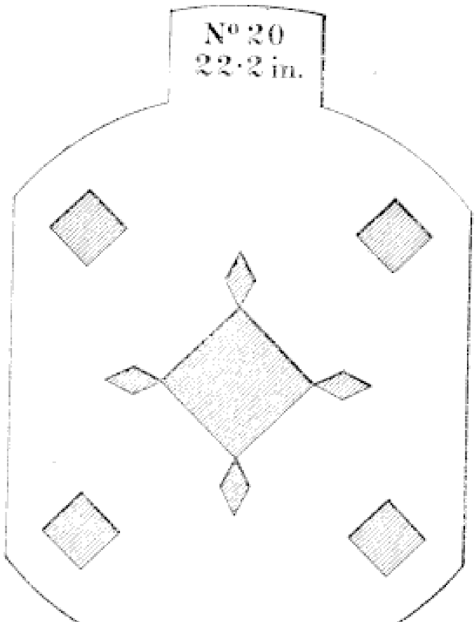

FIG. 27.

Fig. 26 is for copying from originals through a chess-board screen ; it requires two and a half times the exposure now given to produce the same grain.

Fig. 27 is also for copying from an original through a chess-board screen : it has multiple apertures and therefore requires shorter exposure.

All the above are for copying from originals and are given merely as illustrations of this paper. To obtain correct results, some of the following shapes have to be employed.

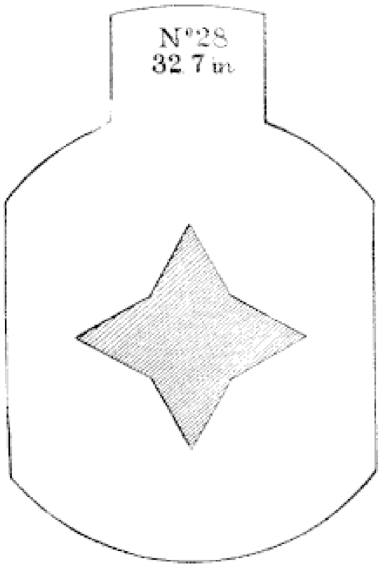

Fig. 28.

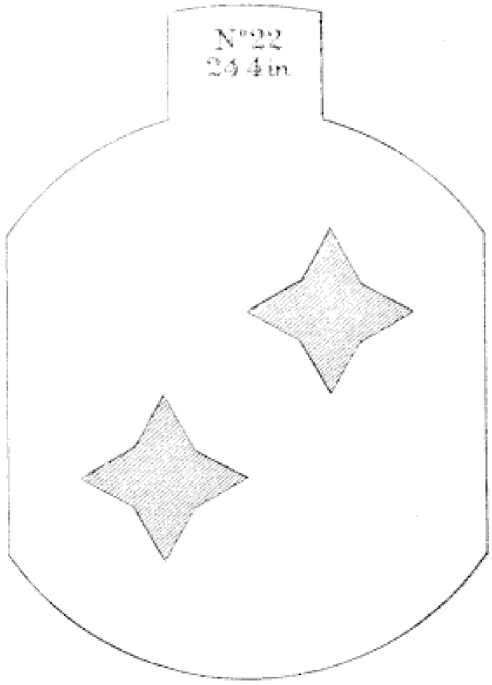

Fig. 29.

Fig. 28 is the single star aperture for the chess-board screen.

Fig. 29 is the double star aperture for a cross-lined screen in which the lines are of equal width and parallel to the sides of the screen.

Fig. 30 is a five-aperture diaphragm for the chess-board screen only. The general rule for making a multiple diaphragm for the chess-board screen is that each star must be inscribed in the alternate squares of a chess board. The rule for the cross-lined screen is that there must be one pair or several pairs of apertures ; the line joining the centres of the components of any one pair must be inclined at 45° to the lines of the screen.

Fig. 31 is a single aperture and double exposure diaphragm for the chess-board screen : it is made in the shape of a reversible Waterhouse diaphragm. The first exposure is given through the full aperture, after which the cap is put on the lens, the diaphragm reversed end for end in the slot and the second exposure given. This diaphragm may, like the others, be made with multiple apertures by the rules given above.

There may be cases where it is desirable to modify the gradations of the print; this can be done by remembering the following rule:

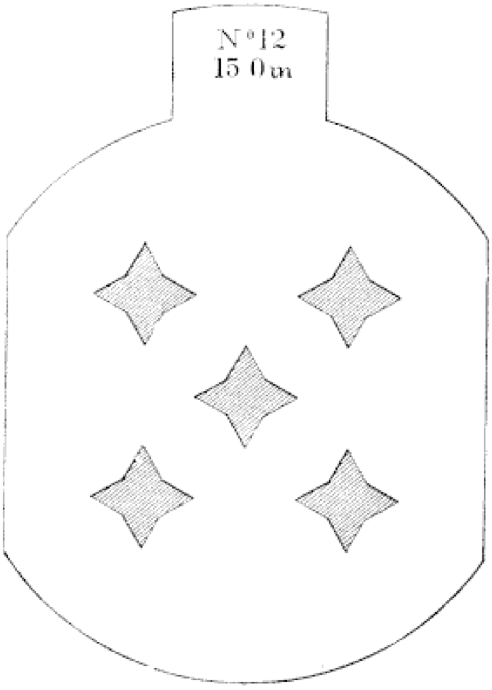

FIG. 30.

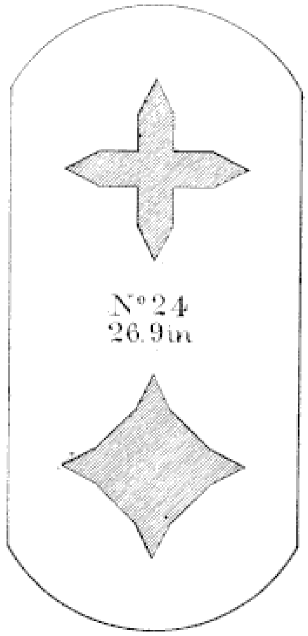

FIG. 31.

The dots, black and white, are enlarged by making the points of the star more acute in the diaphragm's aperture; they are reduced by making the points more obtuse. The squares of the middle tone and the finest dots are not changed.

VI. CONCLUSIONS.

From these investigations we conclude that there are three methods for translating correctly the continuous half-tones of an original into tones consisting of white and black dots.

1st. By copying from the original, giving a first exposure without a screen on the original, and a second exposure, through a chess-board or cross-lined screen, on a sheet of white paper or other source of uniform illumination. This method does not produce dots with edges as sharp and clean as the other two methods.

2nd. By copying from a negative through a chess-board or cross-lined screen. A negative of proper density produces a perfect result, but it gives a transparency and therefore requires some new process for etching the block.

3rd. By copying from the original or printing through a transparency with a vignetted screen in contact with the photographic plate.

This method is unfortunately restricted to dry plates, otherwise it would be the best of the three.

The cross-lined screen mentioned above is one in which the opaque and transparent lines are of equal width and has to be used with a double aperture diaphragm, but it must be remembered that in order to produce as good a result as the chess-board screen, the adjustments of the screen, plate, and diaphragm, would have to be three times more accurate and the screen itself three times more perfect.