

THE PHOTOGRAPHIC RENDERING OF TONE VALUES.

BY

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INTRODUCTION.

PHOTOGRAPHY deals with the reproduction of the tone values of the subject in the form of variations of light and shade in the print, each tone in the original subject being represented by a corresponding tone in the finished print, and it is the object of the photographic process to effect a reproduction in which the scale of tones in the finished print corresponds as closely as possible to that of the subject, or in which the scale of tones is modified in a known manner, either from necessity due to the limitations of the process or in order to produce the desired psychological effect. It should be emphasized at this point that the primary object in making a photograph is not in most cases the exact reproduction of the brightness and contrast of the original, but rather the production on a flat surface of variations in reflecting power such that the subjective impression obtained when this surface is viewed under a specified illumination will be as nearly identical as is possible with that produced in the mind of the observer when viewing the objects photographed. In discussing the reproduction, therefore, a careful differentiation should be made between the two phases of the problem, which may for convenience be termed the objective and subjective phases. The former deals with the reproduction of the objective brightness and contrast of the original, such factors being measurable by the usual physical methods of photometry. The latter, dealing with the subjective evaluation of physical brightness and contrast, requires the application of those psycho-physical laws which determine the subjective impression produced by the action of various physical stimuli when applied to an eye in some specified state of sensitiveness or adaptation. This adaptation level is in turn dependent upon the magnitude and time of application of the physical stimuli.

It is proposed in this article to trace the various steps in the photographic process and to explain the factors which affect the objective photographic rendering obtained, the discussion of

the subjective phase being entirely ignored. The factors of importance in tone reproduction may be classified as those dealing with the distribution of light and shade in the subject, the translation of the tones of the subject in the making of the negative including the effect of exposure and development, the scale of printing papers and the translation of the scale of the negative into the scale of the print, and finally the accuracy of the entire reproduction itself, as shown by a direct comparison of the print with the original subject. The last step in this process will be dealt with in a later paper. The present article is intended to form an introduction to the elementary theory of the subject.

THE DISTRIBUTION OF LIGHT AND SHADE IN THE SUBJECT.

When a pictorial representation of a natural object is made upon a flat surface, its form may be represented by areas differing in brightness and color. A painter, for instance, employs both means, while a black and white draughtsman confines himself to differences of brightness, ignoring color. With the exception of special branch of color photography, photography deals only with the reproduction of objects by different gradations of light and shade, and in this article we shall not only ignore the question of reproduction in color but also the fact that natural objects have different colors, and shall consider the problem of their reproduction as if everything consisted of areas differing only in brightness, that is, a series of grays of which black and white are the limiting members. Thus we shall deal with the tone gradations of natural objects but shall ignore the fact that they have also differences of color. The translation of differences of color into monochrome is best considered as a separate branch of photography, which is called "orthochromatic" photography or the photography of colored objects—and it is not proposed to take up this subject in the present article.

Ignoring the question of color, therefore, it is necessary in order to get a precise objective representation of nature to obtain a reproduction as accurate as possible of the whole scale of tones occurring in the scene which is being photographed.

The word "tone" as used in this paper, it should be noted, is practically synonymous with "brightness," being indicative of the intensity factor of the radiant flux which, when it falls upon the retina produces the sensation of light. The word "tone" has

been used in some cases to indicate the quality factor (*i.e.*, hue, or saturation), but in the literature of photography its usage has been almost exclusively as indicative of the intensity factor. This precedent seems amply sufficient to warrant its continued use in this sense and hence throughout this paper it should be interpreted as referring to the intensity factor, *i.e.*, brightness. Areas differing in tone, therefore, differ in brightness, or if they are subject to identical illumination they differ in reflecting power and a tone scale consists of a series of areas differing in brightness or in the special case of a flat surface uniformly illuminated of areas differing in reflecting power.

In natural objects these tone gradations are produced by differences both in the reflecting power and in the illumination of the object. The brightness of any portion of a natural object will depend, therefore, upon the illumination falling upon it and also upon its reflecting power. Objects differ very much in reflecting power, the range being from 90 per cent. for white chalk to 1 per cent. for black velvet. The ratio of the highest to the lowest brightness present in any scene may be referred to as the "contrast" of that scene, so that if we have a uniformly illuminated field in which is an area of white chalk reflecting 90 per cent. of the light and also black velvet reflecting only 1 per cent., the contrast will be 90 to 1, or simply 90.

Natural subjects like landscapes may have a greater contrast than this owing to their variation, not only in reflecting power but also in illumination; however, most landscapes have less contrast than the example given. As a result of the measurement of a number of photographic subjects, we may say that a contrast of 4 to 1 would be an extremely short scale or low contrast—a range which would occur in such scenes as the streets of a northern city on a dull day in winter. A scale of 10 to 1 would be a very soft contrast, one of 20 to 1 a soft contrast, while a subject having a scale of 40 to 1 would be considered as a subject of normal contrast. The measurement of contrast in natural subjects such as landscapes can be made by means of a portable illuminometer fitted with a standard lamp and calibrated for the measurement of brightness. By the measurement of the brightness values of a number of natural subjects, the greatest contrast was found in a landscape which included a shadow in a wood and sunlit hills above a river. A total range of 250 to 1 (contrast = 250) was

obtained, the sky being 250 times as bright as the deepest shadow in the wood.

In studio work the contrast is governed largely by the character of the lighting. It was, for example, found by actual measurement that the contrast between a white waist and a black skirt on a sitter, when the lighting was of average quality, was 40 to 1, while the same subject under a softer lighting gave a contrast of 30 to 1. In line lighting the contrast obviously may be very great indeed. In general, in home portraiture, it is difficult to keep the contrast low and at the same time secure lightings pleasing from an artistic standpoint. Measurement showed that typical cases gave a contrast of 65 to 1 on the sitter. When rather dark room furnishings form the background, the contrast between, say, a sitter's waist near the window and the darkest portion of the background may easily be 100 to 1.

THE TRANSLATION OF THE TONES OF THE SUBJECT INTO THE OPACITIES
OF THE NEGATIVE.

The purpose of the photographic process is, as has already been mentioned, to reproduce the scale of tones which occurs in the subject photographed as a corresponding scale of tones in the print, and the first step toward accomplishing this is the production of the negative. If this operation does not involve any distortion of the scale of tones, we may say that we have a "technically perfect" negative; and we may define a technically perfect negative as one in which the opacities of the various areas are proportional to the light reflected by the parts of the original subject which they represent.

By the "opacity" of a negative we mean the inverse of the transparency. Thus, if we have light of intensity I falling upon a silver deposit and the deposit transmits an intensity I_1 , then we may write

$$\text{Transparency as } T = \frac{I}{I_1}$$

and

$$\text{Opacity, as } O = \frac{1}{T} = \frac{I_1}{I}$$

Now, it can be shown experimentally that the mass of silver per unit area is proportional to the logarithm of O , and it is

customary in photographic work to call this quantity D , the density, so that we have

$$D = \log O = \log \frac{I_1}{I}$$

In practical photographic work the logarithms used are common logarithms so that a density of unity will correspond to an opacity of 10, and a deposit having this density will transmit $1/10$ of the light. Similarly, a deposit transmitting $1/100$ of the light will have a density of 2, and one transmitting $1/1000$ of the light a density of 3. It will readily be seen that when we place two deposits over each other we can find their joint density by adding the separate densities. Thus, if we have one deposit transmitting $1/a$ of the light and another $1/b$ of the light, the corresponding densities will be respectively $\log a$ and $\log b$. When the two deposits are superimposed, they will transmit $1/a \times 1/b$, corresponding to a density of $\log a + \log b$. We see, therefore, that if we have a geometrical series of opacities, we shall have an arithmeti-

FIG. 1.



Reproduction of sensitometric strip.

cal series of densities; and therefore a geometrical series of opacities will correspond to an equal addition of silver for each step since the silver is proportional to the density and not to the opacity.

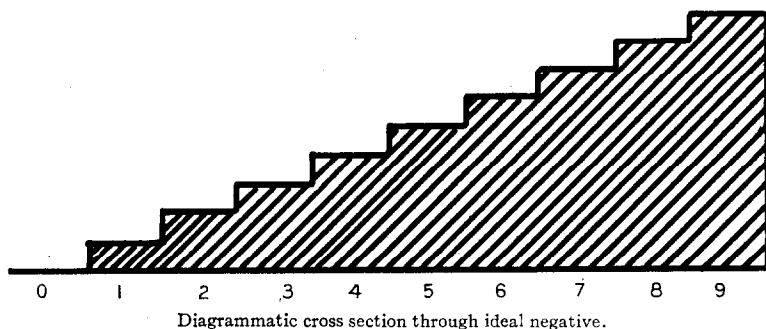
Let us apply this to a photographic example. Take a strip of plate and expose a portion of it to light just long enough to produce on it a barely perceptible blackening after development; then expose another portion for twice the time, another for four times, another for eight times, another for sixteen times, and so on, so that our strip will finally be made up of steps which have received amounts of light in the proportion 1-2-4-8-16-32-64-128-256-512. We might do this by making an instrument which would give different intensities of light in the form of steps and then exposing the plate in this instrument. but in practice it is generally more convenient to give a series of different times

of exposure. Fig. 1 represents the negative we shall get after development.

If the negative correctly represents these different times of exposure in the opacities obtained, the opacities should be in the same numerical ratio as the times of exposure, that is, they should be 1-2-4-8-16-32-64-128-256-512, and since each time the opacity is doubled the density increases by an equal amount, the density (that is, the amount of silver) would be in the proportion 0-1-2-3-4-5-6-7-8-9, as shown in the following table:

Exposures	1	2	4	8	16	32	64	128	256	512
Opacities	1	2	4	8	16	32	64	128	256	512
Densities	0	1	2	3	4	5	6	7	8	9

FIG. 2.

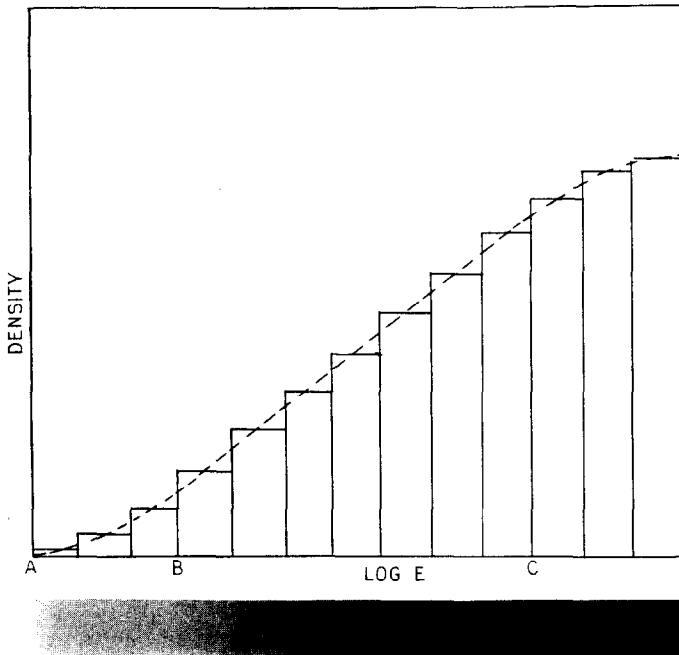


that is, if we cut an imaginary section through the negative so as to show the height of the deposit of silver, it would look as shown in Fig. 2.

If we actually try this experiment upon a plate, however, we find that the densities do not show this equal rise with exposure throughout the entire scale. What we get instead is shown in Fig. 3, and this diagram requires careful study. Starting at *A* and proceeding to *B*, we notice that at the beginning, in the lower exposures, the steps are marked by a gradually *increasing* rise. A negative, the gradations of which fall in this period, will yield prints in which an increasing contrast is shown between tones of uniform increase of brightness; that is to say, the negative will appear what we term "under-exposed." From this period at *B* we pass imperceptibly into the period where the densities show uniform rise for each equal increase of exposure, and here we have our technically perfect negative; that is, one in which

the opacities are exactly proportional to the light intensities of the subject. This is termed the "period of correct exposure," and only through this period of the curve, where the opacities are directly proportional to the exposures and where the densities show an equal increase each time the exposure is doubled, can we get, in the negative, a perfect rendering of the original subject. From the point *C* onwards we have a gradually diminishing in-

FIG. 3.

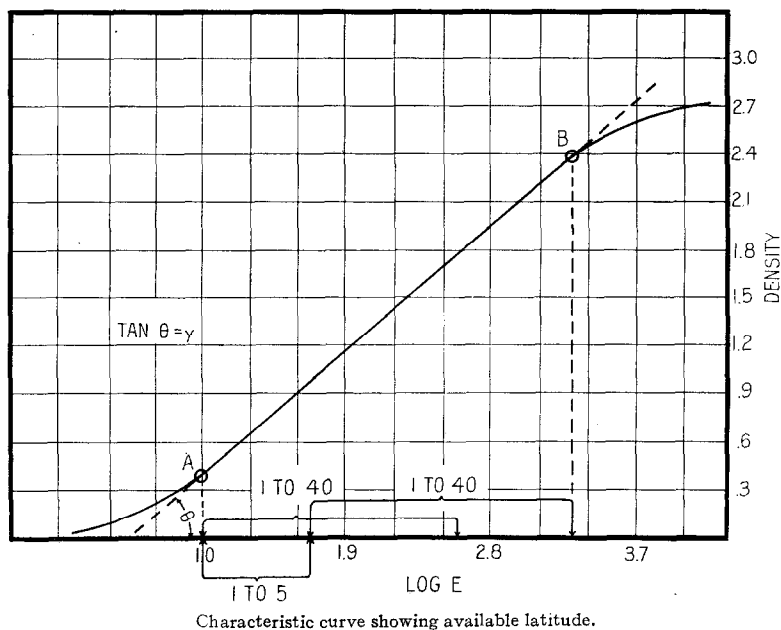


Sensitometric strip with resulting density curves.

crease of density with exposure until finally the increase of density with further exposure becomes imperceptible. This period is the period of over-exposure, in which the opacities of the negative fail to respond to increasing amounts of exposure, and the correctness of rendering is again lost. It will be seen from this curve at once, then, that only through the period of correct exposure, where equal increases of exposure are represented by equal rises in density can the tones of the original subject be correctly reproduced in the negative.

This curve showing the relation between the density and the log exposure was given originally by Hurter and Driffield in their classic paper on photographic theory.* The curve was termed by them the "characteristic curve," and the form in which it is usually plotted is shown in Fig. 4. As has already been stated, throughout the period of correct exposure the curve is represented by a straight line. If this straight line is produced to cut the exposure axis, it will meet it at a point $\log i$, where i was termed by Hurter and Driffield the "inertia" of the sensitive

FIG. 4.



material, the value being stated in exposure units so that the intercept of the straight line on the exposure axis is measured as the logarithm of the inertia.

The tangent of the angle which the straight line makes with the exposure axis was called by Hurter and Driffield the "development factor" and is signified by γ . During development the inertia point i does not change, as is shown in Fig. 5, but the steepness of the straight-line portion of the curve increases

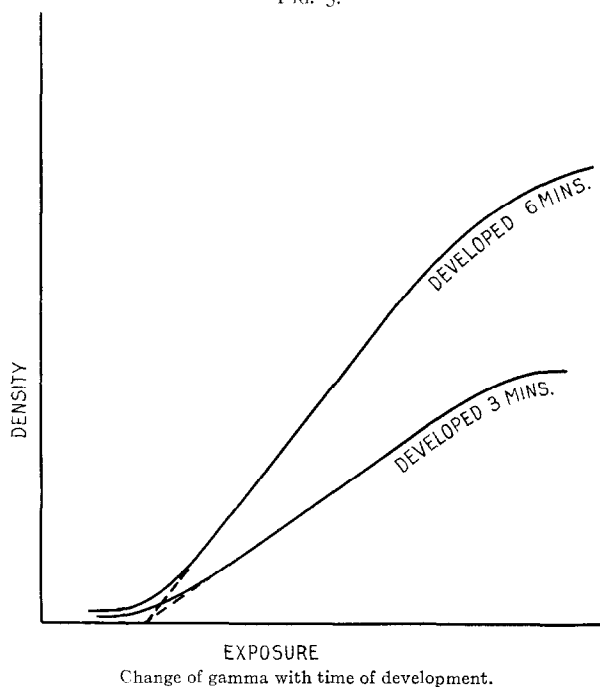
* F. Hurter and V. C. Driffield, *Jour. Soc. Chem. Ind.*, May, 1890.

so that gamma depends upon the time of development. The equation for the straight-line portion of the characteristic curve is therefore

$$D = \gamma (\log E - \log i)$$

A scale of tone values will be proportionately reproduced in a negative in so far, and only in so far, as it falls within the straight-line region of this curve, the length of the straight-line

FIG. 5.



portion being termed the "latitude" of the material. This property varies very much in different negative-making materials, being least in contrasty process plates and greatest in long scale portrait plates. The total range of exposures falling on the straight-line portion of the longest scale plates may be as great as 1 to 200, and a subject having a scale of 1 to 40 may therefore be placed within the straight-line portion of the negative with exposures varying from 1 to 5, this being the effective latitude of exposure available on such a material without any effect being

produced upon the accuracy of the tone rendering. The conditions for correct translation of the tones of the subject into corresponding opacities in the negative are therefore:

1. That the negative material has a long straight-line portion to its curve.

2. That the exposure is such that the scale of intensities of the subject falls entirely within this straight-line portion.

THE EFFECT OF DEVELOPMENT UPON THE SCALE OF THE NEGATIVE.

As is shown in Fig. 5, two negatives developed for different times will give curves similar in shape with their straight-line portions meeting at the same point on the exposure axis, but the slope of the two curves will be different, that developed for the longer time being steeper than that developed for a shorter time. This result was found by Hurter and Driffeld, and it follows from it that the ratio of the densities in a photographic negative remains constant throughout development, each density increasing to the same proportional extent. The value of I is therefore a measure of the contrast of a negative, and it is customary to express such contrasts in terms of the numerical value of γ , *i.e.*, of $\tan \theta$ where θ is the angle made by the straight line with the exposure axis. Thus, with γ equal to unity, the rate of increase of density is proportional to the logarithmic increase of exposure, and the opacities of the negative are exactly proportional to the intensities of the subject photographed.

During development γ increases from 0 to a limiting value γ_{∞} . The rise of γ is exponential, the velocity of development being represented approximately by the equation for a reaction of the first order, which may be written

$$K = \frac{1}{t} \log \frac{\gamma_{\infty}}{\gamma_{\infty} - \gamma}$$

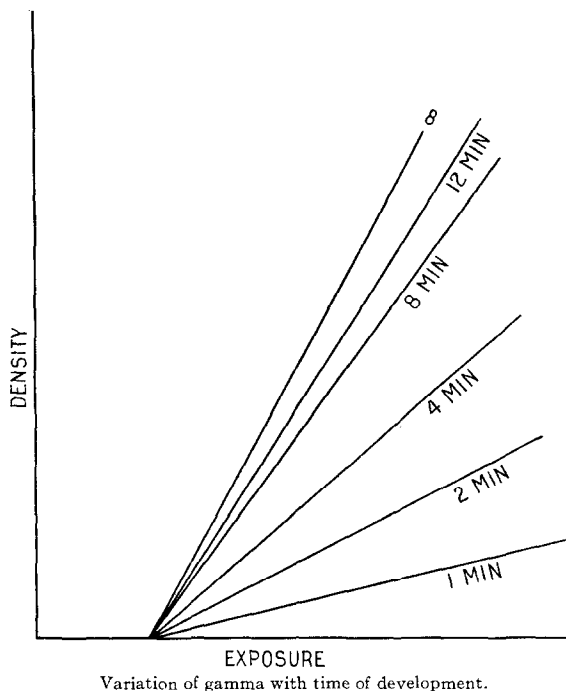
or, in the exponential form

$$\gamma = \gamma_{\infty} (1 - e^{-kt})$$

Figs. 6 and 7 show the calculated γ 's for a material having a γ_{∞} of 20 and a value of k of .100. The value of γ_{∞} depends upon the photographic material itself. High speed portrait plates have low values since no portrait requires development to a γ exceeding unity. Plates used for landscape work and commercial photography have higher values and will give greater contrast on develop-

ment. They develop more quickly and easily and give contrasts exceeding the maximum to which the fast materials can be pushed, while the greatest contrast of all is obtained with the special, low-speed emulsions made for process work, where every effort is made to get the greatest possible contrast in order to obtain clear lines on a completely opaque field. The maximum contrast given by process plates is frequently as high as 4, which

FIG. 6.

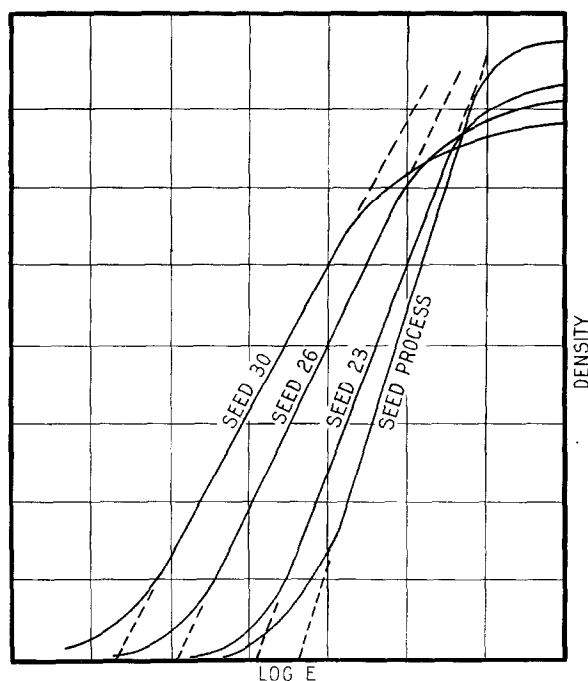


means that, if we have two tones in the original subject, one of which is twice as bright as the other, the part representing the higher tone in the negative will transmit only one-eighth of the light of that corresponding to the lower tone. Fig. 7 shows the curves of four different plates of the same manufacture, each having been developed to the maximum contrast possible. The notable differences in sensitiveness, scale, and contrast are very well shown in this figure.

The contrast to which a negative should be developed will,

of course, depend upon the contrast of the original subject. Suppose that we have a range of brightness values from 1 to 100 in our subject. If we develop the negative to a contrast of unity, and if the length of the straight line—representing the quality of the material—and the exposure are such that we get exact reproduction of the entire scale of the subject in the negative, we shall have a negative in which the ratio of the highest to the lowest

FIG. 7.

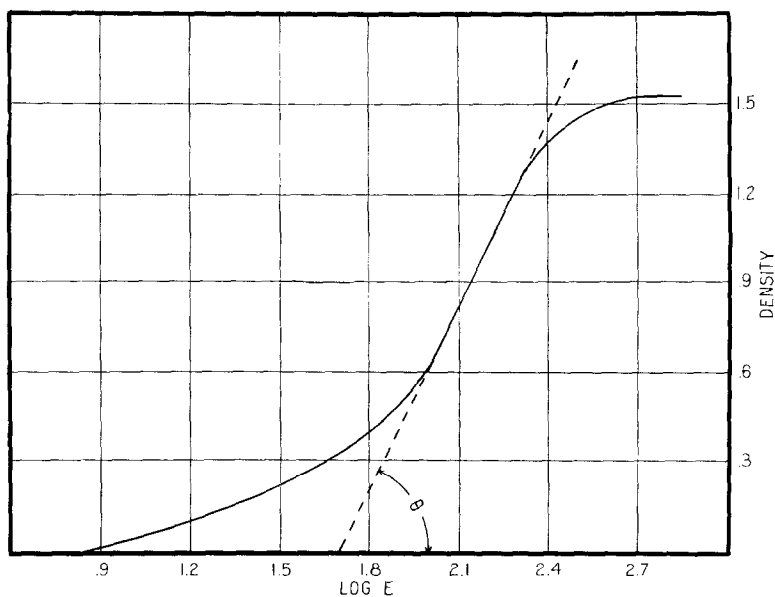


Characteristic curves of typical plates.

transmission is the same as that of the highest to the lowest brightness of the subject; namely, 1 to 100. If this scale of negative densities is too great for printing on the papers which are available, we can reduce the scale by lowering the contrast of the negative; that is, by developing the negative for less time, which will reduce each density in the same proportion. On the other hand, in the case of "flat" subjects (low contrast) we can lengthen the time of development, thus increasing the resulting

contrast in the negative. Provided that the contrast of the subject is not too great for the latitude of the negative material and that the exposure is such that the tone scale of the subject falls on the straight-line portion of the curve, development to a gamma of unity will make the scale of intensities (*i.e.*, transmission values) of the negative the exact inverse of the scale of intensities (brightness values) of the subject.

FIG. 8.



Characteristic curve of developing-out paper.

PRINTING PAPER.

The characteristic curve of a printing paper can be determined in exactly the same way as that of a negative-making material except that instead of measuring the light transmitted by the various densities, the light reflected from the various portions of the print must be measured. We thus get a series of reflection densities from the paper corresponding to the transmission densities of the negative. The characteristic curve of a paper will be of the form shown in Fig. 8.

It will be seen that the following constants will be of importance in specifying the properties of photographic paper. The

maximum black; that is, the reflecting power of the darkest (minimum reflecting power) deposit that can be obtained on the paper with full development and exposure. Such a deposit may reflect from 2 per cent. to 10 per cent. of the incident light, the average value of the maximum black for photographic papers being about 5 per cent., corresponding to a reflection density of 1.30. Matte papers will give a reading from 1.10 up to 1.35; semi-matte papers from 1.35 to 1.50; and glossy papers from 1.50 to 1.8. The total scale of the paper may be defined as the range of light intensities, expressed either in log exposure or exposure units, which can be reproduced by the paper as perceptibly different densities. This must be determined by some assumption of the value

$$\frac{dD}{d \log E}$$

which limits the useful gradient of the curve. In practice, the total scale of the paper is taken as the distance measured on the exposure axis between the points on the curve at which the value of $\frac{dD}{d \log E}$ is .2. The total scale of a paper will consist of three distinct parts—the under-exposed portion, the straight-line portion, and the over-exposed portion of the curve. The slope of the straight-line portion can be represented by γ , though γ does not change with development in the case of gaslight printing papers in the same way as in the case of negative materials. It is quite possible for two papers to have the same scale but different values of γ . This is shown in Fig. 9, where the paper marked *B* has a much steeper straight-line portion than the one marked *A*, but both have the same total scale value.

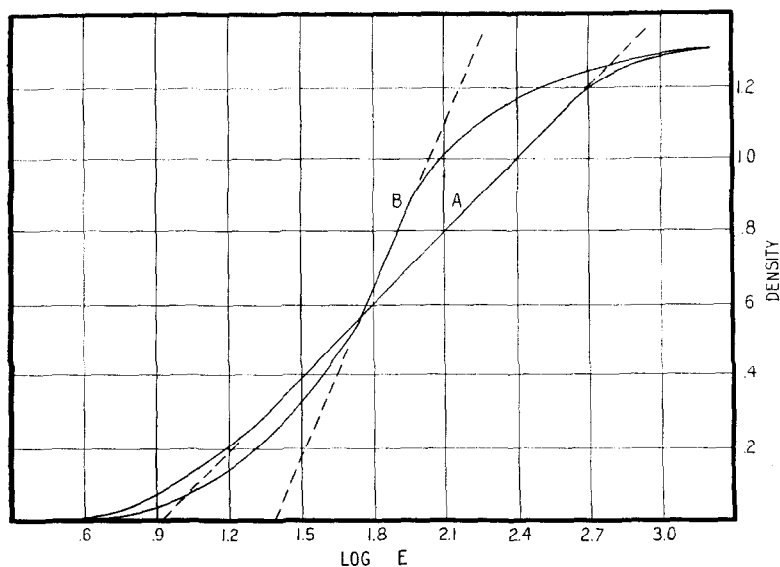
In choosing a paper for printing from a given negative, it is obvious that if all different densities in the negative are to be rendered as different densities in the print, the exposure scale of the paper must be at least as great as the difference between the maximum density and the minimum density of the negative. If the maximum density of a negative is 1.7 and the minimum density is .4, the logarithmic scale of the paper must be 1.3, or the scale in exposure units must be 20.

In order that papers may be suitable for various types of negatives, they are made with different scales. Thus, papers for amateur negatives, which tend to flatness, are made with

fairly short scales ranging from 20 exposure units down to 5 in the most contrasty paper made, this being suitable only for negatives with a maximum density difference of .7. On the other hand, the scales of papers intended for portraiture, where the negatives are of good quality and have a long scale of densities, are of the order of 40 to 60.

Exact reproduction of the tone values of the negative and consequently of the subject upon the printing paper can be accom-

FIG. 9.



Illustrating equality in total scale of different papers.

plished only through the straight-line portion of the characteristic curve of the printing paper. Owing to the narrow range of reflecting powers available in prints, however, it is almost imperative to use the entire density scale of the paper and consequently to sacrifice truth of rendering at both ends of the scale, since the straight-line portion of the curve of the printing paper covers only a small part of the total scale. The ratio of the straight-line portion of the total scale is termed the "rendering power" of a printing paper, and this ratio measures the capacity of a paper to give correct proportional reproduction of a scale of exposures. Thus, a paper that is perfect in rendering power would throughout

its total scale produce densities proportional to the exposure. It is not necessary for correct, proportional rendering for the slope of the straight-line portion to be unity, for as long as the line is straight, the rendering is proportional, but a change in the value of γ will produce a change in the proportionality factor, that is, in the contrast. It is obviously impossible with photographic papers to obtain an exact reproduction of a scale of tones extending over a very wide range such as exists in practical work. As has been shown, it is possible to reproduce exactly in the negative a range of brightness of from 1 to 40 and still retain a latitude of exposure of 1 to 5, but the maximum range of the reflecting power in the straight-line portion of the curve of any printing paper is very limited and in order to reproduce a range of tones greater than this maximum it is necessary either to compress the scale by developing the negative to a lower gamma, thus changing the proportionality factor of reproduction, or to utilize portions of the characteristic curve lying outside the latitude of the paper and thus depart from correct rendering.

EASTMAN KODAK COMPANY,
ROCHESTER, N. Y.
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Pollution of Deep Wells at Lansing, Michigan, is described by the State Sanitary Engineer, MAJOR EDWARD D. RICH, in the *American Journal of Public Health*, 1920, x, 147-151. The water supply of Lansing is derived from 32 wells which vary in depth from 350 to 400 feet. The water became contaminated with polluted ground water; an epidemic of dysentery and typhoid resulted; and chlorination became necessary to provide a safe supply. When such wells are constructed in the best possible manner, three avenues still exist by which dangerous pollution may suddenly occur. The joints and piping may deteriorate. Pumping in excess of the normal capacity of the wells tends to open the texture of sandstones and to enlarge any fissures which may be present; entrance of surface water seepage is thereby facilitated. Another well may be sunk to the same water-bearing stratum in the search for water, oil, or salt, then be abandoned without plugging sufficiently tight to exclude surface water. The conclusion is drawn that deep wells situated in the midst of urban development require the same watchful care that would be given to a shallow well supply or to a surface supply known to be subject to periodical contamination. This care is a requisite even though the depth and mode of construction of the wells would seem to render it unnecessary.

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